Comprehensive Analysis of the Supply Structure and Supply Chain Vulnerabilities of Phosphate Chemical Fertilizers in Japan

Introduction: Geopolitical and Structural Dependencies of Phosphorus Resources in Japan's Agricultural Production Base

In modern agriculture, nitrogen (N), phosphorus (P), and potassium (K) are referred to as the three essential elements of fertilizers. They act as the indispensable foundation for ensuring crop growth and yield, and by extension, national food security. Among these, phosphorus (in the form of P_2O_5) is a critical element that directly participates in cell division, transmission of genetic information (components of DNA and RNA), energy metabolism (a component of ATP: adenosine triphosphate), as well as root elongation, flowering, and fruiting in plants. While nitrogen can be fixed inexhaustibly from the atmosphere (N_2) through the Haber-Bosch process, phosphorus relies entirely on unevenly distributed mineral resources in the earth's crust (phosphate rock) and is an exhaustible resource that cannot be artificially synthesized.

Currently, Japan completely lacks domestic phosphorus resources (economically mineable reserves) and relies on overseas imports for virtually 100% of its supply. This report comprehensively and minutely analyzes the annual supply structure of phosphate chemical fertilizers input into Japanese agriculture, categorized by production route in terms of P_2O_5 (phosphorus pentoxide) equivalent. It details the supply volumes, main products, procurement sources, and inherent structural bottlenecks of each route. The current phosphate supply chain in Japan rests on an extremely fragile equilibrium, intersecting not just with trade imbalances, but also with the volatility of the global energy market, industrial restructuring toward decarbonization (carbon neutrality), the national strategies of resource-holding countries, and the shrinking domestic oil refining infrastructure. This analysis dissects these three primary supply routes to reveal their secondary and tertiary ripple effects, as well as the necessary future supply models.

Route 1: Structure and Vulnerability Analysis of the Product Import Route

The largest supply channel for phosphate fertilizers in Japan is the "Product Import Route," in which fully processed and packaged chemical fertilizers are purchased directly from overseas. This route forms the absolute foundation of domestic supply and functions as the main artery supporting modern conventional agriculture in Japan.

Basic Data on Supply Volume and Market Share

Phosphate fertilizers supplied through this route are mainly ammonium phosphates used as raw materials for highly concentrated compound fertilizers. The following table shows the quantitative overview of the product import route.

Indicator	**Data and Details**
Market Share	Approx. 80% - 85%
Annual Supply (P_2O_5 equivalent)	Approx. 250,000 - 280,000 tons
Main Fertilizer Forms	Ammonium phosphates (MAP and DAP)
Primary Sources	China: 76%, Morocco: 18%, US: 3%, Other: 3%

Ammonium phosphates primarily include monoammonium phosphate (MAP: $NH_4H_2PO_4$) and diammonium phosphate (DAP: $(NH_4)_2HPO_4$). These are highly water-soluble and have an extremely high fertilization efficiency as they can simultaneously supply nitrogen along with a high phosphorus content. In Japan's fertilizer system, they are input into factories as basic raw materials for manufacturing compound fertilizers and are also widely used as straight fertilizers. Consequently, if this route is cut off, Japan's agricultural production is structured to suffer an immediate and fatal blow.

Structural Bottlenecks and Multiple Risks

Due to its overwhelming supply volume, the product import route contains the greatest vulnerability in Japan's food security. The risks inherent in this route go beyond mere market price fluctuations and are directly linked to geopolitical conflicts and the global energy transition.

Geopolitical Risk and China as a Swing Producer

The greatest structural bottleneck of this route lies in its dependence on a single country, China, for over 70% of total imports. In the global ammonium phosphate market, China is the largest producer and simultaneously reigns as a swing producer that dictates global supply-demand balances and prices based on its domestic policies.

In recent years, the Chinese government has positioned "national food security" as its top priority strategy, frequently invoking strict regulations on phosphate fertilizer exports to ensure stable fertilizer supplies and price suppression for domestic agriculture. Specifically, it controls outflows to foreign countries by tightening the export pre-inspection system (CIQ) and introducing de facto export quotas. As a result, phosphate supply to Japan is in a life-or-death situation, subject to direct and immediate restrictions by China's domestic policies and the political decisions of the Communist Party. If China halts exports in alignment with its domestic spring or autumn planting seasons, Japanese fertilizer manufacturers will be unable to procure raw materials, leading to the disappearance of compound fertilizers from domestic store shelves a few months later.

A tertiary ripple effect is the change in demand for automotive batteries accompanying the rapid expansion of the electric vehicle (EV) market. Currently, the adoption of lithium iron phosphate (LFP: $LiFePO_4$) batteries, which do not use rare metals like nickel or cobalt, is surging globally. Within China, there is an accelerating movement to divert high-purity phosphoric acid from low-unit-price agricultural fertilizers to overwhelmingly high-value-added purified phosphoric acid (PPA) for EV batteries. This means that Japan's agricultural system is in direct competition for phosphorus resources not only with China's food security policies but also with the global trend of mobility electrification. Driven by capitalist mechanisms, resources prioritize high-profit industries, placing structural and irreversible pressure on the export capacity of cheap ammonium phosphate for agriculture.

Complete Subordination to the Energy and Ammonia Supply Chain

Manufacturing ammonium phosphate requires reacting phosphoric acid (H_3PO_4) extracted from phosphate rock with "ammonia" (NH_3), a nitrogen source. Ammonia synthesis, the basis of this chemical reaction, is performed via the Haber-Bosch process ($N_2 + 3H_2 \rightleftharpoons 2NH_3$). However, the majority of the hydrogen (H_2) essential for this process relies on fossil fuels such as natural gas (steam reforming of methane: $CH_4 + H_2O \rightarrow CO + 3H_2$), coal, and naphtha.

Therefore, the product import route suffers from a double vulnerability: not only is it facing the limits of phosphorus resource extraction, but it is also completely linked to the global fossil fuel supply chain. When geopolitical shocks occur—such as the European natural gas crisis triggered by Russia's invasion of Ukraine—ammonia production costs soar, instantly reflecting in soaring ammonium phosphate prices. Japan is structured to take a direct hit from the volatility of global energy markets, not just the risk of phosphorus resource depletion, creating a mechanism where fossil fuel price fluctuations directly push up domestic agricultural production costs (fertilizer expenses).

Route 2: Structure and Vulnerability Analysis of the Ore Import and Domestic Processing Route

Overview of Supply Volume and Market Share

The second route involves importing unprocessed phosphate rock from overseas and chemically treating it in Japanese fertilizer plants to manufacture phosphate fertilizers domestically. During Japan's period of high economic growth, this domestic processing route was the mainstay of fertilizer production, but today its share has significantly shrunk due to changes in industrial structure and manufacturing costs.

Indicator	Data and Details
Market Share	Approx. 12% - 14%
Annual Supply (P_2O_5 equivalent)	Approx. 40,000 - 45,000 tons
Main Fertilizer Forms	Single superphosphate (SSP), triple superphosphate (TSP), fused magnesium phosphate (FMP)
Primary Sources (Ore)	China: 27%, Jordan: 21%, Morocco: 21%, Senegal: 14%, Other: 17%

Single superphosphate (SSP), a representative fertilizer manufactured through this route, is produced by decomposing poorly soluble phosphate rock—whose main component is fluoroapatite ($Ca_5(PO_4)_3F$)—with a strong acid, sulfuric acid (H_2SO_4), to convert it into water-soluble monocalcium phosphate ($Ca(H_2PO_4)_2$) that can be absorbed by plant roots. This chemical reaction is expressed by the following formula:

$$2Ca_5(PO_4)_3F + 7H_2SO_4 + 3H_2O \rightarrow 3Ca(H_2PO_4)_2 \cdot H_2O + 7CaSO_4 + 2HF$$

Furthermore, triple superphosphate (TSP) is manufactured as a highly concentrated phosphate fertilizer that does not contain calcium sulfate (gypsum) by decomposing phosphate rock with phosphoric acid instead of sulfuric acid.

Structural Bottlenecks and Multiple Risks

This route of domestic ore processing is expected to function as a risk hedge (maintaining a domestic manufacturing base) against the first route of directly importing finished products. In reality, however, irreversible changes in the domestic industrial structure have forced it into a severe structural contradiction that threatens its very survival.

Collapse Crisis of the "Sulfuric Acid" Supply Chain due to Decarbonization

The greatest blind spot and fatal bottleneck in this route is the procurement of "sulfuric acid," an indispensable solvent for dissolving phosphate rock to make water-soluble fertilizers. In Japan, the primary source of abundant and cheap sulfuric acid is the byproduct (sulfur recovered through the desulfurization process) generated when crude oil imported from regions like the Middle East is refined at domestic oil refineries. Sulfur obtained via the Claus process ($2H_2S + SO_2 \rightarrow 3S + 2H_2O$) at refineries is burned to form sulfur dioxide, which is then oxidized and absorbed to produce sulfuric acid.

Here lies a major tertiary paradox within Japan's national strategy. The "decarbonization (carbon neutrality)" promoted by the Japanese government, the transition to renewable energy, and improved fuel efficiency due to the spread of EVs and hybrid vehicles are structurally and continuously reducing domestic demand for petroleum products, including gasoline. Petroleum distributors are consolidating and closing refineries in response to the declining demand. If the volume of crude oil processed decreases, the amount of byproduct sulfur generated will physically decrease in direct proportion.

As a result, domestic supply of sulfuric acid becomes tight and prices rise. Even if phosphate rock could be stably imported from overseas, if sulfuric acid—the essential solvent for turning it into fertilizer domestically—cannot be obtained or reaches commercially unviable prices, domestic processing lines will physically be forced to stop. A profoundly serious trade-off has emerged: the energy transition for environmental protection and climate change mitigation (Green Transformation) is fundamentally destroying the fertilizer processing infrastructure essential for food production.

Degradation of Ore Quality and Soaring Impurity Treatment Costs

Furthermore, the degradation of phosphate rock quality itself is a global factor. High-grade phosphate ore veins with few impurities are being exhausted worldwide. The ore currently available on the international market increasingly consists of low-grade rock containing relatively high levels of heavy metals and radioactive substances such as cadmium, uranium, and arsenic.

Refining this into safe fertilizers that comply with Japan's strict environmental standards and the Fertilizer Regulation Act requires advanced decontamination processes to remove harmful substances like cadmium, as well as calcination processes that consume vast amounts of energy. The accompanying rise in manufacturing costs has significantly undermined the price competitiveness of domestic products against already cheap imports, causing domestic manufacturers to be unable to recover their capital investments and forcing factory closures.

Route 3: Structure and Prospects of the Domestic Resource and Chemical Extraction Route

Overview of Supply Volume and Market Share

The third route is an unexplored frontier that utilizes purely domestic resources, relying zero percent on imported materials. Specifically, it involves the extraction and recovery of pure phosphate components (crystals) from sewage sludge and digestion effluent generated at urban sewage treatment plants in Japan through advanced chemical processes, converting them into fertilizers.

Note that "sludge compost" (fermenting sewage sludge and returning it to agricultural land) is also widely practiced, but it is excluded from this analysis of "quantitative phosphate supply as chemical fertilizer" because its nutrient content is uneven and it functions primarily as a slow-acting organic fertilizer.

Indicator	**Data and Details**
Market Share	Approx. 0.2%
Annual Supply (P_2O_5 equivalent)	Approx. 500 - 800 tons
Main Fertilizer Forms	Crystallized MAP (Magnesium ammonium phosphate: $MgNH_4PO_4 \cdot 6H_2O$), etc.

Primary Sources	Japan: 100%

The core technology of this route is the "MAP crystallization process." In stages such as the anaerobic digestion process of sewage treatment, a magnesium source like magnesium chloride ($MgCl_2$) or magnesium hydroxide ($Mg(OH)_2$) is added to the digestion effluent where phosphorus and ammonia are highly concentrated. The pH is adjusted to weakly alkaline (around pH 8.0 to 8.5) using sodium hydroxide, etc. This causes phosphate ions, ammonium ions, and magnesium ions in the water to react, intentionally precipitating MAP (struvite) crystals.

Chemical reaction formula:

$$Mg^{2+} + NH_4^+ + PO_4^{3-} + 6H_2O \rightarrow MgNH_4PO_4 \cdot 6H_2O \downarrow$$

The recovered MAP crystals have few impurities and possess "citrate-soluble" properties, meaning they slowly dissolve in organic acids (such as citric acid) secreted by plant roots in the soil. Thus, they serve as an excellent, low-environmental-impact compound fertilizer containing phosphorus, nitrogen, and magnesium.

Structural Bottlenecks and Challenges in Scaling Up

This route holds extremely high strategic value as the "ultimate national security route," fully independent of geopolitical risks, fossil fuel price fluctuations, and exchange rate risks. Theoretically, if all the phosphorus excreted by the Japanese population could be recovered, estimates suggest it has the potential to cover about 10% to 20% of domestic agricultural demand. However, the current market share remains a mere 0.2%, facing clear economic and structural barriers.

Enormous Initial Investment (CAPEX) and Lack of Economic Viability

Installing a crystallization plant alongside a sewage treatment facility to recover high-purity MAP crystals requires a massive capital expenditure (CAPEX) in the hundreds of millions of yen. Furthermore, operational expenses (OPEX) are high, including the cost of purchasing magnesium chemicals to promote crystallization and electricity costs for aeration and agitation.

As a result, the manufacturing cost per ton of phosphoric acid recovered from sewage significantly exceeds the market price of ammonium phosphate imported and mass-produced in giant overseas plants. Currently, most municipalities that have introduced this system, such as Kobe City and Fukuoka City, have done so not as a "business to manufacture fertilizer for profit," but rather as a "maintenance cost reduction measure" to prevent naturally occurring struvite scaling (pipe clogging) inside sewage treatment plant pipes. In other words, it heavily depends on sewerage business budgets overseen by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) and national demonstration experiment subsidies like the B-DASH project, and the reality is that it has not been established at all as an autonomous commercial ecosystem based on market principles.

Fractured Supply Chain and Regulatory/Distribution Walls

Another severe bottleneck is the complete fragmentation of the supply chain from the recovered phosphoric acid to actual agricultural land. Sewage treatment plants are operated by local municipalities (under MLIT jurisdiction), which have neither the sales network nor the expertise to distribute the produced MAP on a wide scale. On the other hand, it is the JA Group and private fertilizer manufacturers (under the jurisdiction of the Ministry of Agriculture, Forestry and Fisheries) that manufacture and distribute fertilizers.

Although recovered MAP is chemically pure, its crystal particle size, moisture content, and grindability differ subtly from conventional imported MAP. Therefore, feeding it directly into the plant equipment (granulation processes, etc.) of existing compound fertilizer factories may cause mechanical trouble, necessitating technical process adjustments. There is very little incentive for private manufacturers to proactively adopt recovered phosphoric acid, which is expensive, unstably supplied, and forces factory line modifications. Siloed bureaucratic administration between ministries and the existing logistics infrastructure predicated on imports form a thick wall preventing the scale-up of domestic resource circulation.

Secondary and Tertiary Ripple Effects and In-depth Macro Environmental Analysis

Synthesizing the quantitative data and structural bottlenecks of the three production routes detailed thus far suggests that the Japanese phosphate supply structure is not merely facing temporary supply-demand tightness or price fluctuations, but an irreversible paradigm shift unfolding over decades. Here, we discuss the deep trends indicated by the data and their ripple effects on Japanese agriculture.

The Limits of "Illusionary Procurement Diversification" and Price Linkage Mechanisms

Currently, the Japanese government and the fertilizer industry are seeking to diversify procurement sources ("China Plus One" strategy) in the first and second routes to break away from excessive reliance on China. Specifically, they are advancing the signing of long-term procurement contracts with countries like Morocco (which boasts the world's largest phosphate rock reserves and whose phosphate industry is practically monopolized by the state-owned OCP Group), Jordan, Senegal, and the United States.

However, analysis of economic market mechanisms shows that while this diversification serves as a certain insurance against physical supply chain disruptions (such as embargoes), it cannot serve as a fundamental hedge against price spike risks. This is because the global phosphate fertilizer market is a fully integrated commodity market.

If China were to restrict its exports, wiping millions of tons of phosphoric acid from the global market, the overall supply-demand balance of the international market would collapse instantly. As a result, the prices of Moroccan and American phosphate fertilizers would also soar instantaneously due to a bidding war by buyers worldwide (including giant agricultural nations like India and Brazil) trying to make up for the decrease in Chinese exports. Even if Japan shifts its procurement routes away from China and secures physical goods, as long as a few resource-rich nations like China and OCP hold pricing power (as price makers) over the entire market, Japanese agriculture cannot avoid the direct hit of massive price pass-throughs (cost-push inflation). Changing the flag of the procurement source makes it impossible to escape the network of global supply tightness and price linkages.

Unintended Side Effects of the Green Transformation (GX)

As mentioned earlier, the tertiary ripple effect that demands the most attention is the structural collision between environmental policies and food security. The nitrogen (ammonia) supporting the first route depends on natural gas, and the sulfuric acid supporting the second route depends on crude oil refining. As Japan and the world shift toward a decarbonized society (carbon neutrality) to combat climate change, shrinking fossil fuel extraction and refining processes paradoxically chips away at the manufacturing base for chemical fertilizers simultaneously.

Including the surge in phosphate demand from LFP batteries, an extremely complex dilemma has been highlighted: macro-level efforts to reduce environmental loads and build a sustainable society (GX) result in "the depletion and price explosion of basic materials essential for nurturing food, humanity's survival base." While energy transitions have alternative technologies (solar or wind), there is no substitute material for the element phosphorus, which is essential for the growth of living organisms. This absolute asymmetry will become the greatest weak point in future national security.

The Hidden Buffer of "Legacy Phosphorus" in Domestic Soil and its Scientific Evaluation

While vulnerabilities on the supply side are extreme, a unique Japanese characteristic emerges as a secondary effect at the feet of the demand side. This is the existence of vast amounts of "Legacy Phosphorus" slumbering in Japan's agricultural soils.

Many of Japan's farmlands consist of Andosols, which are derived from volcanic ash. The most prominent characteristic of this soil is its extremely high "phosphate absorption coefficient." The abundant active aluminum (Al) and iron (Fe) oxides in the soil instantly bind with applied water-soluble phosphoric acid, fixing it in the soil as poorly soluble aluminum phosphate and iron phosphate that cannot be absorbed by plant roots.

To counteract this soil characteristic, Japanese agriculture has intensively applied massive amounts of phosphate fertilizers far exceeding what crops actually absorb every year over the past few decades (over-fertilization). As a result, vast amounts of phosphorus that were not utilized by crops have become insoluble and continue to accumulate in the soil today. Agronomic soil diagnosis data reveal that in many fields, enough legacy phosphorus exists to grow crops for several years without adding any new phosphate fertilizer.

In a worst-case scenario where phosphate supply from overseas is physically severed (e.g., a sea lane blockade due to a Taiwan contingency, or complete embargoes by exporting countries), ironically, this legacy of past over-fertilization, the "legacy phosphorus," is highly likely to function as a short-term breakwater (buffer) to support Japanese food production for a few years.

However, actually converting this legacy phosphorus into a form that crops can absorb (making it available) requires highly advanced soil microbiological approaches, not merely leaving it alone. Specifically, a shift in cultivation techniques is required, such as the proactive utilization of "Arbuscular mycorrhizal (AM) fungi," which form symbiotic relationships with plant roots to explore and absorb poorly soluble phosphorus in the soil and supply it to the plant, and the introduction of specific cover crops (such as hairy vetch and lupin) that secrete massive amounts of organic acids (root acids) like citric acid from their roots to dissolve phosphorus. This signifies a forced paradigm shift from an "external procurement model" reliant on cheap water-soluble fertilizers from overseas to an "internal soil resource mining model" that utilizes unexploited resources slumbering in the country's own soil.

Conclusion: A Paradigm Shift Toward Sustainable Phosphate Supply

Through the comprehensive analysis in this report, it has become clear that Japan's annual supply structure for phosphate chemical fertilizers harbors highly asymmetrical and fragile realities. The "Product Import Route," boasting an overwhelming share (80%-85%), is at the mercy of geopolitics and global energy market hegemony. The "Domestic Processing Route" (12%-14%), once a risk hedge, is self-destructing due to sulfuric acid shortages accompanying decarbonization and ore degradation. The "Domestic Extraction Route" (0.2%), the only hope for purely domestic production, is blocked by economic walls and institutional silos and has not scaled at all.

Maintaining the current absolute volume of annual supply (about 300,000 tons in P_2O_5 equivalent) on the extension of existing supply chains has an extremely high probability of becoming difficult in the future. Securing a stable supply of phosphoric acid is no longer merely an agricultural policy issue; it is a paramount challenge that should be integrated as the core of energy policy, environmental policy, and comprehensive national security policy.

The following drastic directions are strongly suggested for Japan's future strategic approach.

First, massive capital injection at the national level and the establishment of legal frameworks for the commercialization of the third route (MAP recovery from domestic sewage). This must be repositioned from a mere cost-reduction measure for sewerage businesses into a national strategy of "creating a purely domestic fertilizer industrial complex." It is inevitable to design a wide-area purchase guarantee system connecting municipalities and fertilizer manufacturers, and direct financial incentives for farmers and companies utilizing recovered MAP. Rather than giving up on popularization due to high costs, it is necessary to build a mechanism for society as a whole to bear this cost as a security "premium (insurance)."

Second, the thorough implementation of "fertilizer reduction" on the demand side and the societal implementation of precision agriculture. By using the latest soil sensing technology to precisely map the amount of the aforementioned "legacy phosphorus" in each field and scientifically reducing the absolute amount of P_2O_5 inputted in stages, macro-level demand control is required to reduce the denominator of import dependency itself.

Japan's agricultural system is approaching the final stage of transition from a 20th-century mass-input, mass-consumption model predicated on the infinite supply of fossil fuels and exhaustible resources, to a 21st-century survival model predicated on physical resource constraints and thorough regional circulation. Rebuilding the phosphate supply chain is not just a fertilizer issue; it will be the most critical touchstone determining Japan's resilience as a nation and the success or failure of a sustainable food production system.