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Commentary

“Manufactured Criticalities”

How Sulfuric Acid Is Choking the Energy Transition

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Key Points

- Sulfuric acid is a “manufactured criticality” – a byproduct that is a strategic input for fertilizer production and metals processing.
- The Hormuz Crisis has disrupted the supply of approximately 20 million tons of sulfur from the Arabian Gulf, leading to a potential deficit of almost 60 million tons of sulfuric acid, with cascading multisectoral impacts downstream.
- Sulfur prices spiked from approximately $140 per ton in early 2024 to around $500 per ton in early 2026.
- The direct and indirect supply disruption is impacting about a quarter of the global sulfuric acid market and may fuel inflation and volatility across the food, energy, and metals sectors.

Abstract

The February 2026 disruption of the Strait of Hormuz revealed a category of supply chain vulnerabilities that conventional energy security frameworks pay limited attention to. This paper introduces the concept of "manufactured criticalities" – industrial intermediaries whose strategic importance is structurally invisible within conventional security frameworks, becoming visible only at the point of failure. We use sulfuric acid to examine how a hydrocarbon byproduct has become indispensable to fertilizer production, critical mineral processing, and the energy transition. The Arabian Gulf accounts for roughly a quarter of global sulfur production and approximately half of all seaborne sulfur trade. Production disruptions in the region have put approximately 20 million tons of annual sulfur supply at risk, implying a potential sulfuric acid deficit of up to 60 million tons, equivalent to the entire annual demand from global metals processing. Sulfur prices have risen approximately 250% since 2024, yet supply cannot respond: it is determined by hydrocarbon refinery throughput, not downstream demand signals. Standard production statistics compound this vulnerability by conflating resource recovery locations with resource security. The consequences of the Hormuz Crisis are already measurable. In Chile, sulfuric acid costs rose 44% in May; in Indonesia, which sources approximately 75% of its sulfur from the Gulf, nickel processing has been directly disrupted. With approximately 56% of sulfuric acid consumed by fertilizer production, the ramifications extend from mining to food security. As the energy transition deepens and byproduct sulfur supply contracts with potential future hydrocarbon production declines, "manufactured criticalities" may multiply. Addressing them requires a fundamental redesign of how supply security frameworks are assessed, measured, and governed.

Keywords: Sulfur, Sulfuric Acid, Copper, Nickel, Fertilizer, Supply Chains, Energy Transition, Critical Minerals

Introduction

01

The disruption of the Strait of Hormuz in February 2026 exposed how a single maritime chokepoint can significantly impact the global flow of oil-based products, while also revealing the deep intertwining of these products and the supply chains for midstream materials and technologies that are vital to the wider energy sector (Lu 2026). Among the vulnerabilities laid bare is a category of industrial inputs whose strategic significance is rarely visible until they disappear – what this paper terms "manufactured criticalities."

Sulfuric acid, familiar from school chemistry lessons, is crucial to the production of fertilizers and critical minerals, and has been revealed as a key example of these manufactured criticalities (Home 2026b). Manufactured criticalities are industrial intermediaries that sit invisibly at the junction of multiple interdependent supply chains, whose strategic significance is recognized only when supply is disrupted, whether through geopolitical events, sovereign export restrictions, or the structural decline of the upstream industrial processes on which their production depends. Examples of such manufactured criticalities include oxalic acid, tungsten hexafluoride, electronic-grade nitric acid, and battery-grade phosphoric acid (Hidayat 2026b; Bird 2023; Paul et al. 2026).

Sulfuric acid is primarily produced via burning elemental sulfur, which is predominantly (about 90%) a byproduct of hydrocarbon processing – natural gas desulfurization (sweetening) and petroleum refining (CRU 2024). The Arabian Gulf is the dominant node in the global sulfur trade, accounting for roughly a quarter of world sulfur production and approximately half of all seaborne sulfur flows. The region's effective production disruption has delivered both a direct supply shock and a cascade of second-order market responses that have amplified the disruption well beyond the Strait and the commodity markets directly impacted, reaching across a wide range of products and supply chains (Hodgson Savage, and Acton 2026).

As we will show in this paper, the story of sulfuric acid highlights that energy security is becoming more complex through the diversification of the global energy system and the increasing complexity of supply chains. We examine the interlinkages and dependencies between byproducts of hydrocarbon processing and the wider energy system through the lens of sulfuric acid, reflecting on vulnerabilities in the supply chain that have become apparent through the recent crisis. We do this by answering two key questions:

1. What is sulfuric acid, where does it come from, and why has it become a strategic dependency across critical mineral and food supply chains?

2. How have sulfuric acid markets and policymakers responded to the crisis, and what does this reveal about the adequacy of existing supply security frameworks?

Through these questions, we highlight that sulfur shortages are not primarily a story about a single commodity or a single chokepoint. Rather, they are part of a broader story about one of many manufactured criticalities across the energy sector and the economy more generally. Sulfuric acid shortages are constraining copper production in Chile, slowing nickel processing in Indonesia, and raising input costs across critical mineral supply chains on which the energy transition depends. This reveals how a hydrocarbon byproduct has become a binding constraint on the transition away from hydrocarbons, as well as on global food security.

From Hydrocarbon Byproduct to Manufactured Criticality: The Sulfuric Acid Supply Chain

02

Oil's role in modern energy systems extends well beyond its direct combustion as a fuel. Crude oil processing generates petrochemicals and solid byproducts at successive stages of the refining value chain, many of which are indispensable inputs into the supply chains of energy technologies (IEA 2018; Laing and Koroma 2026). At the upstream end of the refining process, desulfurization of sour crude and natural gas yields elemental sulfur, which is the feedstock for sulfuric acid.

Sulfuric acid, the world's most produced industrial chemical (with approximately 270-300 million tons manufactured annually), is primarily produced via the combustion of elemental sulfur through the contact process, with smaller shares derived from processing off-gas from copper and nickel smelters, and from acid regeneration in closed-loop systems (ACS 2025; S&P Global Energy (Platts) 2024). Elemental sulfur is a mandatory byproduct of hydrocarbon processing driven by environmental regulation rather than commercial incentive (Maslin, Van Heerde, and Day 2022; Wagenfeld et al. 2019). This creates a direct and consequential dependency: sulfuric acid supply is structurally tethered to hydrocarbon production.

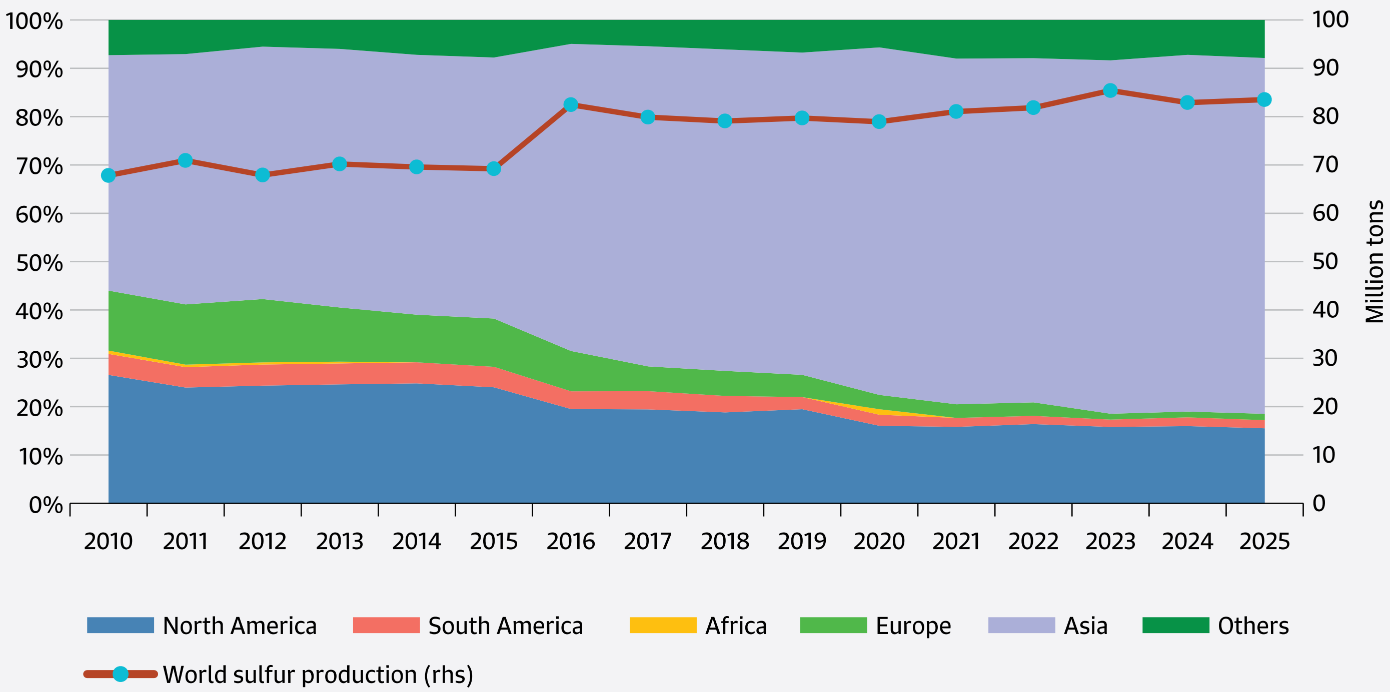
Three-quarters of global sulfur production occurs in Asia, with China accounting for approximately 25% and the Arabian Gulf accounting for a further 25%, or approximately 20 million tons per year (USGS 2025) (Figure 1). Production in the Gulf is driven primarily by sulfur recovery from often imported hydrocarbons.

A kilogram of elemental sulfur yields approximately 3 kilograms of sulfuric acid (Kutney 2023), meaning that Gulf sulfur production (Figure 2) alone supports approximately 60 million tons of acid annually, greater than total global metals processing demand for sulfuric acid (see Table A1 in the Appendix).

Sulfuric acid is an essential input across the supply chains of the critical minerals underpinning the energy transition. In copper mining, heap leach operations using solvent-extraction electrowinning currently represent approximately 20% of primary copper production and are growing as ore grades decline (Feng 2026; ICSG 2025). They depend entirely on sulfuric acid as the leaching reagent. Copper smelters simultaneously produce acid as a byproduct, creating a duality as both consumer and producer, which standard supply chain risk frameworks that track metals rather than chemical intermediates are not designed to capture.

Nickel extraction from laterite ores via high pressure acid leach (HPAL) is even more acid-intensive, consuming 25-30 tons of acid per ton of mixed hydroxide precipitate (Schodde and Guj 2025). Indonesia, which accounts for over half of global

Figure 1. Regional shares of sulfur production.



Source: USGS (2025).

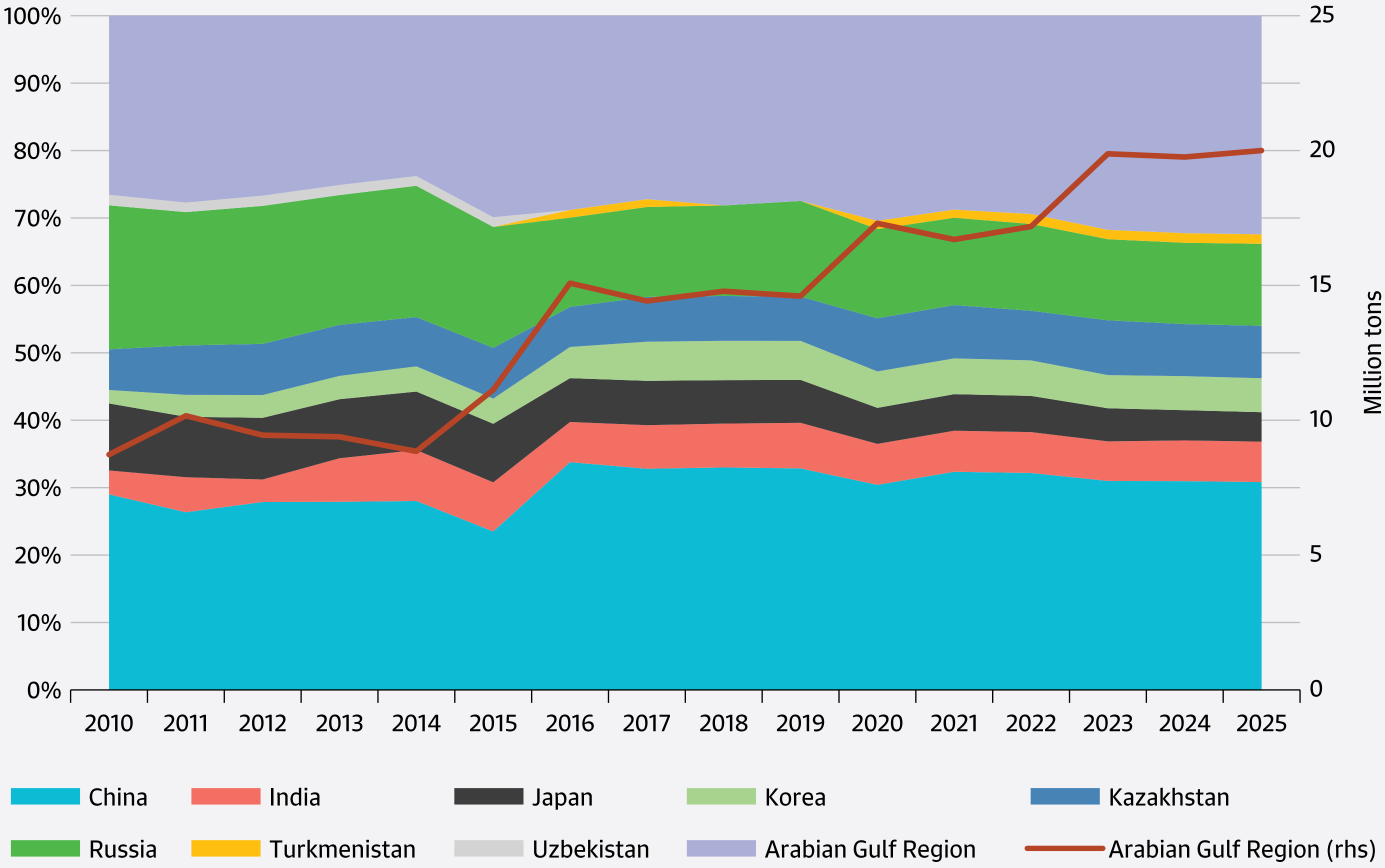
nickel production, sources approximately 75% of its sulfur from the Arabian Gulf, meaning that HPAL-based nickel supply chains face direct exposure to the same Hormuz chokepoint that disrupted oil flows (Home 2026a).

Sulfuric acid is also integral to lithium sulfate processing, rare earth element extraction, and uranium in-situ leaching (see Table A2 in the Appendix). Beyond minerals, approximately 56% of global sulfuric acid is consumed in fertilizer production, digesting phosphate rock into phosphoric acid and producing ammonium sulfate, making it a foundational input to global food security (Bertau et al. 2024; CRU 2024) (see Table A1 in the Appendix for details).

The sulfur shortage has ramifications across other non-critical metals, with supply risks also emerging for sodium metabisulfite, which is the primary reagent for neutralizing cyanide in gold processing. By squeezing gold availability, this sulfur supply disruption has implications for financial and commodity markets amid rising geopolitical and macroeconomic volatility.

What is striking about these dependencies is not their existence, which is well understood within individual industry sectors, but their invisibility in aggregate supply security frameworks. Standard critical mineral assessments track the metals themselves – copper, nickel, and lithium – without systematically mapping the chemical intermediates on which their extraction depends. Standard sulfur production statistics compound this problem by conflating resource recovery location with resource security: a country that appears self-sufficient in sulfur may be entirely contingent on continued hydrocarbon throughput or imported crude feedstocks, leaving it acutely exposed in practice despite appearing secure on paper. The result is a category of manufactured criticality that is recognized within industrial groups but absent from the supply security frameworks that policymakers use.

Figure 2. Breakup of Asian sulfur production.



Source: USGS (2025).

How Have Markets and Policymakers Responded to the Crisis?

03

The disruption to global sulfur and sulfuric acid supply has been transmitted into markets in two distinct but related ways: through price and physical availability. Understanding both requires appreciating a structural feature of the sulfur market that the crisis has made newly visible: pricing power in this market sits with suppliers, not buyers. Unlike most commodity markets, where the largest buyer exercises significant influence over contract terms and price benchmarks, the sulfur market is structurally supplier-priced.

Because sulfur supply is structurally decoupled from downstream demand signals, the 2026 price spike has produced none of the supply responses that conventional commodity markets would generate. Higher prices have not attracted new production because production cannot be increased independently of hydrocarbon throughput. Supply is therefore structurally price-inelastic, with no market mechanism to expand output in response to downstream shortfalls (CRU 2024). Unlike conventional commodities, where price signals attract new investment and expanded production, sulfur supply cannot respond to market volatility independently of the hydrocarbon sector that generates it (Maslin, Van Heerde, and Day 2022).

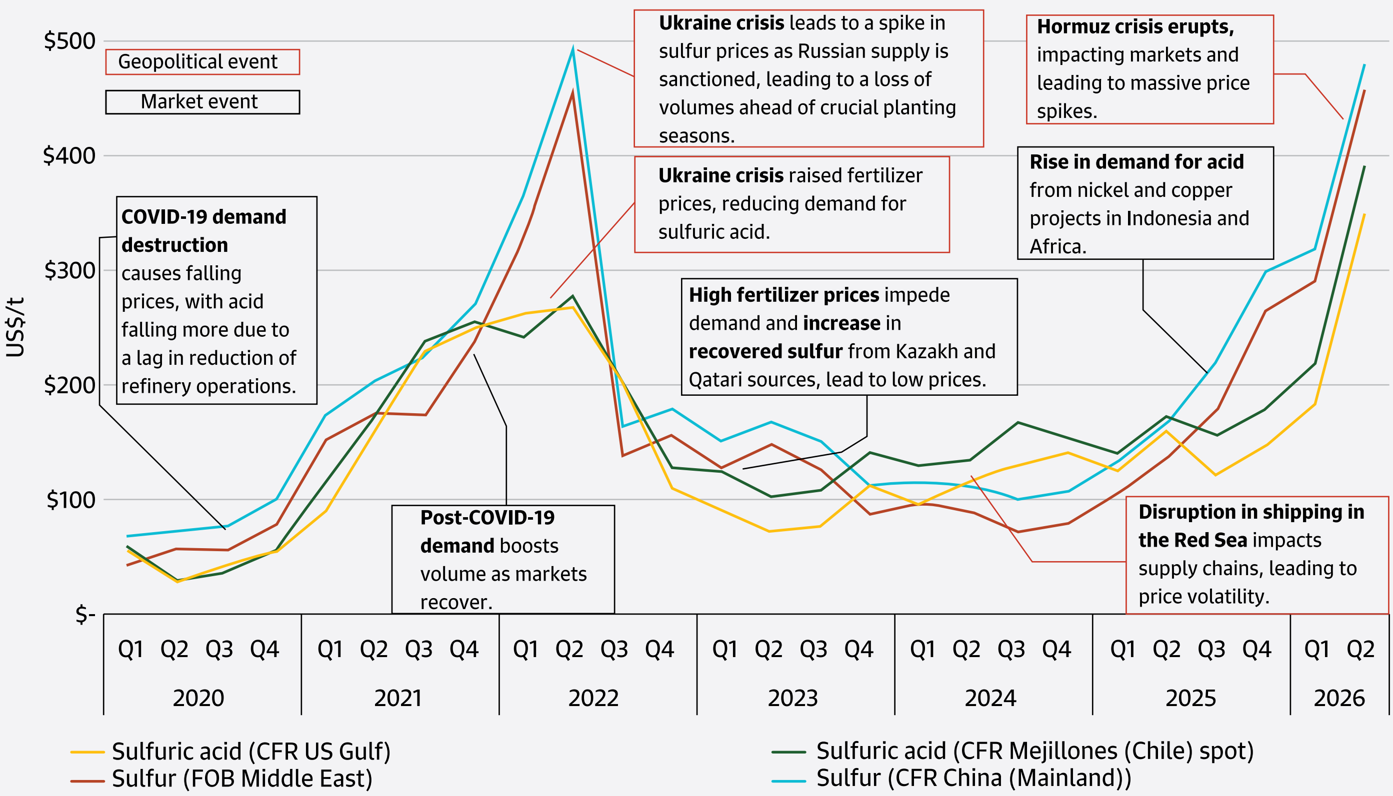
Direct extraction of geologically abundant sulfur from native deposits and pyrite ores has never been commercially competitive with the continuous, near-zero marginal-cost supply generated as a byproduct of hydrocarbon processing, leaving the market with no alternative supply base capable of responding when that byproduct stream is disrupted. The current crisis has made this structural constraint visible: price spikes of the magnitude observed in 2026 would, in any conventional commodity market, be expected to incentivize supply expansion; in the sulfur market, they cannot.

Demand centers, accustomed to supply being effectively guaranteed as an environmental regulatory obligation of the upstream sector, have had little incentive to develop alternatives or sourcing strategies, leaving the market poorly suited to absorbing supply shocks. Critically, the nature of risk has also shifted: where the historical concern was insufficient production capacity, the binding constraint today is logistics. The Hormuz chokepoint has disrupted the maritime corridors through which the Arabian Gulf's export surplus reaches global demand centers (Bazilian, Amoah, and Matisek 2026).

Supply is controlled by a small number of national oil companies and gas processors in the Arabian Gulf, who have limited incentives to expand sulfur output in response to buyer distress, and who have no need to compete aggressively on price during periods of scarcity. China, despite being the world's largest consumer of sulfuric acid, exercises little pricing leverage over the upstream sulfur market because its domestic production, itself a refinery byproduct, is structurally insufficient to replace Gulf imports at scale. The result is a market in which price formation is driven by the supply decisions of a handful of state-controlled hydrocarbon exporters, leaving downstream demand centers structurally exposed during periods of disruption (Kapadia 2026; Hidayat 2026a).

This structural dynamic has shaped the price response to the 2026 crisis. Sulfur prices averaged approximately $140 per ton in early 2024 and rose to approximately $500 per ton by the first quarter of 2026, an increase of approximately 250% over two years and 120% since early 2025 (Intratec 2026; Sharma 2026) (Figure 3). The impact on sulfuric acid prices has been more muted, reflecting the dilution effect of the contact process and the partial availability of alternative production routes: acid prices rose from approximately $95 per ton in early 2024 to approximately $185 per ton by early 2026, an increase of approximately 95% (IMARC 2026; Intratec 2026). However, S&P Global Energy (Platts) projects prices for the latter part of 2026 at between $200-$300 per ton. These increases have translated directly into higher copper production costs. Sulfuric acid represents approximately 20% of total production costs at heap leach operations, adding an estimated $100-$150 per ton to the cost of refined copper (Home 2026b).

Figure 3. Sulfur and sulfuric acid prices 2020-2026.



Source: S&P Global Energy (Platts). © 2026 S&P Global. Used with permission.

Critically, price increases have not triggered supply responses. Some merchant sulfuric acid plants have reduced operating rates where acid selling prices do not cover the higher cost of sulfur feedstock. Others have continued running where acid is strategically essential to captive operations, fertilizer complexes, and mining operations that cannot simply curtail production. This asymmetry highlights the advantages for fully integrated producers who have captive sulfur generation and sulfuric acid production facilities. Such producers can absorb costs at one stage of production and expand margins at others. In contrast, merchant producers compete in a commodity market with little differentiation and are thus more exposed to rising input prices and the resulting lower margins.

Beyond price, the more operationally consequential challenge has been physical availability. China's announcement in late April 2026 that it would restrict exports of industrial-grade sulfuric acid from May 1 to protect domestic agricultural supply during the planting season has tightened an already constrained market (Benchmark 2026; Echemi 2026). China produces approximately 110 million tons of sulfuric acid annually and exports approximately 5 million tons per year, making it the world's largest supplier of merchant acid to international markets (Keen 2026; SMM 2026).

The restriction is notable not only for its scale but also because of what it reveals about the market's architecture. China, despite being the world's largest acid consumer, had itself become dependent on Gulf sulfur to sustain domestic acid production. As a result, the Hormuz disruption did not spare China but rather transmitted through it, converting a Gulf logistics disruption into a Chinese export restriction that then affected downstream buyers in Chile, the Democratic Republic of Congo (DRC), and elsewhere. This is the second-order cascade that the structure of the market makes structurally inevitable (Benchmark 2025).

The consequences have been most acute in the copper sector. In Chile, acid costs rose 44% in a month following China's export restriction announcement, with producers at operations including Escondida, the world's largest copper mine, facing sourcing constraints (Daly 2026). In the DRC, several copper producers have reduced chemical consumption to stretch existing stockpiles, with the Kamoa-Kakula smelter's domestic byproduct acid output estimated at 600,000-700,000 tons per year at full capacity, covering only approximately one-third of the DRC's annual demand of approximately 2 million tons (Tossou 2026).

Russia, Zambia, and Turkey have announced or imposed their own sulfur or sulfuric acid export restrictions since the start of the crisis in late February 2026. Each measure represents a resource-security response to domestic supply pressure, collectively compounding global shortages well beyond what the Hormuz Crisis alone would have caused. The result is a disruption that now affects multiple commodity markets (Stellarix 2026; Keen 2026).

The agricultural sector has faced parallel pressures. Fertilizer producers, already contending with reduced ammonia and urea availability from the Arabian Gulf, face additional cost pressures from rising acid prices (Lima 2026; Herrero 2026). With the disruption coinciding with major planting seasons in the United States and Brazil, there is evidence of emerging crop-switching decisions away from fertilizer-intensive crops such as corn, a significant share of which is used for ethanol production, toward less input-intensive alternatives, such as soy. The downstream implications for biofuel supply and food prices remain uncertain but are under active monitoring by agricultural commodity markets.

The structural supply challenge is the most consequential. In theory, copper could be broadly sulfuric acid neutral: byproduct acid from smelting operations could, in a geographically integrated system, support mine-site leach requirements. In practice, the growing disconnect between mining operations and smelting capacity, driven principally by the expansion of Chinese copper smelting over the past decade, has eroded that integration and created the external acid market dependency which the 2026 crisis has exposed.

Addressing this requires deliberate industrial policy. The policy response to date has been largely reactive: emergency procurement, supply chain remapping, and resource curtailments rather than structural reforms. The crisis has nonetheless demonstrated two things that existing frameworks had not made visible: sulfuric acid is a strategic input whose supply security cannot be assumed, and the geographic concentration of sulfur production and sulfuric acid export capacity creates a compounding vulnerability that no current critical minerals governance framework is designed to monitor or mitigate.

Conclusion

04

The story of sulfuric acid in 2026 is, at its core, a story about what supply security frameworks fail to see. The Hormuz Crisis has exposed a vulnerability in the sulfuric acid supply chain, which had accumulated quietly across decades of hydrocarbon-dependent industrial development and remained invisible to frameworks designed to protect against exactly this kind of disruption.

Three structural features of that vulnerability stand out. First, sulfur supply is more geographically concentrated than headline production statistics suggest because sulfur recovery follows the geography of hydrocarbon processing rather than the geography of demand. Second, the traded sulfur market is a price-inelastic, supply-driven, supplier-priced structure, which means downstream demand centers have limited tools with which to build resilience. Diversification strategies, strategic stockpiles, and hedging instruments have not developed because, until now, they have appeared unnecessary. Third, the primary risk has migrated from production capacity to logistics, a shift that frameworks built around import-dependency ratios are not structured to detect.

Globally, the policy response to the supply shock has been primarily one of resource curtailments, with nations resorting to sulfuric acid export bans, limiting metal processing in response to acid scarcity, and, in some cases, incentivizing acid production from copper smelting (Lv and Munroe 2026). Countries have resorted primarily to resource securitization as a policy response to the inability of the sulfur market to address shortages.

Policy implications from this supply shock extend beyond sulfuric acid. Manufactured criticalities – byproduct-origin, geographically concentrated, price-inelastic, and invisible in aggregate assessments – are a structural feature of modern industrial economies, not an anomaly. Their number and significance will grow as the energy transition lengthens and complicates clean energy supply chains, revealing hidden vulnerabilities. The energy transition's own demand for sulfuric acid through copper and nickel leaching and lithium processing will rise precisely as declining hydrocarbon production reduces byproduct sulfur supply. This structural gap has not been addressed in critical minerals strategies or energy transition roadmaps.

Addressing these vulnerabilities requires two perspective shifts. The first is methodological: supply security frameworks must map chemical intermediates as strategic inputs and disaggregate production statistics by feedstock origin so that concentration metrics reflect true exposure rather than the location of recovery. The second is institutional: critical minerals governance must expand its scope beyond the metals themselves to encompass the processing chemicals on which their extraction depends. The sulfuric acid crisis has offered policymakers a timely and concrete illustration of what happens when policy frameworks lag behind the structural realities they are meant to protect.

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Appendix

Table A1. Sulfuric acid – primary industrial applications.

End-use sector	Share of global sulfuric acid demand (approx.)	Volume estimates (Mt, 2022)	Key applications
Fertilizer production	56%	160 Mt	Phosphoric acid production, diammonium phosphate, monoammonium phosphate, single super phosphate, ammonium sulfate; the dominant driver of sulfuric acid demand globally
Metal processing	19%	55 Mt	Copper SX-EW and heap leaching, nickel HPAL, uranium in-situ recovery/ leaching, titanium dioxide, manganese, nickel sulfate, lithium processing
Chemical manufacturing/ industrial uses/specialized applications	25%	72 Mt	Intermediate chemical synthesis, dyes, pigments, detergents, explosives, water treatment, textiles, paper, hydrofluoric acid, alkylation, aluminum sulfate, battery electrolytes, semiconductor chemicals, steel pickling, petroleum refining, firefighting foams, rayon/cellulosic fibers, and advanced materials

Source: Authors' estimation and CRU (2024).

Table A2. Indicative sulfuric acid requirements.

Product type	Acid required – indicative (acid tons/ product tons)	Source
Diammonium phosphate	1.2	Mosaic (2026)
Monoammonium phosphate	1.0	IFC and World Bank Group (2007)
Triple superphosphate	1.4-1.5	IFC and World Bank Group (2007)
Single super phosphate	0.3-0.4	IFC and World Bank Group (2007)
Ammonium sulfate	0.75	IFC and World Bank Group (2007)
Copper processing (SX-EW heap leach)	2-4 t/t of copper (higher for lower grade operations)	911 Metallurgist (2017)
Nickel processing (HPAL-laterite)	25-30 t/t of MHP intermediate; 35-40t/t of Nickel	Home (2026a)
Lithium carbonate (spodumene route)	0.48 t/t Li_2CO_3 at product level; 0.30-0.40 t/t spodumene concentrate at feedstock level	Rioyo, Tuset, and Grau (2020)
Uranium processing (ISR/ISL)	3-8 t/t U_3O_8	Giusti et al. (2024)
Zinc (electrolytic refining)	0.5-1.0 t/t Zinc	Xin et al. (2022)
Manganese	1.96t/t of electrolytic manganese metal	IMARC (n.d.)
Titanium dioxide (sulfate process)	4.0-4.5 t/t TiO_2 (monohydrate basis)	Maldybayev et al. (2023)
Rare earth elements (REE) processing (bastnasite/ monazite)	0.5-2.0 t/t REE oxide (highly ore-dependent)	Demol, Ho, and Senanayake (2018)

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About the Project

The project “Resource to Revenue: Mapping Saudi Arabia’s Critical Minerals Recycling Potential” aims to build literature around the central question of how Saudi Arabia can build a competitive recycling and mineral processing ecosystem, focusing on issues of critical minerals, energy and midstream processing in light of the emerging geopolitical landscape. It aims to answer research questions at a global level pertaining to the opportunities for recycling to meet the quality and predictability requirements of the critical minerals needed for end-use applications. It also aims to examine questions at a national level regarding the specific challenges facing critical mineral recycling for the Kingdom in terms of security of supply, business models, and policy frameworks.