# Decarbonising the *Phosphate and Potash* Fertiliser Industry

## A science-based approach to reducing emissions from fertiliser production and use

July 2026

An EBRD initiative, developed by ERM and Systemiq, in collaboration with IFA

# Contents

# Acknowledgements


## Strategic Guidance and Leadership

We are deeply grateful for the continuous support and strategic guidance provided by the European Bank for Reconstruction and Development (EBRD), Systemiq, and International Fertilizer Association (IFA) teams. In particular, we would like to recognise Dimitri Koufos, Sam Maayuf, Nicolo Giachino, Charles Fowler, Olivia Becher, Volker Andresen, Patrick Heffer, Laura Cross, Stephen Bell, Rupert Simons, and Paddy Ellen, whose direction and engagement have been critical throughout.

## Advisory Group Contributions

We extend our sincere thanks to our advisory group for their exceptional insights, technical expertise, and constructive challenge, which significantly strengthened the robustness of this work:

- Tibaut Theys (Prayon Technologies)
- Ahmad Al Mbaidin (Arab Potash Company)
- Barbara Novak (World Business Council for Sustainable Development)
- Hayley Zipp, Dana Cartwright, Viviana Huerta and Tariq Kareemulla (International Council on Mining and Metals)

## Broader Industry Participation

We acknowledge the ongoing engagement, openness, and industry perspective provided by key partners including Nadav Even-Hen, Head of ESG & Sustainable Finance Director at ICL, Naoufal Mahdar, Senior VP Decarbonisation & Climate Action and Soumaya Benzennou, Senior Lead Decarbonization Program at OCP, The Mosaic Company, and K+S. We would also like to thank the many organisations that actively contributed through workshops, sharing practical experience, insights, and perspectives: Anglo American; Arab Fertilizer Association; Ballestra; BHP Biliton; Brazil Potash; Compagnie des Phosphates de Gafsa; Elixir Group; European Sustainable Phosphorus Platform; Fertilizer Canada; FLSmidth; Groupe Chimique Tunisien; Haifa Group; International Fertilizer Development Centre; IFFCO; Indorama; Kemapco; Komatsu; Maaden; Metso Group; PhosCo Limited; Rondo; Saskatchewan Mining Association; Siemens Energy; SLB Capturi; Travertine; The Fertilizer Institute; Mohamed VI Polytechnic University.

## Report development and stakeholder engagement

Finally we would like to recognise the ERM team members, whose rigorous analysis, technical expertise, and dedicated delivery underpinned the development of this report: Chloe Bayliss, Chris Sim, Daniel Saxton, David Neilson, Elly Shaw, George Naismith, Hana Douglas, Henry Hall, Isabella Naughton, Lizzie Knight, Michael Azih, Neil Mckenna, Richard Platt, William Page.


# Foreword

European Bank for Reconstruction and Development

*"Decarbonising the phosphate and potash industry is a complex, system-wide challenge that cannot be addressed by any single technology or actor. It requires a coordinated shift in how energy is sourced, raw materials are processed, nutrients are applied, and capital is mobilised across the value chain, particularly in a sector that is both essential to global food security and highly exposed to climate risks. This roadmap captures that complexity without losing sight of practical action, reflecting reality, setting out a credible, layered pathway that distinguishes between what can be achieved today and what depends on enabling conditions such as policy certainty, risk-sharing mechanisms, and cross-sector collaboration. As an institution working at the intersection of climate, investment, and development, the EBRD sees decarbonisation in this sector not as a parallel agenda but as integral to sustainable development, especially in regions where phosphate resources and climate vulnerability coincide. By providing a clear foundation for action and a shared framework for producers, policymakers, and financiers, this roadmap has the potential to catalyse both the investment and the stakeholder alignment needed to drive deep, systemic change."*

***Gianpiero Nacci***
***Managing Director***
*EBRD Climate Strategy and Delivery (EBRD)*

→ The EBRD is a multilateral bank that promotes the development of the private sector and entrepreneurial initiative in 40 economies across three continents. The Bank is owned by 77 countries as well as the EU and the EIB. EBRD investments are aimed at making the economies in its regions competitive, well governed, green, inclusive, resilient and integrated.

# Endorsements

WBCSD – World Business Council for Sustainable Development

*"WBCSD particularly welcomes the strong emphasis in this roadmap on working across industries and value chain collaboration — reflecting the scale of collective effort. Through the WBCSD Agriculture & Food Emissions Reduction Accelerator, we have been working to equip the food and agriculture sector with the tools and partnerships needed to turn decarbonisation ambitions into reality. Outcomes from our initial ERA workshops helped inform this roadmap, and it will in turn serve as a key resource within the ERA toolbox — a clear demonstration of how different channels can work in concert to drive collective action"*

***Diane Holdorf***
***Executive Vice President***
*World Business Council for Sustainable Development (WBCSD)*

→ The World Business Council for Sustainable Development (WBCSD) is the leading community of around 230 global businesses making sustainability performance a key driver for competitiveness. It is a non-profit member-led organization that connects business leaders across sectors and economies, and creates the tools and frameworks to scale collective impact, drive cross-sector innovation, and shape an ambitious, enabling policy agenda.

ICMM

*"The scale of the decarbonisation challenge makes it clear that no single actor can deliver the transition alone. Progress depends on coordinated action across value chains, energy systems, policymakers, financiers and industry. We therefore welcome this roadmap as a practical contribution to that effort, providing a clear framework for collaboration and helping stakeholders identify the actions, investments and enabling conditions needed to accelerate implementation. Its emphasis on shared responsibility and system-wide alignment closely reflects the findings of ICMM's recent From Mine to Grid report, which highlighted the importance of coordinated action to unlock decarbonisation at scale."*

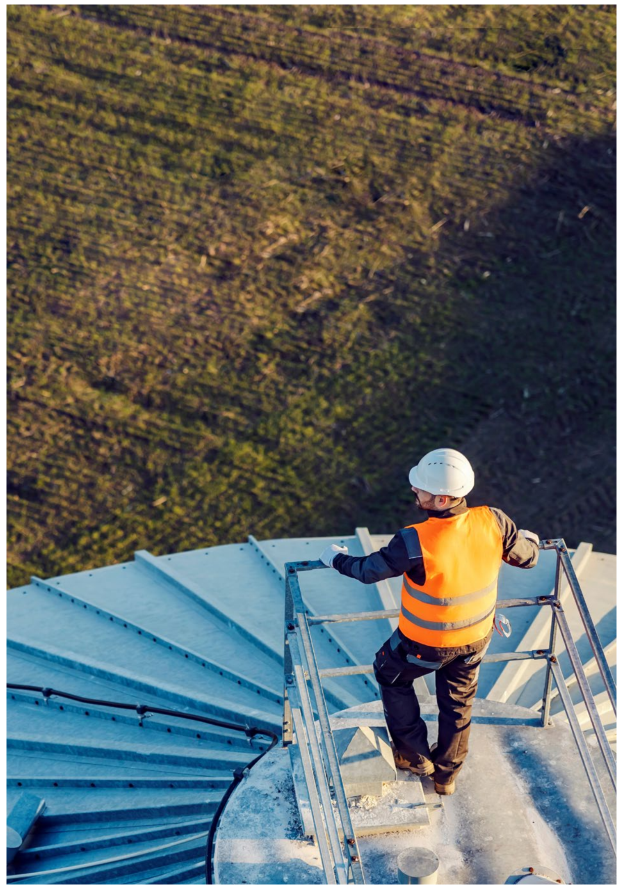
***Dana Cartwright***
***Director of Environment***
*International Council on Mining and Metals (ICMM)*

→ ICMM stands for mining with principles. We bring together a third of the global metals and mining industry, along with key partners to drive leadership, action and innovation for sustainable development, ultimately delivering a positive contribution to society. Through collaboration, ICMM member companies set the standard for responsibly produced minerals and metals in a safe, just, and sustainable world.

# Executive Summary

This roadmap sets out the direction of travel for decarbonising phosphate and potash fertiliser production towards 2050, in alignment with the Paris Agreement and the Intergovernmental Panel on Climate Change's (IPCC) net zero goals[1], while balancing GHG emissions reduction with the need to preserve affordability, food security, and long-term market resilience. Achieving this will require significant technological, policy and investment progress beyond current trajectories.

Therefore, the following roadmap lays out a practical and considered pathway, identifying the transformation required, while highlighting cost-effective strategies, opportunities for cost reduction, the role of new and developing technologies, and the potential for greater supply diversification and resilience. As such, it is intended as a call to action not only for producers, but also for policymakers, governments, and financial institutions, recognising that many of the levers required to enable this transition lie beyond the control of industry alone. Achieving decarbonisation at the pace and scale required will necessitate coordinated action across producers, policymakers, financiers and wider value-chain stakeholders. Furthermore, this roadmap outlines the consequences of inaction, including increased exposure to acute and cumulative climate risks that could threaten the industry. It also sets out the investments and enabling conditions required to deliver the transition, and recommends that the P&K industry adopt a holistic, long term approach to decarbonisation that balances emissions reduction with the need to maintain affordability and global food security.



*Progress will also depend on stronger demand signals across the wider agri-food system, from incentives and support for farmers to adopt more efficient nutrient management practices, to clearer market pull from food companies, retailers and other offtakers for lower-carbon fertiliser value chains.*

1 IPCC. 2022. Climate Change 2022: Mitigation of Climate Change – Summary for Policymakers.

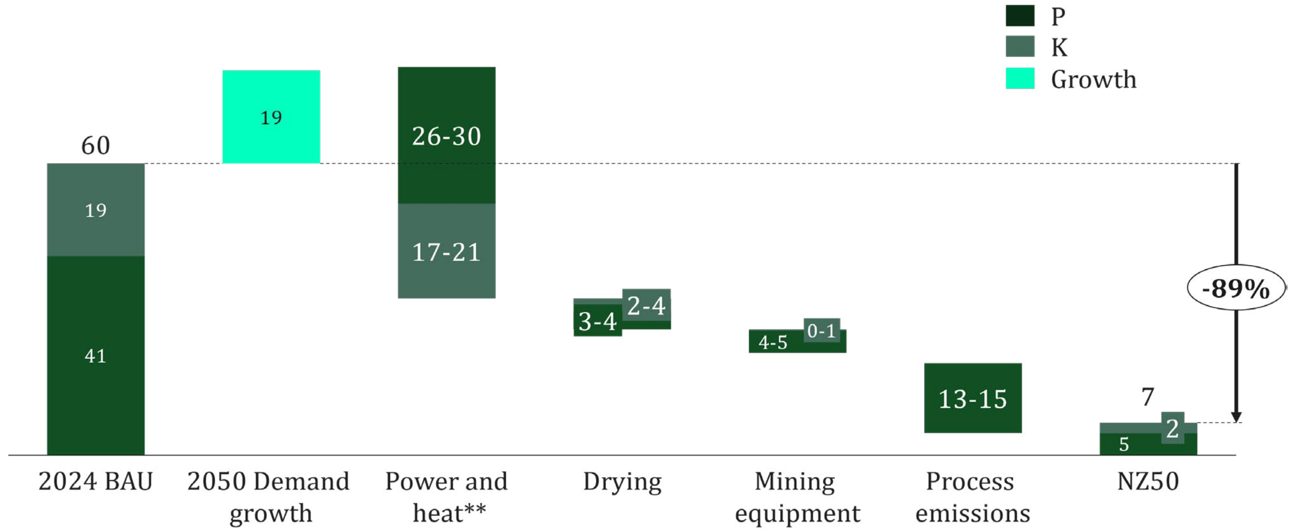
# The long-term direction of travel

This roadmap shows that deep emissions reductions across phosphate and potash production are theoretically achievable, but only through large-scale changes in production systems and regulation that may involve significant economic and environmental trade-offs.

Decarbonisation can also deliver benefits to the industry, such as reducing exposure to volatile raw materials and energy inputs such as ammonia, sulphur, and fossil fuels, as well as improving access to concessional finance. The transition is not a single pathway, nor a uniform timeline. Regional starting points, production pathways, decarbonisation technology readiness levels (TRLs), and access to enabling infrastructure mean that outcomes will vary drastically. Overall delivery risk is therefore defined by TRL, the industry's willingness to explore alternative production pathways, access to low-cost renewable electricity, and supporting infrastructure availability.

**Theoretical Analysis of GHG Emissions Abatement Potential in Global Phosphate and Potash Production by Hotspot, 2050**

*NZ50 Scenario, Million tonnes $CO_2e$ (Production emissions only, excluding upstream and downstream emissions)**



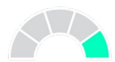

* This analysis shows the most likely range for decarbonisation only, but there is significant variance at asset level which means that the plausible range for each hotspot may vary. This pathway represents the most ambitious scenario, aligned with the Net Zero 2050 goal. Achieving it requires substantial progress in technology deployment, policy support and capital mobilisation.

** Power and heat includes levers looking at decarbonisation of electricity and heat generation. They have been combined given that most facilities in the baseline assumptions currently use combined heat and power (CHP) facilities with sulphur as the energy source in the phosphate industry.

Decarbonisation strategies for fertiliser production can be categorised into two groups: incremental decarbonisation and transformational decarbonisation. The first describes decarbonisation measures which complement, evolve, or are additions to incumbent infrastructure and production processes. The latter defines a system-level shift in the fertiliser production process, avoiding, rather than mitigating, GHG emission hotspots. Transformational decarbonisation can also have additional long-term benefits such as eliminating key constraints such as sulphur dependency and phosphogypsum waste production. While incremental decarbonisation strategies are important for GHG emissions reduction in the near and long term and are discussed in depth later in the report, larger transformational decarbonisation measures such as process route changes, raw materials dependency reduction, and infrastructure build-out will be key to achieving deep decarbonisation and ultimate emissions reduction goals. However, these technologies are at varying stages of maturity and require further demonstration and scale-up to achieve their full decarbonisation potential.

Key trends in both incremental and transformational strategies to reduce production emissions in fertiliser manufacturing, as well as long-term strategies to reduce emissions from fertiliser use, are as follows:

→ **Use of Low Carbon Energy:** Shifting to low-carbon electricity and heat via power purchase agreements (PPAs), certificates, on-site renewables, and low-carbon process heat remains a key decarbonisation lever. While maximising the use of existing sulphur-based energy assets may provide value on-site, cogeneration strategies should be re-evaluated over time by considering carbon capture and sequestration (CCS) or alternative fuels like biofuels, however, these are only viable in select regions where economics, regulatory environment, geology, infrastructure availability allow.

| 9 |  |  |
|---|---|---|
| *Very High Technology Readiness* | *Very High GHG Reduction Potential* | *Low to Moderate Cost of Action* |

**Legend**

- *Very high attractiveness*
- *High attractiveness*
- *Moderate attractiveness*
- *Low attractiveness*
- *Very low attractiveness*

- **Nutrient use efficiency:** Improving nutrient use efficiency (NUE) is a high-impact lever to cut fertiliser use emissions without reducing yields, achieved by minimising over-application and ensuring nutrients are taken up by the crop through best-practice agronomy, including the 4Rs, biologics, precision and digital farming tools, enhanced-efficiency fertilisers, and the elimination of inefficient use where nutrients do not constrain productivity. Alongside these strategies, the long-term soil health should also be considered and assessed to ensure the nutrient use efficiency measures do not further degrade soil quality. Although the largest use-phase GHG reductions are generally linked to nitrogen management (applicable to monoammonium phosphate (MAP), diammonium phosphate (DAP), compounded NPKs and nitrates of potash (NOP) which contain nitrogen), nutrient use efficiency is considered a broader value-chain lever. Specialty fertilizers, controlled-release technologies, precision nutrition, and crop-specific nutrient management strategies can improve overall nutrient efficiency and support both productivity and sustainability objectives.

| | | |
|---|---|---|
| 4-7 | | |
| *High*<br>*Technology Readiness* | *Very High*<br>*GHG Reduction Potential* | *Low to Moderate*<br>*Cost of Action* |

- **Process Emissions:** Phosphoric acid process emissions and fuel emissions are the critical long-term constraint, with abatement reliant on CCS and other technologies that face technical, geological, economic, regulatory, and infrastructure barriers to application in a phosphate & potash sector setting. Reducing fuel-related emissions depends on electrification technology investment and development, renewable power availability, biofuel accessibility, site-specific temperature requirements.

| | | |
|---|---|---|
| 3-9 | | |
| *Low to Moderate*<br>*Technology Readiness* | *High*<br>*GHG Reduction Potential* | *High to Very High*<br>*Cost of Action* |

- **Sulphur:** System-level production shifts to mitigate growing structural risks in today's sulphur-based system, driven by sulphur supply and price exposure as refining declines, rising competition from battery materials, and heightened geo-political volatility. Alternative, non-sulphur based pathways are potentially strategic options, not near term replacements, but could become increasingly competitive mirroring technology diversification already seen across other chemical value chains.

| | | |
|---|---|---|
| 5-9 | | |
| *Moderate*<br>*Technology Readiness* | *Moderate*<br>*GHG Reduction Potential* | *Moderate to High*<br>*Cost of Action* |



## The case for near-term action

Continuing and increasing emissions reduction momentum in the next decade is critical to delivering the industry's long-term decarbonisation pathways. Near-term action limits near-term emissions growth while preserving future optionality by enabling early-stage technologies to scale, de-risk, and decline in cost. Given the capital-intensive nature and long life of phosphate and potash assets, embedding decarbonisation into existing operations is essential to avoid lock-in, mitigate risk to the industry from energy market volatility, and to position the industry for more transformative change post-2035.

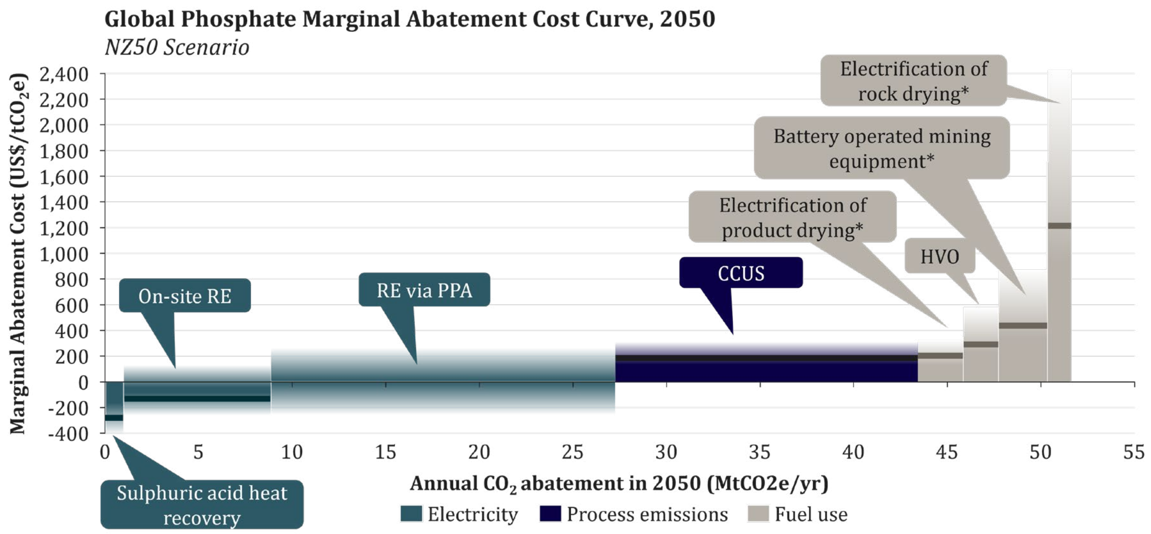
However, decarbonisation must not undermine global food security or affordability. Aggressive absolute interim emissions reduction targets are poorly suited to the sector as they may risk incentivising cuts in fertiliser production, rather than emissions efficiency. Emission intensity targets could be considered, but due to significant region variation in technologies and production processes, setting an industry-wide benchmark and intensity target would be challenging. Asset-level approaches best reflect industry complexity and food security imperatives, while near-term action can still be driven through targeted, economically attractive initiatives as demonstrated by peer hard-to-abate industries that are already moving ahead today with development and investment, for example cement with CCS and chemicals with electrification.

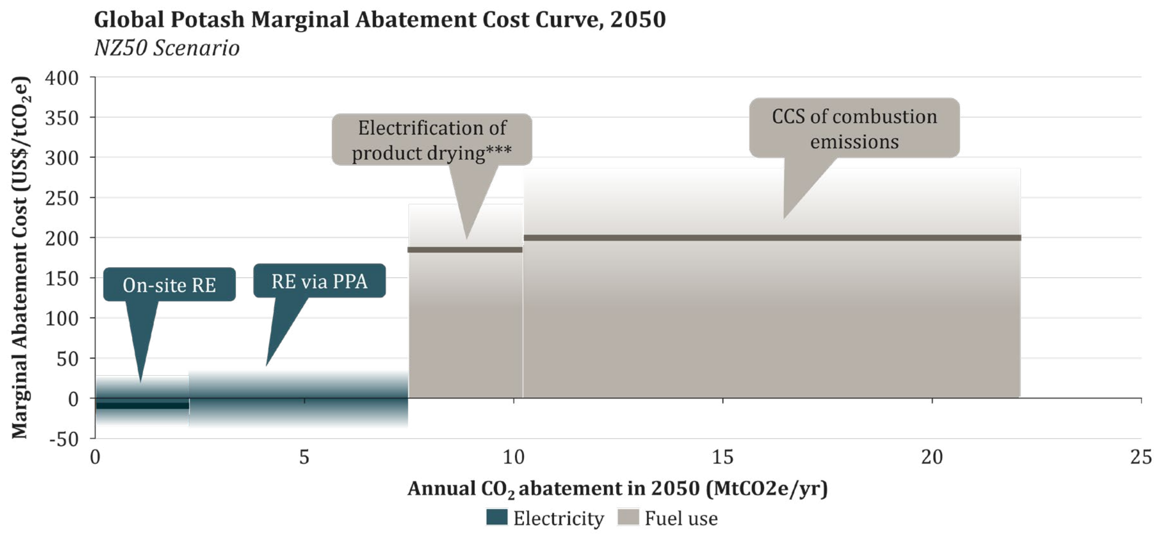
## Investment needs and priority actions

There are a number of non-financial barriers including policy and technology readiness but delivering this transition will also require a step change in investment from across the value chain and from governments. Many decarbonisation levers require substantial upfront capital, some near-term measures can also be financially attractive and deliver positive returns, as shown in the MACC analysis on the following page. While requirements vary by region and production route, the overall cost of decarbonising the production emissions from the industry and meeting a net zero goal by 2050 falls within a **US$ 235-320 billion** range globally. This value shows the sheer scale of the challenge to decarbonise production emissions, but it does not includes the significant investments on infrastructural upgrades, or show the required policy support and demand signals needed to bring about the investment and support each business case. With this in mind, investment priorities are:

- **Production assets,** including retrofits, efficiency initiatives, electrification and upgrades to existing plants using lower carbon processing technologies.
- **Industrial and energy infrastructure,** notably grid reinforcement, access to low-carbon electricity, and alternative fuel and $CO_2$ logistics (where relevant based on economics, regulatory, environmental, supply chain availability).

- **Enabling systems,** including innovation, education, policy frameworks, demonstration, skills, digital tools, co-financing options, and industry coordination mechanisms such as industrial hubs and collaboration that reduce cost and risk over time.
- **Accelerating the transition to a low-carbon agri-food ecosystem** by collective and coordinated action between stakeholders (i.e. producers, farmers, government, etc.) such that the appropriate market signals, incentive structures, product innovation, resilient supply chains and more detailed analysis of use phase emissions are in place.




---

* Needs to be combined with sourcing of renewable electricity

** Battery operated mining equipment with renewable electricity was considered as well but due to the low emissions abatement potential (as most equipment is already electrified), the cost is extremely high and has not been included in this diagram

*** Needs to be combined with sourcing of renewable electricity

### How to interpret MACCs

**Marginal abatement cost curves (MACCs) show the cost of reducing one tonne of $CO_2$e on the vertical axis (height of each bar), while the horizontal width represents the total GHG emissions reduced by that measure in a given year.**

- The order of measures in a MACC does not reflect order of implementation or suggest certain measures over others.
- The results of the MACC reflect today's system configuration and do not account for future gains.
- Strategic and system-level risk are not captured (e.g. sulphur availability, by-product constraints).
- High abatement cost does not imply low long-term relevance.

The analysis shows that some near-term measures can be low-cost or even have a positive investment return such as heat recovery and energy efficiency, but higher-impact abatement requires capital-intensive investment. However, both near and long-term measures depend on policy certainty, technology readiness and infrastructure availability. Capital mobilisation in the long term therefore hinges as much on risk reduction and coordination as on technology cost.

However, the investment case for decarbonising P&K production is not based on climate benefit alone. It has a number of other benefits which strengthen the case for investment. This includes protecting competitiveness, reducing exposure to future cost and policy risks, preserving long-lived asset value, improving access to capital, and strengthening the sector's long-term licence to operate in a decarbonising food system. These associated benefits, like all other investment factors, are heavily dependent on geographical variation and economic starting points.

# Call to action

The transition mapped out in this report is challenging but achievable. In no particular order, it requires:

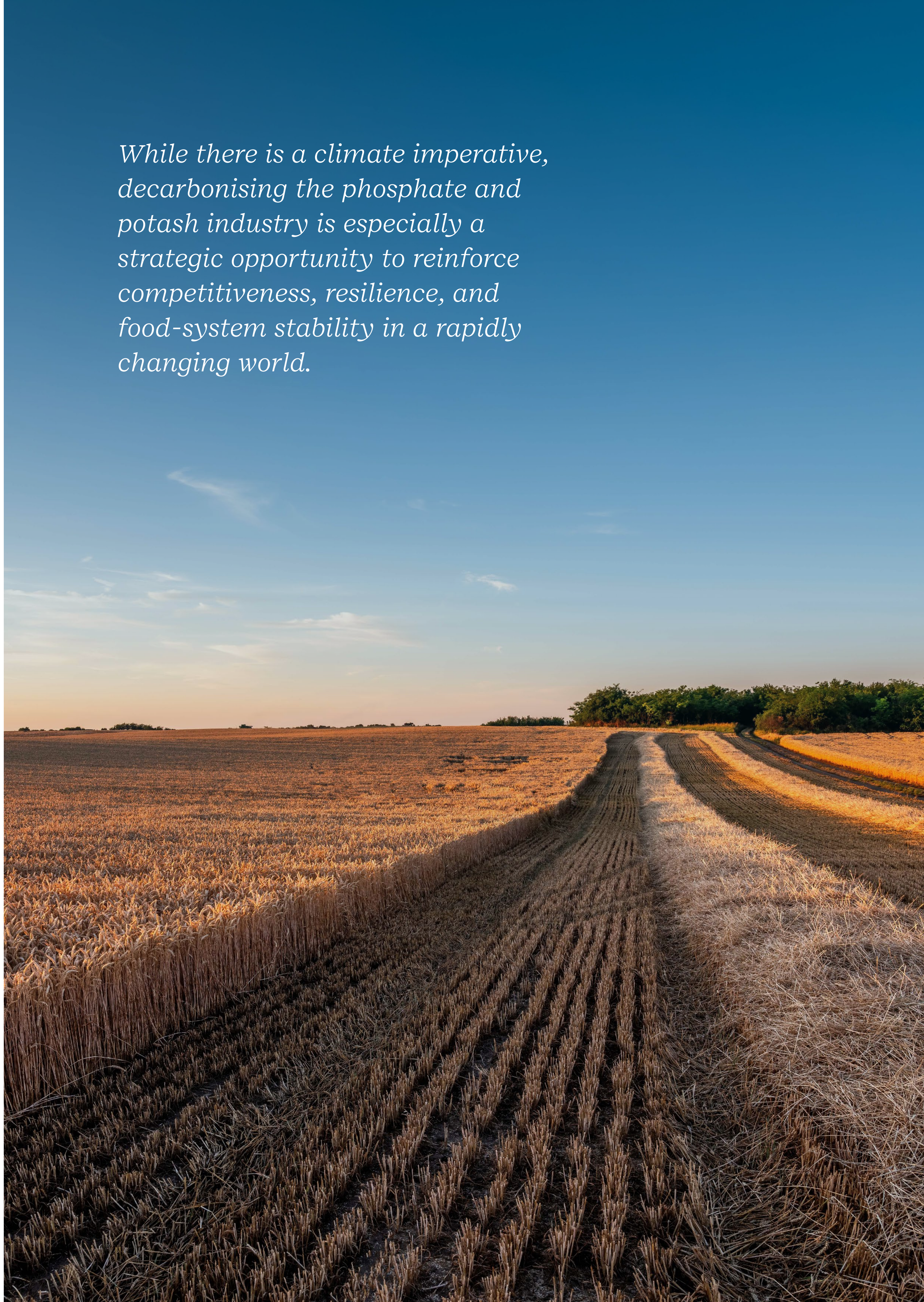
**Agri-food conglomerates and downstream retailers cross value chain collaboration** to create market pull for low-carbon fertilisers to enable upstream investment.

**Financiers** to mobilise capital at scale using blended and risk-sharing mechanisms, and to replicate successful financing models rapidly.

**Policymakers** to provide clear, credible long-term signals and incentives, and to invest in enabling infrastructure rather than prescribing specific technologies.

**Producers** to build upon existing progress and act early on identification and prioritisation of novel technologies, embed decarbonisation readiness into capital decisions, and collaborate on first-of-a-kind solutions.

**Standard setters** to develop fertiliser specific, food-secure target-setting guidance that enables flexible intensity- and asset-based pathways and aligns with agri-food value chain frameworks. This should be underpinned by standardised lifecycle assessment methodologies for fertiliser-use phase $N_2O$ emissions.

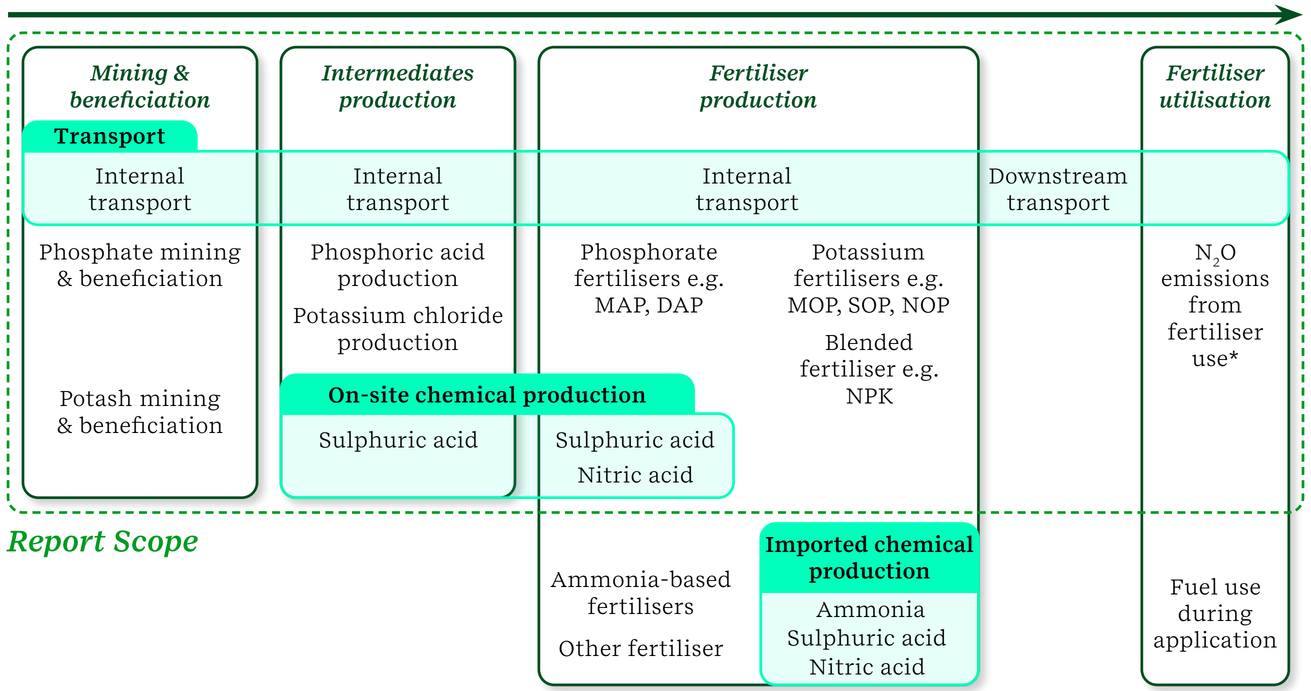


*While there is a climate imperative, decarbonising the phosphate and potash industry is especially a strategic opportunity to reinforce competitiveness, resilience, and food-system stability in a rapidly changing world.*

# Chapter 1.

## Introduction

**Phosphate and Potash Fertiliser Industry Roadmap Scope**




Phosphate and potash fertilisers are foundational to the global food system. Together with nitrogen fertilisers, they underpin agricultural productivity, crop resilience, and food security worldwide. At the same time, their production is energy- and resource-intensive, tightly linked to broader industrial and energy systems, and increasingly exposed to climate, policy, and market risk. As global demand for food continues to grow, the P&K industry faces a material challenge to decouple production from emissions while maintaining affordability and security of supply.

Today, global phosphate and potash demand is rising at a rate of 0.7–1.4% per year (based on ERM analysis with IFA support) due to global population growth and other factors. Besides this predicted growth, the fertiliser sector is included in SBTi's chemicals sector decarbonisation guidance and is expected to reduce emissions at a rate of 4.2% year-on-year[2]. Achieving this level of emissions reduction will require significant innovation, investment and collaboration while maintaining food security and affordability. The P&K industry remains structurally linked to energy intensive production routes, fossil derived inputs, and water intensive processing. Production emissions from phosphate fertilisers are dominated by electricity and process emissions from phosphoric acid production while potash emissions are driven by electricity and fuel use in drying processes. However, for both nutrients, emissions from production are minor relative to the much larger contribution from ammonia production and nitrous oxide emissions during fertiliser use. As such, the P&K industry could benefit

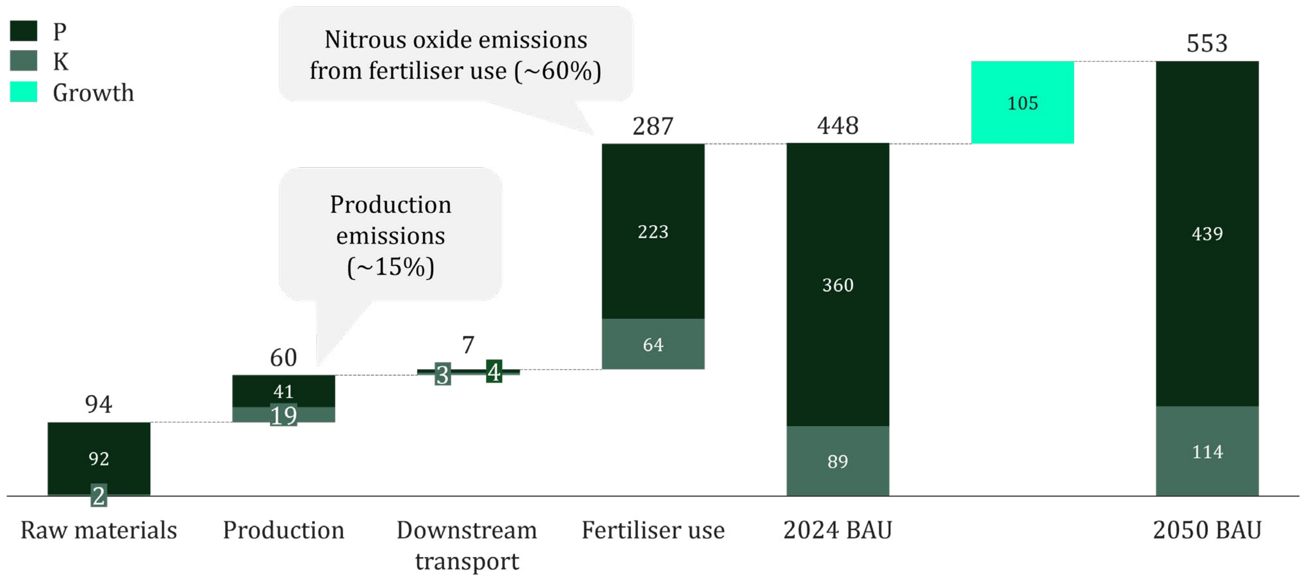
* $N_2O$ emissions from fertiliser-use arise from nitrogen applied to soils. These emissions are considered within the value chain in this report for some P and K containing fertilisers due to their nitrogen content, such as MAP, DAP, and blending NPK fertilisers. The allocation methodology used by the industry is still under development and this diagram is not intended to support adoption of a particular methodology

2 SBTi. 2025. SBTi Chemical Sector Pathways and Implementation Criteria

from working together with nitrogen fertiliser companies on complementary value-chain approaches, including nutrient use efficiency and other downstream measures that can support emissions reductions while maintaining agricultural productivity and food security.

Without any action under the business-as-usual scenario, total sector emissions increase broadly in line with output growth, reaching an estimated **550 $MtCO_2e$ per year by 2050**, an approximate 25% increase from the 2024 baseline with limited scope for efficiency improvements alone to support the decarbonisation of rising demand.

**Emissions of the Phosphate and Potash Industry Value Chain, 2024**
*Million tonnes $CO_2e$ per year*




The combination of climate change impacts and insufficient decarbonisation progress could amplify existing environmental, social, and economic challenges facing the P&K industry, such as:

- **Rising costs and declining competitiveness** as producers remain exposed to volatile energy and sulphur prices, tightening water constraints, and potential carbon pricing mechanisms.
- **Increasing policy and regulatory exposure** as fertiliser production becomes more visible within national industrial decarbonisation strategies, carbon-pricing regimes, and emerging low-carbon product standards.
- **Growing physical risks,** particularly related to water intensity, tailings and phosphogypsum management, and climate-driven stress on infrastructure and resources. This is discussed further in Section 1.1.
- **Food system implications,** as higher and more volatile fertiliser costs caused by fossil fuel price fluctuations risk being transmitted downstream, disproportionately affecting import-dependent regions and agricultural systems with limited flexibility.

It is therefore imperative that the industry has a clear roadmap to decarbonisation that recognises the inherent complexity of the phosphate and potash value chain and is delivered through coordinated, cross-sector collaboration. Crucially, this transition must be designed to safeguard the sector's core function in underpinning global food systems, ensuring that emissions reductions are achieved without compromising affordability and food security. Against this backdrop, the following roadmap sets out a structured framework for decarbonising the P&K fertiliser value chain, identifying the key GHG emissions hotspots from the production and use of fertilisers containing P&K, highlighting priority technologies that can be leveraged for decarbonisation, and emphasising enabling actions required to support implementation across the value chain.

This roadmap was developed by ERM, in collaboration with EBRD and the International Fertilizer Association (IFA), with significant input and effort from industry through workshops, surveys, and feedback. Technical annexes with the detailed methodology and working for the project are available on request from ERM.

## 1.1 Physical climate risk

The phosphate sector faces increasing physical climate risks due to the concentration of reserves in already climate-stressed regions. Operators are experiencing growing impacts at site level, including operational disruption, rising costs, infrastructure damage, insurance pressures, and supply chain instability, all of which are expected to intensify.

The frequency of extreme heat events is expected to increase based on IPCC analysis, reducing productivity, increasing health and safety risks, and driving higher costs for cooling, water use, dust suppression, and equipment maintenance. In parallel, developing occupational heat regulations are also expected to tighten compliance requirements. Wildfires are emerging as a significant threat to operations by disrupting land access, transport corridors, power infrastructure, and communications networks, as demonstrated by the recent mining shutdowns in Canada. Flooding and extreme storms are also causing substantial infrastructure damage and production losses as was seen in Australia in 2025, while also increasing disruption and vulnerability across transport and shipping networks, further raising costs.

At the same time, climate change is increasing the risk of eutrophication and pollution events from phosphorus-rich effluents, tailings seepage, and runoff, particularly as heavy rainfall increases discharge volumes and warmer conditions accelerate algal growth, placing greater pressure on compliance with tightening environmental standards.

Water scarcity remains a critical long-term constraint, particularly in water-stressed regions with a high concentration of production, such as North Africa, the Middle East, and northern China. This is increasing the cost of sourcing, treating, and desalinating water and, in severe cases, may limit or halt operations. Competition for water resources can also introduce indirect social and regulatory risks, including community tensions and stricter governance.

## 1.2 How to read this roadmap

This roadmap covers greenhouse gas emissions (GHG) across the full cradle-to-grave phosphate and potash fertiliser value chain, including raw material inputs, fertiliser production, downstream transport and trade, and emissions associated with P&K fertiliser use in agriculture. This broader system view is important because the sector's climate impact is not limited to production sites alone. However, particular emphasis is placed on production emissions because these are the emissions most directly influenced by fertiliser producers through operational, technological, and capital investment decisions. Other hotspots such as upstream raw materials and downstream fertiliser use remain essential to the overall decarbonisation challenge, but addressing them requires action across a wider set of stakeholders, including ammonia producers, farmers, agri-food companies, financiers and policymakers.

The report should therefore be read in two ways: as a direction of travel roadmap for reducing emissions under producers' direct influence, and as a wider call to action for decarbonising the full fertiliser value chain without undermining food security or affordability. This distinction is important because, for many phosphate and potash products, production emissions are smaller than the wider emissions associated with ammonia and fertiliser use, yet they remain strategically important for competitiveness, regulation, financing and long-term asset resilience. Within production, the roadmap distinguishes between **incremental decarbonisation**, which improves or retrofits incumbent systems, and **transformational decarbonisation**, which changes the underlying production route, raw material dependence or system configuration. Both pathways are necessary: incremental measures are critical for near-term progress, while transformational measures are more likely to be required for deep long-term emissions reduction.

The scenarios presented in this report are intended as illustrative pathways rather than fixed forecasts. **Business-as-usual (BAU)** shows the consequences of limited action under expected demand growth and existing technology trends. **The Net Zero Emissions by 2050 (NZ50) scenario** and **the Net Zero Emissions by 2070 (NZ70) scenario** represent more ambitious decarbonisation pathways developed for this project to test what would be required under different transition pathways. Some sections of the report, particularly those covering fertiliser-use emissions, draw on complementary external analyses and therefore use related but not identical scenario frameworks; where this is the case, the report notes the shared assumptions and any important differences in system boundaries or analytical approach. They are not prescriptive blueprints for every producer or region, and they do not imply that all assets should follow the same sequence of actions. Instead, they provide a structured way to compare the scale of change required, the role of near-term versus long-term levers, and the enabling conditions needed for delivery. Throughout the report, these pathways should therefore be understood as decision-support frameworks for a diverse and highly heterogeneous sector, not as a single universal trajectory.

# Chapter 2.

The phosphorus (P) and potassium (K) industry



The scope of the phosphate and potash industry in this report covers greenhouse gas emissions associated with the entire cradle-to-grave fertiliser value chain, including raw material inputs, production of fertiliser products, downstream transport via trade and fertiliser use in agriculture. These are the major sources of emissions for the industry with minor contributions from other parts of the value chain. Production emissions are considered under the direct operational control of P&K fertiliser producers with the system boundaries for direct emissions shown in Section 2.3.

## 2.1 Role of phosphorus and potassium

Phosphorus (P) and potassium (K) nutrients are central to the global fertiliser system and agricultural production. Around 95% of phosphorus (as phosphate fertiliser)[3] and 85–95% of potassium (as potash fertiliser)[4] consumption is used in agriculture to provide the necessary P and K nutrients to agricultural crops, directly linking these materials to food production across the globe. Changes in their availability, cost, or environmental performance have system-wide implications for global food security and affordability.

Their widespread application has contributed to long-term productivity gains and the Green Revolution through the 20th century which has supported food security and economic development. Phosphorus and potassium play distinct but complementary roles in healthy crop production.

- **Phosphorus** supports strong root development and energy transfer as a key part of adenosine triphosphate (ATP). Phosphorus is not soluble in water but needs to be replenished regularly as it is depleted over time by runoff (caused by significant rain events) and crop harvesting or residue removal. In soils with significantly depleted phosphorus levels, agricultural activities are not possible even with other nutrients. By fuelling plant photosynthesis, phosphorus also helps sequester atmospheric carbon into the soil.
- **Potassium** enhances the rate of photosynthesis, strengthens plants and makes them more resistant to disease. Potassium is soluble in water and therefore needs to be replenished regularly as depletion also occurs via harvesting, residue removal and runoff. “Potash” refers broadly to potassium-bearing rocks and minerals that are mined and used to produce potassium fertilisers.

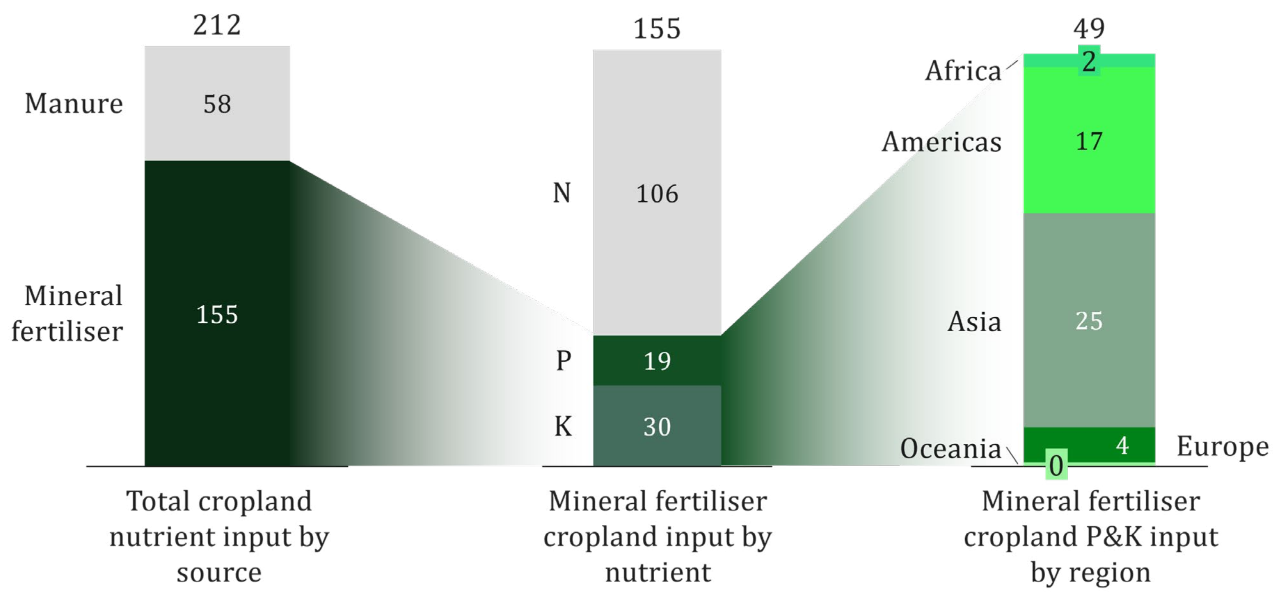
3 ADBG & IGF: Phosphate fact sheet

4 Natural Resources Canada

Production of phosphate and potash requires emission-intensive inputs, such as sulphur, electricity, fuels, and water, and generates phosphogypsum (in the case of phosphate products), tailings, and effluents that require careful management. As a response to market demand for nitrogen as a nutrient in fertiliser products, many producers blend ammonia-derived fertiliser products with phosphate or potash to form NPK complex fertilisers.

### Total Fertiliser Agricultural Use, 2023

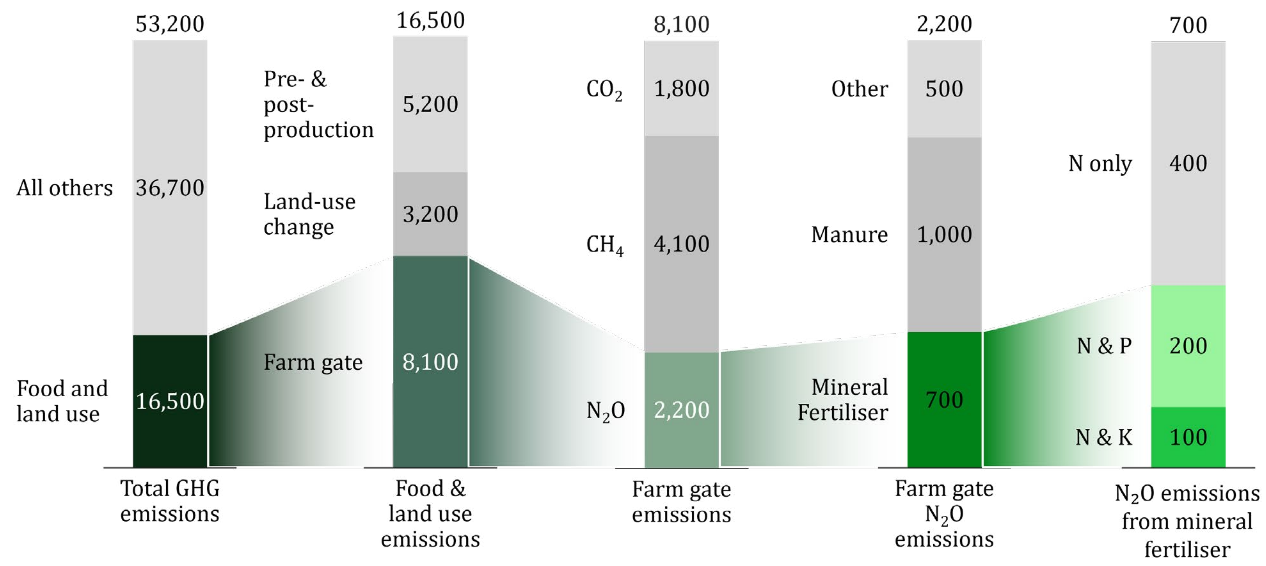
*Million Tonnes Per Year of Nutrient*




Most P&K products (>90%) are used as fertilisers and are indirectly linked to emissions of nitrous oxide from application of nitrogen, phosphorus and potassium (NPK) fertilisers[5]. The extent of these emissions is dependent on the nutrient content of the final NPK fertiliser product. The remaining 10% is used in the chemical, food & beverage, battery, pharmaceutical and glass sectors. Taken together, these interactions show that decarbonising phosphate and potash products and fertilisers must be addressed as part of a broader transition across fertiliser supply chains, energy systems, and food production, rather than as a production-only challenge.

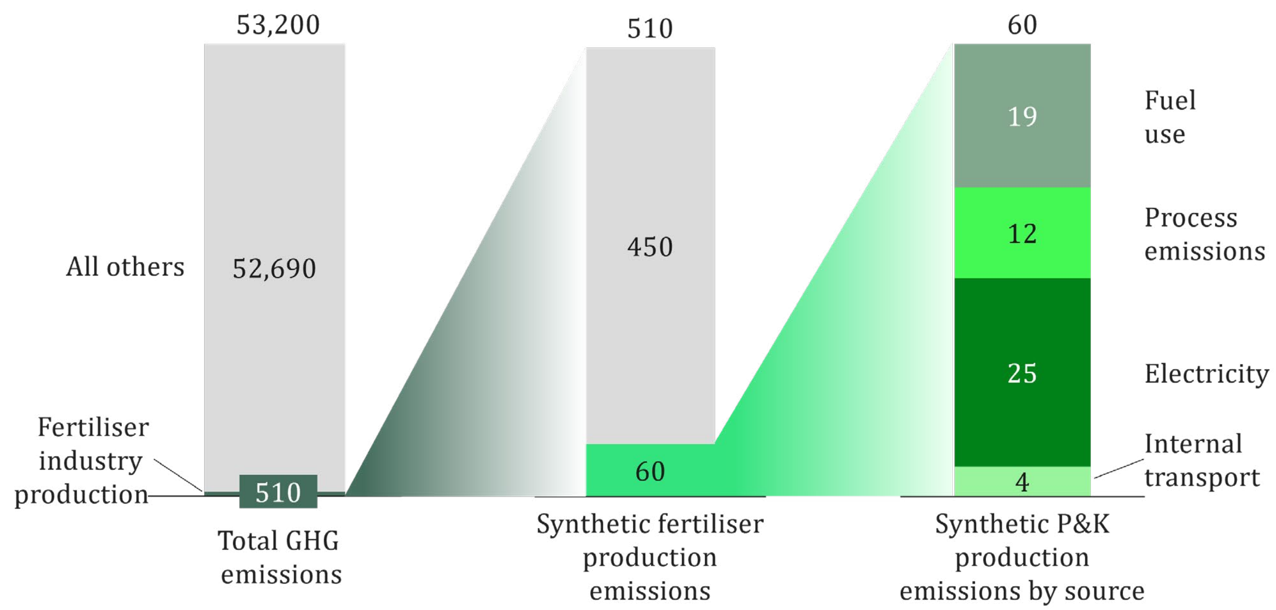
### Total Emissions (Gt $CO_2e$) for Agri-food By Greenhouse Gas (GHG) and Primary Source

*Million Tonnes Per Year of Nutrient*




### Total GHG Emissions for Fertilisers by Emission Source, 2024

*Million Tonnes $CO_2e$ Per Year*




5 IFA. 2010. *Sulphur and Sustainable Agriculture.*

## 2.2 Market outlook

Global demand for phosphate and potash fertilisers is shaped by long-term trends in agricultural production, crop patterns, and population growth. In 2024, global demand for phosphate fertilisers was estimated at around 150 million tonnes across products such as MAP, DAP, SSP, TSP, and NPK compounds[6]. Demand is concentrated in key crop growing regions such as East Asia, South Asia, and Latin America, where large populations and limited land drive crop intensification. For the same period, global potash fertiliser demand was approximately 62 million tonnes, with muriate of potash (MOP) accounting for greater than 90% of volumes. Latin America is a key driver of potash demand given the significant volume of soybean and sugarcane crops that require high potassium application rates. Beyond fertiliser application, future phosphate demand is driven by growth in other competing applications such as lithium iron phosphate batteries, for example.

Because phosphate rock and potash salt deposits are unevenly distributed, production is concentrated in a relatively small number of regions, making global markets for raw materials required for fertiliser production, and fertilisers themselves, sensitive to supply and trade route disruptions caused by regional geopolitical tensions – most recently affecting global sulphur supply. Phosphate fertiliser production is concentrated in China and Morocco, although significant deposits in India, Saudi Arabia, and Russia lead to significant market share from these regions too. For potash, significant deposits in Canada mean that it is the largest producer of potash fertiliser globally followed by Russia, Belarus, and China.

6 Product Definition

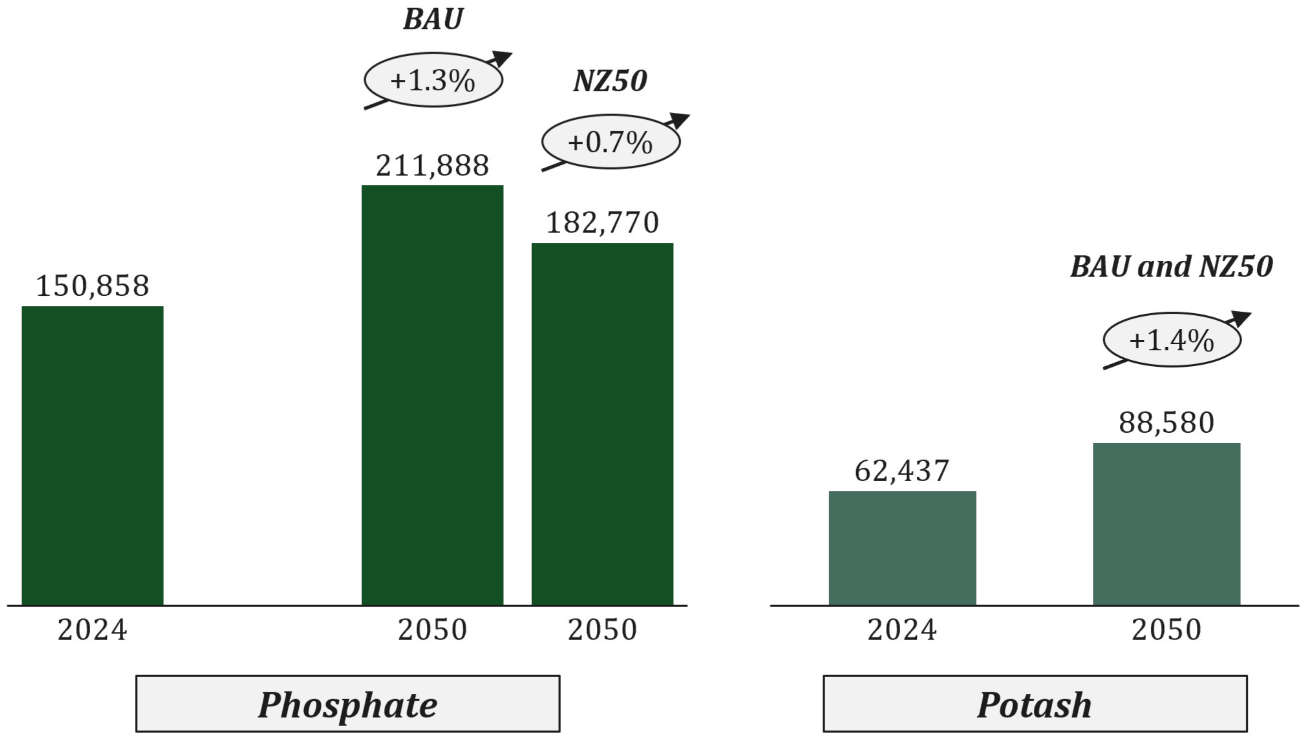
**Phosphate products**

MAP/DAP = Monoammonium Phosphate / Diammonium Phosphate
SSP = Single Superphosphate
TSP = Triple Superphosphate
NPK = Chemically granulated compounds containing Nitrogen, Phosphorus and Potassium

**Potash products**

MOP = Muriate of Potash
MgSOP = Magnesium Sulphate of Potash
SOP = Sulphate of Potash
NOP = Nitrate of Potash

**Phosphate and Potash Fertiliser Demand Growth to 2050 by Scenario (KTA of Fertiliser)**




| Region | % CAGR (BAU) | % CAGR (NZ50) | % CAGR (BAU and NZ50) |
|---|---|---|---|
| | Phosphate | | Potash |
| Europe | 0.8% | 0.3% | -0.4% |
| Eastern Europe and Central Asia | 1.6% | 1.1% | 1.0% |
| North America | 1.4% | 0.8% | 1.0% |
| South America | 1.6% | 0.9% | 1.4% |
| Africa | 1.8% | 1.2% | 1.1% |
| Middle East | 1.9% | 1.3% | 1.2% |
| South Asia | 1.6% | 1.0% | 1.3% |
| Asia | 1.0% | 0.5% | 2.0% |
| Oceania | 1.4% | 0.6% | 1.0% |

Looking forward, demand for phosphate and potash fertilisers is expected to grow as crop output expands to support a growing global population. This future demand growth can be viewed under two scenarios:

01 **Business as usual** trajectory, reflecting the sector's current trajectory for nutrient-use-efficiency and existing emissions intensity for the grid and raw materials. Under this demand scenario, the combined P&K fertiliser demand is expected to reach **300 million tonnes by 2050**[7].

---

02 **Net zero emissions** pathways aligned with science based targets for 2050 and 2070 both assume improvements in nutrient use efficiency and the use of net zero raw materials. The 2050 scenario aligns electricity decarbonisation with announced national targets, whereas the 2070 scenario assumes a net zero electricity grid by 2070. Under both pathways, total fertiliser demand is still projected to reach close to **280 million tonnes by 2050**[7].

These scenarios have been specifically designed for this project by ERM and do not align with other scenarios unless explicitly stated.

Meeting this additional demand will require new phosphate and potash production capacity and potentially lead to increased absolute emissions. However, the emissions intensity of this increased production capacity can be reduced by low-carbon production technologies (energy efficiency, electrification, fuel-switching, CCS, etc.), improved nutrient use efficiency, and broader changes across fertiliser and food systems.

Long-term demand forecasts have been developed using the best available data but remain subject to uncertainty and may change in response to evolving global conditions. Key drivers that could influence future phosphorus demand include:

- → Climate change, which is expected to further degrade soil quality and intensify nutrient depletion
- → While global cultivate land area may remain stable or decline, rising global food demand is likely to require the expansion of cultivated land in some regions, even where agricultural efficiency improves, therefore sustaining baseline phosphorus demand growth. This will be particularly relevant in areas with phosphorus or potassium-deficient soils.

7 ERM analysis with IFA Market Intelligence support. Reported value is in product tonnes, assuming that the product breakdown/mix remains the same over the forecast period from a 2024 baseline.



## 2.3 Production technologies

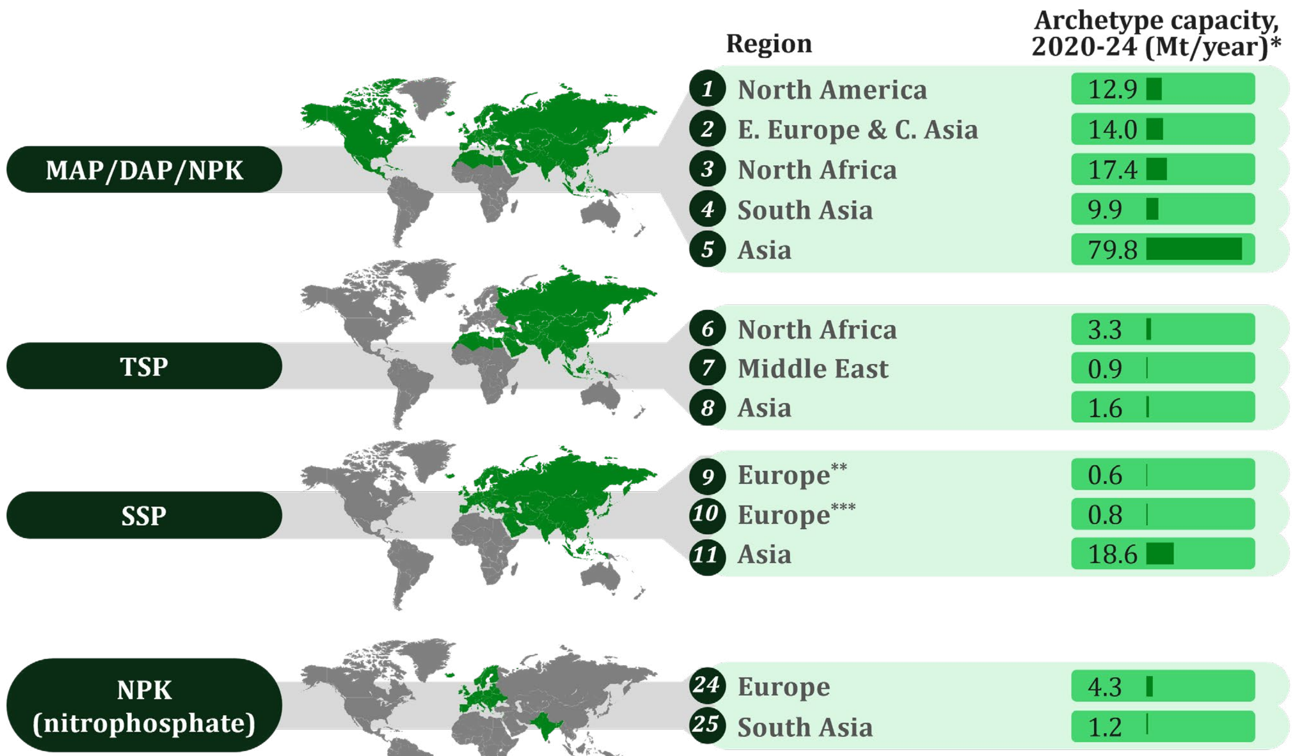
Phosphate and potash fertilisers are produced through distinct production technologies, each characterised by different raw-material inputs, processing steps, and GHG emission drivers. The sector is inherently complex with over 700 facilities globally using different production routes shaped by geology, resource availability, competitiveness, and regional energy systems.

### Phosphate Fertiliser

Production of phosphate fertiliser can be divided into three archetypal process steps:

**System Boundary for the Phosphate Industry**

**Global capacity is dominated by MAP, DAP, and NPK systems, with production concentrated in a small number of major regions. Other routes such as TSP, SSP, and nitrophosphate-based NPK, are more region-specific, reflecting differences in business strategy and technology availability.**




*Based on historic production data from IFA (2020-2024)
**On-site production of sulphuric acid
***Imported sulphuric acid

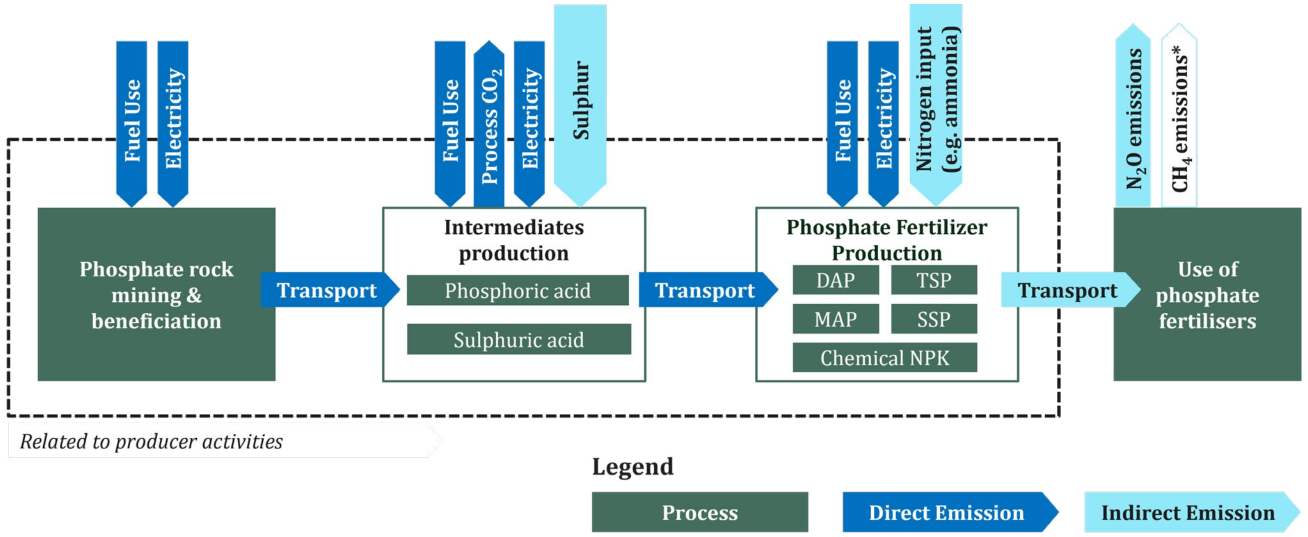
1. **Mining & beneficiation of phosphate rock** involves the extraction of crude phosphate rock from the ground, then crushing and grinding it to reduce particle size, followed by separation processes to increase the concentration of $P_2O_5$ (the standard measure of phosphate content). The resulting product is known as beneficiated phosphate rock. There are two separate processes for the beneficiation of phosphate rock: wet and dry, which are associated with different emission profiles due to the use of calcination in the dry process. The emission profile is further influenced by the deposit quality (which has significant regional variation). Key energy use includes diesel for mobile mining equipment, electricity for crushing and grinding, and natural gas (or fuel oil) for drying the rock.

2. **Intermediate production of phosphoric acid** is typically completed using the 'wet process'. This involves the dissolution of beneficiated rock with a strong acid to produce phosphoric acid – a key intermediate in the production of the final fertiliser product. Producers have traditionally used sulphuric acid (as opposed to nitric or hydrochloric acid) due to its lower cost, high availability and because the gypsum byproduct is easier to manage (high filterability). Sulphuric acid production is typically integrated on-site as its production from sulphur produces significant amounts of energy which can be used as a non-carbon source of steam and electricity. As a result, heat recovery is key with imported energy requirements being as low as 5% using the most efficient techniques[8]. The process also involves the production of phosphogypsum which is the largest by-product by volume. Between four and five tonnes of phosphogypsum is produced for every tonne of phosphoric acid produced. The major 'hard-to-abate' emission hotspot for the industry is the production of process carbon dioxide during the digestion of phosphate rock. This is caused by calcium carbonate in the phosphate rock feed.

3. **Phosphate fertiliser production** involves the production of MAP/DAP, NPK compounds, TSP or SSP via various routes with most, excluding SSP, involving the use of phosphoric acid and reacting it with another raw material, e.g. ammonia (MAP/DAP, NPK compounds only), phosphate rock (TSP), MOP (NPK compounds). SSP production uses sulphuric acid and phosphate rock. Fertiliser production is also typically integrated upstream with phosphoric acid production to take advantage of the excess energy from sulphuric acid production. Key energy hotspots include primary fuels (natural gas or fuel oil) for product drying and electricity for various purposes.

8 Metso Outotec HEROS™ Heat Recovery System

### Capacity Breakdown for the Phosphate Industry




Global capacity is dominated by integrated MAP, DAP, and NPK systems, with production concentrated in a small number of major regions as shown in the diagram below. Other product routes, such as TSP, SSP, and nitrophosphate-based NPK, are more region-specific, reflecting differences in business strategy and technology availability.

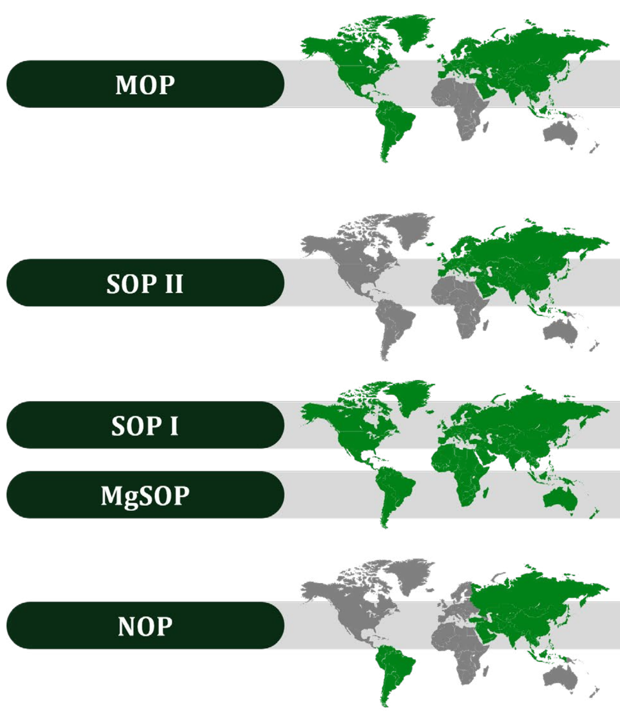
* Methane emissions are from eutrophication caused by run-off of excess phosphate nutrients. It is a wider environmental impact for the industry to consider but is not within scope for this roadmap

## Potash Fertiliser

Production of potash fertilisers can be divided into two archetypal steps:

### System Boundary for the Potash Industry

> **MOP accounts for most of global capacity in regions with large, accessible deposits such as Canada and Russia, while SOP, NOP and MgSOP are produced at smaller scale and in more limited locations due to higher processing complexity and cost.**



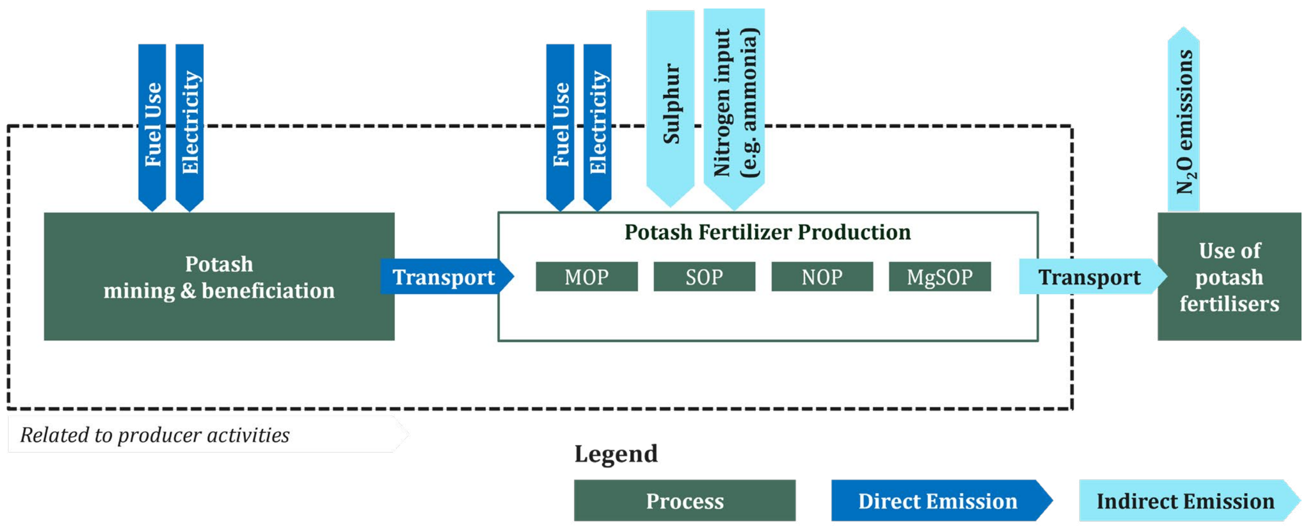

| Archetype | # | Region | Archetype capacity, 2024 (Mt/year)* |
|---|---|---|---|
| MOP | 12 | South America | 2.0 |
| MOP | 13 | Europe | 5.1 |
| MOP | 14 | E. Europe & C. Asia | 28.3 |
| MOP | 15 | North America | 25.1 |
| MOP | 16 | East Asia | 9.6 |
| MOP | 17 | Middle East | 6.5 |
| SOP II | 19 | Asia | 4.5 |
| SOP II | 20 | Europe | 0.7 |
| SOP I | 18 | Global | 2.9 |
| MgSOP | 21 | Global | 0.9 |
| NOP | 22 | Asia | 0.4 |
| NOP | 23 | South America | 0.2 |

*Based on historic production data from IFA (2020-2024)

1. **Mining & beneficiation of potash** involves extracting potash ore from a deposit and processing it to produce a marketable fertiliser product or an intermediate for further refining. In many cases, products such as MOP, SOP I (different from SOP II, explained below), and MgSOP can be produced through mining and beneficiation alone, although this is highly dependent on the deposit. MOP, the most widely used potash fertiliser, is produced mainly through conventional underground mining and solution mining while natural brine extraction is a secondary source produced by certain key regions as shown by the system boundary for the potash industry. Key energy use across these routes includes diesel for mobile mining equipment, natural gas (or fuel oil) for drying, and electricity for processing plants and fixed underground infrastructure.
2. **Potash fertiliser production** as a separate step is only relevant in unique cases where the final product from beneficiation is not a ready-to-use fertiliser product. This is the case for SOP II produced by reacting MOP with sulphuric acid (via the Mannheim process) and NOP produced via the reaction of MOP with nitric acid. In both cases, energy hotspots include use of fossil combustion fuels (e.g. natural gas or fuel oil) for process heat and electricity. Nitrous oxide emissions can also be produced from nitric acid production without the latest abatement technology.

For **potash fertilisers**, production patterns are driven primarily by geology rather than process choice. MOP accounts for the majority of global capacity in regions with large, accessible deposits such as North America and Eastern Europe, while SOP, NOP and MgSOP are produced at smaller scale and in more limited locations due to higher processing complexity and cost.

### Capacity Breakdown for the Potash Industry

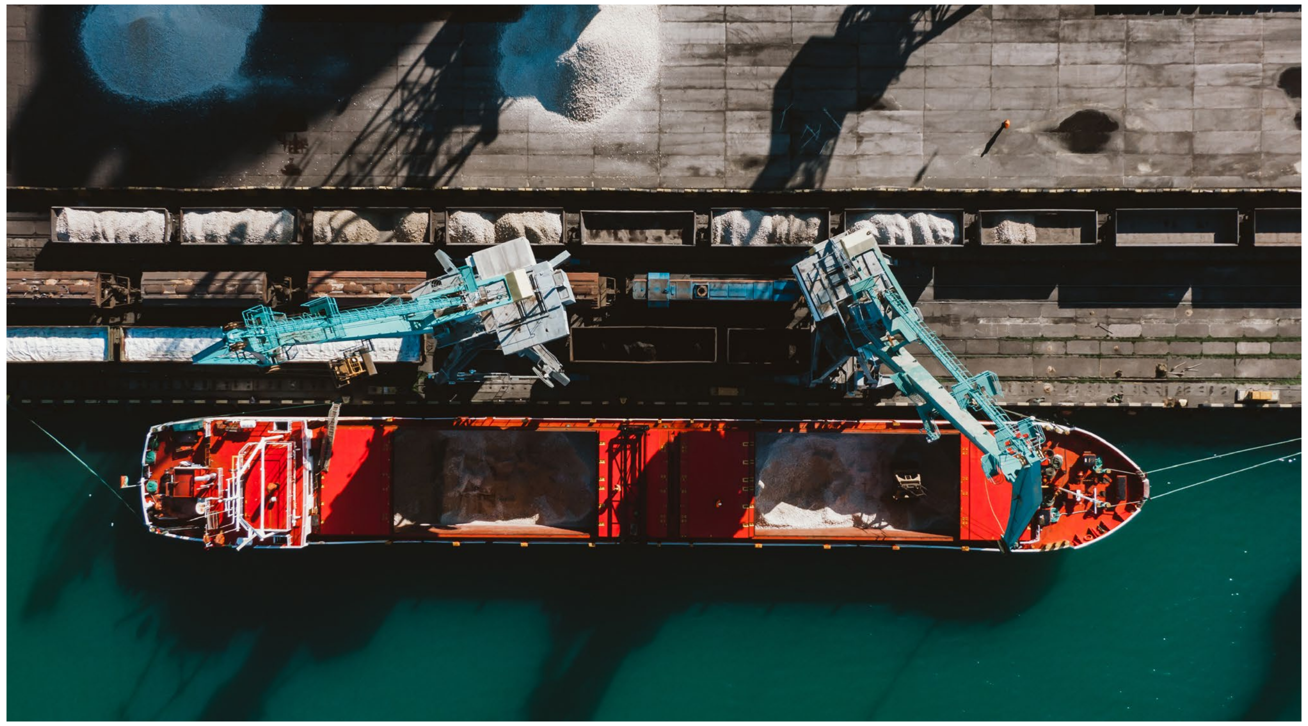


## 2.4 GHG baseline

In alignment with the scope of this roadmap, the GHG emissions baseline for the phosphate and potash industry covers the entire cradle-to-grave fertiliser value chain, including raw material inputs, production of fertiliser products, downstream transport via trade and fertiliser use in agriculture. These are the major sources of emissions for the industry with minor contributions from other sources. All major GHG emissions are accounted for including carbon dioxide, methane and nitrous oxide, while other sources, such as refrigerants, are out of scope. A baseline year of 2024 has been used. All data used to formulate the GHG baseline was drawn from publicly available literature and have been reviewed by stakeholders. As a result, the baseline data may not reflect an individual operator's data (i.e. different hotspots may be present) but is intended to reflect the industry as a whole. The analysis has an inherent level of inaccuracy due to the global natural of the baseline.

The system boundaries for direct emissions in Section 2.3 show production emissions fall under the direct operational control of P&K fertiliser producers. Under production emissions, the key areas for focus as shown in the graphic below are fuel use, electricity, process emissions, and internal transport. Depending on whether the producer uses grid electricity or generates it on-site, these emissions could be either direct operational (on-site generation) or indirect electricity related emissions (grid electricity). This categorisation varies significantly depending on the site. In some cases, raw materials such as ammonia are also under direct control of producers but this is portfolio dependent.

In 2024, total emissions from the phosphate industry value chain were estimated at approximately 360 million tonnes of $CO_2e$ per year, while the potash industry accounts for around 89 million tonnes of $CO_2e$ per year. For the phosphate industry, production emissions (within direct operational control) account for 11% of total value chain emissions with process emissions and electricity being the major hotspots. Raw material emissions contribute 26% of total emissions (particularly those linked to ammonia). In contrast, emissions from potash production (21% of total emissions) are dominated by fuel use and electricity and are significantly higher than raw material emissions, reflecting the lack of use of ammonia for key potash products such as MOP. Although the proportion of value chain emissions under direct producer influence is small, these emissions are still of strategic importance to address. Only monoammonium phosphate (MAP), diammonium phosphate (DAP), compounded NPKs and nitrates of potash (NOP) contain nitrogen and therefore ammonia production emissions are applicable only to these products. The impact of leaving production emissions unaddressed will increase the investment risks associated with producers as these emissions may increasingly translate into financial impacts (via carbon pricing, regulatory requirements or market expectations) seen on the balance sheet / profit-and-loss statements and reduce their competitiveness as climate related regulations become more stringent.



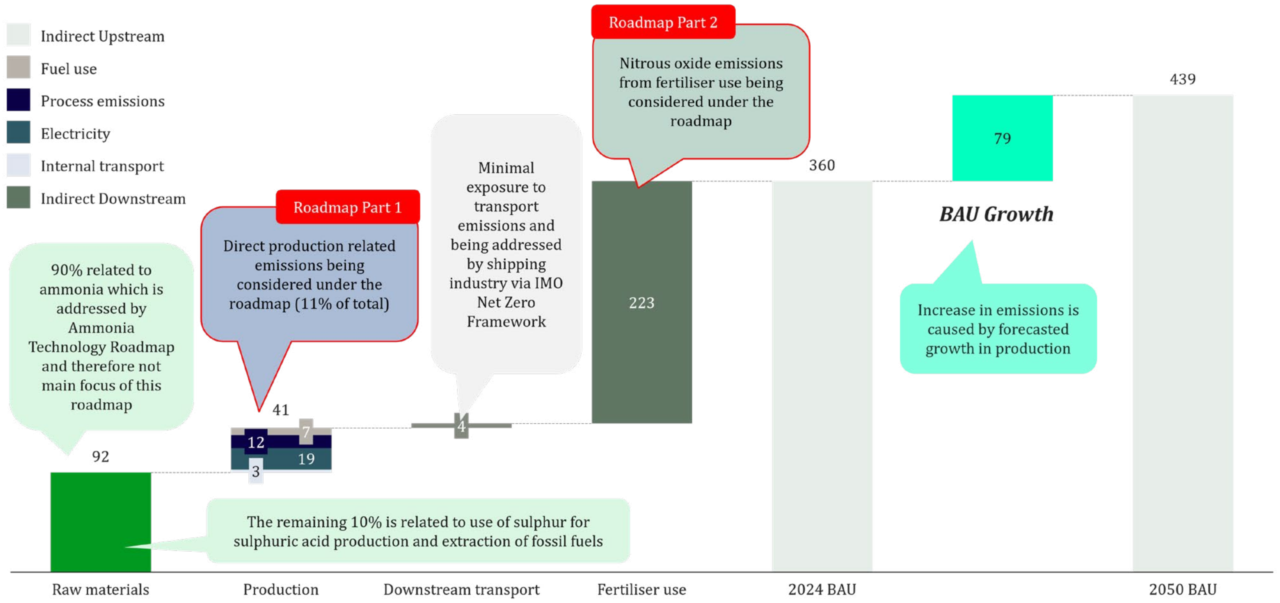
The methodological approach taken in this analysis to estimate GHG baseline emissions was a value-chain approach, inspired by the GHG Protocol's Corporate Accounting and Reporting Standard. A key difference, however, is that instead of calculating emissions at a site or company level, emissions are totalled at a value-chain level, encompassing activities from mining through to fertiliser use. This was done by using the archetypes shown in Section 2.3, deriving activity data from publicly available sources to represent different process steps in the value chain, and multiplying these by regionally and sectorally relevant emission factors. From this, emissions from the entire value chain of different fertiliser types were calculated.

No emissions were allocated out of the system to co-products, nor were emissions allocated to specific products, as is done in lifecycle assessment methodologies such as ISO 14040/44 and ISO 14067. It is recognised that, under these methodologies, a number of scientifically justified allocation approaches have been proposed that allocate emissions according to the nitrogen content responsible for generating N2O. Under these approaches, nutrient components containing no nitrogen (e.g. phosphorus) are not allocated fertiliser-use N2O emissions, while nitrogen-containing components are allocated emissions in proportion to their nitrogen content. As a result, this project should not be used by third parties in evaluating and confirming the methodology for attributing or allocating fertiliser-use emissions to companies, products or sites.

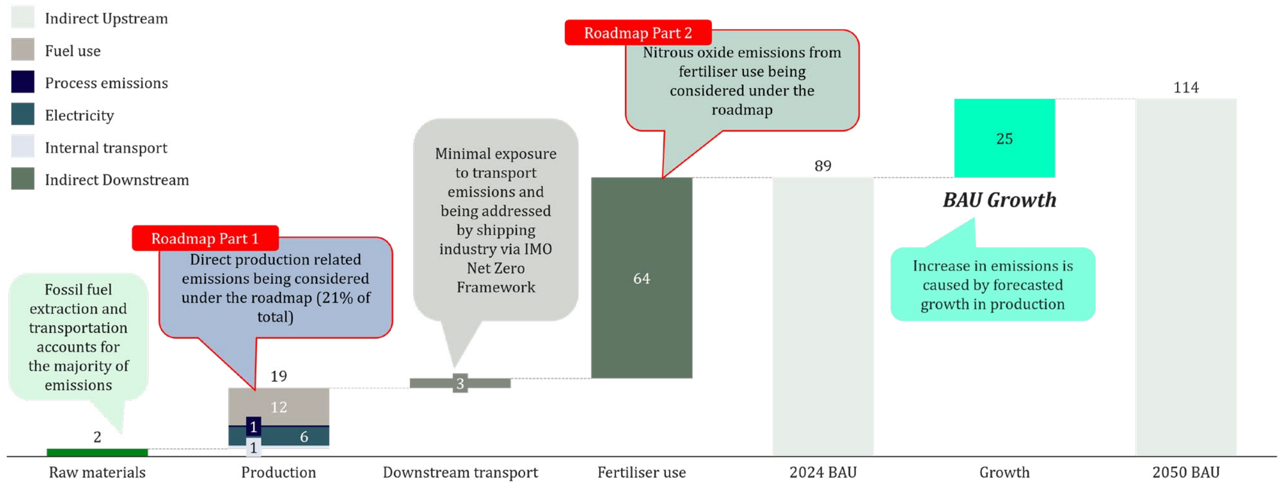
Further research on fertiliser-use emissions, conducted with industry engagement, such as the work being developed by the IFA, will provide an opportunity to evaluate these approaches and work towards an industry-harmonised lifecycle assessment methodology for use-phase emissions.

*Under a business as usual trajectory, total emissions increase broadly in line with production growth. By 2050, emissions from the phosphate industry value chain are expected to reach approximately 440 $MtCO_2e$ per year, while emissions from potash fertilisers reach around 115 $MtCO_2e$ per year.*

**Emissions of the Phosphate Industry Value Chain, 2024**
*Million Tonnes $CO_2e$ Per Year*




**Emissions of the Potash Industry Value Chain, 2024**
*Million Tonnes $CO_2e$ Per Year*




However, across nitrogen-containing phosphate and potash products (e.g. MAP, DAP, NOP, NPK), the largest share of emissions occurs downstream during fertiliser use in the field through the volatilisation of nitrogen. These emissions are out of direct operational control and may be somewhat disconnected from the producers depending on their business strategy, e.g. blenders and distributors can sit between producers and farmers giving two steps of separation. There is a level of influence possible through product design and agronomic support but this is dependent on the business strategy of the producer. Furthermore only monoammonium phosphate (MAP), diammonium phosphate (DAP), compounded NPKs and nitrates of potash (NOP) contain nitrogen and therefore fertiliser use emissions are applicable only to these products although producers can influence these emissions if their business strategy allows for it.

Under a business as usual trajectory, total emissions increase broadly in line with production growth. By 2050, emissions from the phosphate industry value chain are expected to reach approximately **440 $MtCO_2e$ per year**, while emissions from potash fertilisers reach around **115 $MtCO_2e$ per year**[9]. This indicates that incremental efficiency improvements alone are not sufficient to offset rising demand, reinforcing the need for structural changes across energy systems, raw material inputs, production technologies, and fertiliser use practices for meaningful emissions reduction.

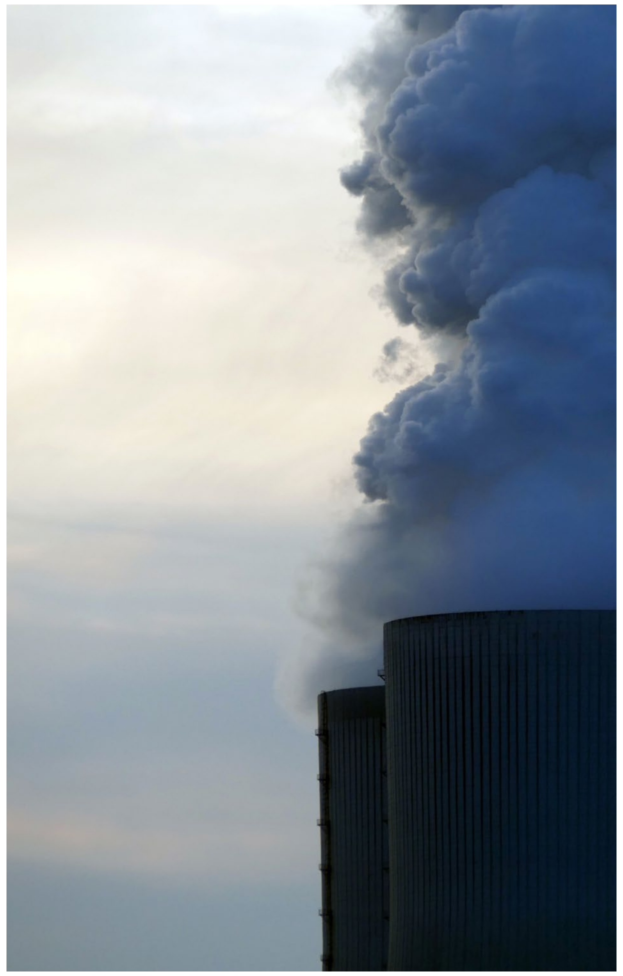
*Emissions are expected to remain concentrated in high-volume, mainstream products (e.g. MAP/DAP/NPK for phosphate and MOP for potash), reflecting their dominant role in global supply of fertiliser. Regional shares are also expected to remain stable, with the Americas, Asia-Pacific, and EMEA each retaining a significant contribution to total emissions. This highlights that abatement must be delivered across all major regions and core products, rather than being concentrated in a small subset of markets or specialties.*

9 ERM Analysis

# Chapter 3.

## Decarbonisation pathways for the sector

This section outlines different incremental and transformational pathways available for emissions reduction across the three major hotspots identified in Section 1: production, fertiliser use, and raw materials. This sector is vital for global food security and affordability; therefore, decarbonisation strategies must be carefully designed so as not to undermine these goals and as a result, the sector should be considered hard to abate. Furthermore, because the industry varies significantly by region and asset, tailored approaches are necessary. The following section can be seen as a framework for further asset-level assessments by industry players.



## 3.1 Long-term decarbonisation pathways for production

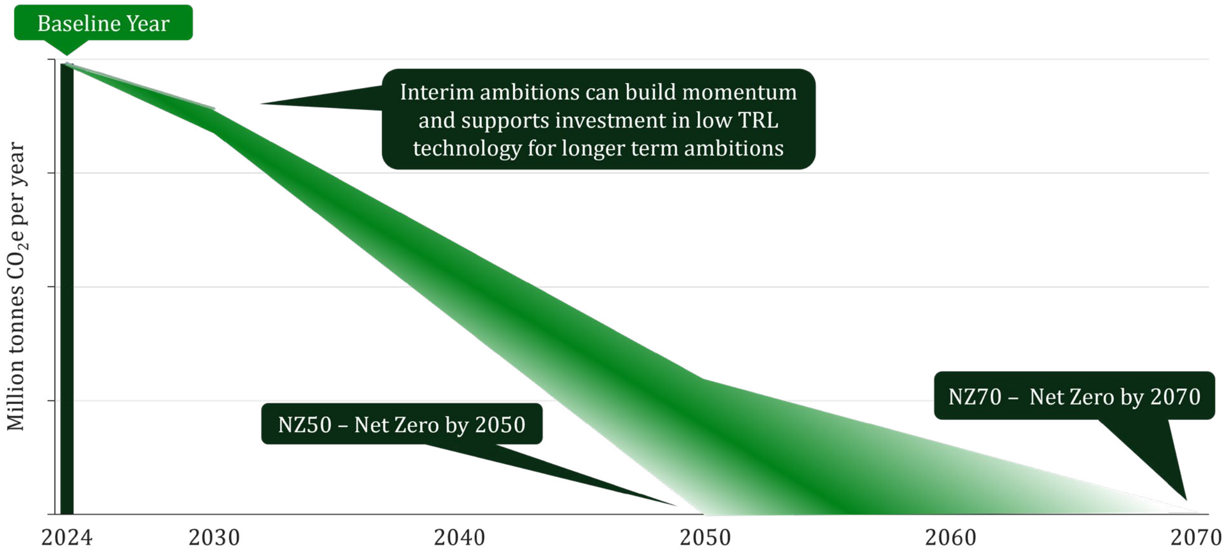
This section explores two illustrative long term transition pathways for production emissions from the phosphate and potash industry. The Net NZ50 scenario aligns with science-based targets to limit long-term global warming, while the NZ70 scenario aligns with IFA's Ambition Statement for reducing GHG emissions associated with nitrogen fertiliser production. The Business as Usual (BAU) scenario is used as a comparator to reflect the consequence of inaction by the industry. Importantly, these scenarios have been specifically designed for this project by ERM and do not align with other NZ50 and NZ70 scenarios unless explicitly stated.

**Scenario Description Table**

| | | External Factor Assumptions | | |
|---|---|---|---|---|
| | **Description** | **Nutrient Use Efficiency** | **Grid Electricity** | **Raw Materials** |
| Business as Usual (BAU) | Reflects the sector's current trajectory, influenced by existing and announced policies | Reflects current trajectory in nutrient use efficiency | Grid emission intensity levels are maintained at 2024 levels | Emission intensity levels are maintained at 2024 levels |
| Net Zero 2070 (NZ70) *Part of Roadmap* | Aligns with IFA's Ambition Statement for reducing GHG emissions associated with nitrogen fertiliser production by an average of 70% by 2050 | NUE improves by 12% and phosphorus use efficiency by 18% compared to the BAU scenario. Potassium use efficiency stays the same. | Net Zero Emissions by 2070 for electricity | Net Zero Emissions by **2070** for raw materials |
| Net Zero 2050 (NZ50) *Part of Roadmap* | Illustrative scenario that aligns with science based targets of net zero by 2050 to limit long-term global warming at 1.5 °C above pre-industrial levels | NUE improves by 12% and phosphorus use efficiency by 18% compared to the BAU scenario. Potassium use efficiency stays the same. | Announced National Targets for electricity | Net Zero Emissions by **2050** for raw materials |

The pathways for individual companies are likely to show significant regional variation. Differences in production routes, baseline emissions intensity, policy support and access to low carbon energy and infrastructure (e.g. $CO_2$ pipelines) mean that regions and producers are likely to decarbonise at different rates and through different combinations of measures. As a result, the net zero aligned and sustainability driven pathways should be understood as defining a range of possible outcomes, rather than a single prescriptive route for the sector.

**Illustrative reduction pathway**

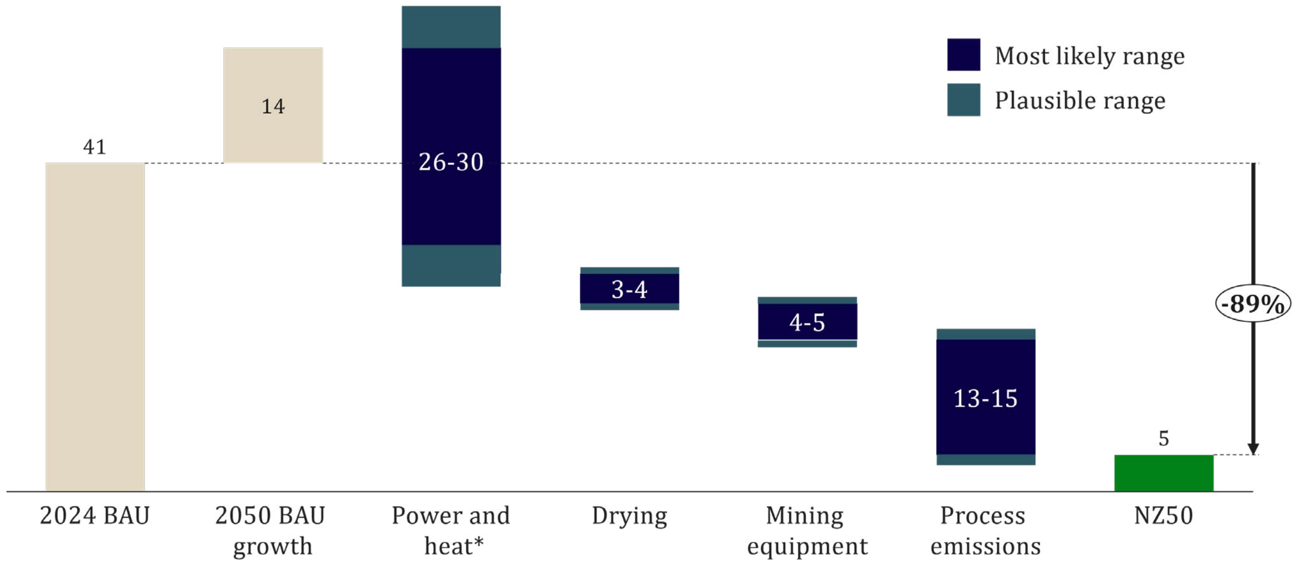



As highlighted in Section 1.2, the key areas for focus within production emissions and under operational control by fertiliser producers are fossil fuel use, electricity use, process emissions, optimising existing self-generation capacity (via heat recovery) and internal transport. The major use of fuel in this industry is natural gas or fuel oil in drying processes and diesel in mining equipment. There is significant regional variety in type of fuels used based on the availability of resources and supply chains and individual sites will need to investigate the feasibility of different decarbonisation options. Although grid-supplied electricity emissions are technically indirect, several decarbonisation levers can be deployed before 2050 to increase the producer's ability to manage and reduce these emissions (subject to country regulations that authorise self-generated production). Acting on them can deliver faster reductions than waiting for the grid to decarbonise.

Process emissions are a key consideration for the phosphate industry, but not for the potash industry, and remain one of the sector's most challenging emissions sources and will require continued innovation and deployment of emerging abatement technologies.

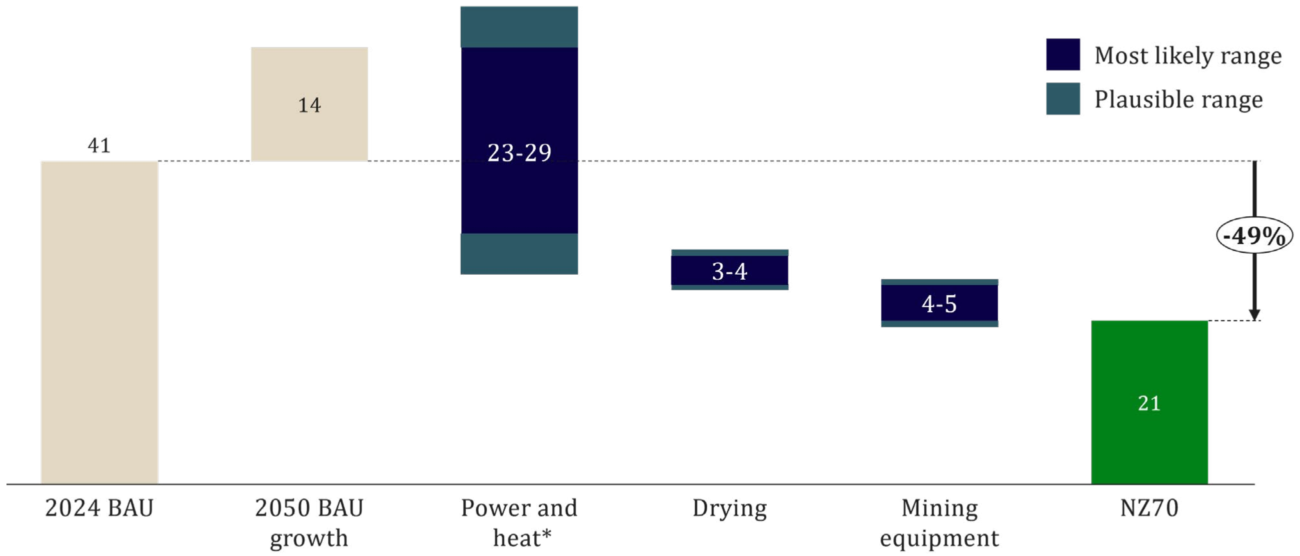
**Global Phosphate Production GHG Emissions Reduction Potential by Hotspot, 2050**

*NZ50 Scenario, Million tonnes $CO_2e$ (Production emissions)*




**Global Phosphate Production GHG Emissions Reduction Potential by Hotspot, 2050**

*NZ70 Scenario, Million tonnes $CO_2e$ (Production emissions)*




* Power and heat includes levers looking at decarbonisation of electricity and heat generation. They have been combined given that most facilities use combined heat and power (CHP) facilities with sulphur as the energy source.

Under the NZ70 and NZ50 pathways, production emissions reductions from existing phosphate and potash production assets are achieved through a layered set of measures, combining near-term deployable actions with longer-term technologies that mature over time. The following values are a static estimate based on currently available data for technologies and the global industry. It may not be representative of an individual site's or region's own emissions reduction potential and further site-level and regional-level roadmaps are recommended before conclusions can be drawn. Furthermore, the exercise is illustrative and does not account for current technical and policy barriers; it highlights the scale of transformation required under different transition pathways.

---

*By 2050 under the NZ50 scenario, both phosphate and potash production emissions would have to fall by* ***85-95%*** *with residual emissions of* ***5-15%*** *of the 2024 baseline. Residual emissions are the uncaptured emissions from CCS due to the assumed capture rate, and downstream transport. For the NZ70 scenario, emissions reduction would have to be approximately* ***50%****.*

---

Highlighted in the following points are incremental measures that can be used to mitigate GHG emissions that arise from the existing fertiliser value chain. System-level transformational decarbonisation measures, which are vitally important for achieving significant emission reductions, are discussed further in Sections 3.3 and 3.4.

**Electricity decarbonisation is a crucial enabling lever** across both phosphate and potash production, looking at the industry holistically, as it not only reduces indirect electricity-related emissions but also enables the electrification of other activities. For the potash sector, decarbonisation of electricity is a critical lever for reaching net zero by 2050 (NZ50) given the significance of the power and heat emissions hotspot. There are also two main pathways depending on the strategy of a fertiliser producer, although some producers may choose to combine different mechanisms based on regional and asset-level variation.

01 **Grid-supplied electricity:** Depending on region, emission reductions could be achieved through procurement of low-carbon electricity, including via the use of market-based mechanisms such as energy attribute certificates (EACs) or power purchase agreements (PPAs). Over the longer term, grids are expected to become cleaner with the rollout of low-carbon electricity. Furthermore, in some regions, the use of nuclear small modular reactors (SMRs) shows growing potential.

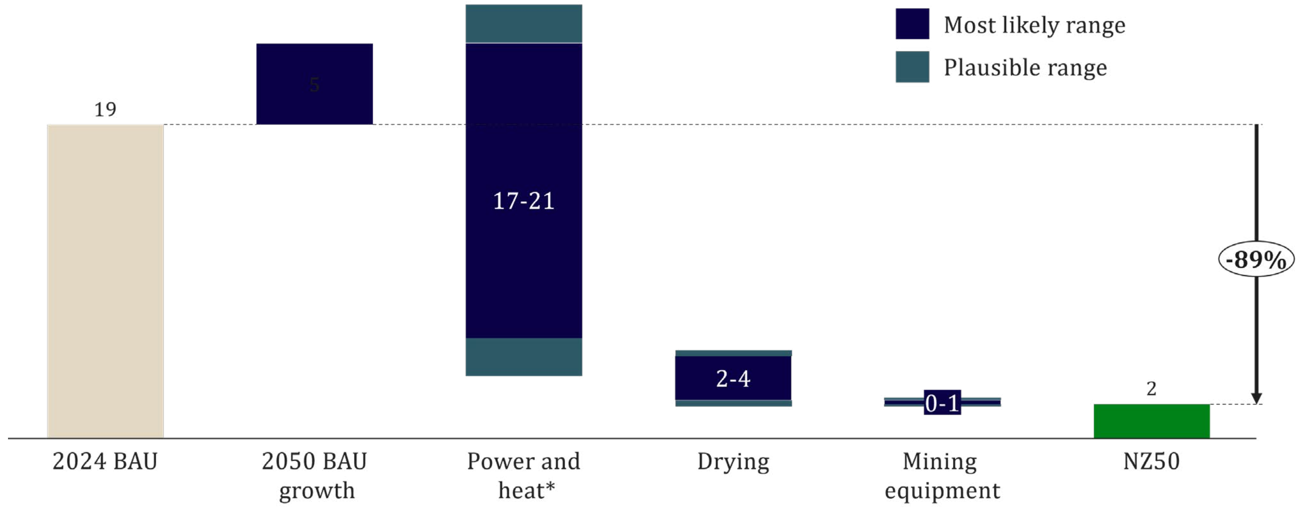
02 **On-site generation:** Over the longer term, decarbonisation of on-site generation could be achieved through optimising existing self-generation capacity (via heat recovery) where possible, and investing in on-site renewable capacity, CCS or alternative fuels (e.g. biomass). However, these technologies (especially CCS) are dependent on the regulatory landscape, geographic factors, TRLs, as well as regional supply chains and economics. Economics and emissions reduction over the long term may also favour reviewing on-site power generation strategies once the generation facility reaches end-of-life.

**Drying processes are a major source of fuel-related emissions,** particularly for the phosphate industry. Technology opportunities for drying depend on the temperature requirements for the drying process. Rock drying processes require temperatures of up to 1000ºC (a key technical bottleneck) while fertiliser product drying temperatures are between 400ºC and 700ºC (depending on the product), as well as the feasibility of fuel switching (e.g. sulphur, biomass or biomethane) and electrification on a regional basis. Depending on specific temperature and thermal power requirements, electrification is seen as a key lever for drying decarbonisation but only when combined with renewable electricity. Other options that are still being developed, but are potentially viable in the longer-term, include radio frequency drying, electrostatic separation (that removes the need for drying completely in potash production by replacing the flotation process), heat pumps, heat batteries and, if possible, post-combustion CCS.

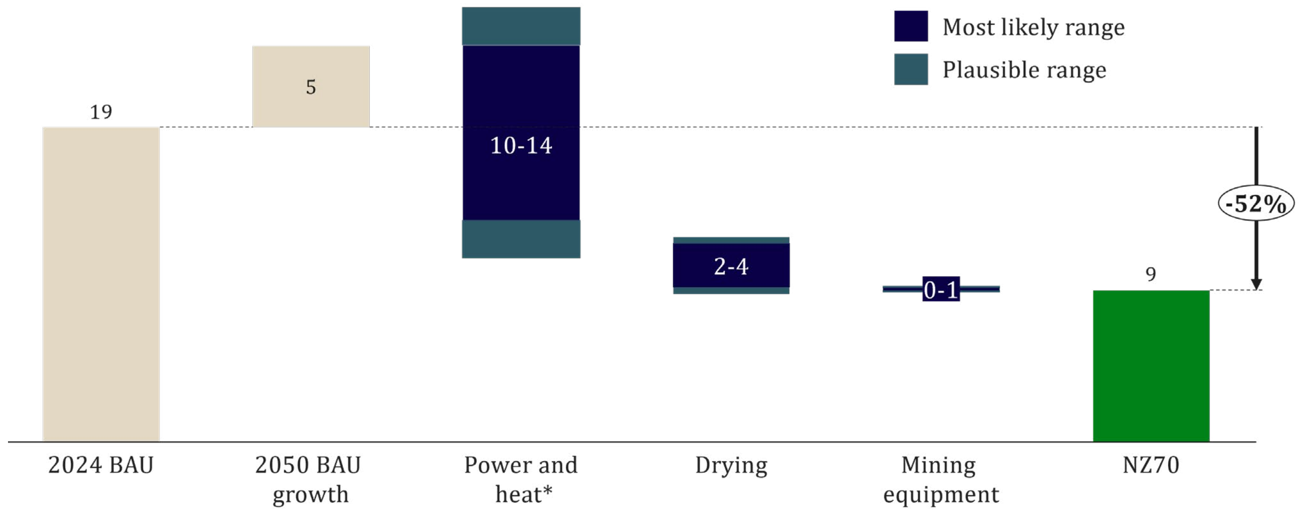
**Mining equipment emissions** can be reduced through continued operational efficiency improvements, fleet electrification using low carbon electricity, low carbon fuels such as hydrotreated vegetable oil (HVO), and, where feasible, greater use of conveyors (powered by renewable electricity) or slurry pipelines. The relevance and feasibility of these measures vary significantly by mining method. In potash production, which is mainly underground, much of the fixed infrastructure is already electrified, but mobile equipment still partly relies on diesel and electricity is often fossil fuel based. In these cases, the main decarbonisation levers are switching to low carbon power and gradually electrifying mobile fleets. By contrast, phosphate production is typically based on open-pit mining, where diesel-powered mobile equipment remains more common because of operational flexibility requirements. As a result, fleet electrification, supported by low carbon fuels, is a key pathway for reducing emissions. Similar principles apply to internal transport, where electrifying material movement, such as through conveyors, electric haulage, or rail, can further reduce emissions, subject to site-specific and logistical constraints.

**Process emissions, relevant to phosphoric acid (carbon dioxide, $CO_2$) and nitric acid production (nitrous oxide, $N_2O$)**, are addressed initially through **$N_2O$** abatement strategies and process efficiency measures. Nitric acid is required for NOP production, whereas phosphoric acid is a key intermediate for many phosphate fertilisers. These emissions sources are likely to represent the sector's most significant long-term decarbonisation challenge. Further reductions rely on developing CCS approaches to address process emissions from phosphoric acid production. This is a key difference between the NZ50 and NZ70 scenarios and unlocking net zero by 2050 requires overcoming technical, economic and regulatory barriers to do with CCS. These include bolt-on units for existing acid plants, advanced acid leaching techniques that capture high-purity $CO_2$ at lower cost, calcination of phosphogypsum using sulphur combustion with sulphuric acid regeneration to capture $CO_2$ released from carbonates in phosphate rock, the Merseburg process for phosphogypsum, and carbonate mineralisation techniques. However, there are still significant technical (e.g. fluoride and hydrofluoric acid contamination of flue gas), logistical, geological and economic barriers which are preventing adoption of CCS in the near term. $N_2O$ emissions from nitric acid production fall under either process emissions or upstream emissions depending on the plant boundaries. These emissions are distinctly different from $N_2O$ emissions from fertiliser use, which occur downstream of fertiliser production in the value chain and are out of the direct control of the fertiliser producer although they do have the ability to influence them depending on their business strategy.

**Global Potash Production GHG Emissions Reduction Potential by Measure, 2050**
*NZ50 Scenario, Million tonnes $CO_2e$ (Production emissions)*




**Global Potash Production GHG Emissions Reduction Potential by Measure, 2050**
*NZ70 Scenario, Million tonnes $CO_2e$ (Production emissions)*




The phosphate and potash industry sits at the intersection between mining and chemical processing. Mining brings an inherent level of complexity and asset-level variability as well as impacting the technologies used for downstream chemical processing. As a result, the pathways for decarbonisation of the key hotspots are asset-specific and the results shown here may not be applicable and should be viewed as part of a global toolkit for decarbonisation.

* Power and heat includes levers looking at decarbonisation of electricity and heat generation. They have been combined given that most facilities use combined heat and power (CHP) facilities with sulphur as the energy source.

## 3.2 Near-term actions for production emissions reduction

Achieving the long term decarbonisation pathways outlined in this roadmap will depend on **early action across the value chain, including producers, through the rest of this decade and into the early 2030s**. However, producers are starting from different baselines, with some having already implemented elements of early action while others remain at earlier stages of the decarbonisation journey. Given the challenging economics of P and K production, priority is likely to be given to measures that reduce cost or deliver net positive financial returns. Near term actions can therefore serve a dual purpose: helping to moderate emissions growth in the short term while also supporting the maturation of early TRL technologies, so they can scale and become more cost competitive over time. Given the capital intensive nature of phosphate and potash production, acting within today's production systems is important to preserve optionality and enable more transformative change after 2035, while continuing to support the supply needed to meet future food demand.

However, early action will need to be balanced with the sector's role in supporting global food security and affordability. In this context, sector-wide interim absolute emissions reduction targets may be difficult to interpret and apply, particularly where demand for phosphate and potash fertilisers is expected to continue growing. A complementary focus on emissions intensity may therefore provide a useful way to track progress while recognising the need to maintain supply. At the same time, the applicability of any single industry-wide intensity benchmark is likely to be limited by regional differences, production routes and technology choices. Improvements in NUE and greater product optimisation or substitution may reduce fertiliser use at a system level over time, but these are more likely to emerge as longer-term demand-side benefits. There are some nutrient use efficiency practices, enhanced efficiency fertiliser and precision agriculture solutions that are commercially available today that could contribute to near term efforts as well. For that reason, interim metrics may be most meaningful when applied at asset or company level, alongside broader efforts to encourage near-term decarbonisation action across the sector.

There are several case studies from which phosphate and potash producers can learn, drawn from other hard-to-abate and emission-intensive industries that are acting now with success in development and scaling of these technologies. The below graphic shows some initiatives that could be applied, after reviewing asset-level feasibility, in the near term with a high potential for economic success. It should be noted that these opportunities are not universally applicable to all production sites. Furthermore, a key message from these initiatives is that near-term retrofits preserve optionality rather than locking production assets into a long-term solution.

### Mining and beneficiation

In the near term, emissions reductions could be delivered through fleet electrification and fuel substitution within existing mining operations. Battery-electric, trolley-assist systems in open-pit environments, and use of HVO or other low-carbon liquid fuels are available as pilots for light-duty engines, while options for heavy-duty equipment are still developing, albeit rapidly.

| 6-9 *Technology Maturity* | *Cost of Action* | *GHG Reduction Potential* |
| --- | --- | --- |

### Downstream transport

While not considered in the emissions reduction pathways for the industry, transportation emissions can be reduced today using commercial and cost-effective levers in some cases. Near-term abatement focuses on modal efficiency and electrification where infrastructure exists. Electric rail could potentially be deployed in some regions, while battery-electric trucks can be applied to shorter haul routes. These levers are contingent on a grid carbon intensity being low enough to reduce emissions against a diesel counterfactual. For export-oriented assets, early adoption of low-carbon shipping fuels supports emissions reductions without changes to core production processes[10].

| 8-9 *Technology Maturity* | *Cost of Action* | *GHG Reduction Potential* |
| --- | --- | --- |

10 IMO approves net zero regulations for global shipping

### Efficiency initiatives

Energy efficiency measures represent cost-effective actions available at nearly all sites. These include heat integration, equipment upgrades, insulation, improving heat recovery from sulphuric acid production, and operational optimisation. Such measures reduce both fuel and electricity demand and are critical enablers for subsequent electrification and power decarbonisation.

| 9 | | |
| --- | --- | --- |
| *Technology Maturity* | *Cost of Action* | *GHG Reduction Potential* |

### Process heat and drying

Emissions reductions from process heat and drying are achieved through efficiency improvements, CHP[11] optimisation (if applicable) as well as partial electrification and fuel switching where feasible. These measures reduce fossil fuel intensity while maintaining product quality and throughput.

| 7-9 | | |
| --- | --- | --- |
| *Technology Maturity* | *Cost of Action* | *GHG Reduction Potential* |

### Process emissions

Near-term abatement of process emissions focuses on $N_2O$ abatement from nitric acid production and process optimisation. There are limited opportunities to reduce process emissions significantly in the near term.

| 9 | | |
| --- | --- | --- |
| *Technology Maturity* | *Cost of Action* | *GHG Reduction Potential* |

11 Combined Heat and Power

### Waste emissions

Early actions emphasise water recycling and improved management of phosphogypsum to combat physical climate risk. There are potential business cases for gypsum valorisation and co-product recovery on a site-by-site basis[12]. This could also have the added benefit of contributing to decarbonisation by displacing higher-emissions inputs, such as gypsum, in other industries.

| 6-9 | | |
| --- | --- | --- |
| *Technology Maturity* | *Cost of Action* | *GHG Reduction Potential* |

### Electricity

Before full grid decarbonisation is realised, producers can reduce electricity-related emissions at a quicker pace through EACs, PPAs, and on-site renewable generation. For on-site electricity generation, focus should be on efficiency initiatives and the rollout of best available technology.

| 9 | | |
| --- | --- | --- |
| *Technology Maturity* | *Cost of Action* | *GHG Reduction Potential* |

**Legend**

- *Very high attractiveness*
- *High attractiveness*
- *Moderate attractiveness*
- *Low attractiveness*
- *Very low attractiveness*

12 2025_IFA_Phosphogypsum_From_Waste_to_Inventory.pdf

**Lessons from Parallel Industries**

**Cement sector carbon capture (process emissions)**

Heidelberg Materials' Brevik CCS (online in 2025) is presented as the world's first industrial-scale CCS facility in the cement sector, enabled through Norway's Longship programme (capture integrated with shared transport/storage)[13].

**Chemicals (steam crackers → electrified process heat)**

BASF/SABIC/Linde have commissioned a large-scale electrically heated steam-cracking demonstration to replace fossil fuel furnace heat (6 $MW_{th}$ for temperatures of around 900°C)[14] with renewable electricity, explicitly targeting very large $CO_2$ reductions for one of the chemical sector's most energy-intensive steps.

**Glass (hybrid electric furnaces + recycled feedstock)**

The flat-glass sector is piloting hybrid furnaces combining electric melting with oxy-gas combustion, positioned as a scalable route for deep emissions cuts while maintaining product quality; some projects explicitly pair electrification with higher recycled glass (cullet) use to reduce raw-material emissions.

13 Heidelberg Materials. 2025. Heidelberg Materials inaugurates the world's first industrial-scale carbon capture facility.

14 BASF, SABIC, and Linde celebrate the start-up of the world's first large-scale electrically heated steam cracking furnace

## 3.3 Exploring non-sulphur based pathways

Decarbonisation of phosphate production is not limited to incremental decarbonisation by improving existing processes. Over the long term, further emissions reductions may require rethinking the underlying phosphoric acid production systems themselves, particularly where current routes face structural constraints under net zero transitions, notwithstanding the volatile political situations in key regions. While incremental decarbonisation of existing wet-process assets remains essential in the near term, continued reliance on sulphur-based routes may constrain deep decarbonisation in some regions, and producers may wish to evaluate a broader range of process routes alongside optimisation of established systems. As decarbonisation pressures intensify and sulphur market dynamics evolve, alternative process routes may therefore become increasingly important as part of the sector's long-term strategic optionality. Several system level factors highlight the importance of considering alternative pathways:

01

**Sulphur dependency**

The conventional wet-process routes rely on sulphur as a raw material, linking phosphate production to sulphur supply and price. The benefits of using sulphur relate to the cogeneration opportunity enabled by on-site sulphuric acid production and the low-carbon energy source it provides. However, as refinery activity declines under net zero scenarios and demand for sulphur from battery raw material production grows, this dependency creates long-term cost and supply risks. As a result, there is a tension between these long-term risks and the efficiency benefits of sulphur use.

02

**Food security**

Amidst geopolitical tensions and the resulting impact on the conventional trading corridors, reliance on a single raw material, i.e. sulphur can create issues for food security globally. Diversifying the raw materials for production of phosphate and potash fertiliser can support resilience[15].

15 IFA 2010 – Sulphur and Sustainable Agriculture.pdf

### Phosphogypsum generation

03 Existing sulphur-based routes generate large volumes of phosphogypsum, intensifying challenges related to waste management, land use, and environmental risk, and potentially constraining future expansion.

### Non-sulphur pathway opportunity

04 Alternative pathways potentially offer long-term strategic optionality by enabling phosphoric acid production without dependence on sulphur as a key input. As illustrated in the graphic below, these include electrified thermal phosphoric acid, the ODDA process with nitric acid, and electro-thermal or chemical routes based on alternative acids such as HCl. Their relevance will depend on local economics, technology maturity, power availability and product strategy.

Against this backdrop, alternative phosphoric acid systems represent strategic options rather than a single prescribed pathway and may co-exist with sulphur-based pathways over the long term as well. Their relevance will vary by region, energy access, requirements for retrofits compared with new-build systems, incumbent infrastructure, and long term market conditions. This is analogous to other mineral and chemical value chains where multiple processing routes coexist, for example in nickel processing where pyrometallurgical and hydrometallurgical routes are used in parallel depending on resource characteristics, product requirements and regional economics.

## Phosphoric Acid System Comparison

### KEY CONSIDERATIONS

**Sulphur dependency**

Since 2023, sulphur prices have risen by 5-6x and are currently at US$550+ per tonne. As the energy transition reshapes oil refining capacity, long-term sulphur supply may come under pressure, highlighting the value of continued monitoring and diversification options

**Phosphogypsum**

Existing production routes lead to PG production creating significant environmental risks and land constraints if not properly managed, regulated or re-used

**Net Zero**

Electrified and non-sulphur systems could become more competitive under net zero scenarios

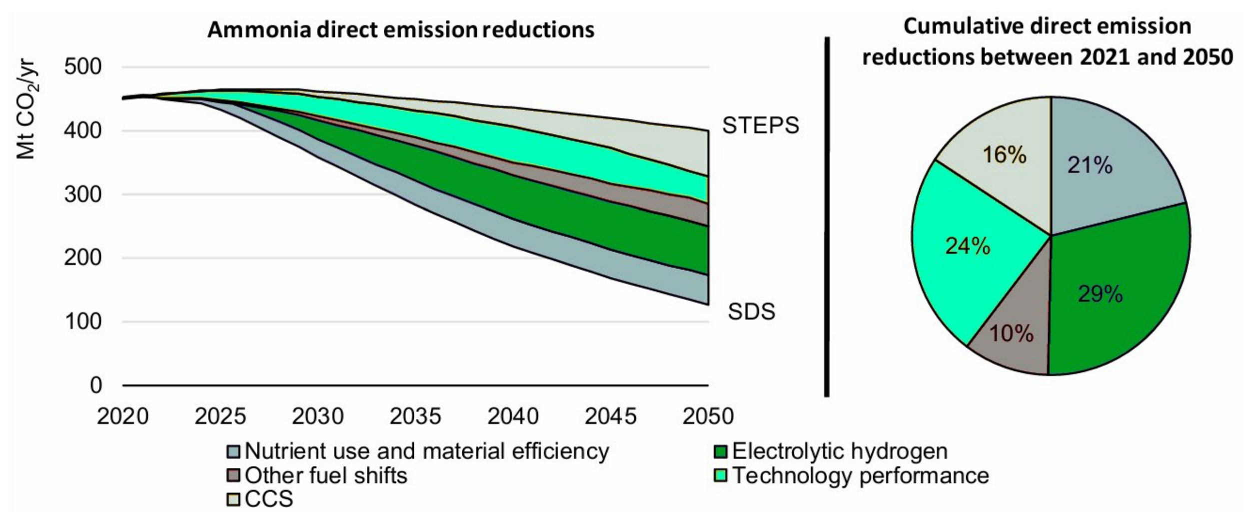
### OPTIONS

| System | Route | Strength | Constraint | Decarb Approach | Net Zero Alignment |
|---|---|---|---|---|---|
| Sulphur (Incumbent) | *Wet process integrated with sulphuric acid* | *Proven and low cost* | *Sulphur dependency and PG production* | *Incremental improvement of existing assets* | ▼▼ *Refineries* |
| Electricity | *Electrified thermal phosphoric acid* | *No sulphur dependency or PG production, can be electrified* | *High cost currently and emissions dependent on energy source* | *System change with greenfield investment* | ▲ *with renewables* |
| Nitrogen-integrated | *ODDA process with nitric acid from ammonia* | *No sulphur dependency or PG production* | *High cost currently and emissions dependent on ammonia source* | *System change with greenfield investment* | ▲ *with green ammonia* |
| Emerging | *Electro-thermal or chemical, alternative acids e.g. HCl* | *No sulphur dependency or PG production* | *Low maturity for emerging routes* | *System change with greenfield investment* | ▲ *with renewables* |

# 3.4 Exploring ammonia decarbonisation pathways

Ammonia is a critical upstream input for nitrogen-containing phosphate fertilisers and a major source of embedded emissions for the sector. The IEA Ammonia Technology Roadmap sets out pathways to reduce emissions from ammonia production through a combination of efficiency improvements, fossil-derived ammonia with carbon capture (blue ammonia), and a transition toward electrolytic ammonia from low-carbon power (green ammonia), with scenarios aligned to net zero energy system trajectories by 2050. Progress along these pathways has a direct bearing on the lifecycle emissions of phosphate fertilisers that integrate nitrogen via NPK compounds, enabling emissions reductions even without changes at downstream fertiliser plants.

**Ammonia Direct $CO_2$ Emission Reductions in the Sustainable Development Scenario by Mitigation Strategy[16]**




IEA Scenarios: STEPS = Stated Policies Scenario; SDS = Sustainable Development Scenario. Note: CCS = carbon capture and storage.

**Only an array of mitigation measures can significantly reduce emissions from ammonia production. Nutrient use and material efficiency, electrolytic hydrogen and CCS account for two-thirds of the cumulative emission reductions in the Sustainable Development Scenario.**

16 IEA Ammonia Technology Roadmap

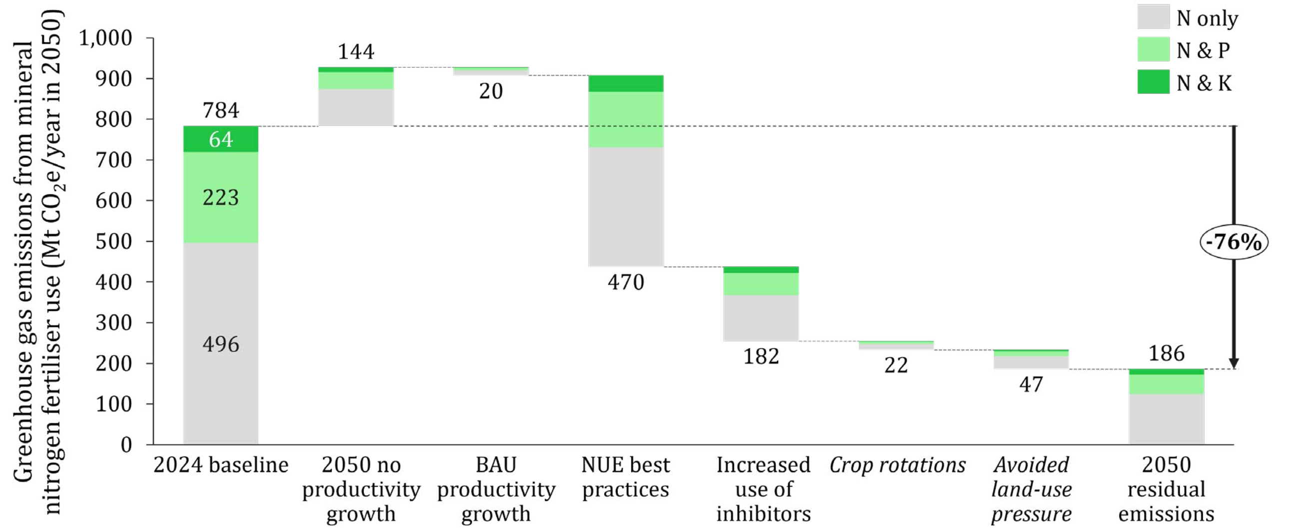
## 3.5 Nutrient use efficiency and fertiliser use emissions reduction pathways

*The following section does not argue for blanket reductions in fertiliser use. Instead, it focuses on improving nutrient use efficiency so that emissions can be reduced while maintaining yields and supporting food security.*

GHG emissions arising from fertiliser use beyond the farm gate remain a critical part of the wider system context. Nitrogen-based fertilisers are often combined with phosphate and potash fertilisers in blends or compounds and are an important source of agricultural $N_2O$ emissions associated with nitrogen losses from soils, which contribute materially to total agri-food greenhouse gas emissions. At the same time, the quantification of these emissions remains an active area of scientific and methodological development: understanding of soil-plant-nutrient dynamics continues to evolve, and emission factors are being refined as new evidence becomes available. While these emissions are clearly relevant at a system level, their magnitude can vary significantly by crop, soil, climate, management practice and product type, and estimates should therefore be interpreted as indicative rather than universally fixed. For the phosphate and potash sector, these are indirect emissions and are the result of using nitrogen raw materials for chemically granulated NPK compounds produced at ammonium phosphate facilities or for NOP fertiliser. Demand-side measures therefore play an important complementary role in reducing the full lifecycle footprint of mineral fertilisers. This section draws on SYSTEMIQ's 2022 report *Reducing Emissions from Fertiliser Use*[17]. The fertiliser-use pathways are therefore presented as a separate analytical lens from the production-emissions scenarios in this report: while both use a shared underlying demand baseline, including BAU fertiliser demand, they were developed using different assumptions, system boundaries and abatement levers and should not be compared directly on a like-for-like basis.

17 Reducing Emissions from Fertiliser Use, SYSTEMIQ (2022)

**Decarbonising Mineral Fertiliser Use Scope 3 – Average $N_2O$ Emission Reduction Potential**
*Million Tonnes $CO_2e$*




Reductions in emissions from fertiliser use are driven primarily by **improving how nutrients are applied and utilised in agricultural systems**, rather than by changes to fertiliser manufacturing alone. Many of these measures are technically well understood and already available, but their impact depends on adoption rates, farm-level decision-making, workforce capabilities, farmer education, training, advisory and extension support, and broader food system dynamics:

→ **Improving nutrient use efficiency (NUE)**

Improving NUE reduces $N_2O$ emissions per unit of nitrogen applied by minimising over application and nutrient losses, while maintaining or improving crop productivity through better-targeted nutrient management. It can also lower input costs, reduce nutrient losses to water and air, and support more resilient soil and crop management over time. With adoption of NUE occuring at the farm level, improving NUE can introduce agronomic and yield performance risks, as reducing fertiliser application from levels considered 'safe' exposes farmers to uncertainty. Producers can therefore play an important enabling role through product innovation, including enhanced efficiency fertilisers and tailored formulations, as well as agronomic guidance, digital tools, field trials and partnerships across the value chain to support uptake. This includes wider adoption of best management practices such as the 4Rs (right source, right rate, right time, and right place), precision agriculture, digital agronomy, enhanced efficiency fertilisers, and the elimination of inefficient fertiliser use where yields are not constrained by nutrient availability.

→ **Increased use of fertiliser inhibitors**

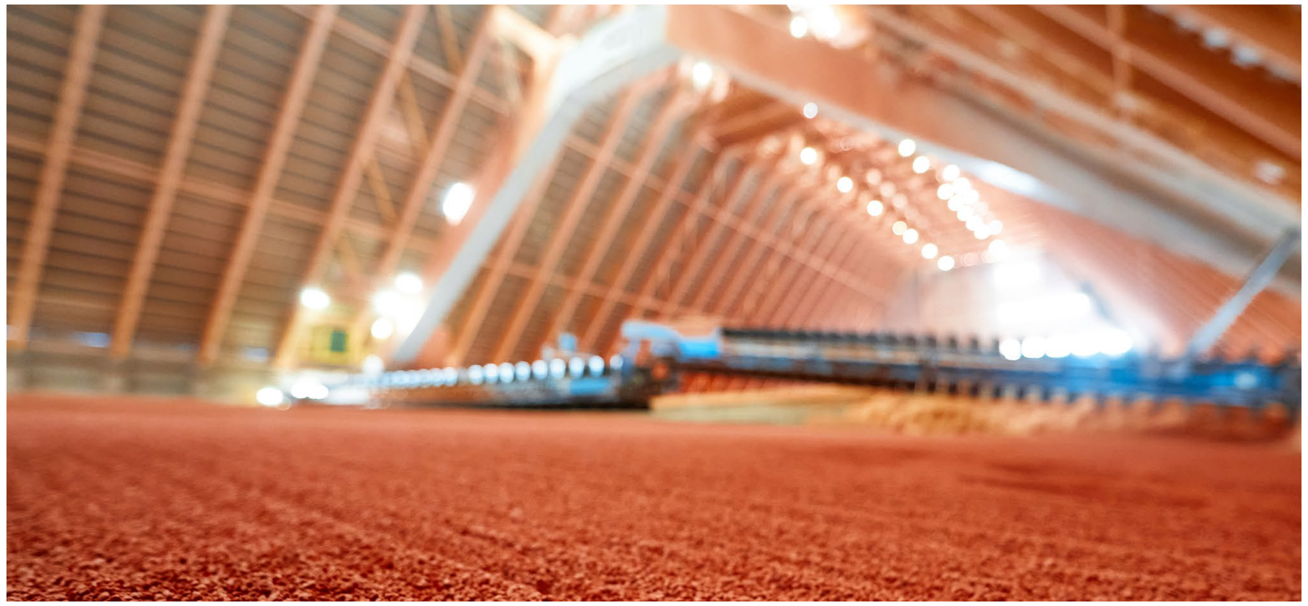
Nitrification and urease inhibitors can reduce both direct and indirect $N_2O$ emissions by slowing nitrogen transformation processes in soils. These measures are attributable to fertiliser formulation and use guidance, making them relevant to downstream emissions associated with fertiliser products, although their effectiveness depends on crop type, soil conditions, and appropriate application. In practice, inhibitors often act more as an insurance policy: in rainfed agriculture they tend to be more effective in wetter years and less impactful in drier years, whereas under irrigated conditions they can be effective more consistently across growing seasons.

→ **Wider food system and land-use changes**

Structural changes such as increased use of nitrogen-fixing crops in rotations, improvements in overall agricultural productivity, and reduced land-use pressure can lower the demand for mineral nitrogen fertiliser and associated emissions. These measures depend on cropping systems, consumer behaviour, and land-use decisions, and typically fall outside direct control of fertiliser producers.

→ **Biologics Products**

New technologies and innovations in biologicals and products supporting soil biology can improve NUE and thereby reduce emissions.



**Key Methods to Reduce Emissions from Fertiliser Use**

**FARM LEVEL**

**Improving nutrient use efficiency**

- → Scale best management practices (e.g. 4Rs) via precision agriculture, digital agronomy and fertiliser-as-a-service
- → Increase uptake of enhanced efficiency fertilisers (e.g. CRF)
- → Eliminating inefficient fertiliser use

*Counts Scope 3 Cat. 11 for fertiliser producers.*

**PRODUCT LEVEL**

**Increased use of inhibitors**

- → Nitrification and urease inhibitors reduce direct and indirect $N_2O$ emissions by modifying nitrogen transformation pathways at application
- → Emissions reductions are attributable to fertiliser product and counted towards targets
- → Environmental impacts require further research

*Counts Scope 3 Cat. 11 for fertiliser producers.*

**SYSTEM LEVEL**

**Wider food system changes**

- → Expanding N-fixing crops and productivity gains reduce fertiliser demand and emissions but require land-use, cropping and diet shifts
- → These are system-level (FLAG) measures and cannot be claimed towards fertiliser product Scope 3 Category 11 targets

*FLAG only. Not counted towards Scope 3.*

Soil carbon sequestration is not seen as a core mitigation lever due to limited scalability, high cost, and stringent accounting requirements. Under the GHG Protocol Land Sector and Removals Guidance[18], inclusion in corporate inventories requires site-specific primary data, statistically robust evidence of carbon stock changes, full traceability, continuous monitoring, and full accounting for reversals, creating significant implementation complexity.

In practice for the phosphate & potash industry, these requirements are particularly challenging given the need for implementation across fragmented farm-level supply chains, making measurement costly and difficult. Consistent with SBTi FLAG guidance, companies are therefore expected to prioritise direct emissions reductions, with removals playing a supplementary role. While soil carbon approaches are improving, they are not yet sufficiently verifiable or scalable to serve as a core mitigation pathway; the current strategic focus therefore remains on proven and readily verifiable measures.

18 LSR Guidance, GHG Protocol (2026)

# Chapter 4.

Economics and investment requirements



## 4.1 Production emissions

### 4.1.1 Cost of abatement

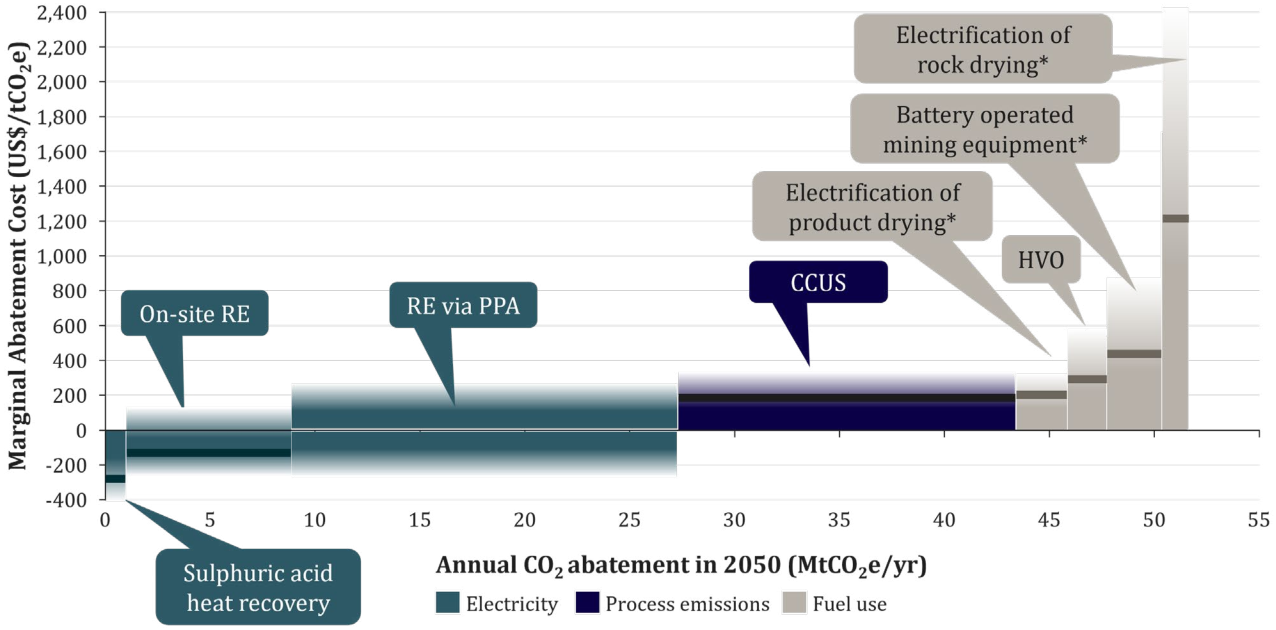
To support prioritisation and investment decisions, the roadmap assesses the cost and potential of key decarbonisation levers using a global marginal abatement cost curve (MACC). The MACC compares a range of technology and system options across phosphate and potash production, illustrating how abatement potential and cost vary by lever. Cost data was based on best available public sources, and it is acknowledged that there is a degree of uncertainty associated with the results. To factor this in, error bars have been included to display uncertainty. Decarbonisation technologies were selected from a long list of possible measures using a multi-criteria analysis. This will be available in the technical Annex.

The MAC analysis highlights that low- and negative-cost options are often more bankable in the near term, primarily through energy efficiency, operational optimisation, renewable electricity and selected electrification measures where low-carbon power is accessible and cheap (e.g. curtailed electricity). Higher-cost options, including full electrification, alternative process routes, and carbon capture, tend to deliver deep decarbonisation but require supportive market conditions such as technology and supply chain readiness, policy mechanisms and clear demand signals to stimulate higher capital investment.

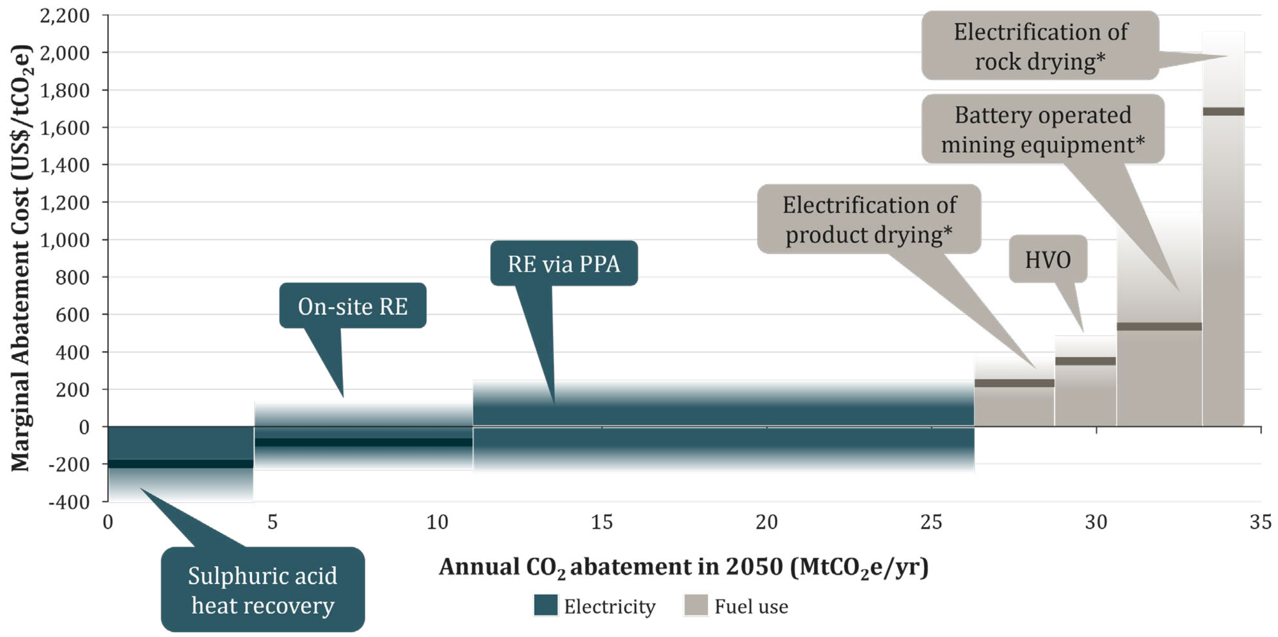
Importantly, the global MACC is intended as a high-level screening tool to compare the relative order of magnitude, timing and cost sensitivity of different abatement levers across the sector, rather than to prescribe asset-level investment decisions. Abatement costs are not uniform across time, region or technology. They are sensitive to assumptions on energy pricing, emission factors, and policy context. As such, the MACC should be interpreted as a strategic comparison tool, rather than an asset level cost forecast. To avoid double-counting, levers are treated as mutually exclusive, so the aggregate abatement should not be read as the total achievable in any given year.

*MACCs are therefore useful for understanding the relative cost of individual abatement levers, but they should not be used on their own to determine long-term production system choices.*

**Global Phosphate Marginal Abatement Cost Curve, 2050**
*NZ50 Scenario*



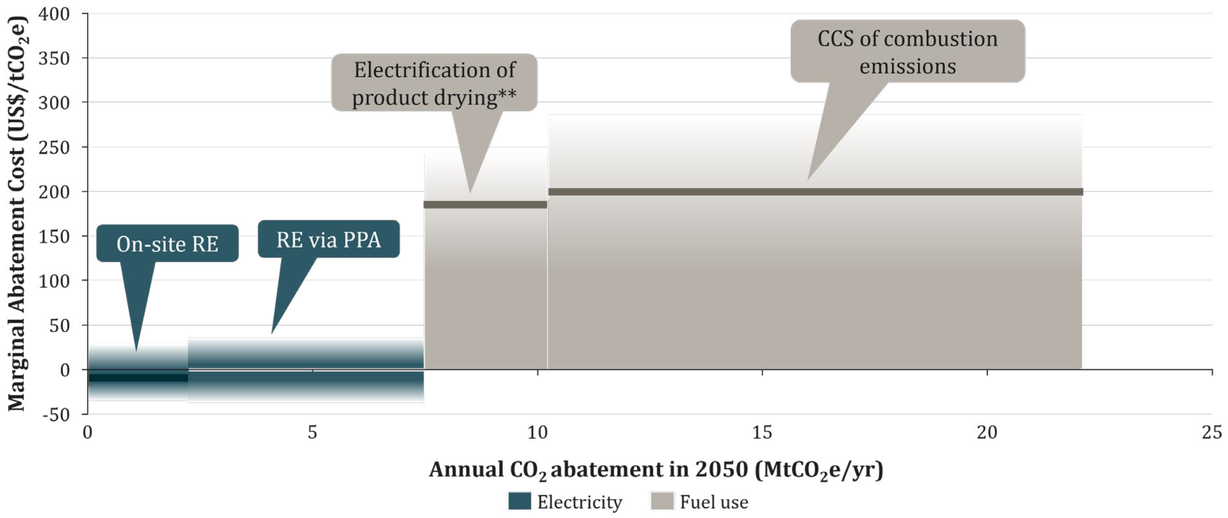

**Global Phosphate Marginal Abatement Cost Curve, 2050**
*NZ70 Scenario*



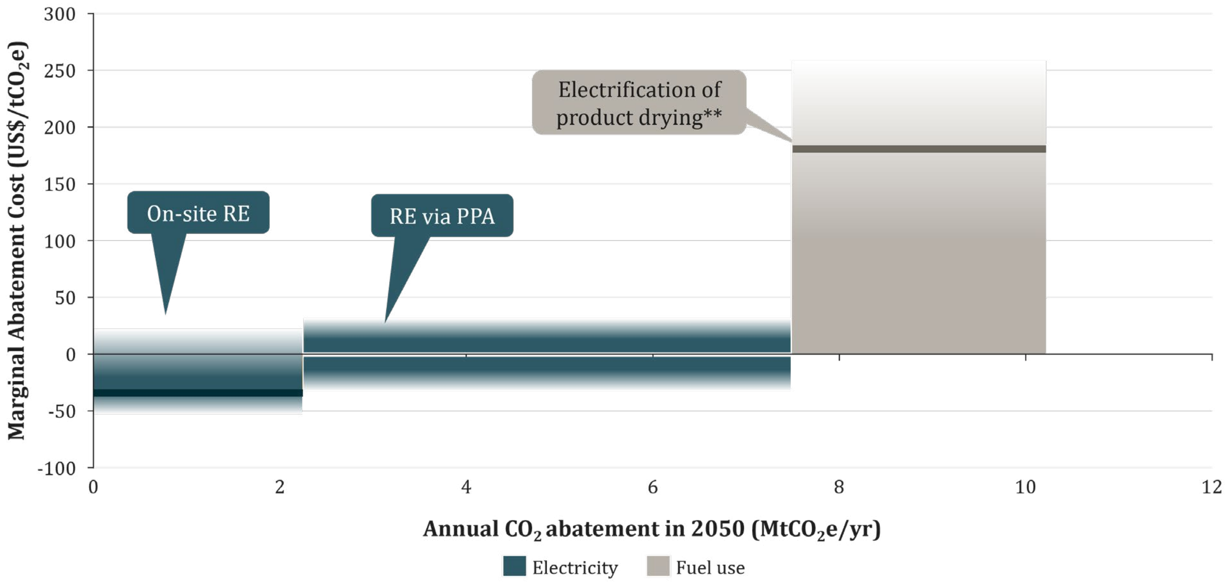

For the phosphate industry, electricity and fuel use decarbonisation represent potential opportunities for emissions reduction in a cost-effective manner currently. As a first step, producers should consider energy efficiency initiatives as outlined in Section 3.2 given these are likely to be low CAPEX, high return initiatives. While they are unlikely to bring significant emissions reduction, they can result in positive returns on investment, especially in regions with elevated energy pricing. In regions with access to low-cost, low-carbon power via market mechanisms or via on-site generation, producers should start to consider feasibility studies for their implementation at an asset-level as well. Drying and process emission decarbonisation is currently a high-CAPEX, low-return investment due to the early maturity of decarbonisation technologies in this area e.g. CCS, electrification, electrostatic separation. This reflects the earlier conclusions that both hotspots will require further technological development and deployment to unlock deeper emissions reductions.

* Needs to be combined with sourcing of renewable electricity

**Global Potash Marginal Abatement Cost Curve, 2050**
*NZ50 Scenario*




**Global Potash Marginal Abatement Cost Curve, 2050**
*NZ70 Scenario*




A similar situation is observed for the potash sector where electricity decarbonisation and energy efficiency levers can be cost effective depending on individual asset constraints. The major 'hard to abate' hotspot is product drying with several early-stage options for producers albeit none that are economically competitive currently.

---

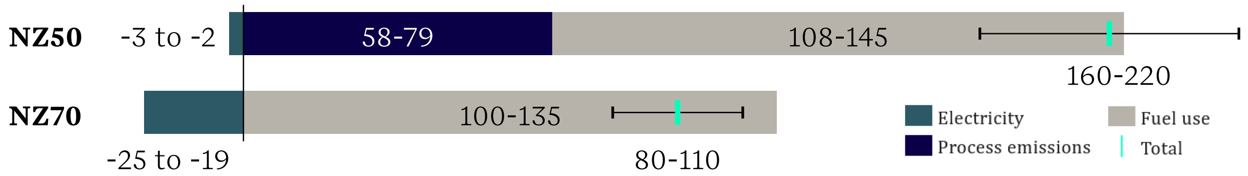
* Battery operated mining equipment with renewable electricity was considered as well but due to the low emissions abatement potential (as most equipment is already electrified), the cost is extremely high and has not been included in this diagram

** Needs to be combined with sourcing of renewable electricity

### 4.1.2 Investment needs

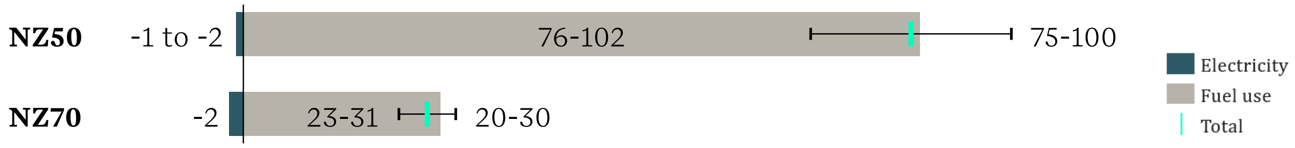
Delivering the decarbonisation pathways set out in this roadmap will require substantial upfront investment as well as ongoing operating expenditure to maintain the decarbonisation levers over their lifetime. The following estimates only consider direct investment in reducing production emissions, and exclude investment in enabling infrastructure such as grid network upgrades, $CO_2$ transport, and low-carbon fuel supply chains, all of which are integral for the deployment and scaling of many decarbonisation levers.

**Total Cost of Phosphate Decarbonisation by 2050 by Emission Hotspot**
*NZ50 and NZ70, $ Billion*




The total cost of decarbonisation for existing phosphate production assets (including all investment and operating expenditure associated with reducing production emissions only) between 2024 and 2050 is estimated at **US$ 160-220 billion** (weighted average MAC of **US$ 150 per tonne $CO_2$e**) under the NZ50 scenario and **US$ 80-110 billion** (weighted average MAC of **US$ 112 per tonne $CO_2$e**) under the NZ70 scenario. As expected, deeper decarbonisation requires higher total expenditure because higher-cost technologies, based on currently available data, are increasingly required to meet the NZ50 scenario ambition. The use of CCS **(US$ 60-80 billion under NZ50 scenario)** to abate process emissions and decarbonisation of rock drying via electrification **(US$ 45-55 billion under NZ50 scenario)** are currently the most cost-intensive levers.

**Total cost of Potash Decarbonisation by 2050 by Emissions Hotspot**
*NZ50 and NZ70, $ Billion*




In comparison, the total cost of decarbonising the potash industry between 2024 and 2050, including both capital and operating expenditure, is estimated at **US$ 75-100 billion** under the NZ50 scenario (weighted-average MAC of **US$ 160/t$CO_2$e**) and **US$ 20-30 billion** under the NZ70 scenario (weighted-average MAC of **US$ 95/t$CO_2$e**).

The analysis has only focused on asset-level investment and there would have to be further outlay into supporting infrastructure and systems which facilitate decarbonisation.

### 4.1.3 Investment case

Investment in sustainability is under pressure from a number of global factors such as the geopolitical climate and rising costs. While the need for investment in the P&K industry and the wider fertiliser sector remains clear, this heightened scrutiny has made investment decisions more difficult to justify.

Despite these challenges, there is still a strong strategic case for targeted capital deployment into industry decarbonisation. The following five pillars broadly outline the rationale for investment:

→ **Protecting competitiveness and reducing future cost exposure**
Investment in decarbonisation is not only about reducing emissions; it is also about reducing exposure to structural costs and margin risk. As discussed already in this report, volatile energy prices, sulphur dependency, carbon pricing mechanisms and regulatory exposure, and infrastructure constraints pose significant threats in the coming decades. Investment would limit this exposure, avoiding future cost burdens, protect margins, and future-proof core assets.

→ **Advantageous access to capital**
A solid sustainability track record and credible decarbonisation pathway positions producers in a way that they are more likely to have access to concessional finance, secure public support, and demonstrate lower transition risk.

→ **Preserving asset value and avoiding lock-in**
Due to the nature of long-life, capital-intensive assets, delayed investment in decarbonisation increases the risk of lock-in to higher-emission systems which could lead to higher-cost retrofits down the line. Investment would preserve optionality and reduce the risk of stranded assets.

→ **Supporting food-system resilience and long-term market relevance**
Resilience of the food-system against wider geopolitical headwinds is key to insulating the industry from future price shocks, supply constraints, and market volatility as a result of the industry's current fossil dependency.

→ **Strengthening resilience, licence to operate, and strategic positioning**
Investment in decarbonisation would legitimise the industry's strategy to not only governments, but also to the public. This would facilitate a more durable alignment with policy, continue a strong standing with customers and downstream value chain partners, and generate greater credibility with civil society and local stakeholders to operate and grow in a transitioning economy.

The realisation of these benefits will depend on a multitude of factors such as geography and policy maturity.

## 4.2 Fertiliser use

From a GHG emissions abatement cost perspective, improving nitrogen use efficiency is the most economically attractive lever. Interventions such as optimised application practices and fertiliser-as-a-service models can deliver net cost savings while maintaining or improving yields. While some technologies (e.g. precision agriculture) require upfront investment, the overall cost profile is typically favourable as well.

**Fertiliser Use Emission Reduction Measures and Associated Cost Ranges**

| | Min | Max |
|---|---|---|
| **1) Improving N-use efficiency** | **-€880/t $CO_2$e Cost saving measures (fertiliser-as-a-service)** | **+€320/t $CO_2$e Additional cost measures (precision agri. rollout)** |
| **2) Increased use of inhibitors** | **-€340/t $CO_2$e Urease inhibitors (ammonia volatilization reduction) in China** | **+€70/t $CO_2$e Nitrification inhibitors in US** |
| **3) Wider food system changes** | **+€100/t $CO_2$e Low end of farm economics range** | **+€1,030/t $CO_2$e High end, reflecting lack of offtake markets** |

The use of enhanced efficiency fertilisers, such as inhibitors and controlled release fertilisers, presents a more mixed cost profile. Some applications can still deliver cost-effective abatement, particularly where they reduce nitrogen losses and improve crop uptake. However, in many cases, they introduce an incremental cost per tonne of emissions reduced, especially with ammonium phosphates, driven by added input pricing. This means adoption is often more sensitive to local economics, policy support, or incentives.

Broader food system changes are the least economically feasible with interventions such as shifts to nitrogen-fixing crops or dietary changes carrying high and highly variable costs. In many cases, the absence of established markets or price premiums for alternative crops can further increase the economic burden. Focusing on practical abatement levers while continuing to monitor emerging solutions provides the most credible pathway to deliver near-term impact and build the foundations for deeper decarbonisation over time.

# Chapter 5.

Enabling emissions reduction in phosphate and potash production



## 5.1 System-level constraints and enablers

The ability to decarbonise phosphate and potash production is shaped not only by the incumbent technologies already installed at individual sites, but also by system-level conditions that sit largely beyond the direct control of producers, e.g. technology readiness and location. These factors determine which abatement options are feasible, when they can be deployed, and at what cost, and therefore define both the opportunities and limits of near- and long-term action.

→ **Availability of low-cost renewable power**

Access to affordable, low carbon electricity is a critical enabler across decarbonisation pathways, underpinning electricity decarbonisation and the electrification of selected process heat and drying applications where feasible. Regions with early access to reliable renewable power can decarbonise more rapidly, while constrained or high carbon power systems increase costs and limit viable options.

→ **Sulphur and ammonia market dynamics**

Phosphate production remains structurally linked to upstream sulphur and ammonia markets. Reliance on refinery derived sulphur exposes producers to long term supply and price risks, particularly under net zero transition scenarios where fossil fuel refining declines, while sulphur demand from battery metals and other emerging applications may add further market pressure. At the same time, the carbon intensity of ammonia strongly influences the lifecycle emissions of nitrogen containing fertilisers. Progress in decarbonising these inputs can enable emissions reductions independently of plant level changes.

→ **Infrastructure constraints**

Access to grid connections, renewable energy assets, alternative fuel supply networks, and $CO_2$ transport and storage infrastructure shapes the feasibility and timing of higher-impact abatement options. These infrastructure requirements often extend beyond individual facilities and depend on coordinated investment across energy and industrial systems. Such coordination can further enable decarbonisation through shared assets and the development of circular practices. In many cases, this constraint is the rate-limiting step in producers' decarbonisation journeys.

→ **Climate change and adaptation**

Building resilience requires proactive adaptation measures that stay ahead of escalating physical climate risks, particularly extreme heat, flooding, wildfire risk and water scarcity. These pressures can disrupt operations, increase costs and constrain future expansion, making adaptation an important enabling condition alongside decarbonisation.

→ **Demand signals for low-carbon fertiliser**

Demand signals for low-carbon fertiliser from the agri-food industry, such as agri-food conglomerates and retailers, remain limited relative to the scale of investment needed, despite Scope 3 emissions reduction goals being set. Stronger demand signals and market recognition for lower-carbon products would significantly accelerate deployment of higher-CAPEX decarbonisation technologies. At the same time, some early examples suggest this is beginning to change, including PepsiCo's agreement with CF Industries to deploy certified low-carbon urea ammonia nitrate (UAN) in its potato supply chain and PepsiCo's agreement with TalusAg on low-carbon ammonia environmental attributes to help build market demand for lower-emissions fertiliser inputs. These early signals are likely to emerge first in more differentiated or premium value chains, where added costs can be absorbed more easily without materially affecting broader food affordability.

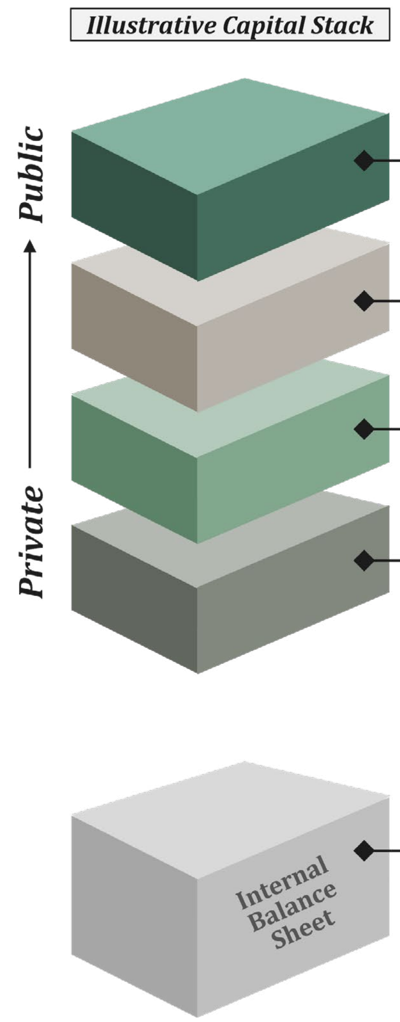
## 5.2 Financing and policy mechanisms

Delivering the decarbonisation pathways set out in this roadmap will require large-scale capital mobilisation across a diverse set of technologies, many of which are capital-intensive, long-lived, and exposed to policy, infrastructure and market risk. While some measures can be financed through conventional balance-sheet investment, enabling deeper and faster abatement will require a blended approach to financing, supported by coherent, predictable and incentivising policy frameworks. Regional differences will influence the weighting of financing solutions and may also require additional climate finance instruments, such as the Just Energy Transition Partnership, to enable decarbonisation.

### Potential financing mechanisms

A range of financing instruments can support deployment of low-carbon technologies across the phosphate and potash value chain, depending on technology maturity and risk profile:

**Illustrative Capital Sources for Decarbonisation**




| | Description | Examples |
|---|---|---|
| **Concessionary public capital** (e.g. grants) | Non-repayable public funds for reducing upfront CAPEX and de-risking early technologies | **Canadian ACT program** provided $1.9 million grant for decentralised green ammonia fertilizer system |
| **Concessional Debt or Soft Loans** | Below-market or long-tenor debt or equity used to bridge financing gaps | **EBRD** issues $80m loan to **Egypt Green** to install 100MW electrolyser to produce green ammonia |
| **Equity** | Risk-bearing capital seeking medium-to-long-ter m returns | **Apollo** invests directly via private-equity vehicles to fund decarbonisation retrofits |
| **Commercial Debt** Incl. sustainable bonds | Market-rate debt for commercial technologies that generate predictable cashflows | **Canada Infrastructure Bank** working alongside the SREP program to provide low-cost financing for clean power |

The extent to which a company can absorb decarbonisation CAPEX on its **own balance sheet i.e. equity**, is shaped by its financial capacity, tolerance for investment risk, and the priority it places on achieving sustainability targets

Further financing mechanisms are emerging in the industrial decarbonisation sector and are increasingly being used to help bridge the funding gap for capital-intensive decarbonisation projects, including green bonds, sustainability-linked loans and bonds, transition finance instruments, Carbon Contracts for Difference (CCfDs), and region-specific support mechanisms such as the EU Innovation Fund and other public-sector industrial decarbonisation programs. Decarbonisation technologies typically have uncertain returns, so private capital may require public de-risking using mechanisms such as loan guarantees or public-private partnerships. Importantly, no single financing model applies across all decarbonisation levers.

The appropriate mix of funding sources varies by technology type, project phase, and level of system integration:

- **Operational and efficiency measures** (e.g. energy efficiency, yield improvement) are often savings-led and can be financed predominantly through balance-sheet capital and conventional debt.
- **Electrification** measures introduce higher upfront capital costs and greater exposure to power prices and grid risk, often requiring grants and long-term electricity contracts to unlock debt financing.
- **Bolt-on solutions** such as CCS typically face high capital intensity and uncertain long-term revenues, making public funding, concessional finance, and risk-sharing instruments critical in early deployment.
- **Utility-scale energy supply assets** (e.g. on-site renewables) are more likely to attract external equity and project finance, particularly where long-term offtake contracts or regulated frameworks exist.

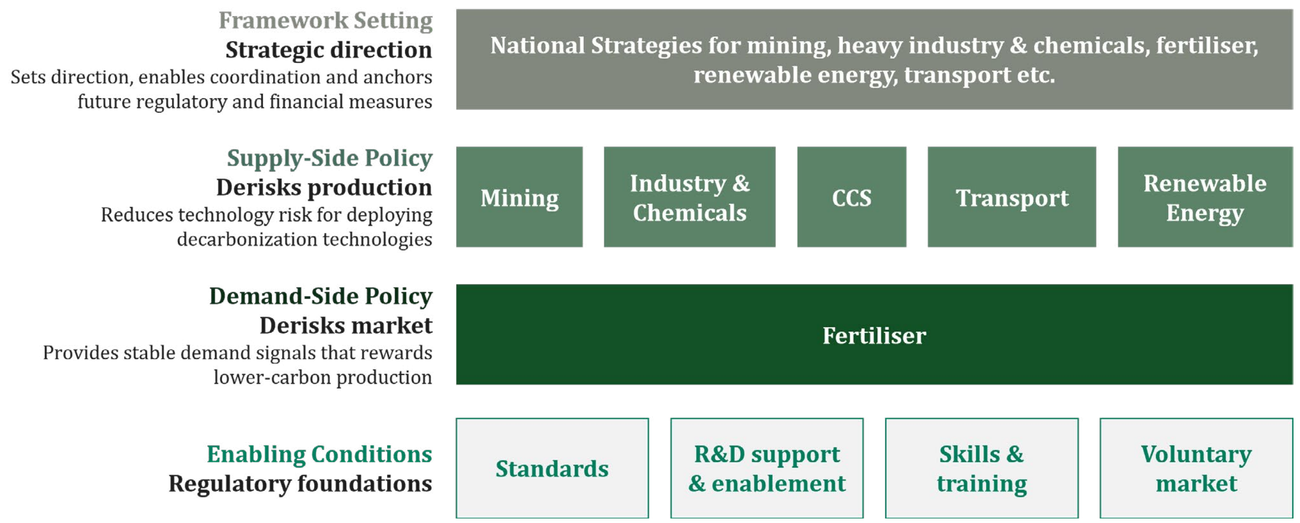
Financiers face several structural gaps and risks when investing in sector decarbonisation. Policy support can help address these gaps by reducing risk and improving investment visibility, rather than prescribing specific technologies. Key risks include:

- **Unpredictable regulatory direction**, creating uncertainty around future returns
- **High upfront capital costs**, especially for capital-intensive technologies
- **Uncertainty in long-term revenues**, linked to carbon and energy prices
- **Lack of bankable long-term offtake arrangements**, particularly for low-carbon products due to lack of demand signals

### Elements of an enabling policy framework

An effective policy framework for phosphate and potash decarbonisation should aim to cover the full value chain and is unlikely to be supported through a dedicated, standalone policy package. Instead, implementation will occur through integration with broader cross-sector frameworks, because the barriers facing P&K production overlap significantly with other hard-to-abate industries. In practice, P&K technologies will be supported through policies aimed at several sectors including mining, chemicals, heavy industry, agriculture, food and beverages, energy and circular economy systems.

**Simplified Policy Framework**




For the phosphate and potash sector specifically, policy applicability will vary by region and institutional context:

- Regions with established industrial and energy transition frameworks can explicitly integrate P&K policy into existing strategies.
- Regions without dedicated frameworks can embed P&K within cross-sector industrial decarbonisation strategies.
- Markets with strong grant or innovation programmes can extend eligibility to P&K-specific technologies, while others may rely initially on concessional finance or guarantees via national development institutions.

Taken together, financing and policy mechanisms are central to translating technical potential into real-world deployment. Coordinated action between producers, financiers, and policymakers will be required to align capital flows with the long-term transformation pathways set out in this roadmap, while preserving flexibility for regional and asset-specific solutions.

CASE STUDY

# Low-carbon electricity via onsite generation

APPLICABLE PRODUCTS

| | | | |
|---|---|---|---|
| MAP/DAP/NPK | | | TSP |
| SSP | NPK | MOP | NOP |
| MgSOP | | SOP 1 | SOP 2 |

**Measure Description:** Behind-the-meter generation of low-carbon electricity to reduce grid electricity imports.

## Policy Mechanisms

Policies are required to reduce cost differentials to grid electricity.

| | Onsite renewables | Renewables via PPA | Low TRL power incl. nuclear |
|---|---|---|---|
| Framework setting | Low Carbon Energy Strategy | | |
| Supply-side support | Revenue support | | R&D and revenue support |
| Demand-side support | Government procurement, carbon pricing and mandated targets | | |

## Financing Sources

Financing structures reflect the capital-intensive but relatively low-risk nature of mature low-carbon electricity technologies.

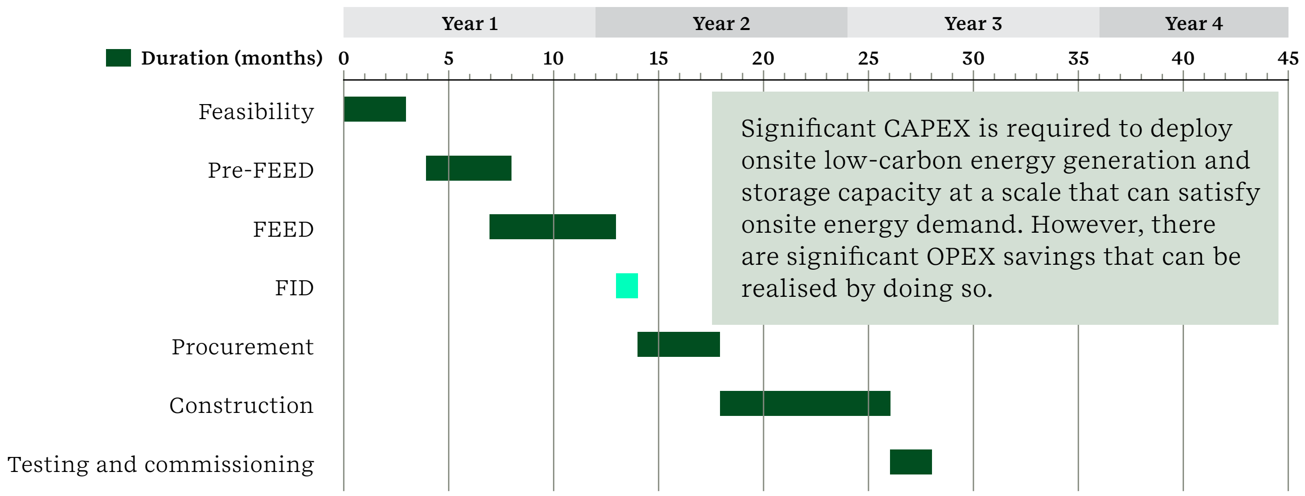
**Development**

- **Balance** sheet limited to site identification and interconnection studies
- **External equity** e.g. infrastructure funds may carry most early development

**FID to Operation**

- **External equity** likely to be dominant
- **Debt** via project finance where there is bankable long-term PPA

## Timeline and Major Project Milestones




* Vestas. 2025. Vestas secures order for wind project to power cement factory in Italy.

CASE STUDY

# Electrification of drying/heat

APPLICABLE PRODUCTS

| | | | |
|---|---|---|---|
| MAP/DAP/NPK | | | TSP |
| SSP | NPK | MOP | NOP |
| MgSOP | | SOP 1 | SOP 2 |

**Measure Description:** Electrically-heated indirect rotary kilns for phosphate / potash drying operations.

## Policy Mechanisms

Policy support is required to overcome technology scale-up hurdles and close the cost gap versus fossil-based heat.

| | CHP | Electrification of heat | Low TRL electrification technologies |
|---|---|---|---|
| Framework setting | Industry & Chemicals Strategy | | |
| Supply-side support | Revenue support | Capital and revenue support | R&D and revenue support |
| Demand-side support | Government procurement and carbon pricing | | |

## Financing Sources

Financing requirements reflect the high upfront CAPEX and increased ongoing electricity costs.

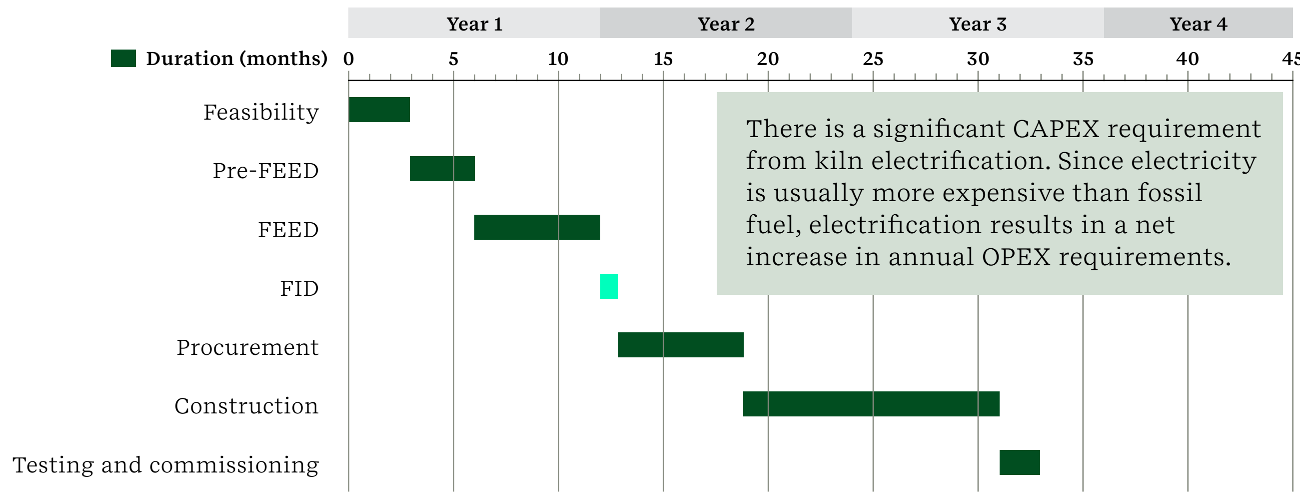
**Development**

- **Balance sheet** contributes to fund techno-economic or grid studies
- **Grants** required to cover unprofitable component

**FID to Operation**

- **Balance sheet** may fund core equipment replacement
- **Grants** may support ongoing operational premium
- **Debt** may be unlocked with long-term electricity contracts stabilising cash flows

## Timeline and Major Project Milestones




* BASF, SABIC, and Linde. 2024. Start-up of the world's first large-scale electrically heated steam cracking furnace.

CASE STUDY

# Carbon Capture & Storage

**Measure Description:** Carbon capture and permanent storage to abate process and combustion flue gas emissions.

APPLICABLE PRODUCTS

| | | | |
|---|---|---|---|
| MAP/DAP/NPK | | | TSP |
| SSP | NPK | MOP | NOP |
| MgSOP | | SOP 1 | SOP 2 |

### Policy Mechanisms

Policy support is critical to enable CCS deployment by addressing its high cost of abatement and lack of inherent revenue.

| | CCS of process emissions | Low TRL capture technologies |
|---|---|---|
| Policy layer | Policy mechanisms | |
| Framework setting | Industry & Chemicals Strategy | |
| Supply-side support | R&D, capital and revenue support | R&D and revenue support |
| Demand-side support | Government procurement and carbon pricing | |

### Financing Sources

Financing requirements reflect the very high CAPEX, limited direct revenue streams, and first-of-a-kind risk.

- External equity
- Debt

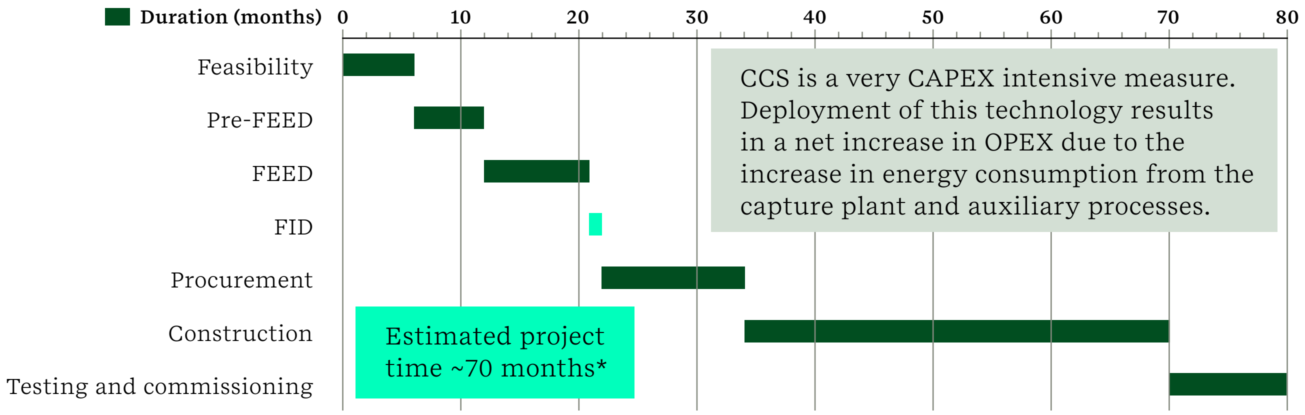
**Development**

- **Grants** likely to be pivotal in early phases
- **Balance sheet** may pay for site capture screening and integration

**FID to Operation**

- **Grants** may still be material to bridge FOAK costs and sector entry
- **Balance sheet** needed for on-site capture unit

### Timeline and Major Project Milestones**




* Heidelberg Materials. Brevik CCS – world's first carbon-capture facility in the cement industry.

** Based on ERM experience and may not reflect individual company experiences



## 5.3 Value chain collaboration

Delivering this roadmap will require collaboration across the full value chain in order to:

1. **Achieve emissions reductions**
2. **Safeguard food security and affordability**
3. **Maintain profitable business operations for P&K fertiliser producers**
4. **Strengthen resilience across the wider agri-food system**

Phosphate and potash fertilisers underpin global agricultural productivity, meaning that decarbonisation pathways must be implemented in a way that avoids supply disruptions or cost impacts that could undermine access to food, particularly in import-dependent and developing regions.

The **2025 WBCSD Business Breakthrough Barometer** provides global view on how leading businesses are negotiating their transition to net zero, identified that the phosphate fertiliser sector lacked clear guidance on a pathway to decarbonisation[19]. In mid-2024, IFA initiated the mobilisation of this roadmap with the EBRD in order to foster further cross-industry engagement for the phosphate and potash fertiliser sectors. This demonstrates how participation can not only identify critical barriers, but also connect the right stakeholders to stimulate collective action across a value chain and address shared challenges.

19 World Business Council for Sustainable Development (WBCSD). Business Breakthrough Barometer 2025

Multi-stakeholder platforms such as the **WBCSD Emissions Reduction Accelerator (ERA)**[20] further illustrate how coordinated, value chain-based approaches can accelerate emissions reduction while unlocking business value and strengthening business resilience. ERA was launched at COP30 in 2025, and one of its two flagship pilots focuses directly on lowering emissions from fertiliser production and use. The platform has the following key objectives:

01 Convening stakeholders across the fertiliser value chain and the broader agri-food system to leverage collective action in accelerating the transition toward a low-carbon, resilient food system that no single company or industry can achieve alone,

02 Bringing together stakeholders from adjacent sectors, including energy, utilities, and other manufacturing industries, to share learnings and cross-pollinate decarbonisation technologies and approaches,

03 Identifying how advances in AI and AgTech can support decarbonisation pathways, reduce costs, improve operational efficiency, and unlock new business value across the fertiliser and agri-food sectors,

04 Supporting the creation of an enabling policy environment through a value chain-based approach, recognising that different stakeholders across the value chain may require distinct policy interventions to scale decarbonisation innovations,

05 Supporting the development of market-forming and demand-side mechanisms, including market-based mechanisms (such as EACs), to accelerate global demand activation for low-carbon fertilisers,

06 Advancing Product Carbon Footprint (PCF) transparency and interoperability across all fertiliser types through initiatives such as Partnership for Carbon Transparency (PACT).

20 World Business Council for Sustainable Development (WBCSD). Emissions Reduction Accelerator (ERA).

*Implementation will require phased deployment, combining near-term, cost-effective measures with longer-term structural investments as enabling conditions mature. These investments should be distributed across the value chain to avoid placing a disproportionate burden on any single part of the system. Coordination with wider energy system development, infrastructure planning, agricultural transition strategies as well as appropriate policy frameworks, is essential to ensure that fertiliser decarbonisation supports, rather than constrains, food system resilience.*

# Chapter 6.

Call to action roadmap

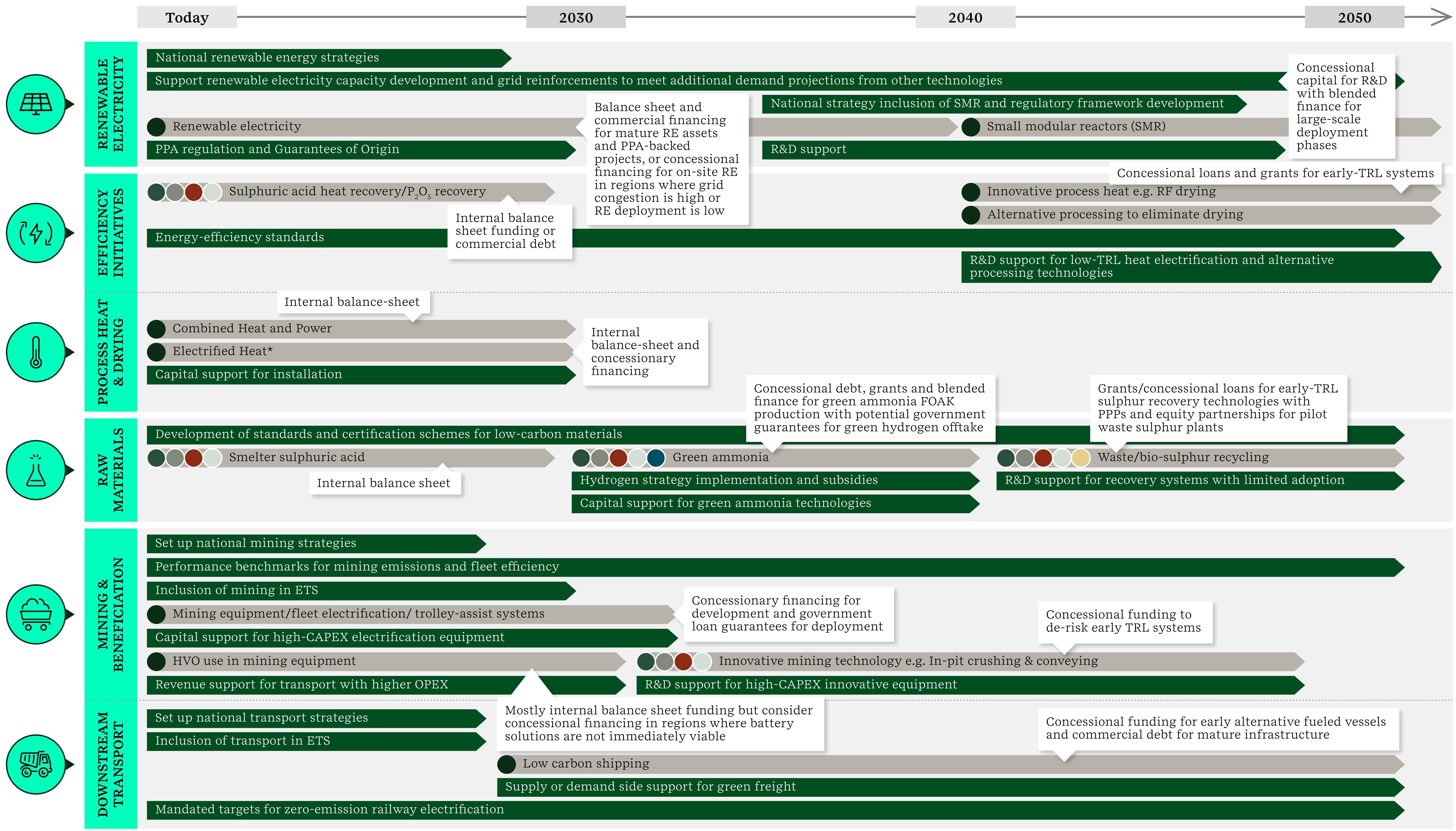


This section sets out the actions needed to move from ambition to implementation. It brings together the priority steps and direction of travel required to accelerate decarbonisation across the P&K value chain and clarifies which stakeholder groups are best placed to take them forward. The section is intended to provide a practical roadmap for action: first by outlining the key actions over time, and then by showing how delivery depends on coordinated efforts from producers, policymakers, financiers, and wider agri-food stakeholders.

## 6.1 Action framework

The following graphics aim to summarise key actions, both near and long term, for different stakeholder groups. Actions are intended to set a direction of travel with applicability depending on regional variations and regulatory environments. Asset-level assessments should be performed to identify which actions are applicable.

## Call to Action Roadmap




* Heat electrification can be economic under some cases e.g. lower temperature applications with access to low-cost electricity

**LEGEND**

Technology | Finance | Policy & Enabling Actions

All products

**Phosphate products**: MAP/DAP/NPK, TSP, SSP, NPK

**Potash products**: SOP, NOP

## Physical Climate Risk Roadmap

Today — 2030 — 2040 — 2050

**Extreme heat and prolonged heatwaves are projected to increase sharply by 2050 across key producing countries & wildfires are becoming a critical operational threat**

### EXTREME HEAT

- **Worker behavioural change:** adapted worker schedules (early morning/ nights, breaks, rotations) and water and hydration protocols (misting stations, availability, PPE)
- **Heat monitoring systems** on site, heat stress indices and early warning system
- **Cooling infrastructure:** shaded rest areas, cooled control rooms, ventilation in underground operations, cooling for critical equipment (generators, transformers etc.), and specification of machinery for high-temperature operations, including regular inspection of overheating sensitive components

### WILDFIRE

- **Vegetation Management:** clearing perimeters and firebreaks around sensitive infrastructure (processing plants, power lines, storage)
- **Monitoring and early detection:** satellite monitoring, weather tracking, on-site fire surveillance during high risk periods
- **Emergency response planning:** fire suppression equipment, trained emergency teams, evacuation procedures, coordination with local authorities

**Flooding and extreme storms are causing major operational and supply chain disruptions**

### FLOOD RESILIENCE

- **Water control and drainage:** engineered solutions to redirect stormwater (channels, culverts, ditches), dewatering systems to prevent pit or underground flooding (pumps), and retention/ detention ponds to store runoff and reduce peak flows
- **Tailings facility** to prevent overtopping and instability, emergency spillways and flood routing
- **Infrastructure:** elevation of critical systems, real-time monitoring and retaining structures/ vegetation

**Rising water stress is increasing costs, constraining operations, and heightening social, regulatory and pollution risks (reduced freshwater availability, intensified runoff, eutrophication)**

### WATER STRESS

- **Alternative water sources:** mine pit dewatering reuse, rainwater harvest, treated municipal wastewater near WWTP, brackish or seawater desalination
- **Process water reuse** counter-current filter washing (up to 20–35% reduction), FSA scrubber liquor recovery (up to 40–60% reduction and revenue), evaporate condensate reuse, cooling tower cycles or concentration (15–25% reduction) and membrane treatment for effluent (60–80% reuse)
- **Water recovery:** thickeners (55–80% recovery), filtered tailings (80–90% recovery), pond covers (60–80% evaporation reduction) or closed-loop pond recycling (90–100% recovery)

**Caveat:** Prioritisation and sequencing of financing for these resilience solutions requires a more in-depth analysis of local material risks for each asset.

LEGEND

Technology

Policy & Enabling Actions

Mining | Processing | Both

# 6.2 Stakeholder-specific priorities

## Food-agri companies and retailers

*Agri-food conglomerates, retailers and farmers play a critical role in reducing fertiliser-use emissions and creating market pull for lower-carbon fertiliser value chains, while ensuring food affordability is maintained. In practice, improving nutrient use efficiency through better field-level management is often the most immediate and scalable lever, while willingness to pay a premium for lower-carbon products is likely to depend on stronger downstream demand signals and broader market support.*

- Driving consistent demand signals through procurement practices, sustainability requirements, Scope 3 targets, and premium-crop or low-carbon product strategies led by agri-food conglomerates and retailers, while recognising that broader market pull will be needed before costs can be passed through at scale.
- Participating in demonstration and pilot programmes to validate agronomic performance, while enabling retailers, trusted advisors and farmer groups to support wider adoption of 4R practices, improved nutrient use efficiency, and innovative products. Better data sharing, field-level insight and collaboration across the value chain will be important to target interventions effectively and scale adoption.
- Communicating sustainability attributes transparently to consumers, while avoiding adverse impacts on food prices or access.

## Producers

*Producers are central to implementing and accelerating deployment of decarbonisation technologies within existing and new assets.*

- Identifying and prioritising near-term technologies for pilots and early deployment (e.g. efficiency and renewable electricity measures)
- Optimising existing production processes and the on-site recovery of co-generated heat and power
- Embedding asset-level decarbonisation planning into capital investment decisions to avoid lock-in
- Forming co-development partnerships with technology providers and equipment manufacturers
- Engaging downstream actors to build acceptance and align production changes with market needs
- Harmonisation of public and private sectors' reporting of product-level emissions to enable downstream Scope 3 Category 11 accounting and target-setting

## Financiers

*For financiers, priorities focus on mobilising capital at scale and reducing risk for first movers.*

- Deploying risk-sharing instruments and blended finance to support early-stage and first-of-a-kind projects
- Co-financing industrial demonstration projects alongside producers and public institutions
- Supporting long-term contracts and credit-enhancement mechanisms that improve bankability
- Building sector-specific expertise to replicate successful financing models across regions and archetypes

## Policymakers

*Governments and public institutions play a critical enabling role by creating stable conditions for investment and adoption, as well as actively supporting capability building, farmer education, extension services and adoption across the agricultural system.*

- Encouraging national decarbonisation strategies for mining and fertiliser industries
- Providing capital support (e.g. grants, tax credits, guarantees) to bridge early-stage cost gaps
- Developing demand and supply-side policy instruments to accelerate technology development and deployment.
- Investing in grid reinforcement and access to renewable energy (as well as other shared infrastructure, such as $CO_2$ transport) for industrial clusters.
- Supporting training, extension services, and advisory systems to build capability and accelerate adoption of best-practice nutrient management and emissions reduction practices.
- Driving awareness-building and knowledge transfer programmes across the agricultural value chain to enable low-cost, near-term emissions reductions through improved fertiliser use practices

## Standard setters

### Leverage fertiliser-specific, food-secure, science-based pathways

*Standard setters have a critical role in providing clear, credible and sector appropriate guidance and target-setting frameworks that reflect the unique challenges and opportunities across the phosphate and potash fertiliser value chains.*

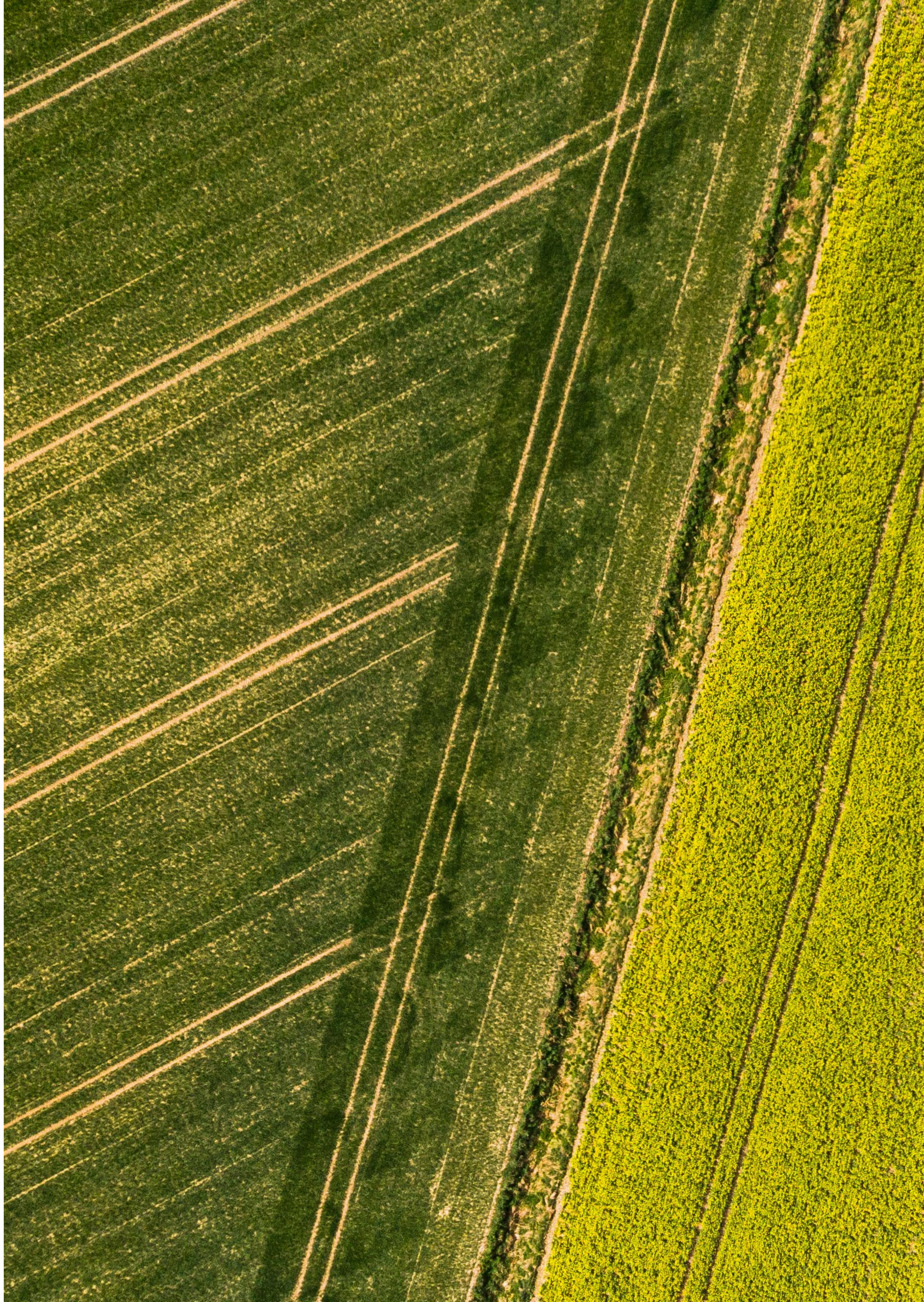
*Producers require dedicated guidance that accounts for their products in sustaining agrifood systems, while reflecting the heterogeneous production routes, the regional constraints affecting producers differently, and the broader technology, cost, and deployment constraints.*

→ **Integrate food security and system-level considerations into target design**
Ensure that methodologies explicitly balance emissions reduction with maintaining fertiliser availability, affordability, and global food security, avoiding incentives that could constrain production rather than improve efficiency.

→ **Enable flexible asset- and sectoral intensity-based approaches**
Support the use of sectoral emissions intensity metrics and asset-level pathways where appropriate, reflecting the sector's variability and avoiding one size fits all absolute reduction trajectories which could impact food security.

→ **Facilitate alignment across the agri-food value chain**
Promote interoperability with FLAG, food company Scope 3 frameworks, and product carbon footprint methodologies to enable consistent demand signals and value chain accountability.

→ **Strengthen approaches for fertiliser use emissions**
Support the development of standard guidance for scientifically robust, practical, and industry-informed life cycle assessment methodologies for fertiliser use $N_2O$ emissions, including attribution and allocation approaches that reflect the underlying emission mechanisms. Such guidance should account for the high variability of these emissions, their dependence on soil conditions, and the challenges associated with direct measurement.



# Chapter 7.

## Glossary of terms



This glossary explains key abbreviations and technical terms used throughout the report. Definitions are indicative and intended to help non-specialist readers interpret the analysis consistently.

## 7.1 Key abbreviations

***ATP (Adenosine triphosphate)***

A molecule that stores and transfers energy in living cells and is essential to plant growth and metabolism.

***BAU (Business-as-usual)***

A reference scenario showing how emissions, production or demand could evolve without additional mitigation beyond current or expected trends.

***CAGR (Compound annual growth rate)***

The average annual growth rate of a metric over a specified period, assuming growth compounds over time.

***CAPEX (Capital expenditure)***

Upfront spending on assets, equipment or infrastructure.

***CCS (Carbon capture and storage)***

Technologies that capture carbon dioxide emissions and transport them for permanent storage, usually underground.

***CHP (Combined heat and power)***

A system that produces electricity and useful heat from the same fuel source to improve energy efficiency.

***$CO_2e$ (Carbon dioxide equivalent)***

A unit used to compare the warming impact of different greenhouse gases on a common basis – can be denoted as $MtCO_2e$ (million tonnes).

***DAP (Diammonium phosphate)***

A phosphate fertiliser containing both nitrogen and phosphorus.

***EAC (Energy attribute certificate)***

A certificate representing the verified environmental attributes associated with a defined unit of energy, which can be traded separately from the physical energy itself to support tracking and claims.

***EMEA (Europe, the Middle East and Africa)***

A regional grouping used in business and market analysis.

***ETS (Emission Trading Scheme)***

Market-based policy mechanism used to reduce greenhouse gases by setting a cap on total emissions within an industry.

***FSA (Fluosilicic acid)***

Highly corrosive by-product of phosphoric acid production

***GHG (Greenhouse gas)***

A gas that traps heat in the atmosphere and contributes to climate change.

***HVO (Hydrotreated vegetable oil)***

A renewable liquid fuel that can substitute for diesel in some applications.

***IFA (International Fertiliser Association)***

A global industry association for fertiliser producers and related stakeholders.

***IPCC (Intergovernmental Panel on Climate Change)***

The United Nations body that assesses climate science and related mitigation and adaptation pathways.

***MAC(C) (Marginal abatement cost/ Marginal abatement cost curve)***

A tool that compares emissions reduction options by abatement potential and cost per tonne of $CO_2e$ reduced.

***MAP (Monoammonium phosphate)***

A phosphate fertiliser containing nitrogen and phosphorus.

***MgSOP (Magnesium sulphate of potash)***

A potash fertiliser that supplies potassium, magnesium and sulphur.

***MOP (Muriate of potash)***

A potassium fertiliser, usually potassium chloride, that accounts for most global potash use.

***$N_2O$ (Nitrous oxide)***

A potent greenhouse gas and a key source of emissions associated with fertiliser use and some industrial processes.

***NOP (Nitrate of potash)***

A potassium fertiliser that supplies both potassium and nitrate nitrogen.

***NPK***

A fertiliser blend or compound containing nitrogen (N), phosphorus (P) and potassium (K).

***NZ50***

The report's illustrative pathway aligned to a net zero objective by 2050.

***NZ70***

The report's illustrative pathway aligned to a net zero objective by 2070.

***P&K (Phosphorus and potassium)***

A shorthand used in this report to refer to phosphorus- and potassium-containing fertilisers and their value chains.

***PCF (Product Carbon Footprint)***

The greenhouse gas emissions associated with a product across defined life-cycle stages, usually expressed per unit of product.

***PPA (Power purchase agreement)***

A contract to buy electricity, often used to secure renewable or low-carbon power over the longer term.

***PPE (Personal protective equipment)***

Gear designed to protect wearers from workplace or environmental hazards.

***SBTi (Science Based Targets initiative)***

An organisation that develops standards and guidance for corporate emissions reduction targets aligned with climate science.

***Scope 1, 2 and 3 emissions***

Greenhouse gas accounting categories covering direct emissions (Scope 1), purchased energy emissions (Scope 2), and other value chain emissions (Scope 3).

***SMR (Small nuclear reactors)***

Nuclear fission reactors that are designed at smaller capacity and built as modules on site.

***SOP (Sulphate of potash)***

A potassium fertiliser, usually potassium sulphate, used where chloride-sensitive crops or additional sulphur supply are important.

***SSP (Single superphosphate)***

A phosphate fertiliser that supplies phosphorus and sulphur.

***TRL (Technology readiness level)***

A scale describing the maturity of a technology from early research to commercial deployment.

***TSP (Triple superphosphate)***

A concentrated phosphate fertiliser that supplies phosphorus without nitrogen.

***UAN (Urea ammonium nitrate)***

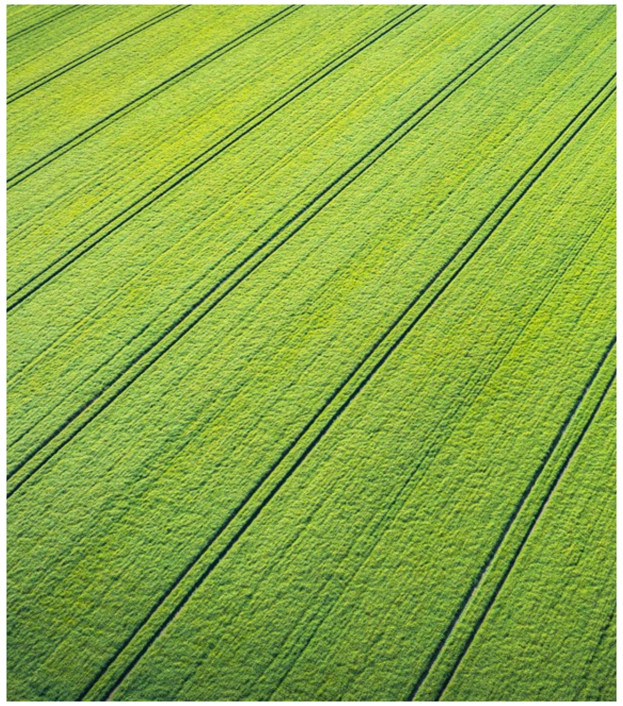
A liquid nitrogen fertiliser solution.

***WBCSD (World Business Council for Sustainable Development)***

A global business organisation focused on sustainable development and corporate climate action.

***WWTP (Waste water treatment plant)***

Cleans used water and sewage from homes, businesses and industries before discharge into the natural environment.



## 7.2 Technical terms

***4Rs***

A nutrient stewardship framework based on the right source, right rate, right time and right place.

***Enhanced efficiency fertilisers***

Fertiliser products designed to improve nutrient availability or reduce nutrient losses.

***Incremental decarbonisation***

Measures that reduce emissions by improving or retrofitting existing systems without changing the underlying production route.

***Nitrification inhibitor***

A substance added to fertiliser to slow the conversion of ammonium into nitrate in soils.

***NUE (Nutrient use efficiency)***

The effectiveness with which applied nutrients are taken up and used by crops to produce yield.

***Phosphogypsum***

A calcium sulphate-rich by-product generated during phosphoric acid production from phosphate rock.

***Precision agriculture / digital agronomy***

The use of data, sensors and digital tools to optimise input use and support better agronomic decisions.

***Transformational decarbonisation***

Measures that reduce emissions by changing the underlying production route, system configuration or raw material dependence.

***Urease inhibitor***

A substance added to urea-based fertiliser to slow the conversion of urea into ammonia.

# Chapter 8.

## References


African Development Bank (AfDB) and Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development (IGF). *Phosphate Fact Sheet.*

AGC Glass Europe and Saint-Gobain Glass. *Design of a hybrid mid-sized pilot furnace for flat glass (Volta project).*

BASF, SABIC, and Linde. 2024. *Start-up of the world's first large-scale electrically heated steam cracking furnace.*

Heidelberg Materials. *Brevik CCS – world's first carbon-capture facility in the cement industry.*

Heidelberg Materials. 2025. *Heidelberg Materials inaugurates the world's first industrial-scale carbon capture facility.*

Intergovernmental Panel on Climate Change (IPCC). 2022. *Climate Change 2022: Mitigation of Climate Change – Summary for Policymakers.*

International Energy Agency (IEA). 2021. *Ammonia Technology Roadmap.*

International Fertiliser Association (IFA). 2025. *Phosphogypsum: From Waste to Inventory.*

International Fertiliser Association (IFA). 2010. *Sulphur and Sustainable Agriculture.*

International Maritime Organization (IMO). 2025. *IMO approves net-zero regulations for global shipping.*

Metso Outotec. *HEROS™ Heat Recovery System.*

Natural Resources Canada. *Potash Facts.*

Science Based Targets initiative (SBTi). 2025. *SBTi Chemical Pathways and Implementation Criteria.*

SYSTEMIQ. 2022. *Reducing Emissions from Fertiliser Use.*

Vestas. 2025. *Vestas secures order for wind project to power cement factory in Italy.*

World Business Council for Sustainable Development (WBCSD). *Business Breakthrough Barometer 2025*

World Business Council for Sustainable Development (WBCSD). *Emissions Reduction Accelerator (ERA).*

# About ERM

We are the world's largest advisory firm focused solely on sustainability, offering unparalleled expertise across business and finance.

With more than 50 years of experience, our ability to integrate sustainability solutions and our depth and breadth of technical knowledge are why organizations choose to partner with us as their trusted advisor.

LinkedIn: linkedin.com/company/erm
Website: erm.com

## Sustainability is our business