Overview

Conventional nitrogen fertilizer manufacturing involves energy-intensive fossil fuel operations, which contribute significantly to the 10.7 to 12.0 gigatonnes of annual CO₂ emissions. Additionally, sources of mined phosphorus and potassium are diminishing or experiencing supply chain disruptions.

Background: Annual agricultural emissions range between 10.7 and 12.0 gigatonnes of CO₂ equivalent. Fertilizer production represents a sizeable proportion of these emissions, and the most crucial macronutrients — nitrogen, phosphorus, and potassium — are vulnerable to future supply chain restrictions.

Market data: China is the leading fertilizer consumer worldwide, followed by India and the U.S. The global organic fertilizer market is expected to reach $19.88 billion by 2029, and fertilizer demand is far outweighing supply.

Opportunities: Alternative ‘green’ methods for fertilizer production include green ammonia synthesis and nutrient recovery from phosphorus- or nitrogen-containing wastes. Many such processes are now commercialized.

Key benefits: Utilizing liquid, solid and biosolid waste products for nutrient recovery reduces harmful emissions and accelerates the development of greener fertilizer production for a sustainable future in agriculture.

Rethinking modern agricultural methods

With global food shortages and finite fertilizer resources, a rethink of modern agricultural methods is vital, especially owing to the substantial carbon footprint. Alternative sustainable methods are leading the way in the future of farming and food production.

<table>
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<th>Biorefineries</th>
<th>Biochar (charcoal)</th>
<th>Green ammonia</th>
<th>Nanoscale and controlled-release fertilizers</th>
<th>Struvite</th>
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<td>Combined production of sustainable energy, biofuels, food, chemicals, and nutrient-rich fertilizers that utilize renewable biomass as a feedstock</td>
<td>Anaerobic pyrolysis of organic matter, e.g., dead plants or leaf litter are clean and energy-efficient approaches to producing stable carbon</td>
<td>Producing 100% renewable and carbon-free ammonia using renewable energy, nitrogen, and water</td>
<td>Controlled-release formulations would increase the efficacy of nitrogen and phosphorus delivery while decreasing environmental nitrogen and phosphorus loss</td>
<td>Struvite (MgNH₄PO₄), a crystalline mineral composed of magnesium, ammonium, and phosphate, is a sustainable means for phosphorus recovery from wastewater and is used in fertilizer production</td>
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Industry innovation in nutrient recovery

Nutrient recovery processes are being commercialized to help streamline efficiencies, reduce costs, and minimize environmental impact. Some examples include:

1. **Pearl® and WASSTRIP® technologies (Ostara Nutrient Recovery Technologies Inc., Canada)**

   are key processes for phosphorus removal used to produce Crystal Green®, a sustainably recovered slow-release fertilizer. The Root-Activated™ release optimizes uptake and protects local water resources while increasing yield.

2. **The Aqua2™N Process (Easymining Services, Sweden)**

   recovers nitrogen from sludge liquor. Nitrogen is adsorbed and harvested as crystals, which are then repurposed for fertilizer production.

3. **AshDec® Thermochemical P-Recovery system (Metso Outotec, Finland)**

   improves plant availability and reduces heavy metal content through the recovery of phosphorus from sewage, sludge, and ash. The phosphorus product is citrate soluble, and phosphorus release is controlled.

4. **The RecoPhos Project (The RecoPhos Consortium)**

   is a multidisciplinary project undertaken by academia, industry, and enterprise. The objective is to recover phosphorus from sewage, sludge, and ashes using an innovative reactor, to implement a fully operational bench scale reactor and design a pilot scale plant.

5. **AirPrex® (CNP CYCLES GmbH, Germany)**

   is a patented sludge optimization process that improves biological phosphate elimination. In the AirPrex® reactor, digested sludge is treated to precipitate MAP or struvite.

Abbreviations: MAP = magnesium ammonium phosphate; WASSTRIP® = Waste Activated Sludge Stripping to Remove Internal Phosphorus.

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The future of fertilizers

Comprehensive research highlights numerous innovations in nutrient waste and wastewater recovery, as well as environmentally friendly fertilizer production methods. Sustainable agriculture will be a key contributor toward minimizing energy consumption and protecting the finite nature of global phosphorus, nitrogen, and potassium reserves.

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