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COPPER AND URANIUM: THE COMING DIVERGENCE

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Copper and Uranium: The Coming Divergence

"How the world's biggest offshore wind company was blown off course: Denmark's Ørsted was once seen as a model for how oil and gas giants could go green. Its recent troubles suggest that things may not be so easy" Financial Times, December 5th 2024

"Amazon, Google make dueling nuclear investments to power data centers with clean energy. Nuclear energy is a climate solution in that its reactors don't emit the planet-warming greenhouse gases that come from power plants that burn fossil fuels." Associated Press, October 16th 2024

We turned bullish on copper in the second quarter of 2016 when copper was $2.10 per pound. In the essay "Renewables and the Upcoming Huge Bull Market in Copper," we outlined how the positive fundamentals emerging in global copper markets were overshadowed by the prevailing pessimism of copper prices that had fallen below $2 per pound.

We explored the traditional drivers of copper demand and delved into the impending impact of renewable energy expansion—a topic few investors contemplated at that time. Since that essay, copper prices have surged nearly 150% and copper stocks have been superb performers. The COPX, the most popular copper equity ETF, has soared almost 500%, significantly outpacing the S&P 500's 260% return over the same period

Today, everybody's a copper bull. The metal has transformed from an unremarkable commodity into a must-have asset, even for those adhering to strict ESG mandates, chiefly due to its critical role in the renewable energy sector—a connection we extensively explored nearly 8 years ago. Investors now hail copper as the "greenest" of metals and believe investments in renewable energy can only skyrocket. What's not to love?

This optimistic outlook is epitomized in S&P Global's influential report, "The Future of Copper," published in July 2022—a document that has become the gospel for copper bulls. S&P Global asserts: "Technologies critical to the energy transition—such as EVs, charging infrastructure, solar photovoltaics (PV), wind, and batteries—all require much more copper than conventional fossil-based counterparts. The rapid, large-scale deployment of these technologies globally, particularly EV fleets, will generate a huge surge in copper demand."

S&P Global projects that copper demand will double between 2023 and 2035, climbing from 25 million tonnes to nearly 50 million tonnes. Almost half of this increase—about 17 million tonnes—is expected to come from renewable sources. Copper demand is anticipated to grow at a compounded annual rate of nearly 6%, doubling the growth rate of the previous two decades. Additionally, S&P Global foresees significant structural deficits emerging in global copper markets by the mid-2030s, driven by surging demand and stagnant mine supply.

If you asked us in 2016 whether these projections were reasonable, we would have agreed. However, since then, our perspective on renewables and their impact on global copper markets has radically changed. After extensive study of the energy efficiency of renewables compared to hydrocarbons and nuclear power, we've concluded that large-scale adoption of renewables—including EVs—will be unfeasible unless societies are willing to accept substantial declines in economic growth and living standards—a topic we'll revisit shortly. Our research suggests that the universally bullish copper demand forecasts are poised to unravel, potentially leading to bearish copper price implications.

Shifting our focus to uranium, in the first quarter of 2018, just after uranium prices bottomed at $17 per pound, we published our first bullish report: "Uranium: The Quiet Before the Storm," highlighting the positive fundamentals that had emerged in global uranium markets which had been ignored by investors still reeling from the Fukushima nuclear accident seven years prior.

Since then, uranium prices have climbed over 300% and companies like Cameco—

the Western world's largest uranium producer—have delivered returns exceeding 550%, vastly outperforming the general market's 150% gain in the same timeframe.

Much like copper, investor sentiment toward uranium has turned markedly bullish. The looming structural deficit in global uranium markets is now widely acknowledged. Also, the significant advantage of generating electricity from uranium—namely zero CO2 emissions—is finally being recognized as an essential positive by environmentally conscious investors.

As evidence of this change, we highly recommend Oliver Stone's 2023 documentary, "Nuclear Now—Time to Look Again." The renowned filmmaker was the highlight of that year's Davos conference with his compelling argument that nuclear power offers a clean and reliable alternative to fossil fuels—a viewpoint that resonated with the Davos attendees.

From a contrarian standpoint, the newfound popularity of both metals might raise cautionary flags about potential investment pitfalls. Should investors consider selling both metals? In the short term, we remain bullish on both copper and uranium. However, we believe a crucial fundamental divergence is emerging that will make one metal a far superior investment over the coming decade.

When the enthusiasm for renewable investments peaked at the end of the last decade, consensus opinion focused on the declining "levelized cost" of wind and solar electricity as proof of their inevitable dominance. The prevailing belief was that as these costs fell below those of hydrocarbon-generated power a massive expansion of the renewable industry was all but guaranteed.

However, our research revealed severe flaws in this framework. We argued that focusing solely on declining operating costs--cost that were distorted by falling commodity prices and interest rates---failed to capture the actual expenses associated with renewables. Instead, we turned to the Energy Return on Investment (EROI) framework championed by energy scholars such as Charles Hall, Mark Mills, and Vaclav Smil. We found this approach more accurately reflected the actual costs of renewable, hydrocarbon, and nuclear power investments.

By applying the EROI concept and recognizing that technologies with inferior energy efficiency have never supplanted those with superior efficiency (and vice versa), we feel better equipped to understand the forces shaping investments in renewables, hydrocarbons, and nuclear power, as we progress through this decade.

Though it might seem academic, adopting new technologies based on their relative EROI is a common real-world phenomenon. Consider two examples from a familiar industry, occurring just years apart.

In 1956, ocean liners carried 80% of passenger traffic between North America and Europe. The Boeing 707 took to the skies two years later, connecting New York, London, and Paris. By 1964, jets had captured 80% of transatlantic passenger traffic, decimating the ocean liner business in just six years. The reason? The 707 transported passengers one mile using 40–60% less energy than ocean liners. The superior efficiency of flying across the Atlantic in the Boeing 707 made the competition obsolete.

You might argue that reduced travel time was the decisive factor causing the demise of the ocean liner industry, but consider another scenario where the new technology offered even faster travel, but inferior efficiency. The result: the new technology failed to displace the old technology.

By the mid-1960s, aviation experts like Juan Trippe, CEO of Pan American Airways, who pushed Boeing relentlessly to build the 707 jet, believed supersonic aircraft were destined to displace subsonic jets. Boeing and a British-French consortium raced to develop aircraft that could cross the Atlantic in three hours. While Boeing abandoned its SST project in 1971, the Concorde entered service in 1976. Simply put, the Concorde was an engineering marvel that offered a huge advancement in the technology of air travel. However, despite cutting transatlantic travel time in half, the Concorde consumed 50% more energy per passenger mile than its competitor--now the Boeing 747. Its inferior energy efficiency prevented it from gaining market share or profitability. Instead of displacing subsonic jet travel, the Concorde never amounted to more than a plaything for Hollywood celebrities, investment bankers, and rock stars. High energy consumption prevented mass adoption. The last flight of the Concorde took place in 2003, three years after the unfortunate Paris crash, which produced a wave of negative publicity from which the plane never recovered.

These examples illustrate the importance of energy efficiency and how it often trumps other advantages such as speed. Applying this framework to various means of energy production, we believe societies will increasingly question their commitments to renewable investments. Replacing energy sources with EROIs of 30:1 (hydrocarbons) with those of 10–15:1 (offshore wind) or 5:1 (solar farms) will lead to severe economic destabilization.

If lower EROEIs indeed have such destabilizing effects, investors must reconsider the widespread assumption that renewable-driven copper demand will double global consumption rates in the next decade.

When we wrote our bullish copper essay in 2016, we had only started to explore the energy efficiency of renewables and we believed they had a strong case for increased adoption, especially amid rising energy costs. However, subsequent research convinced us that renewables would not achieve the penetration levels predicted by bodies like the International Energy Agency and firms like S&P Global.

In recent years, investors have rallied around copper as the quintessential "green" metal. Our research indicates that the surge in copper demand from renewables will fall short. The highly bullish sentiment, based on flawed assumptions about renewable energy adoption, is likely to unravel as the decade progresses.

At the October 2022 Grant's Interest Rate Observer conference, we cautioned that further investments in renewables could have dire, unappreciated consequences. We told the Grant's audience: "Attempts to fulfill various green initiatives, such as achieving carbon neutrality by 2035, will create many losers and few winners. Economic growth will be severely impacted and CO2 reduction goals will not be met. Due to their inferior energy efficiency, renewables produce only marginal surplus energy. Since surplus energy drives economic growth, pursuing renewables hampers economic progress and leads to destabilization—as evidenced by Europe's current struggles."

If this doesn't describe the economic agony that grips Europe today, we don't know what does.

Volkswagen's recent announcement of plans to close up to three German manufacturing facilities underscores the deep-rooted problems afflicting Germany in particular and Europe in general. Over the past fifteen years, Germany has invested nearly $1 trillion in renewable energy, primarily wind and solar, doubling its electricity production capacity. Concurrently, the government phased out nuclear power—its most energy-efficient source—greatly escalating the country's energy problems. Pre-Fukushima, nuclear plants supplied about 25% of Germany's electricity; today, none remain operational. Replacing nuclear power with renewables, an energy source with far less efficiency , has led to unintended and unfortunate outcomes—precisely as we predicted.

In summarizing our views at the Grant's conference, we concluded:

1. Inferior Energy Efficiency Limits Renewables: Due to their lower energy efficiency, renewables cannot displace traditional hydrocarbons, even if CO2 costs are internalized.

2. Adoption Requires Government Intervention: Large-scale renewable adoption hinges on heavy government subsidies. --Look no further than the US's "Inflation Reduction Act" or California banning new gasoline-fueled car sales by 2023..

3. Unfortunate Outcomes Are Inevitable: Pursuing green initiatives via renewables will severely restrict economic growth and CO2 reduction targets will not be met. The minimal surplus energy from renewables makes economic expansion challenging, leading to destabilization. Ironically, increased investment in renewables may result in higher CO2 emissions due to their poor energy efficiency.

In contrast, the fundamentals of uranium could not be more different. The nuclear power industry is on the cusp of radical change with the advent of molten-salt small modular reactors (SMRs), a significant technological advancement that promises to boost both the energy efficiency, and the perceived safety of nuclear fission.

Regarding renewables, we are just where the Concorde was in 1975—there was huge hype, but the underlying problem of energy efficiency couldn't be overcome and the Concorde was never successful. However underlying fundamentals in the nuclear power generating business and uranium markets put the world just where the Boeing 707 was in 1957—one year before it entered scheduled service. With the 707's huge lift in energy efficiency, the global travel world was about to be disrupted--with huge societal benefits that are still being felt. The SMR, we believe, is the Boeing 707 of today.

Currently, nuclear power relies on large, high-pressure, water-based reactors, which are already highly energy-efficient. For every unit of energy invested—from mining uranium to constructing power plants—we get 100 units of energy output.

However, these reactors require operating pressures of over 2,000 psi to prevent water from boiling at core temperatures of 600°C. The pressurized vessel necessitates massive amounts of steel and concrete, consuming significant energy in construction—about 60–70% of the total energy invested.

Molten-salt SMRs, on the other hand, operate at atmospheric pressure since molten salt boils at 1,400°C--far above the reactor's core temperature. The low pressure reduces the need for heavy materials and complex safety systems. We estimate that SMRs require 80% less energy to build than traditional reactors, boosting the EROI from 100:1 to 180:1. We believe the steel and cement requirements of a molten-salt SMR are almost 90% lower per kWh than a high-pressure water-cooled reactor. By drastically lowering the energy required for steel, cement, and manufacturing, an SMR's EROI is nearly double that of a pressure water reactor.

The molten salt-based small modular reactor (SMR) is not only a marvel of energy efficiency, but it also introduces advancements in operational safety--important to an industry haunted by its history. The specters of Three Mile Island, Chernobyl, and, most recently, Fukushima still loom large in the public imagination, underscoring the necessity of a technology that prioritizes operational security and safety. Here, the molten salt SMR again distinguishes itself. With a circulatory fluid boiling point far beyond the 600-degree Celsius range and a design that operates at atmospheric pressure, it sidesteps the Achilles' heel of traditional water-cooled reactors--- the risk of leaks and explosions related to high-pressure operating environments. The threat of radioactive water or vapor scattering into the air becomes essentially impossible with an SMR.

Safety isn't the only point of distinction. SMRs powered by molten salt leverage HALEU—High-Assay Low-Enriched Uranium—fuel enriched to 20% U-235, compared to the 5% used in traditional reactors. HALEU burns hotter, reducing radioactive waste by as much as 90% compared to older designs. Far less waste addresses a criticism that has dogged nuclear power for decades.

Despite these advances, nuclear power remains the "most successful failure of all time," as energy economist Vaclav Smil aptly describes it. Antiquated designs and a persistent fear of nuclear calamity have betrayed promises of an energy utopia. Lewis Strauss's 1954 prophecy that nuclear electricity would be "too cheap to meter" and Nobel laureate Glenn Seaborg's 1971 vision of a world in 2000 powered 100% by nuclear energy now read like wistful fantasies. Instead, nuclear contributes a meager 9% to global electricity generation today.

This stagnation stems from a fateful decision made nearly seventy years ago. Admiral Hyman Rickover, the U.S. Navy's nuclear program architect, dismissed molten salt reactors in favor of water-cooled designs. His reasoning was pragmatic: water-cooled reactors suited the Navy's maritime-water based environment--molten salt explodes when coming in contact with water. But this choice chained the nuclear industry to a design optimized for submarines, not power grids. Smil observed that today's pressurized water reactors are little more than "beached versions" of

Rickover's submarines. The molten salt alternative, with its inherent safety and efficiency, was left behind. Today, the industry is finally shaking free of its midcentury constraints. Molten salt SMRs are poised to revolutionize energy production, addressing the fears of past accidents and the CO2 crisis that looms over our planet. Data centers—prodigious energy consumers—are already adopting this technology to meet their immense demands-- the uranium section of this letter lists all recent announcements. Regulatory hurdles remain formidable, but the momentum is undeniable.

The implications for investors are equally profound. The choice, as we see it, is between uranium and copper—between investing in the Concorde, a technological marvel that failed to take flight commercially, and the Boeing 707, the plane that launched the jet age. The Concorde sits in museums today; the legacy of the 707 is written in the contrails crisscrossing the globe. The parallels between SMRs and the energy revolution they promise are clear. At Goehring & Rozencwajg, we know which side of history we want to be on.

The Depletion Paradox

The great drama of American shale production may now be nearing its final act. For years, we have anticipated that the relentless growth in shale output would crest by late 2024 or early 2025, catching many off- guard. In hindsight, even this expectation might have erred on the side of caution. Quietly and without much fanfare, both shale oil and shale gas appear to have passed their zenith several months ago. Recent data from the Energy Information Agency (EIA) reveal that shale crude oil production reached its high-water mark in November 2023, only to slide 2%—roughly 200,000 barrels per day—since then. Likewise, shale dry gas production peaked that same month and has since slipped by 1%, or 1 billion cubic feet per day. The trajectory from here, according to our models, looks steeper still.

Our view has been met with no shortage of skepticism. Many of our conversations with clients and industry insiders suggest a broad belief that today's declines are but a pause, not a prelude to sustained contraction. Optimists contend that higher prices and a deregulatory push will spark a new wave of drilling and fresh production gains. After all, President-elect Trump's "Three Arrows" energy plan prominently promises a 3-million-barrel-per-day increase in US oil-equivalent production. But we see this optimism as misplaced. The primary forces behind the current downturn are neither policy-related nor purely economic—they are geological and inexorable. Depletion, not market dynamics or regulatory overreach, is the central culprit.

Admittedly, the incoming administration features several well-informed and capable figures in the energy sphere, including Chris Wright and Scott Bessent. Their leadership will undoubtedly foster a favorable climate for drilling activity. Yet, even with their expertise and the administration's likely zeal for energy development, we remain convinced that these efforts will struggle to offset the entrenched declines now gripping the shale sector. The geology of the shale patch has spoken, and its verdict seems increasingly final.

Our thesis is built upon the enduring insights of the late Dr. M. King Hubbert, whose groundbreaking prediction of the peak in conventional U.S. crude production in 1970 remains a landmark in energy analysis. In this essay, we aim to show how we have adapted Hubbert's foundational work, augmenting it with the latest advances in artificial intelligence, neural networks, and machine learning to address the complexities of shale production. The implications of our findings are profound. Our edge lies in an uncommon synthesis: the marriage of cutting-edge computational techniques with deep, domain-specific expertise in the energy sector.

Too often, we observe legacy oil and gas analysts tethered to antiquated models, while AI practitioners—adept at the math but unfamiliar with the nuances of resource extraction—arrive at flawed conclusions. Neither approach alone suffices anymore. Our unique combination of skills allows us to reach conclusions that defy conventional wisdom, and we are confident these conclusions will ultimately prove prescient.

Let us explain why.

In recent months, we've engaged with a range of investors and oil industry executives. While many grasp the logic behind our analysis, few are ready to accept its implications. At a recent talk before an audience of oil and gas operators at the Houston Petroleum Club, the most common counterargument boiled down to this: if shale production continues to decline, higher prices will follow. And with higher prices, operators know precisely where to drill next. Each operator, brimming with confidence in their ability to boost production, assumes that the industry as a whole will do the same.

The rationale seemed straightforward: with the rig count far below previous peaks, availability is unlikely to be a bottleneck. While the remaining drilling locations might be less productive, they could still yield acceptable returns at elevated oil and gas prices. Given the vast number of undrilled but economically marginal locations, operators were convinced that U.S. shale production would rebound swiftly, negating any nascent rally in prices.

Yet, as we will argue, this collective confidence may rest on shaky ground. The factors driving shale's decline are far more structural than the industry at large appears willing to admit.

Our models point to a sobering conclusion: even with substantially higher prices and an abundance of undrilled locations, production is set to continue its decline. We call this phenomenon the "depletion paradox." It is a familiar story, and history provides a clear precedent.

Consider the case of conventional U.S. crude production in the 1970s. Production peaked in November 1970 at 10 million barrels per day, with oil priced at just $3.18 per barrel. At that time, the industry operated a modest 302 rigs drilling for oil. The first OPEC oil crisis in 1973 sparked a response from President Nixon in the form of Project Independence—a sweeping initiative aimed at reversing the decline in U.S. output through deregulation and expedited permitting. Much like today, optimism abounded among oil producers, who believed that higher prices would unleash a drilling boom and restore U.S. production growth. They were confident they knew where to drill; all they needed was the right price signal.

Prices soared from $3.18 per barrel in 1973 to $34 per barrel by 1981. Producers, true to their promises, responded with vigor. The rig count climbed from 993 in 1973 to a staggering 4,500 by late 1981. Yet despite this unprecedented surge in drilling activity, U.S. oil production steadily declined throughout the 1970s. By the end of 1981, production had fallen to 8.5 million barrels per day—far below the peak achieved a decade earlier and lower than when Nixon announced his ambitious goals.

Three decades later, in 2010, U.S. oil production hit a nadir of 5 million barrels per day, even as prices hovered around $100 per barrel—30 times higher than in 1973. The depletion paradox had firmly taken hold. The industry's assumption—that higher prices alone could counteract geological realities—proved tragically flawed. Today, as we observe the shale sector grappling with similar dynamics, it seems history may once again be repeating itself.

We believe the U.S. shale sector now stands at a crossroads eerily similar to that faced by conventional oil production in 1973. While shale's achievements have been extraordinary, they remain subject to the inexorable forces of depletion. Yet, the industry, Wall Street, and the President-elect appear poised to repeat the missteps of half a century ago.

The lessons of history are clear: enthusiasm for growth, however well-intentioned, cannot override the fundamental constraints of geology. And if we fail to heed these lessons, we risk not just disappointment, but the stark realization that higher prices and bold policy initiatives are no match for depletion's steady advance.

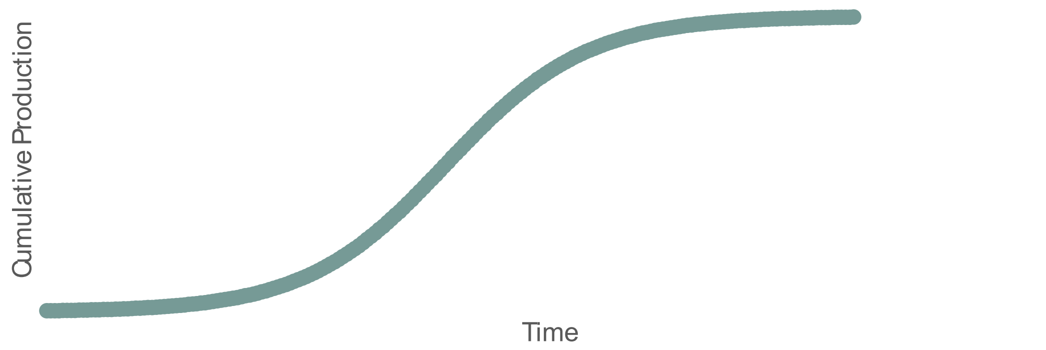
King Hubbert – a History

M. King Hubbert, a geologist for Shell, was born in 1903 and left an indelible mark on the study of petroleum resources. In 1956, during a meeting of the American Petroleum Institute, he presented a bold prediction: U.S. oil production would peak in 1970 at around 10 million barrels per day. At the time, his assertion seemed audacious, even implausible—after all, U.S. production had been rising steadily since Colonel Drake's first successful well nearly a century earlier. Hubbert faced significant skepticism, but history proved him right. In November 1970, just as he had forecasted, U.S. production reached its apex and began its long decline.

Although Hubbert's name is widely associated with the concept of "peak oil," surprisingly few have taken the time to engage deeply with his original work. His conclusions may have sparked controversy, but the principles underpinning them are remarkably straightforward.

Hubbert's central argument was simple yet profound: every hydrocarbon basin is a finite resource. As such, the cumulative production of a field will follow a predictable trajectory. It begins at zero, rises as extraction ramps up, and ultimately reaches an upper limit that represents the total recoverable resource in the basin. When plotted over time, cumulative production inevitably traces a curve with this general shape:

FIGURE 1 Cumulative Production Over Time



Source: G&R.

While Hubbert acknowledged that the exact profile of production could vary widely, he emphasized that it would always slope upward—what mathematicians call "monotonically increasing"—as cumulative production can only grow, never shrink. For instance, a field developed rapidly might display a near-vertical rise, while one extracted at a steady pace might show a slower, more linear progression before reaching its upper bound.

Hubbert proposed using a logistic curve to approximate this behavior. The logistic curve forms a smooth, symmetrical "S" shape: it starts at zero, accelerates as production ramps up, and eventually approaches a fixed value, which represents the basin's total resource. This elegant model captured the essential dynamics of resource depletion and provided a framework that has shaped energy forecasting ever since.

Taking the derivative of cumulative production with respect to time reveals the field's production profile. For a logistic cumulative production function, this derivative yields a bell-shaped curve, perfectly symmetric around its peak—a hallmark of Hubbert's framework.

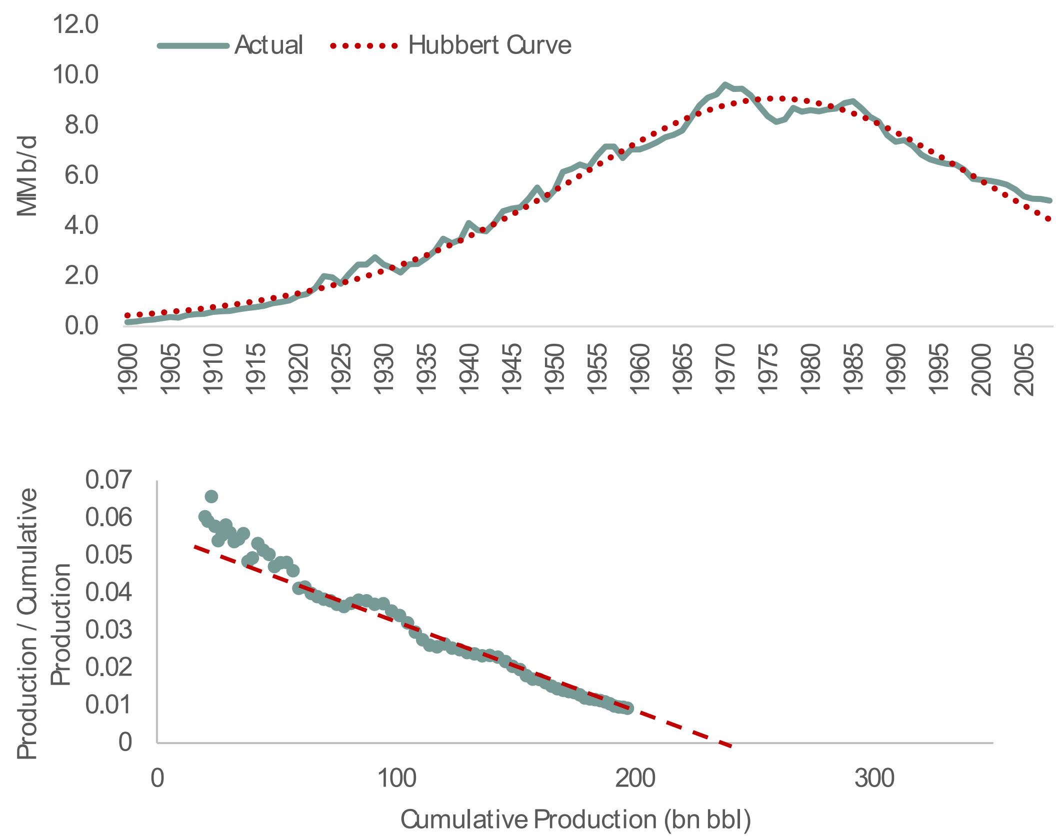
Hubbert also introduced a second groundbreaking concept: his eponymous "linearization." By plotting the ratio of annual production to cumulative production (P/Q) against cumulative production (Q), he observed that after an initial period of variability, the relationship settled into a straight line. This insight provided a powerful analytical tool. By extrapolating the line to the point where P/Q reaches zero, one could estimate both the field's ultimately recoverable reserves and the coefficient of its production profile. With these two parameters in hand, constructing a Hubbert Curve became straightforward, allowing analysts to predict both the timing and magnitude of a field's production peak.

One of Hubbert's key insights was that a field typically reaches its peak when half of its reserves have been extracted. While intuitively satisfying, this idea raises an intriguing paradox: why should production stop growing when half of the field's reserves still remain? The answer lies in the complex interplay between depletion and production dynamics—a concept that underscores the limits of extraction and the inevitability of decline, even in the presence of significant remaining resources. This "depletion paradox" remains a cornerstone of modern resource analysis.

The paradox has vexed petroleum engineers since Hubbert first introduced it. Frustratingly, Hubbert himself was unable to offer a satisfying explanation from first principles. He openly acknowledged that his choice of a logistic curve—and the resulting bell-shaped production profile—was not rooted in theory but rather in its consistent empirical success.

The logistic curve, as Hubbert noted, reliably described the production rollovers of many smaller fields he studied during the 1950s. This empirical track record lent the model its credibility and ultimately guided Hubbert to his now-famous prediction of the U.S. oil production peak in 1970. While the curve's elegance and accuracy cemented its place in resource analysis, the lack of a deeper theoretical underpinning left its critics unconvinced, ensuring the paradox would remain a subject of debate.

FIGURE 2 Hubbert Curve & Linearization for US Conventional Production



Source: EIA and G&R.

Explaining Hubbert – From Macro to Micro

Although the logistic curve has demonstrated its predictive prowess, it's surprising how little attention has been given to the reasons behind its effectiveness. Much of the criticism aimed at Hubbert's model arises from this very ambiguity. The curve works—but why? Without a solid understanding of the underlying mechanisms, many find themselves rejecting the "depletion paradox." After all, wouldn't higher prices or new technologies accelerate development and override the limits of depletion?

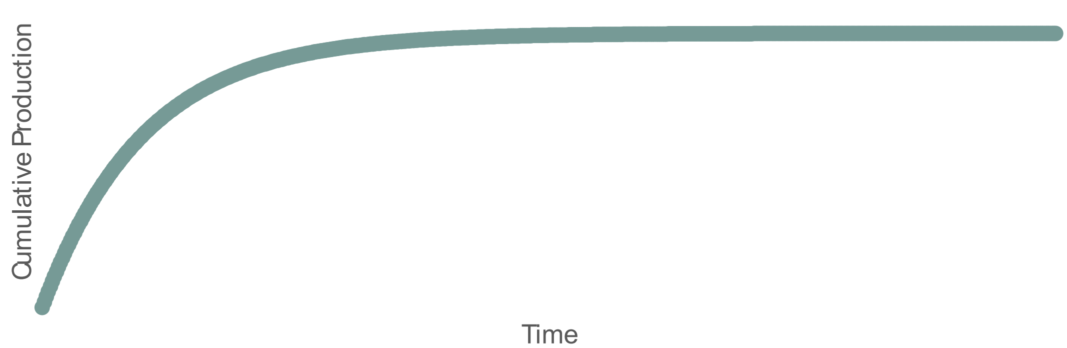
Yet, history has taught us a different lesson. Despite ample profits and a legion of engineers, the industry in the 1970s couldn't outmaneuver the realities of depletion. To shed light on this paradox, perhaps it's time to shift our focus from the macro level of entire fields to the micro dynamics of individual wells.

Imagine, if you will, a hypothetical oil field endowed with an infinite number of identical wells,each drilled at a constant rate indefinitely. In such an admittedly unrealistic "infinite" field, one might expect production to grow endlessly. However, the reality is that the field's output would ramp up and eventually plateau at a fixed rate. This might sound counterintuitive at first glance, but it becomes clear upon closer examination.

In the early days of the field's development, every new well adds directly to total production. Once these wells are online, they begin to decline in output in a predictable fashion. In the following period, new wells continue to contribute the same volume of fresh production, but now the growth is partially offset by the declining output of the older wells.

As long as the production from new wells exceeds the cumulative declines from existing ones, the field's overall output continues to grow. However, the base decline—the total reduction from all the aging wells—also increases. The field will keep expanding until the additions from new wells exactly balance out the base declines. At that juncture, the field reaches equilibrium, and total production levels off.

FIGURE 3 Unlimited Identical Wells Drilled Constantly



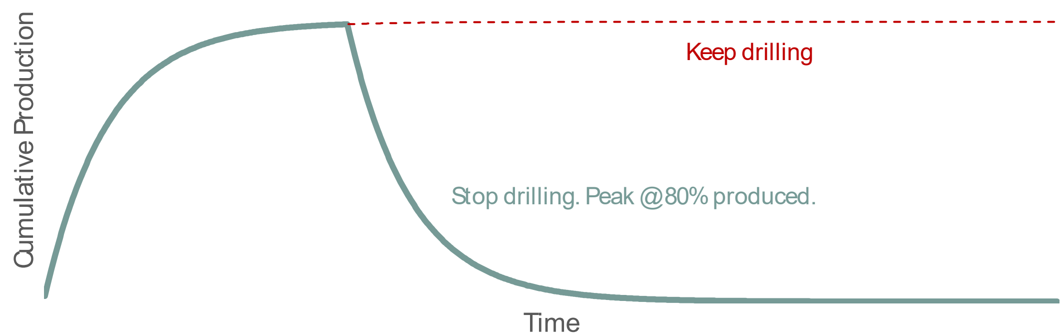
Source: G&R.

This scenario illustrates why even infinite potential can't escape the constraints of depletion. It underscores a fundamental truth: growth is bound not just by resources but by the interplay between new additions and inevitable declines. Higher prices and technological advancements may influence the pace, but they can't alter the underlying dynamics that eventually lead to a plateau in production.

Of course, no field is truly infinite. Oil and gas deposits are the result of geological processes spanning hundreds of millions of years, and every field's resource base is, by nature, finite. If we adjust our earlier assumption and consider a field with a fixed number of identical wells drilled at a constant rate until the resource is exhausted, a different production profile emerges.

Under these conditions, production initially grows as new wells come online, eventually reaches a plateau, and then falls off sharply. The resulting curve bears little resemblance to the symmetric bell-shaped profile of Hubbert's logistic model. Instead, the peak occurs much later in the field's lifecycle, at a point where approximately 80% of the ultimate recoverable reserves have already been extracted.

FIGURE 4 Fixed Number of Identical Wells Drilled Constantly To Exhaustion



Source: G&R.

This revised scenario highlights the impact of finite resources on the dynamics of production. While the plateau phase might offer the illusion of stability, the eventual sharp decline serves as a stark reminder of the field's limits. It's a pattern that underscores the inexorable pull of depletion, even when development appears robust and ongoing.

More Realistic Examples

Thus far, our examples have been deliberately simplified, designed to illustrate key principles. Of course, no field is infinite, and no prudent oil producer would drill a fixed number of wells without regard to inventory or strategic considerations. These examples, however, provide a useful baseline as we begin to relax assumptions and introduce more realism into the model.

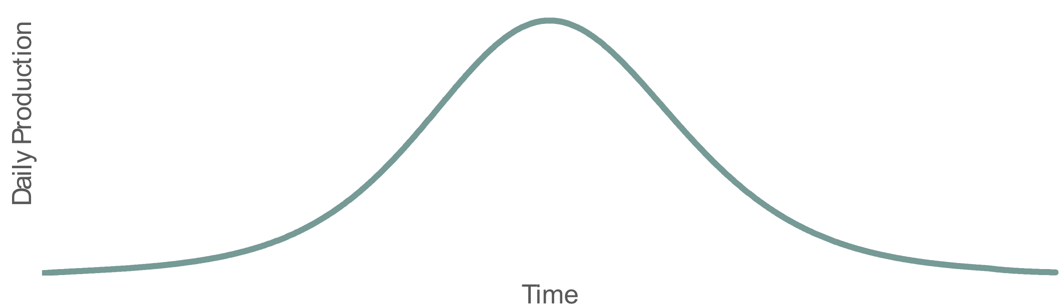
In practice, oil companies face two critical constraints: how much to drill and where to drill. An energy executive must decide how to allocate capital and human resources across a given field. Early in a field's life, these decisions are marked by uncertainty. The field is unproven, cash flow may be limited, and companies tend to proceed cautiously, drilling slowly at first.

As the field demonstrates its potential and begins to generate cash flow, development accelerates. The goal at this stage is to maximize present value by ramping up activity quickly, deploying more capital and resources to extract as much value as possible. However, this phase doesn't last indefinitely. As undrilled locations become scarcer, companies naturally slow development. The desire to maintain an adequate reserve life index and the practical constraints on further expansion lead to a deceleration in activity.

Interestingly, the trajectory of the drilling schedule itself often traces a bell-shaped curve. It begins with a slow ramp-up, accelerates to a peak as activity intensifies, and eventually tapers off as the field matures. This pattern mirrors the life cycle of resource extraction and reflects the broader dynamics of balancing opportunity with constraint in the development of finite resources.

If we assume constant well productivity and a logistic drilling schedule, the field's cumulative production will follow a classic logistic curve, while its production profile will take the shape of a perfect bell curve. In this scenario, production reaches its peak precisely when half of the field's recoverable reserves have been extracted. This inflection point coincides with the company's decision to slow drilling activity, marking the transition from growth to decline.

FIGURE 5 Fixed Number of Identical Wells Drilled With Variable Schedule



Source: G&R.

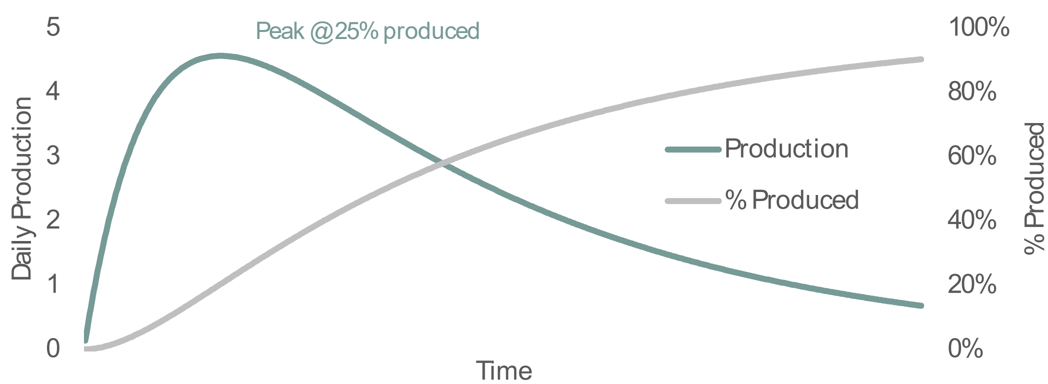
The symmetry of this model underscores the intrinsic relationship between drilling intensity and resource depletion, offering a tidy framework for understanding how production evolves under controlled conditions.

The second constraint oil companies face is where to drill. To maximize net present value, operators typically prioritize their best prospects first. This is true both within a single basin, where they aim to target the "sweet spot," and across a broader portfolio, where they allocate resources to the most promising basins. As a result, it's reasonable to assume that, over time, per-well productivity will begin to decline as the best locations are exhausted.

Earlier, we observed that an unlimited number of wells with constant productivity leads to a production plateau. Introducing declining well productivity, however, inevitably results in falling production. If we now assume an infinite number of wells, but drilled in such a way that well productivity steadily degrades, production will exhibit a different trajectory: it will grow, plateau, and then roll over. The decline on the right-hand side of the curve will be more gradual than the initial ramp-up on the left.

For instance, if new well productivity decreases by 5% each year, production peaks after only 20% of the ultimate resource has been extracted. Interestingly, the rate of degradation influences the timing of the peak in a somewhat counterintuitive way. The steeper the degradation, the later the field will reach its peak. A field with new wells declining in productivity by 10% per year, for example, will peak after 25% of its reserves have been produced. This dynamic illustrates how depletion interacts with productivity and timing, shaping the trajectory of production in unexpected ways.

FIGURE 6 Constant Drilling of Wells Whose Productivity Degrades by Year



Source: G&R.

In practice, a constant interplay exists between drilling schedules and well quality. Given the finite nature of resources and the imperative to maximize present value, the pace of drilling becomes a pivotal factor. Drill too quickly, and you exhaust the most productive areas at an accelerated rate. Drill more slowly, and you extend the life of the field, albeit at the cost of delayed returns.

As a result, every field's production is shaped by a dynamic balance between the rate of drilling and the degradation of well quality over time. The production profile that emerges reflects this delicate equilibrium, with the field's trajectory dictated by the interplay between resource depletion and development strategy.

Conventional US Production – A Case Study

With a clearer grasp of Hubbert's principles and the intricacies of well-level development, we might ask: What insights emerge from the downturn in U.S. oil production that began in 1970?

During its growth phase, U.S. drilling activity was remarkably steady. Between 1900 and 1945, the industry consistently drilled about 50 million feet annually. Over this period, as the industry matured, productivity didn't just increase—it soared. Output per foot drilled grew sixfold, rising from a modest 0.5 barrels per foot to nearly 3 barrels per foot.

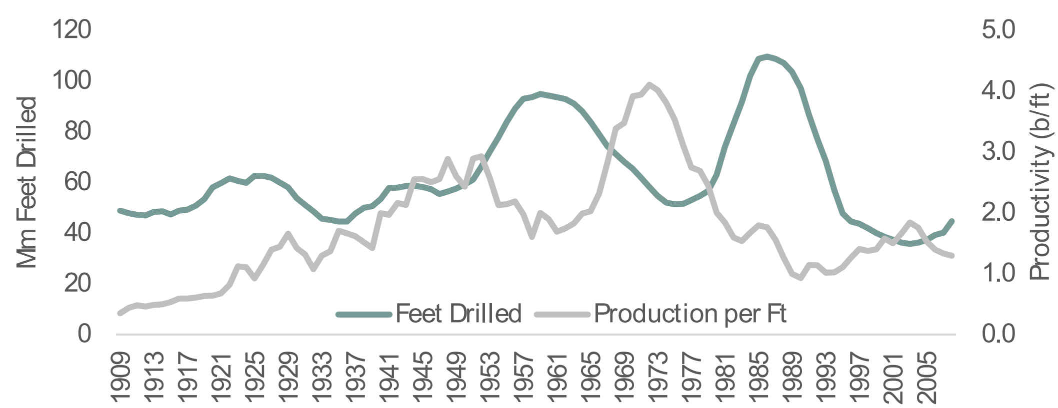
By the late 1950s, a significant shift occurred. Drilling activity surged by 70%, reaching nearly 100 million feet. Yet paradoxically, productivity halved to just 1.5 barrels per foot. As a result, new production edged up by only 20%, despite the sharp increase in drilling efforts. As total production expanded, depletion rates climbed as well, trimming net production growth by a third. The U.S. was gradually stepping onto a plateau.

In the late 1960s, production quotas and regulatory measures caused drilling to slow by 40%. This slowdown prompted companies to "high-grade" their inventory, focusing on their most promising prospects. Productivity more than doubled, and gross new production increased by nearly 50%.

Starting in 1970, productivity began its relentless decline as the prime areas of the best fields became fully developed. By the mid-1980s, productivity had fallen by nearly 75%. A surge in drilling activity—spurred by President Nixon's policies—could not compensate for the plummeting productivity, and gross new production dropped sharply. Total production had peaked in 1970 and continued to fall throughout the decade.

Thus, we see that drilling activity and well productivity often mirror each other inversely. As one rises, the other falls, illustrating the complex dynamics at play in the industry.

FIGURE 7 US Feet Drilled & Productivity



Source: EIA.

The industry, in its way, wasn't entirely wrong. They did have an abundance of new drilling locations—though of a decidedly lower quality. What they failed to grasp was the unforgiving reality of relentless base declines. It took only a tipping of the scales in new production to trigger a steep and inevitable downturn in overall output.

When examining gross new additions—calculated as productivity multiplied by feet drilled—a striking pattern emerges. This metric forms its own bell-shaped curve, one that closely mirrors the famous Hubbert curve. This played out even with an abundance of available drilling locations and despite high oil prices. The underlying cause? A steady erosion of productivity per foot drilled. The industry was running out of the highest-quality areas to exploit. And once those prime locations were exhausted, increased drilling activity only served to offset gains with corresponding declines in productivity, culminating in the rollover.

The result was a near perfect Hubbert curve, with production peaking once half the recoverable reserves had been produced.

Turning to the Shales

Equipped with our framework, what can we discern about the shale revolution?

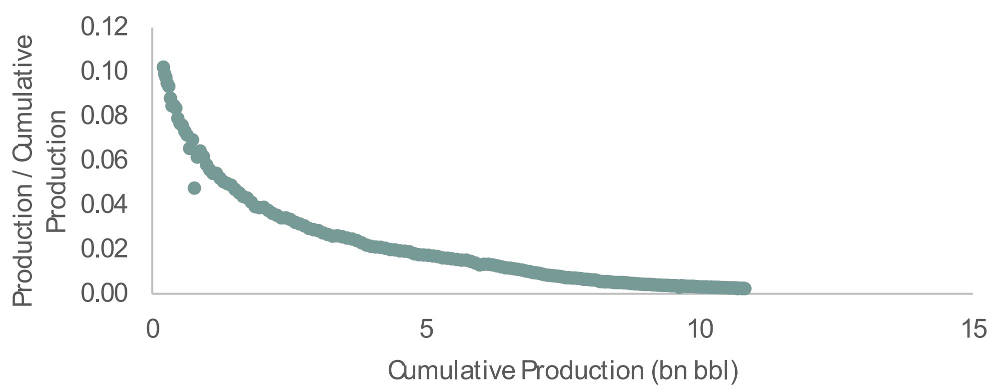
In many ways, shale basins differ markedly from conventional fields. They are vastly more aerially extensive and boast orders of magnitude more drilling locations. Early shale plays were even likened to "manufacturing processes," evoking a factory more than a traditional oil field.

Yet shale brings its own complexities. Productivity across a basin can vary dramatically, with the best areas often yielding four times the output of the worst. Applying our earlier reasoning, it's reasonable to assume that well degradation would take on a larger role, leading to production profiles characterized by earlier peaks and extended right-hand tails. Experience has borne this out.

Another defining feature of shale wells is their distinctive production pattern. They tend to produce at very high rates initially, followed by steep declines, and eventually settle into a prolonged period of low-rate output. This behavior stems from the nature of hydraulic fracturing, which releases a surge of trapped fluid—"flush" production—followed by a slower, drawn-out bleed of fluids from the formation over time.

Given these unique dynamics, it's unsurprising that shale wells defy traditional Hubbert Linearization. When plotting the ratio of production to cumulative production against cumulative production (P/Q vs. Q), the result is no longer a straight

FIGURE 8 Fayetteville Hubbert Linearization

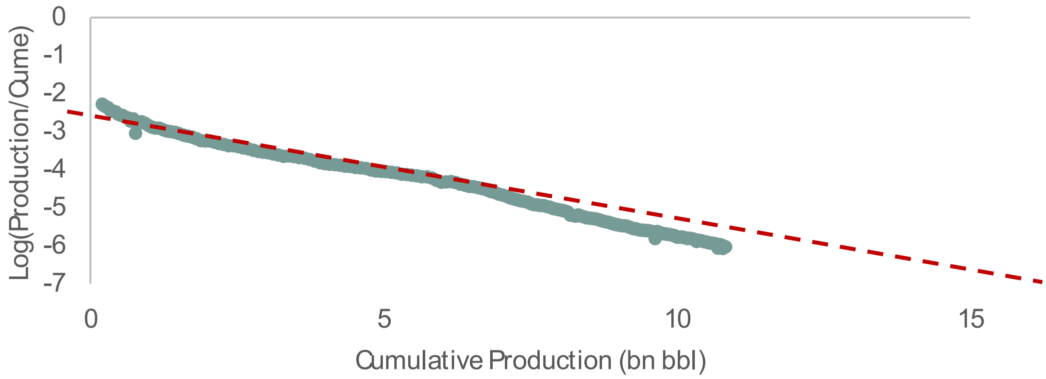


Source:NoviLabs.

line but a curve—a testament to the distinct nature of these wells.

Early analysts often struggled to apply conventional Hubbert Linearizations to shale basins, leading to forecasts that were, at best, imprecise. The difficulty lay in the fact that the production plots were not straight lines. Yet, upon closer examination, a surprising discovery emerged: while the relationship isn't linear, it is perfectly logarithmic. Plotting the logarithm of P/Q against Q produces a straight line, one that can be extrapolated with remarkable accuracy.

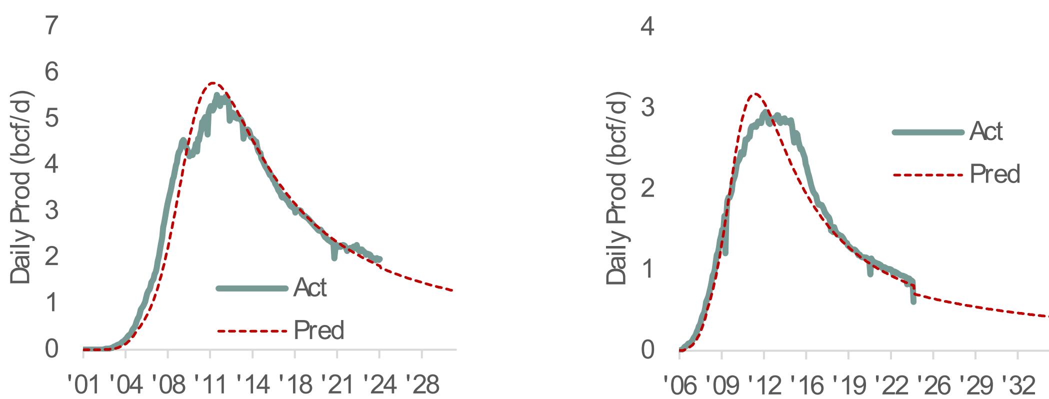
FIGURE 9 Fayetteville Logrithmic Hubbert Linearization



Source:NoviLabs.

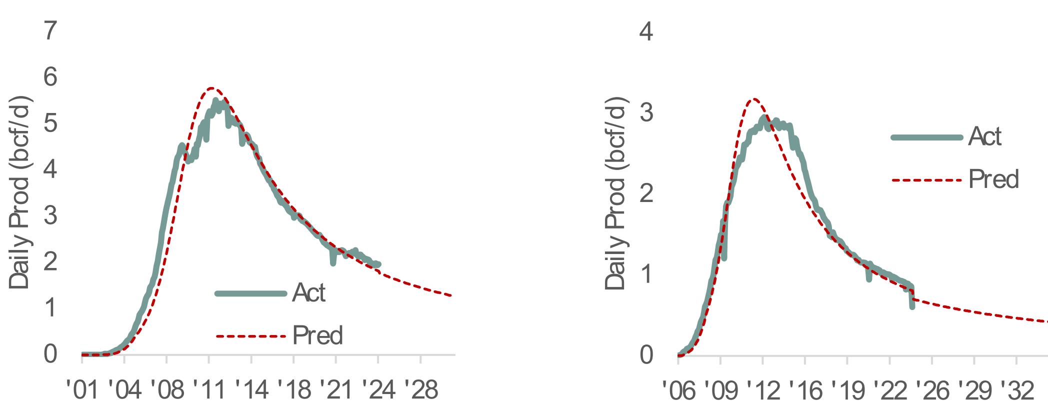
This logarithmic approach enables extremely precise forecasting of shale production profiles. Strikingly, no other analysts or academics appear to have arrived at this conclusion. Using this method, we accurately predicted the rollovers in major plays like the Barnett, Fayetteville, Eagle Ford, and Bakken. These fields have since

FIGURE 10a Barnett and Fayetteville Logrithmic Hubbert Curve



Source:NoviLabs and G&R.

FIGURE 10b Bakken and Eagle FordLogrithmic Hubbert Curve

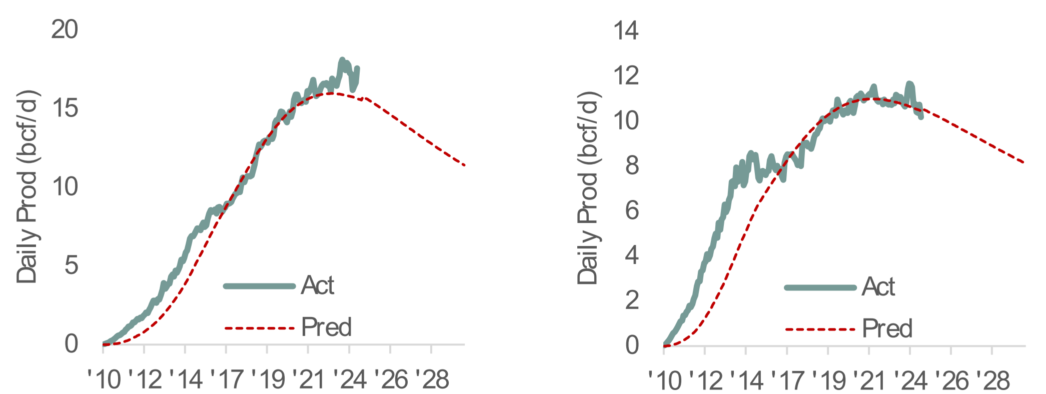


Source:NoviLabs and G&R.

declined anywhere from 26% to 80%.

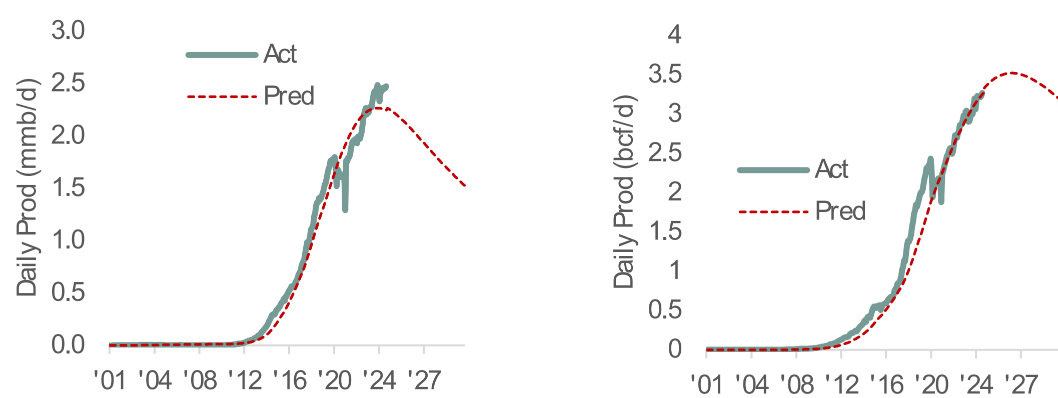
The same analysis now reveals that both subbasins of the Marcellus have rolled over, as has the Midland side of the Permian Basin. The Delaware side of the Permian

FIGURE 10b SW & NE MarcellusLogrithmic Hubbert Curve



Source:NoviLabs and G&R.

FIGURE 10b Midland & Delaware Permian Logrithmic Hubbert Curve



Source:NoviLabs and G&R.

and the Haynesville are expected to follow shortly.

Beyond predicting rollovers, the logarithmic Hubbert Linearization also captures the longer right tails that are characteristic of shale basins. For instance, the Fayetteville and Barnett production profiles have been distinctly asymmetric, declining more slowly than they ramped up. Our logarithmic model identified this trend with precision.

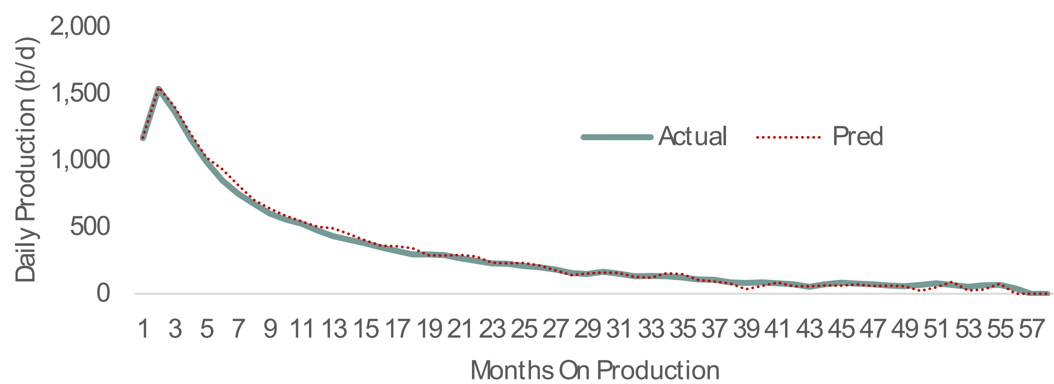
By applying this tool, we can accurately estimate the recoverable reserves of each basin and predict the timing of peak production. According to the logarithmic Hubbert Curves, most shale basins reach their peak after approximately 30% of their recoverable reserves have been produced. This longer right tail is a hallmark of well degradation and highlights the gradual drilling out of the cores.

Enter Neural Networks

To validate our ultimate recoverable reserve estimates from logarithmic linearizations and explore shifts in well productivity, we turned to artificial intelligence. Frustrated with the limitations of conventional tools, we began developing our own in 2019. The result is a sophisticated toolkit of neural networks and machine learning models, custom-built for the task at hand.

As we've noted, our unique position combines deep domain expertise with a strong grasp of artificial intelligence. While AI has become a buzzword, and everyone now claims expertise, we've been training and refining deep neural networks since 2019. Unlike the sprawling large language models like ChatGPT, our models are purpose-built and pragmatic. Instead of mimicking human thought, they are trained to predict shale well production based on subsurface geology, regional trends, and well completion designs.

FIGURE 11 Midland Basin Type Curve vs. Actual



Source:G&R.

The payoff has been remarkable. For instance, the next chart illustrates our models' predicted average type curve for the Midland side of the Permian Basin against actual well results, achieving an R^2 of nearly 0.98.

Since starting this journey, we've rebuilt our models several times, each iteration leveraging the latest advancements in technology and architecture. We know encorporate well completion data such as fluid and proppant loading and lateral length; suburface geological data such as permiability, porosity, clay content, thermal maturity, organic content and pressure; geological trend data, itself learned from a deep neural network; and spacing data related to neighboring wellbores. Our current iteration integrates tools like Random Forest models, a deep neural network to uncover hidden geological patterns, and cutting edge methods useful for intrepreting the results. The results are striking.

First, we mapped each basin, identifying the remaining drilling locations by formation horizon. For the Midland side of the Permian Basin, it's clear that many top-tier locations have already been developed. While significant numbers of undrilled wells remain, they are located in far less productive parts of the field.

Next, we estimated the ultimate recoverable reserves for each well—drilled and undrilled—aggregating the results to compare with our linearizations and cumulative production to date. This approach, moving from a "top-down" basin view to a "bottom-up" well-level perspective, confirmed the robustness of our methods. Remarkably, our AI models produced reserve estimates within 15% of the logarithmic linearizations for oil and within 14% for gas.

Across all fields, our linearizations suggest that basins will roll over when approximately 28% of their reserves are produced. Our machine learning models show oil shales are now 28-32% depleted, while gas shales are 30-34% depleted. This points to a slowdown driven by depletion, not price or regulation.

Indeed, total shale oil and gas production likely peaked late last year. Both are already down 1%, and our models predict year-over-year production declines will turn sharply negative within six months.

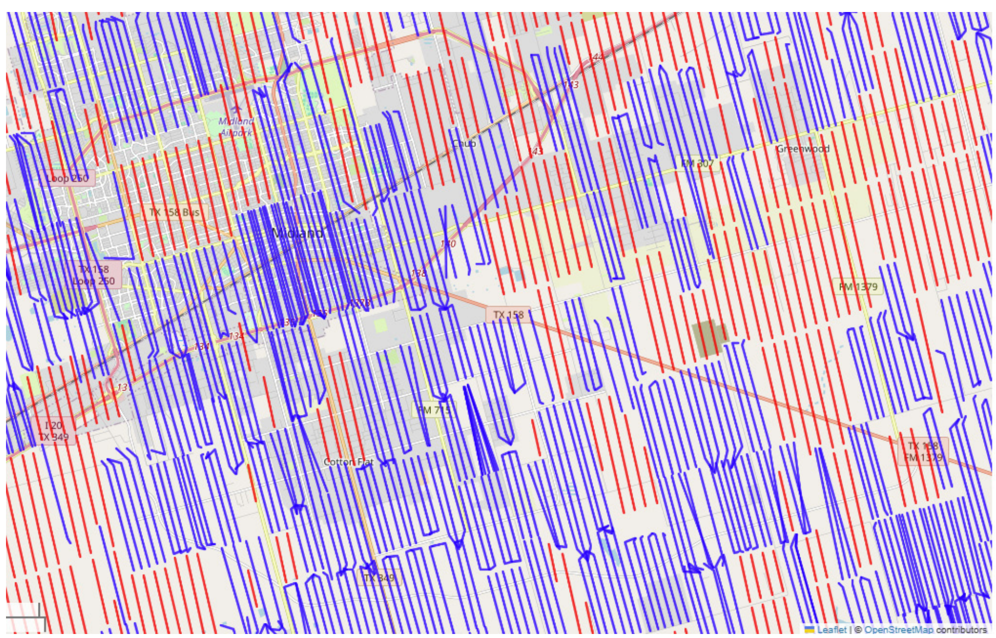
Depletion Paradox Redux

This slowdown couldn't come at a worse time. Since 2010, the growth in global oil demand has been entirely met by shale crude and NGLs. Domestically, shale gas production has suppressed prices to 80% below global levels, fueling the largest-ever rollout of natural gas-fired electricity generation and LNG export capacity in U.S. history. Yet few have considered the implications of sourcing sufficient feedstock. With Americans consuming as much energy from natural gas as from oil, what happens if prices converge with global levels?

Even with rising prices, we doubt shale production will surge. History offers a lesson. The unexpected production rollover in the 1970s was driven by declining per-well productivity—a pattern we believe will repeat.

Today, 60-70% of all shale production comes from wells less than three years old,

FIGURE 12 Drilling Map of Midland County Permian



Source:NoviLabs and G&R.

making production trends highly sensitive to changes in new well productivity. Yet the remaining undrilled locations are, on average, 35% less productive than wells drilled in 2023, primarily due to inferior geology. This degradation is not easily remedied.

Should higher prices or deregulation spur drilling activity, the likely outcome would be plummeting productivity, much as occurred in the 1970s. Despite increased drilling, total production would struggle to grow, constrained by the quality of remaining inventory and the relentless pace of depletion.

Between 1973 and 1985, the U.S. drilled more conventional well feet than during any other 13-year period. Yet production still declined. Today, we face a similar paradox: while undrilled locations remain and higher prices may render them economic, it is unlikely they will materially boost total U.S. production. In the end, the paradox remains—depletion is an unstoppable force, and it is becoming harder and harder to keep up.

3rd Quarter 2024 Natural Resource Market Commentary

Natural Gas

In the volatile world of U.S. natural gas, the past quarter unfolded with all the drama of a Shakespearean act. Prices began at a modest $2.60 per Mcf, buoyed by the quiet equilibrium of early spring. But by mid-June, the plot had transformed. An unseasonal heat wave gripping the central United States sent prices soaring to $3.15, a rally that spoke as much to the market's sensitivity as it did to the hot weather. Yet, as quickly as the heat arrived, it receded. Milder temperatures reclaimed the stage and gas prices tumbled in response, bottoming at $1.90 by the end of August.

While market participants obsessed over weather patterns, few paused to consider the silent protagonist in this unfolding drama: inventories. The 2023–2024 winter, among the warmest on record, left a legacy of near-record storage levels. At the outset of the injection season, inventories stood at a staggering 700 Bcf—or 40%—above the ten-year average. Yet, tight fundamentals have nearly erased this surplus in a remarkable turn. Over the third quarter alone, inventories were drawn down by almost 400 Bcf. By quarter's end, storage levels stood less than 5% above the norm, a quiet but profound shift that few have fully grasped.

This brings us to the present moment, where the market stands at a crossroads. If the coming winter delivers typical cold—after two years of unseasonable warmth—U.S. natural gas prices could well align with international benchmarks which currently hover near $14/MMBtu. The implications are vast, mainly as U.S. natural gas production, once seemingly boundless, now hints of rolling over.

Over the past fifteen months, growth in U.S. gas production has stalled. Indeed, in the past seven months, production has begun to contract. Since peaking in December 2023, U.S. dry gas supply has fallen by 3 Bcf per day—a 3% decline. Year-over-year data tells a similar story, with dry gas production now down by 1.2 Bcf per day, slightly more than 1%.

The natural gas bears, ever resourceful, have latched onto recent productivity data, pointing to gains in drilling efficiency across several shale plays as evidence of a potential resurgence. Yet this narrative, seductive though it may be, demands scrutiny. Our analysis, informed by deep neural networks, reveals that these productivity gains are not the herald of renewed growth but rather the predictable consequence of declining rig counts.

Consider this: in August 2022, the Baker Hughes natural gas rig count stood at 166. By February 2024, that number had dropped to 121, a 27% decline. Over the past seven months, the rig count has fallen further, reaching just 101—a 17% plunge in a remarkably short time. As every seasoned industry observer knows, exploration and production companies cut their least productive rigs first, leading to an inevitable but temporary boost in reported drilling productivity.

But this veneer of efficiency masks a more profound truth. Producers, facing dwindling options, have concentrated their remaining rigs on the final Tier 1 drilling areas within their plays. This "high-grading" of inventories explains the reported productivity gains of the past eighteen months but also signals an endgame. Our analysis suggests that Tier 1 drilling inventory in these plays is rapidly being exhausted. The accompanying graphics in this letter's "Shale Fields and the Hubbert Curve" section lay bare this reality, using the Marcellus as a case study in depletion dynamics.

The broader picture is no less sobering. All U.S. natural gas production sources, whether from dedicated shale gas plays or associated gas from shale oil operations, are plateauing. Against this backdrop, demand is poised to surge. LNG exports are set to expand dramatically, while the data center boom adds another layer of consumption to the mix.

The result? A market that is shifting, after fifteen years of structural surplus, toward a long-running structural deficit. The abundance of shale gas has defined the natural gas story for the past decade and a half. That era, we believe, is drawing to a close, and the implications for prices—and the broader energy landscape—are profound.

Oil

"Hedge Funds Have Never Been This Bearish on Brent Crude Before."
— Bloomberg, September 13th, 2024

The global crude oil market is steeped in gloom, its mood defined by a persistent, almost compulsive bearishness. The numbers tell the story: West Texas Intermediate crude has fallen 16%, while Brent is down 14%. Investors, spurred by fears of weak demand, whisper of a resurgence in U.S. shale production, and rumors of OPEC retreating from its production cuts, have retreated en masse. The malaise is so pervasive that even casual observers can't miss it—headlines like Bloomberg's serve as both symptom and diagnosis.

Yet, this moment offers something extraordinary for those with a contrarian bent. To them, today's bearish consensus echoes another time and place: 2003. It's an

FIGURE 13 Economist Cover

Source:Economist.

audacious comparison but not an unwarranted one. For readers who need reminding, 2003 was a year of extraordinary pessimism in oil markets. The Economist, never shy about forecasting the end of an era, ran a now-infamous August 2003 cover story titled "The End of the Oil Age."

The reasons for their bearishness then are eerily similar to those dominating headlines today: weak demand, this time exacerbated by structural changes in the post-9/11 economy and surging non-OPEC supply.

What happened next, of course, defied nearly everyone's expectations. Oil prices, seemingly buried under the weight of bearish consensus, staged a rally for the ages, climbing nearly fivefold over the subsequent five years. At the heart of this surge was something no one saw coming: a sharp, unexpected slowdown in non-OPEC supply growth. Only a handful of voices, including ours, predicted this pivotal shift, rooted in dynamics first described by King Hubbert.

Today, we find ourselves standing at a similarly critical juncture. Forces like those of 2003 are re-emerging, this time with U.S. shale oil at the epicenter. Just as the North Sea and Mexico's Cantarell fields dominated non-OPEC supply growth in the 1990s, U.S. shale has been the primary driver of non-OPEC growth over the past fifteen years. But the signs of exhaustion are mounting. Production growth is slowing rapidly across nearly all shale plays, with the Permian Basin as the lone, albeit faltering, exception.

The parallels with 2003 don't end there. Back then, as non-OPEC supply growth sputtered, OPEC began regaining market share and pricing power—a position they leveraged to stunning effect. We believe this pattern is about to repeat. This letter's "Hubbert Peak" section lays out the forces driving the current slowdown in shale production, which has accounted for 90% of non-OPEC supply growth over the past decade and a half. Just as in 2003, OPEC stands poised to reassert its dominance—and, just as before, they are likely to wield their power with precision.

The sheer magnitude of bearish sentiment makes today's setup particularly intriguing. Markets have a peculiar way of punishing consensus and the current alignment of factors suggests that today's pessimism may be tomorrow's opportunity. History tells us that significant shifts in oil markets often arrive unannounced and when they do, the magnitude of change can be breathtaking.

At the close of 2003, few could have imagined the bull market in oil that was about to unfold. Yet it did, fueled by dynamics many failed to appreciate until long after. Today, the stage is set for a similar reversal. The global oil market weighed down by the relentless pessimism of the crowd is once again presenting a rare investment opportunity.

The lesson of 2003 is as relevant now as it was then: when conventional wisdom becomes too comfortable, the market's pendulum is often poised to swing the other way. Investors would do well to remember that history, like oil itself, tends to flow in cycles.

Coal

The coal market was quiet and trendless through the third quarter. In the U.S., Powder River Basin prices eked out a modest 3% gain, while Central Appalachian coal slid by 10%, and Illinois Basin coal followed suit with an 8% decline. Overseas, the picture was similarly mixed: Australian thermal coal prices, represented by Newcastle benchmarks, advanced 9%, while South African thermal coal, measured at Richards Bay, dipped by 6%. Meanwhile, Chinese steelmakers' warnings of severe overcapacity cast a shadow over seaborne hard-coking coal prices, sending Australian hard-coking coal down nearly 10%.

U.S. coal equities—what few remain publicly traded—faltered dramatically in July and August, plunging by nearly 15%. But then mid-September saw a sharp reversal. China announced a major stimulus plan which ignited a furious rally, leaving the Dow Jones/Wilshire U.S. Coal Index up 15% for the quarter. History, as it often does, offered its own commentary: coal stocks have been the vanguard of every commodity bull market over the past 125 years. The pattern appears intact. Since the broader natural resource equity market bottomed in the summer of 2020, coal stocks have risen nearly sevenfold—outstripping other commodities and every major equity index, including the high-flying Nasdaq 100.

Since their peak in the summer of 2022, coal stocks have traded sideways. Yet signs suggest the Dow Jones/Wilshire Coal Index may have broken out to the upside. Should natural gas prices surge, as anticipated, utilities could pivot back to coal—a substitution the U.S. hasn't seen in over a decade. Additionally, the re-election of Donald Trump to the presidency introduces a political wildcard. A less coal-hostile administration could ease the regulatory pressures that have weighed on utilities, slowing the closure of coal plants still in operation.

Coal stocks, in the meantime, languish at remarkably low valuations. After two years of listless trading, they could be poised for a resurgence. The natural gas market faces transformative shifts and, when combined with a friendlier political backdrop, the stage is set for a potential rally of notable proportions. For investors not constrained by ESG considerations, the opportunity seems compelling: coal stocks, long maligned, may once again earn their place in the limelight.

Gold & Precious Metals

Gold and silver prices increased in the third quarter, with gold climbing 13% and silver advancing 6%. Both metals have broken through significant technical levels—gold at the end of February and silver at the beginning of May—and their subsequent trajectories have been extraordinary. Since its breakout, gold has surged nearly 35% while silver, following its May rally, has gained 25%. These moves' sustained strength and persistence suggest that precious metals have entered robust, new bull markets.

For a deeper dive, see the precious metals section of this letter where we explore the renewed interest of Western investors in the physical gold and silver markets. We also examine the notable behavior of central banks and the puzzling apathy Western investors continue to exhibit toward gold equities. This investor indifference, particularly striking given the compelling valuations of gold stocks, is a theme we analyzed in detail in our previous letter.

The early stages of a gold and silver bull market are unfolding, offering investors a rare opportunity. With precious metals markets gathering momentum, we believe it is essential to maintain substantial exposure to this sector.

Uranium

Despite a steady price performance in the third quarter, the news flow in the uranium market was anything but quiet. Prices began the quarter at $86 per pound, high for the period, and drifted slightly lower to close at just under $82 per pound. While price volatility was absent, the torrent of uranium-related news more than compensated.

The most significant supply-side development came on August 23rd, when Kazatomprom, the world's largest uranium producer, announced a substantial downgrade to its 2025 production guidance. In August 2023, the company had laid out ambitious plans to produce 79–80 million pounds of uranium in 2025—a dramatic 45% increase over 2023 levels. These goals had raised eyebrows during our April 2024 visit to Almaty, where we met with Kazatomprom executives. Our observations strongly suggested these targets were unattainable, a conclusion we shared in a blog post published two days before the company's announcement. True to our forecast, Kazatomprom's half-year update revealed a 13-million-pound shortfall against its initial 2025 projections, exacerbating the structural deficit in global uranium markets through 2030.

During our Almaty meetings, we also probed Kazatomprom on how much of its projected 2024 and 2025 production increases had been sold forward through contracts. While the company deflected our queries, their 2024 half-year financial statements revealed a notable 20% year-over-year decline in U3O8 inventories. It appears that reduced production targets for 2024 have been offset by inventory drawdowns, with 3.3 million pounds of uranium sold from stockpiles. Kazatomprom's inventories now stand at 16 million pounds—a 40% reduction from five years ago. This sharp inventory decline raises the possibility that Kazatomprom may eventually need to enter the spot market to fulfill forward sales commitments, creating a potentially bullish inflection point.

The quarter's most surprising news arrived just as it drew to a close. Microsoft announced a landmark deal to reopen the Three Mile Island Unit 1 nuclear facility which has been idle since 2019. Under the agreement, Microsoft will purchase 100% of the facility's output to power its data centers. Following this, Google and Oracle unveiled plans to invest in small modular reactors (SMRs) for their own data center energy needs.

For a deeper analysis of these developments, refer to the uranium section of this letter, where we delve into the implications of these announcements. They reinforce our conviction that SMRs will dominate the nuclear power industry in the decades to come. This transformation carries enormous implications—not just for global climate goals, as SMRs replace coal-fired generation, but also for economic growth. SMRs are up to six times more energy efficient than hydrocarbon-based power generation, capable of providing the surplus energy needed to drive an increasingly power-intensive global economy.

The adoption of SMRs represents a paradigm shift in uranium demand, introducing step-change increases that remain conspicuously absent from most analysts' models. With fundamentals for the uranium market growing increasingly bullish, these recent developments underscore the transformative potential of nuclear power in the 21st century.

Agriculture

Agricultural markets remained subdued in the third quarter as the 2024 North American harvest progressed. The USDA's latest *World Agricultural Supply and Demand Estimates (WASDE)* offered few adjustments to 2024–2025 grain ending stocks. Against this backdrop, grain prices drifted lower, weighed down by persistent bearish sentiment.

Corn prices averaged $3.90 per bushel in the third quarter, a 12% decline from the $4.45 average in the second quarter. Soybeans averaged $10.25 per bushel, down 14% from $11.85, while wheat prices fell 10% to $5.45 per bushel from their previous $6.10 average. Speculative traders maintained historically bearish positions, particularly in corn and soybeans. July saw corn futures hit their second-largest net short position ever, with nearly 240,000 contracts sold short. Similarly, soybean futures recorded their second-largest bearish position in August, with 185,000 net shorts, only surpassed by March's record of 200,000. Though slightly less aggressive, wheat traders ended the quarter still net short.

Yet, this bearish speculative activity sharply contrasts commercial traders' behavior—the so-called "smart money." Commercials have maintained near-record long positions, a strong indicator that the two-and-a-half-year bear market in grains, which has seen prices retreat by over 50% from their post-Russian invasion highs, could be nearing its end.

What might catalyze a reversal?

At our 2024 Investor Day, Shawn Hackett, author of the *Hackett Agricultural Report*, provided compelling insights into potential drivers. Hackett's presentation focused on the alignment of solar and planetary cycles, suggesting the onset of another Gleissberg Cycle—an 88-year phenomenon tied to eight 11-year solar cycles. Historically, the last Gleissberg Cycle coincided with the devastating Dust Bowl of the 1930s. While this theory remains controversial, Hackett and we at Goehring & Rozencwajg see a connection.

Current conditions lend weight to the argument. Extreme droughts are already gripping major agricultural regions like Brazil, Ukraine, and Russia—among the worst in over a century. Could these record droughts be early signs of the Gleissberg Cycle's influence on global climate patterns? And could the U.S. Midwest, which has thus far been spared, soon experience similar drought conditions?

Hackett highlighted an intriguing parallel: the recent dry spell in the eastern United States. Cities like New York, Philadelphia, and Washington, D.C., have set records for lack of precipitation, with New York experiencing its second-longest dry stretch in recorded history. Moreover, much of the country, especially the Midwest, is now grappling with moderate to extreme drought conditions, a pattern reminiscent of the fall of 1929, which preceded the historic drought of 1930 and the onset of the Dust Bowl.

Valuations in agricultural markets remain extraordinarily cheap and bearish psychology still dominates. If the Gleissberg Cycle does usher in a prolonged drought, it could fundamentally alter global grain market dynamics, driving prices sharply higher and positioning agricultural equities as market leaders. This potential inflection point is one we will monitor closely in the months ahead.

Base Metals & Copper

Base metals and copper prices firmed in the third quarter, driven by the Chinese government's unexpected stimulus package announced on September 24th. Measures included reducing mortgage rates for existing homeowners, lowering commercial banks' reserve requirements, and creating a $100 billion facility to accelerate sales of unsold housing stock and support the stock market. The announcement sparked a sharp rally in Chinese equities and ignited investor optimism that China's economic slowdown might stabilize.

Zinc led the base metals rally with a 5% gain, followed by aluminum (up 3.5%), copper (up 2.5%), and nickel (up 1.5%). Copper and base metal equities also performed strongly. The COPX copper equity ETF advanced 4.8%, while the XBM CN ETF, which tracks the S&P Global Base Metals Index, rose 5.22%.

This letter's introductory essay explored the increasingly uncertain outlook for renewable energy and its implications for global copper demand. Investors in copper markets have adopted bullish stances in recent years, heavily influenced by aggressive demand forecasts from consulting firms. These forecasts are rooted in assumptions about widespread renewable energy adoption—assumptions we now view as overly optimistic due to the low energy efficiency of renewables.

For a deeper dive, we encourage you to read the copper section of this letter, where we examine emerging supply and demand dynamics in the global copper market. Despite intensifying challenges in China's property development sector, Chinese copper consumption continues its strong growth. This growth appears tied to massive investments in wind and solar farms to reduce China's reliance on imported energy. We attempt to disentangle copper consumption driven by these renewable projects from the baseline copper demand required to support China's growing per capita GDP. As we've highlighted in previous letters, China is now overconsuming copper for the first time in twenty-five years—a trend that is partially linked to its renewable energy investments, a largely underexplored aspect of global copper demand that we aim to quantify.

While we remain bullish on copper in the short term due to strong demand and a deceleration in supply growth over the past nine months, we urge caution over the long term. Cracks are beginning to form in the widely accepted bullish copper narrative. Both supply and demand dynamics warrant closer scrutiny, particularly as demand assumptions tied to renewables face growing challenges.

A New Dawn for Nuclear Power

It is no small irony that Three Mile Island, once a byword for the peril of nuclear energy, now stands poised to symbolize its renaissance. As The *New York Times* reported on November 11th, 2024, nuclear power plants, once the target of fierce opposition, are now coveted for their ability to produce massive amounts of electricity without the emissions that contribute to climate change. A transformation in perception is underway, and with it comes a surge of activity in the nuclear industry—one that bodes well for uranium's future.

The virtues of nuclear power, long overshadowed by fear and controversy, are finally being recognized across the spectrum—from investors and electricity consumers to government officials and the global environmental community. These virtues, which we've outlined in detail, are so compelling that a worldwide nuclear boom is underway. The uranium market is positioned for a period of unprecedented excitement.

The signs are everywhere. Microsoft recently announced a groundbreaking partnership with Constellation Energy to reopen the Three Mile Island Unit 1 reactor which has been shuttered since 2019. The plant's troubled history, particularly the infamous 1979 accident at its second reactor, makes this announcement extraordinary. Microsoft has agreed to purchase all the electricity generated by the plant at a rumored premium exceeding 100% above wholesale prices—a move that underscores the strategic value of nuclear power in today's energy landscape.

Hot on the heels of this development came another seismic event. On September 30th, Holtec International secured a $1.5 billion loan guarantee from the U.S. Department of Energy to reopen the 800-megawatt Palisades Nuclear Plant in Michigan which had ceased operations in 2022. But Holtec's ambitions don't stop there. The company plans to install two small modular reactors (SMRs) on the site, adding 600 megawatts of new capacity while leveraging existing infrastructure. This dual strategy of reviving old plants and pioneering new technologies exemplifies the forward momentum of the nuclear industry.

Meanwhile, Google has made its own bold move, becoming the first company to sign an agreement with Kairos Power, a developer of molten salt-based SMRs. The deal paves the way for up to 500 megawatts of nuclear-generated electricity to power Google's data centers. Kairos's press release captured the significance of this partnership: "Having an agreement for multiple deployments is important to accelerate the commercialization of advanced nuclear energy by demonstrating the technical and market viability of a solution critical to decarbonization power grids while delivering much-needed energy generation and capacity." In other words, Google is not merely buying power; it is helping to usher in a new era of nuclear energy.

Even Amazon has entered the fray, albeit with complications. In March, the company struck a deal to buy power for its nearby data center campus directly from Talen Energy's Susquehanna Steam Electric Station, one of the largest nuclear plants in the U.S. This arrangement, which would have allowed Amazon to bypass the grid, was blocked by the Federal Energy Regulatory Commission (FERC) on November 4th. In reality, FERC's rejection, ostensibly over grid reliability concerns, was a move to protect local grid operators and consumers from losing access to affordable power.

In its agreement with Talen, Amazon was attempting to buy power directly from the plant itself, not the grid system. In the parlance of the power-generating business, Amazon was attempting to get "behind the meter," effectively stepping in front of consumers who had to buy their metered electricity off the grid. The FERC rejected the proposal, stating it may harm national security and grid reliability. However, the FERC's rejection of the Amazon deal centered on its negative impact on local grid operators and their residential customers--who now would be power short and forced to purchase more expensive power from other electricity providers.

While the decision might seem bearish for nuclear at first glance, it is anything but. As Cameco noted on its recent earnings call, FERC's stance effectively forces data centers to either reopen old plants or build new ones---a win for aggregate uranium demand either way.

Finally, Meta Platforms has made its nuclear ambitions known, albeit indirectly. The discovery of a rare bee species on the proposed site delayed plans for a new data center which was to be powered by electricity generated from a nearby nuclear power plant. Still, the *Financial Times* revealed that CEO Mark Zuckerberg remains committed to nuclear power to solve Meta's energy needs. Frustrated by the limited nuclear options in the U.S. compared to China's aggressive adoption of the technology, Meta is reportedly exploring various deals for carbon-free energy, with SMRs high on the list.

These announcements underscore a simple but powerful truth: long-maligned and underutilized nuclear power is the only viable solution for the energy-intensive demands of the modern world. Over the past several years, we've had to increase our uranium demand estimates by nearly 40 million pounds as plant closures have been deferred and new-build plans have accelerated. With the introduction of SMRs, offering even greater efficiency and safety, the nuclear industry is poised to take another transformative leap.

The clearest indication that nuclear power is entering a new golden age is the enthusiasm of data center operators who represent the cutting edge of electricity consumption.. These companies understand that nuclear energy addresses not just availability and cost concerns but also the pressing challenges of CO2 emissions and climate change.

For investors, the uranium story has never been more compelling. The developments we witness are not merely bullish—they are the harbingers of a seismic shift. Like the nuclear industry itself, the uranium market is on the cusp of a remarkable transformation.

Precious Metals: The Return of the West

In the tumult of the global gold market, the past four years have unfolded as a clash of opposing forces. On one side, the steady drumbeat of rising real interest rates beginning in early 2021 prompted Western investors to liquidate gold holdings with an enthusiasm as familiar as it is predictable. Conversely, an equally determined cadre of global central banks emerged as voracious buyers, amassing reserves with a resolve that seemed to shrug off conventional market pressures.

Initially, it appeared the sellers were winning. By the third quarter of 2022, the price of gold had fallen 20% from its highs. Yet, as often happens in markets governed by crosscurrents, the story took an unexpected turn. Central bank buying surged to unprecedented levels in 2022, ultimately overwhelming Western selling. The result was a sharp reversal: gold prices began a remarkable ascent, climbing steadily through 2023 as central banks continued their buying spree. By the middle of 2024, the gold price had vaulted over 70% above its 2022 lows, an extraordinary feat given the headwinds.

However, the market appears poised on the brink of a fundamental transformation. Central banks, though still buyers, have eased back from the feverish pace of the past two years. Meanwhile, the tide of Western investor sentiment, long bearish, seems to be turning. Declining real interest rates are enticing these erstwhile sellers to reverse course. Between October 2020 and May 2024, the eighteen physical gold ETFs we track collectively shed 1,200 tonnes, rivaling the massive outflows of 2012–2015. But since mid-May, these same ETFs have pivoted, accumulating 150 tonnes—a decisive shift that mirrors broader changes in sentiment.

Silver, often the forgotten sibling of gold, tells a parallel story. From 2021 through early 2024, Western investors liquidated physical silver holdings with abandon, reducing ETF reserves by 13,000 tonnes—two-thirds of the silver amassed during the buying phase of 2019–2021. Yet here, too, the tide has turned. Since May, these ETFs have added 2,500 tonnes of silver, echoing the shift in gold markets.

The current buying phase starkly contrasts the brief resurgence of Western gold demand following Russia's invasion of Ukraine. Then, gold ETFs accumulated nearly 400 tonnes within two months, but the rally proved short-lived, lacking confirmation from the silver market. Today, the synchronized accumulation of gold and silver suggests a deeper, more sustained shift.

Central banks remain in the picture, albeit with a somewhat reduced role. In the third quarter of 2024, they purchased 186 tonnes of gold, down 40% from the same period a year earlier. The Polish National Bank led the charge, adding 42 tonnes to bring gold to 16% of its reserve assets, with plans to push that figure to 20%. India followed, adding 13 tonnes in the third quarter after purchasing 18 tonnes in each of the first two quarters. Noticeably absent was China, which, after dominating as the largest central bank buyer in 2023, has now sat out for two consecutive quarters—a pause that reflects the dampening effect of gold's recent price surge.

For 2024, total central bank purchases through the first three quarters reached 694 tonnes—a 17% decline from 2023's record-breaking pace, yet still the third-highest on record. These figures suggest that central banks, while no longer driving the bus, remain key players in what could be a historic transition in global monetary regimes.

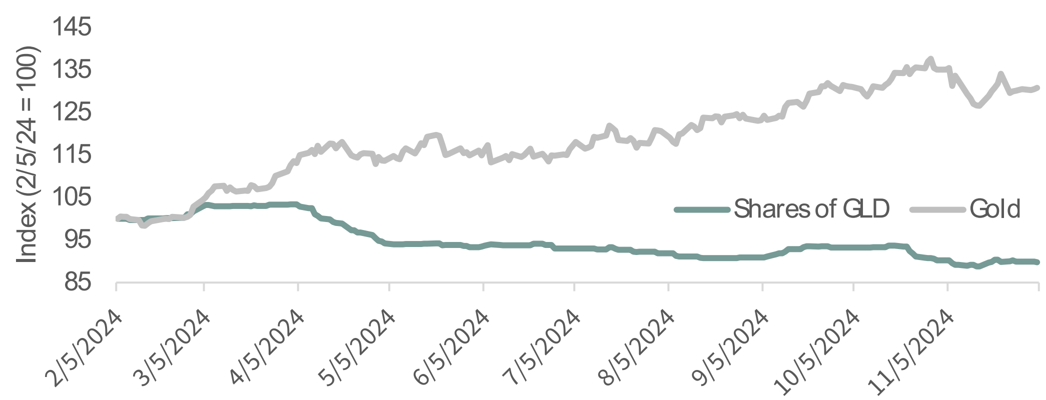
Similar seismic shifts occurred in the early 1930s, the late 1960s, and the turn of the millennium. While the specifics of the impending change remain elusive, the outcome—a serious debasement of fiat currencies relative to gold and other real assets—seems all but inevitable. The price of financial assets will be debased relative to gold and other real assets which happened in the four other monetary regime changes that took place last century. The subject of monetary regime change and its impact on gold prices is a subject we have extensively covered in previous letters.

If central banks set the stage for gold's recent rally, the return of Western investors could amplify the narrative. Gold prices are in the midst of a substantial bull market, yet investors interest in gold equities remain eerily muted. By several metrics, gold stocks today are as cheap as they were in 1999–2000, a period marked by deep skepticism and relentless selling from European central banks. For more details on the cheapness of gold stocks, please consult our 2Q24 letter.

Despite a 15% rise in gold prices since our last letter, the GDX—the most widely held gold equity ETF—has seen outstanding shares shrink by 5% over the past three months. Since gold's breakout in March, GDX shares have contracted by nearly 20%, even as gold prices climbed over 30%. This peculiar divergence—the rising price of gold versus waning interest in gold equities—is a study in investor psychology.

The chart below illustrates this anomaly, juxtaposing the advancing gold price against the declining shares outstanding of GDX.

FIGURE 14 Shares Outsanding of GDX vs. Gold Price



Source:Bloomberg.

For all the fascination with the "Magnificent Seven" tech stocks, the numbers tell a different story. While the QQQ ETF, which tracks the NASDAQ 100, is up 23% year-to-date, gold and gold equities, as measured by the GDX, have risen 38% and 34%, respectively. Yet the broader investing public remains fixated on tech, oblivious to the quiet outperformance of precious metals.

We believe we are witnessing the early stages of a gold bull market that will run for years. The current disinterest in gold equities represents a remarkable opportunity for contrarian investors. Gold stocks will likely be viewed as indispensable assets when this bull market reaches its zenith. For now, however, the prevailing disinterest offers a golden—if undervalued—opportunity.

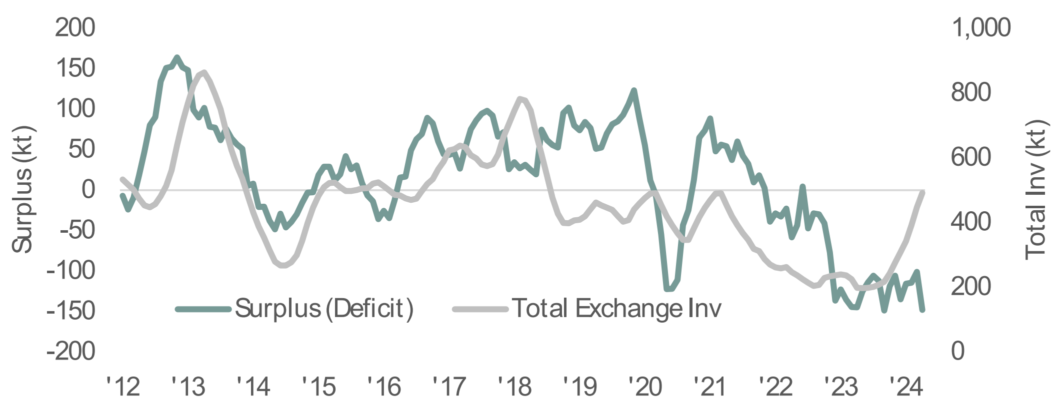
The Curious Case of Chinese Copper Consumption

In last quarter's letter, we outlined a rising tide of bearish signals within the global copper market. Chief among them was the growing divergence between our modeling of monthly copper market surpluses and deficits and the behavior of mobilizable copper inventories—those inventories readily shifted into and out of exchange warehouses. While monthly data often carries significant variability, consistent surpluses tend to elevate exchange inventories, whereas sustained deficits typically draw them down.

Beginning in late 2019, our modeling indicated that the global copper market had swung decisively into deficit. Naturally, we anticipated that inventories held at exchanges would begin a prolonged decline.

Indeed, this expectation was realized. After peaking at over 900,000 tonnes in early 2018, exchange inventories—driven by the market's deficit conditions—steadily shrank to a little over 160,000 tonnes. This extreme tightness triggered the copper short squeeze that rattled the COMEX futures exchange in April and May. Yet, paradoxically, even as our modeling continues to point to persistent deficits, exchange inventories have surged.

FIGURE 15 Copper Surplus (Deficit) vs. Inventory



Source:WBMS and Bloomberg.

As the chart illustrates, exchange inventories have tripled since the short squeeze. The critical question now is whether this surge reflects unexpected demand weakness or some temporary dislocation in copper flows caused by the squeeze itself. Are traders stockpiling inventories as a precaution, wary of being caught in another financial squeeze? It's a plausible theory—especially given that inventories, after spiking to over 600,000 tonnes, appear to be edging downward again. This trend demands close monitoring.

The latest data from the World Bureau of Metal Statistics (WBMS) confirms that global copper demand remains robust, outpacing supply. Through the first eight months of 2024, copper demand grew by nearly 4%, evenly split between developed and developing economies. Among OECD countries, copper consumption rose a healthy 3.2%, while non-OECD nations—driven by standout gains in Malaysia, Taiwan, Vietnam, and Brazil—saw consumption grow by a remarkable 8.3%.

China, however, tells a more nuanced story. Having posted a 13% year-over-year surge in copper consumption in 2023, growth has decelerated sharply in 2024, with consumption rising just 3% through the first eight months.

On the supply side, the torrid pace of growth in copper output from the Democratic Republic of Congo (DRC) has eased significantly. Mine supply, which was growing at an annualized rate of 6–7% earlier this year, has moderated to around 3% year-over-year growth.

In our last letter, we discussed how China—the dominant driver of copper demand for the past quarter-century—has now entered an era of overconsumption. For years, we rejected the popular narrative that China was consuming copper at unsustainable levels. Our models consistently showed that Chinese copper demand aligned with the nation's GDP growth and per capita income.

In 2018, for instance, we estimated that China required 196 pounds of invested copper per person to sustain a GDP per capita of $9,600. This estimate exactly matched China's actual installed copper stock. However, since then, copper consumption has soared above trend. By 2023, China's copper investment per capita reached 280 pounds—40 pounds above the 240 pounds necessary to support its GDP per capita of $12,100. By the close of 2024, we project this figure will rise to 306 pounds, exceeding the required level by 45 pounds.

This overconsumption is partially explained by China's massive investments in renewable energy and electric vehicles (EVs). From 2018 to 2024, China added 1,100 gigawatts of renewable power capacity. This boosted China's copper demand by 15 million tonnes we estimate. Over the same period, the addition of 22 million EVs added another 1.3 million tonnes of copper demand. Even accounting for these "new" sources of demand, however, China has overconsumed by an additional 15 million tonnes in just six years—most of it concentrated in the past two.

As we look toward 2025, it is clear that China has transitioned from underconsuming copper to overconsuming it—a shift with significant implications. This represents another bearish data point in the copper demand story. For 15 years, hedge funds and market analysts speculated endlessly about China's supposed overconsumption of copper. Ironically, now that the overconsumption is real, the copper analytics community remains conspicuously silent.

In the near term, global copper market trends remain bullish. However, emerging signs—like China's overconsumption—suggest a less favorable long-term outlook. These developments warrant close scrutiny as we assess the evolving dynamics of the copper market.

and "expect"). Although we believe that the beliefs and expec tations reflected in such forward-looking statements are reasonable, we can give no assurance that such beliefs and expectations will prove to be correct. Various factors could cause actual results or performance to differ materially from those discussed in such forward looking statements. All expressions of opinion are subject to change. You are cautioned not to place undue reliance on these forward-looking statements. Any dated information is published as of its date only. Dated and forward-looking state ments speak only as of the date on which they are made. We undertake no obligation to update publicly or revise any dated or forward-looking statements. Any references to outside data, opinions or content are listed for informational purposes only and have not been independently verified for accuracy by the Adviser. Third-part y views, opin ions or forecasts do not necessarily reflect those of the Adviser or its employees. Unless stated otherwise, any mention of specific securities or investments is for illustrative purposes only. Adviser's clients may or may not hold the securities discussed in their portfolios. Adviser makes no representations that any of the securities discussed have been or will be profitable. Past performance is not a guarantee of future result