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The Australian Nitrogen Fertiliser Value Chain

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Abstract

Over the past century nitrogen fertilisers have become a key input into Australian cropping and pasture systems. In relatively recent times, concern has been raised about environmental damage caused by their use. Australia has a well-developed market for nitrogen fertilisers, but little is documented about how the wider value chain of fertiliser operates. The focus of this paper is on describing the operation of the nitrogen fertiliser value chain in Australia and the potential role of enhanced efficiency fertilisers in the market. If economic, enhanced efficiency fertilisers are a technology with the potential to deliver improved environmental outcomes. A global value chain perspective is taken which encompasses both onshore and offshore firms that produce, distribute and retail nitrogen fertilisers across Australia. Data was collected through internet resources, phone interviews with participants in the fertiliser value chain and from government statistics. With this data, the nitrogen fertiliser value chain was mapped to trace, and understand, the flow of product and the form and extent of services, and value, added by the different firms operating along the value chain.

Whilst a number of enhanced efficiency fertilisers exist in the Australian fertiliser market, uptake by farmers has been low and slow. Most of the deployment of enhanced efficiency fertilisers is done at the distribution level of the value chain by a small number of lead firms. The descriptive information provided in this paper is the basis for a companion paper assessing the performance of the fertiliser value chain which leads to suggesting ways in which the uptake of enhanced efficiency fertilisers might be increased.

Keywords: Enhanced efficiency fertilisers, nitrogen fertilisers, value chain analysis, value chain map

Introduction

Until the early 20th century, agricultural production systems had limited options for restoring and raising nutrient levels and soil fertility. These options included animal manures, mined rock fertilisers, avian excreta, and pasture leys. Each of these methods came with limitations.

The introduction of the Haber-Bosch process in the early 20th century allowed farmers to significantly increase productivity and production by growing and utilising crops and pastures more intensively. The Haber-Bosch process involves combining hydrogen from methane with concentrated atmospheric nitrogen to form ammonia. Ammonia is the singular chemical precursor to all modern synthetic nitrogen fertilisers. Erisman *et al.* (2008) estimated that over 3.5 billion people are better fed due to the productivity gains arising from the use of synthetic nitrogen fertilisers. The application of synthetic nitrogen fertilisers is one of the major factors that moved humanity beyond the Malthusian bounds of historical soils, just as steam power revolutionised industry (Malm, 2016). Consequently, nitrogen fertilisers are a critical part of contemporary global agricultural production systems.

Synthetic nitrogen fertilisers did not emerge in isolation from other key innovations. Nitrogen, part of the mid-20th century Green Revolution innovations of high-yielding varieties of grain responsive to fertiliser and irrigation, chemical control of weeds and pests, mechanisation and expansive irrigation infrastructure (Evenson and Gollin, 2003), all contributed to a doubling of global grain yields. Locally, nitrogen fertiliser has been critical to improving and maintaining the productivity of Australia's soils that are low in nutrients (Eldridge *et al.*, 2018).

Overall, the move to using increasing amounts of synthetic nitrogen fertiliser allowed a worldwide shift to intensive, broad-scale and continuous farming systems, increasing the productivity of land through greater yields. Gains in farm profit from fertiliser use and increased labour productivity enabled hitherto marginal lands to be brought into production (Pingali, 2012) – all of which increased the aggregate supply of agricultural commodities and contributed to the decline in real agricultural commodity prices.

However, the introduction of synthetic nitrogen fertilisers has come with trade-offs. Whilst large (but difficult to quantify) positive externalities have been generated by the productivity gains provided by the introduction of nitrogen fertilisers into agriculture, their use has led to significant negative externalities which have the potential, on a case-by-case basis, to adversely affect the quality of the surrounding natural environment. A negative externality is defined as the situation where the private cost of either production or consumption of a good is accompanied by an added cost on parties not involved in the production or consumption transaction, i.e. a cost that is not borne by the producer or consumer (OECD, 1993). A common example of this is carbon emissions, where the social cost of carbon dioxide emissions (and equivalents in nitrous oxide and methane) from burning fossil fuels, using nitrogen fertiliser and from sources of methane, are not borne by the producers or users of the goods and services created that caused the emissions (Tol, 2011). These social costs are borne instead by the whole of society through anthropomorphic climate change. Losses from applications of nitrogen fertiliser include, as well as nitrous oxide, nitrogen fertiliser run-off leading to eutrophication of waterways (Smith and Schindler, 2009), nitrate leeching into water tables and reducing water quality (Thorburn *et al.*, 2003), and gaseous losses of ammonia which can cause human health problems (Reay *et al.*, 2012). The complex interdependencies that make up human, agricultural and environmental sustainability make the issue of feeding the world population without excessively damaging the natural environment an especially fraught challenge.

With rising concern surrounding anthropogenic climate change, there has been a reinvigoration in thinking of ways that pollution in all forms can be reduced. The fertiliser industry is focusing on technological and productivity-enhancing changes in the nitrogen fertiliser market, including enhanced efficiency fertilisers (EEFs). These are fertiliser products designed to reduce nitrogen losses from productive use, maintaining productivity and profitability of agricultural production systems while at the same time reducing the social costs associated with their use (Chen *et al.*, 2008; Timilsena *et al.*, 2015). Understanding how and where EEFs may fit in the present nitrogen fertiliser value chain, their price points, and the profitability of EEFs relative to regular fertilisers, is key to assessing the potential role these new nitrogen fertilisers may play.

This is the context in which the Australian nitrogen fertiliser value chain is described and analysed in this research. The aim is to better understand the current and potential role of EEFs and how they can be integrated into Australian agriculture. First, a brief history of nitrogen fertiliser production is provided and then the Australian fertiliser market is described. Next, the governance structure of how the nitrogen fertiliser value chain operates is considered using the framework laid out in Gereffi *et al.*

(2005). Using this framework, the product flows along the value chain are identified and analysed. This approach includes examining how nitrogen fertilisers are manufactured, distributed, and retailed to Australian producers.

In a subsequent paper (Wirtz *et al*., 2023) the way operators along the value chain communicate, both upstream and downstream, in responding to changes in market demands is examined as part of a performance assessment. The intent is that, with understanding of how the value chain works, both offshore and onshore, gaps in the value chain may be identified that could present opportunities for EEFs to be better supported.

History of the Nitrogen Fertiliser Market

'While in 1900 the world consumption of the three principal mineral fertilisers, nitrogen (N), phosphoric acid (P_2O_5), and potassium (K_2O) did not reach 4 million tons of fertiliser units, in 1950 it was a little over 17 million tons, and, at the end of the 1980s, it reached 130 million tons.' (Mazoyer et al., 2006)

Historically, mass production and adoption of nitrogen-based fertilisers was a by-product of war-time explosives industries and they were then brought into mass use globally during the Green Revolution of the early Post-War era (Graham, 2003).

The origins of the Australian fertiliser industry also lie in industrial chemistry and explosives manufacturing. Largest among the companies that supplied nitrate chemicals was Imperial Chemical Industries Australia and New Zealand (ICIANZ), a British firm organised in Australia during 1928 as a merger of the local Nobel Industries, Brunner Mond and Co., United Alkali Company, and British Dyestuffs Corporation. It became Orica in 1998 after a series of divestments and mergers in the Australian chemicals industry (Cytowicz *et al.*, 2009).

The current major Australian firms are derived from this long history of industrial mergers and acquisitions in the Australian fertilisers and chemicals industry. The origins of Incitec Pivot Limited can be traced to two major Australian fertiliser companies: Pivot Limited, which itself was the Phosphate Co-operative Company of Australia based in Victoria (Incitec Pivot Limited, 2019), and Incitec Limited, starting as Australian Co-operative Fertilizers in Queensland. Both companies merged in 2003 (ACCC, 2002) as a result of the flow-on effects of the Millennium Drought, consolidating the market share of both firms into a centralised business. At the time of this merger, Incitec Pivot held fertiliser production facilities that have since closed: a 90kt/year granulated ammonium phosphates plant in Newcastle; a 450kt/year superphosphate plant in Portland; and a 350kt/year superphosphate plant in Cockle Creek. Declining demand in the Australian fertiliser market, as a result of the Millennium Drought, saw these plants become unprofitable at a time when there was a broader shift away from standalone phosphate fertilisers to using imported high analysis fertilisers such as mono-ammonium phosphate (MAP) and di-ammonium phosphate (DAP) (ACCC, 2008) (see Figure 1 and 2).

Australia's second largest nitrogen fertiliser firm Cuming Smith British Petroleum (CSBP) shares a similar history to that of Incitec Pivot. Initially starting as the Perth-based Cuming Smith and Co. in 1910, the company merged with the West Tasmanian based Mount Lyell Mining and Railway Company and Westralian Farmers' Superphosphates to form CSML. Later, Boral purchased Mount Lyell's one third share before eventually selling their share to British Petroleum in 1963. Finally, in 1979 the firm was taken over by the Westralian Farmers' Co-operative (now Wesfarmers) which itself had gained one third control after merging with Westralian Farmers' Superphosphates.

Figure 1. Total mono-ammonium phosphate imports into Australia by world region since 1990 (tonnes)

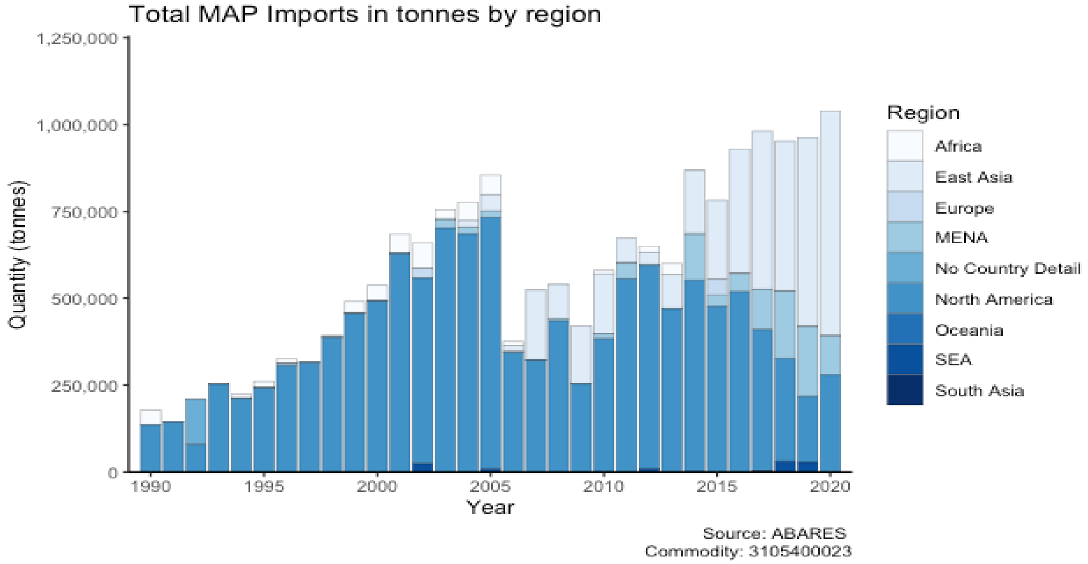
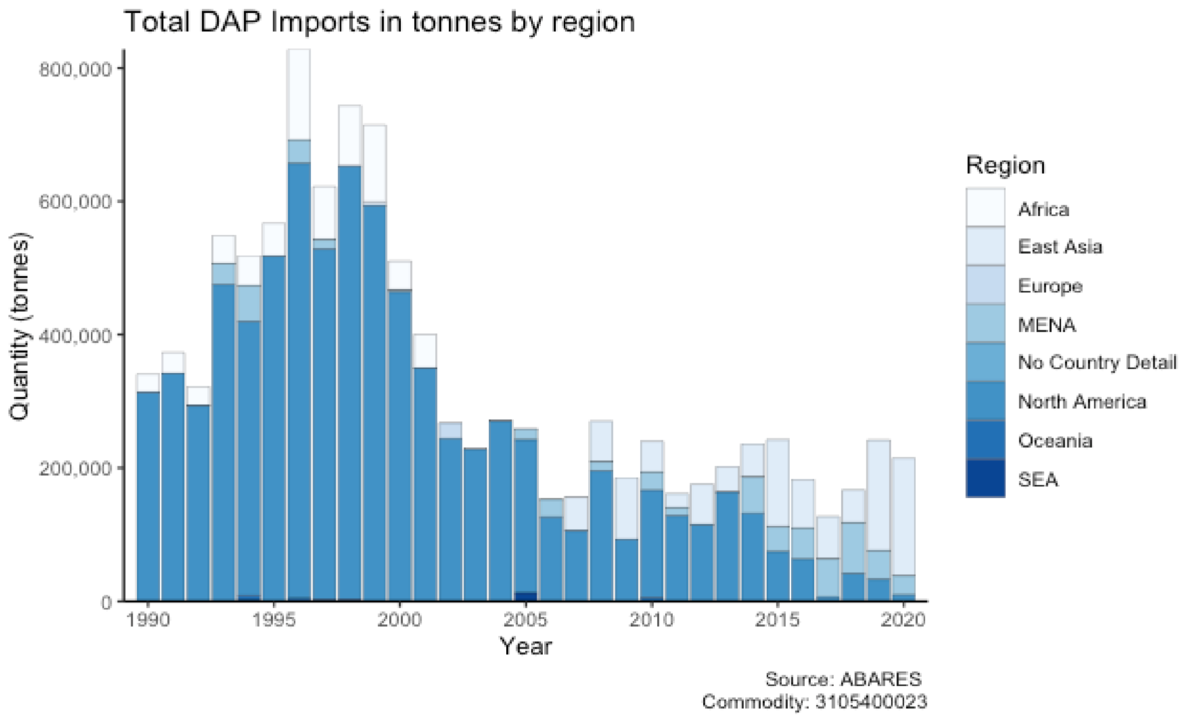


Figure 2. Total di-ammonium phosphate imports into Australia by world region since 1990 (tonnes)



Enhanced Efficiency Fertilisers

Enhanced efficiency fertilisers are nitrogen fertilisers that reduce nutrient losses and increase plant uptake (Snyder, 2017). This is achieved through a range of methods, including urease and nitrification inhibitors and slow-release coatings (details of these different forms of EEFs are provided later in the paper). Silva *et al.* (2017) found that an average of 31 per cent of urea applied to crops and pastures was lost via ammonia volatilisation pathways. This occurs through urease enzymes present in a number of soil microbes which hydrolyse urea into dissolved carbon and gaseous ammonia, raising soil pH in the process (Mobley and Hausinger, 1989). Nitrification is the process where ammonia is converted into nitrate via a two-step oxidation process causing losses via nitrous oxide and nitrate leeching (Schmidt, 1982). The scale of losses from these two processes varies widely depending on many factors (Cameron *et al.*, 2013). The aim of using EEFs is to reduce these losses from applied nitrogen and the costs they incur.

Adoption of EEFs in Australian agriculture has been low, being used on just 8 per cent of the total area under fertiliser use (ABS, 2017). Calculating the optimal level of nitrogen fertiliser application depends on the marginal cost of extra production. With each extra applied unit of nitrogen fertiliser, the additional yield diminishes until it is uneconomic (marginal private benefits are less than the cost of additional fertiliser costs). Whether EEFs are economic compared with traditional nitrogen fertilisers depends on the cost per hectare of EEF (not per unit of fertiliser) and the maximum profit that can be achieved, compared with the cost per hectare of traditional nitrogen fertilisers and the maximum profit that can be achieved. A positive difference in profit provides the incentive to adopt EEFs.

This decision to use fertiliser at levels that maximizes profit is less clear when the costs and benefits of risk and uncertainty are part of the decision problem. Diminishing returns to extra fertiliser means that the loss of profit from using too little fertiliser can be greater than the loss of profit from using too much fertiliser, thereby creating an incentive to ‘insure’ against loss of yield by using a bit extra fertiliser than ‘risk-free’ profit maximizing principles would suggest. Paulson and Babcock (2010) address these complexities by examining how nitrogen fertiliser is over-applied as a blunt hedge against climate and market volatility while counterintuitively increasing the variable costs and thus the risk of loss of gross margin too. The presence of correlated volatility between wheat, urea, and natural gas prices (Figures 3 and 4) is a further complicating dimension to the choice of the optimal amount of nitrogen fertiliser to use.

From an Australian perspective, while there has been research into EEFs adoption in Australia, the challenges that may exist preventing their adoption have not been carefully considered in the context of an examination of the performance of the whole Australia nitrogen fertiliser value chain.

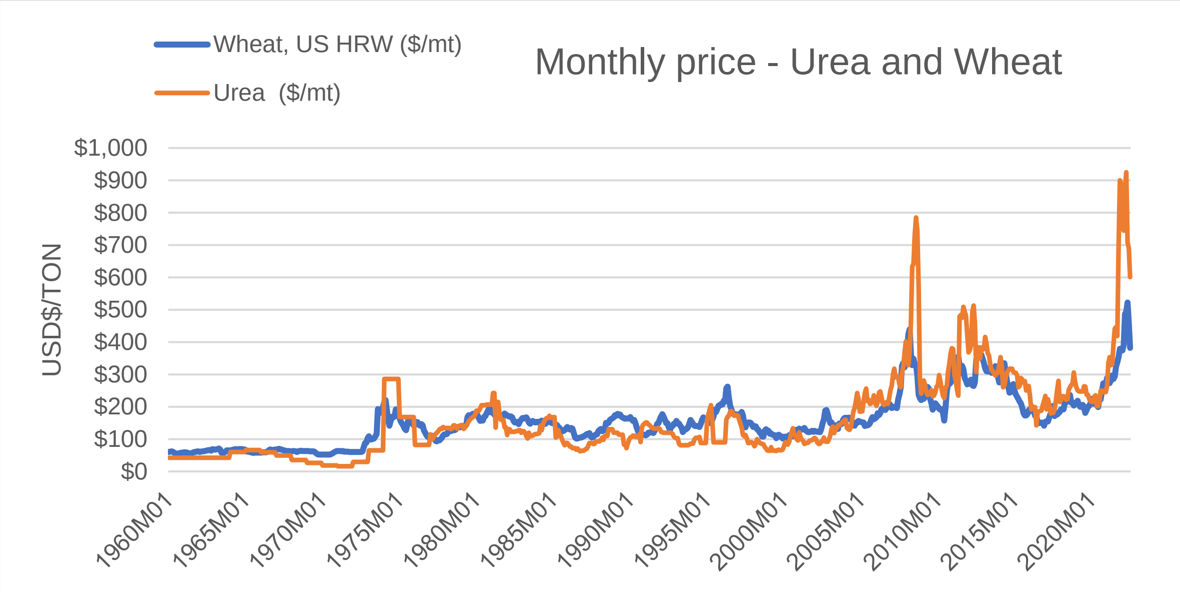
Value Chain Analysis

Nitrogen fertilisers are intermediate inputs into agricultural production systems. They are supplied through market linkages which connect farmers who are geographically dispersed across considerable distances to their source of these inputs. A range of services such as transport, agronomic services, product upgrading, and retailing are added to the raw material which incur costs but also add value for the next users of the product. This process can be understood through the ‘value chain’ concept. Value chains describe the two-way nature of how these linkages influence a product before it reaches its final destination (Kaplinsky and Morris, 2001). Under contemporary value chain frameworks, the process of adding net value to raw materials can be analysed to draw a number of insights, from competitiveness (Porter, 1985) to environmental sustainability (Soosay *et al.*, 2012).

The concept of the ‘value chain’ was first described by Porter (1985) who conceptualised all the activities that are undertaken by firms to produce a final product. Porter focussed on how the performance of a business could be assessed in the framework of an individual firm’s competitive advantage. This is done through considering the firms along a broader value chain by offering competitive goods and services in relation to its suppliers and customers.

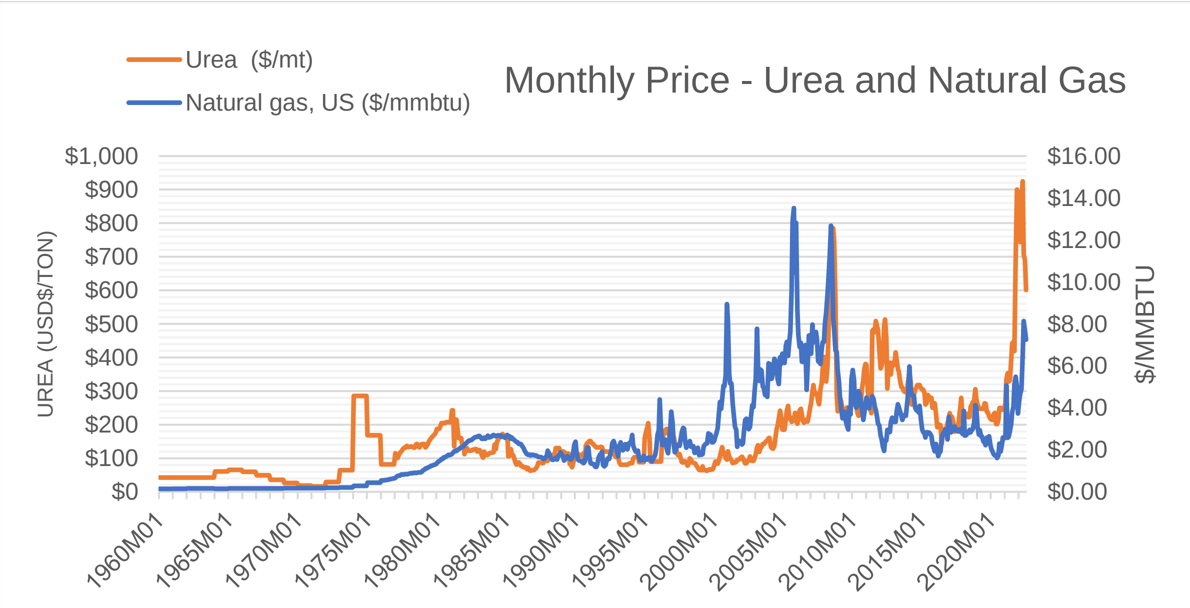
The definition of environmental sustainability in the value chain literature has been a widely debated topic. Definitional debates as well as differing approaches on achieving ‘sustainability ‘were analysed in Vermeulen and Seuring (2009) and Seuring (2011) who sought to develop a general theory of sustainability for future supply chain management literature.

Figure 3. Monthly prices of spot US hard red wheat and spot urea



Source: The World Bank (2022)

Figure 4. Monthly prices of spot Henry Hub natural gas and spot urea



Source: The World Bank (2022)

The theory focusses on how firms pursue and achieve the simultaneous but sometime contradictory aims of improving profitability and minimising environmental externalities, and especially exploring the economic trade-offs for a firm, and ways value chain research can guide policy makers and businesses.

Kaplinsky and Morris (2001) set out examples for points of entry for value chain research depending on the overall goal of the enquiry. Since the aim of this research is to provide an overview of the nitrogen fertiliser value chain considering the roles of independent buyers, key producers, and key retailers, as well as how enhanced efficiency fertilisers have been integrated, the approach is to map forwards from production to retail. This approach enables the direction and reasons for product flows to be determined through the value chain participants.

A variety of methods have been used to gauge product flows and determine the various cost components involved with their movement from production to consumption. Phone interviews and government supplied statistics were used. The competitive nature of the nitrogen fertiliser industry, as well as the fact that large components of these value chains are operated by unlisted companies, means that researchers encounter commercial-in-confidence issues and an unwillingness to share private information. There are also considerable gaps in data collection from the Australian Bureau of Statistics (ABS) and the Australian Bureau of Agricultural and Resource Economics and Science (ABARES), especially since 2017. Here, priority was given to available data provided from publicly listed companies found in annual reports and investor information, supplemented by discussion with key industry personnel.

Governance is key to understanding how firms in the chain coordinate production (Gereffi, 1994; Gereffi *et al.,* 2001). Governance structures are described by Gereffi *et al.* (2005) as a spectrum of coordination that exists from markets with low intrinsic coordination to hierarchies dominated by vertically integrated firms with rigid coordination structures (Figure 5). In this concept is the idea of 'lead firms' which exhibit varying levels and types of power on the broader value chain.

Australia's Fertiliser Market

Lead firms

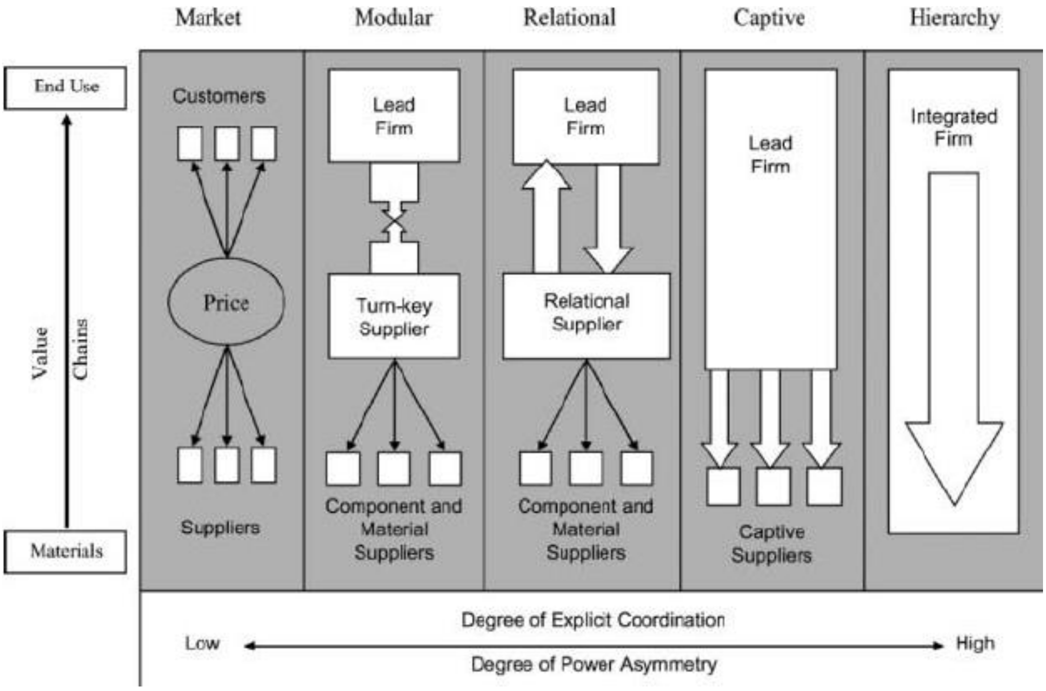
Lead firms are defined as participants along the value chain which have strong forward and backward linkages with a significant number of other value chain participants. This often includes activities such as importation, inventory aggregation and distribution.

The Australian fertiliser market is split into two geographical regions: Western and Eastern Australia. In these two geographic regions, two firms have largely dominated, as mentioned above. Incitec Pivot and CSBP have combined market shares of approximately 53 per cent of the overall Australian distribution market by volume (IBIS World, 2022b). Incitec Pivot retains a significant share of the distribution market in Eastern Australia via major importation, domestic manufacturing, and distribution operations, as does CSBP in Western Australia.

Incitec Pivot Fertilisers (IPF), as distinct from the wider Incitec Pivot Limited organisation, serves primarily Eastern Australia and is regarded as an industry leader with around a 40 per cent market share in the wholesale trade over the last decade (IBIS World, 2022b). IPF's operations extend through domestic production, import, value add activities and most importantly, distribution.

The firm IPF previously operated Australia's second largest nitrogen fertiliser plant at Gibson Island, Brisbane, which had a production capacity of approximately 1,500-1,700 tonnes per day (tpd), a single-superphosphate manufacturing plant in Geelong[i], as well as Australia's lone commercial rock phosphate mine, Phosphate Hill, southeast of Mt Isa. The closure of Gibson Island was announced in 2019 for a slated end of 2022 closure. Currently there are tentative plans to convert the plant into a site for zero-emissions 'green' ammonia production in conjunction with Fortescue Future Industries but as of early 2023 (*Charlie Lawson*, *pers comm*), few details have emerged regarding the future of the site.

Figure 5. The five types of value chain governance structures



Source: Gereffi *et al.* (2005)

The firm IPF operates a total of 25 distribution centres in Eastern Australia that serve as the nodal transport point for the company's distribution network between import/production and retail. Of the 25, 16 are termed primary supply centres and 9 are regional supply centres. Through these centres, the company supplies a further ~1,000 dealers and agents. This relationship is intermediated through a B2B (Business-to-business) e-commerce web portal named '*Fertshed'* which allows IPF dealers and agents to manage supply through an integrated web platform to coordinate truck scheduling, order management and warehousing.

Wesfarmers, through its industrial chemicals division CSBP Fertilisers based in Kwinana, Perth, is the primary fertiliser producer and importer in the West Australia market. Recent statistics on CSBP's market share in Western Australia are scant, but in a 2010 submission to the ACCC (ACCC, 2010), CSBP estimated a 61 per cent market share in Western Australia, down from an estimated 89 per cent in 1995-96. The Kwinana plant has an ammonia capacity of approximately ~330-350kt year / ~1,000 tonnes per day. Information was unavailable for CSBP's phosphate fertiliser production capacity. The company supplies a broad array of independent farm supply outlets as well as major chain retailers. The Western Australian segment of Elders has an exclusive supply agreement with CSBP (Thompson, 2016).

The Norwegian company Yara International, through its subsidiary Yara Australia entered the Australian fertiliser market in 1996 under the organisation's former name Hydro Agri Australia. Until August 2022, Yara Australia operated a liquid fertiliser mixing business in South-Eastern Australia via Yara Nipro, which were acquired by Incitec Pivot Fertilisers[ii]. Yara Australia operates a ~2,000/tpd ammonia production plant on the Burrup Peninsula, near Karratha, with approximately half of the ammonia capacity used at an adjacent ammonium nitrate plant which is run as a joint venture between Yara Australia and Orica. This plant serves as the primary source of explosives for the wider Pilbara mining industry.

Orica also serves as a significant participant in the Australian fertiliser market through its role as Australia's largest integrated chemicals manufacturer. Orica's Kooragang Island facility in Newcastle has a capacity of approximately 1,000/tpd of ammonia, though a large share of that production volume is dedicated towards explosives manufacturing in the form of ammonium nitrate for the Hunter valley coal mining region.

Koch Fertilisers Australia is a significant lead distribution firm which entered the Australian nitrogen fertiliser market in 2010[iii]. Koch operates primarily in Eastern Australia through seven distribution centres mainly in the south-Eastern half of the country[iv] in major ports located near key agricultural regions. Koch operations supply two major segments: bulk commodity fertilisers and EEF products. Koch supplies two N-(n-butyl) thiophosphoric triamide based (NBPT) EEF products under the Agrotain and NEXEN labels. NEXEN is a urea product with an Agrotain applied coating. Koch also operates a B2B online booking system like that of IPF's '*Fertshed*' under the name '*Koch Reservations'*. This system allows customers to communicate orders with Koch fertiliser dealers, who can then coordinate with Koch's broader distribution network. Koch supplies nitrogen fertiliser products to a range of distributor chains such as Elders and Nutrien Ag, as well as a significant number of independent farm supply stores[v].

Elders Limited is a significant operator in the fertiliser retail and wholesale components of the nitrogen fertiliser value chain (IBIS World, 2022a). Elders operates across a variety of rural industries in regional and urban Australia, primarily focused on farm supply, agronomy, financial services, and real estate. Elders Rural Products is the segment of the business that operates in the nitrogen fertiliser value chain through fertiliser input sales and agronomic services. Elders Rural Products operates approximately 400 stores across both Eastern and Western regional Australia. In Western Australia, Elders exclusively supplies CSBP-labelled fertiliser products (Thompson, 2016).

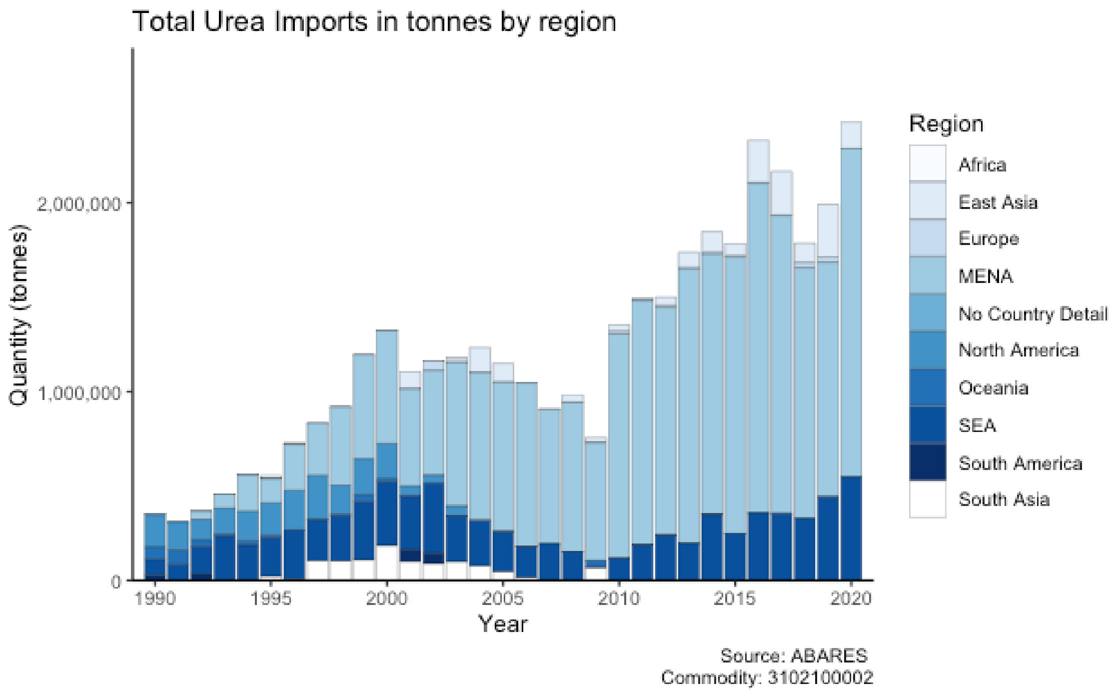
Nutrien Ag Solutions Australia operates in a similar fashion to that of Elders Limited, with the firm's focus being primarily farm supplies and services. Nutrien Ag is a relative newcomer to the Australian nitrogen fertiliser retail market, being formed in 2019 as a merger of Ruralco and Landmark. Nutrien Ag, and its previous iteration, Landmark, are subsidiaries of the Canadian fertiliser company Nutrien, formed out of a merger of PotashCorp and Agrium. Nutrien Ag is a major retailer of nitrogen fertiliser products across Australia with approximately 400 locations.

Combined Rural Traders (CRT), unlike other retail chains such as Elders, is a collective retail group made up of over 300 independent outlets, but it is also a subsidiary of the Nutrien Ag group. CRT members are primarily farm supply and service stores with integrated agronomists. Very little information is available on CRT. The business model uses affiliated stores that are independently owned but are in a formal relationship with CRT for greater supply chain efficiencies. Nutrien Ag achieves greater volume of fertiliser sales as CRT is exclusively supplied by Nutrien Ag fertiliser products. The individual member retail outlets operating in the CRT supply chain are in a way a reversal of captive suppliers represented in Gereffi *et al*. (2005), instead being captive retailers to a distribution-centric lead firm, resulting in greater explicit coordination.

Trade into Australia

The value chain literature does explore the increasing competition between differing structured global and localised value chains as a result of innovation and deployment of IT systems that have encouraged a reshaping of the competitive landscape in an increasingly globalised world (Gereffi *et al.*, 2005) . Even since 2007-08 there has been a substantial increase in net Australian fertiliser imports (Figure 6), as new enterprises have entered the increasingly globalised nitrogen fertiliser market. This has given rise to buyer-driven value chains through the connection of low-cost, export-orientated industrial countries to high value markets. The Qatar Fertiliser Company (QAFCO), the Saudi Basic Industries Corporation (SABIC), and Fertil, a venture by the Abu Dhabi National Oil Company, are the three largest individual firms supplying fertiliser into Australia, all of which are state owned export ventures (Figure 7).

Figure 6. Total urea imports into Australia by world region since 1990 (tonnes)

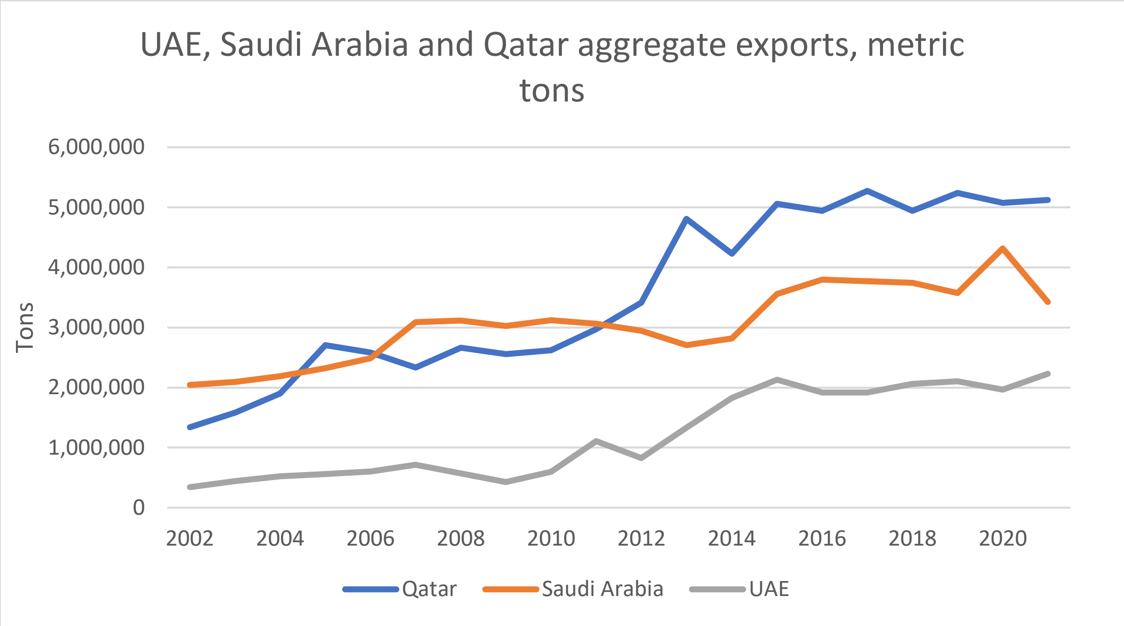


Increased export volumes have grown significantly via integration into existing national value chains, thereby increasing overall competition supply in the market. The rise of state-backed corporations involved in the fertiliser export trade can be compared to the rise of state-owned petroleum companies and the formation of OPEC during the mid-1970s. Prior to the 1970s, much of the world's oil and gas production and distribution was controlled by seven major oil and gas supermajors until the growth of state-owned enterprises during that period (Blas and Farchy, 2021). Similarly, during the last 20 years, there has been a significant growth in the export capacities of state-owned and backed fertiliser companies in Asia, largely in the Gulf States and China. Prior to this, a significant share of the world fertiliser export market was made up of a few major companies such as Yara/Norsk Hydro, Agrium/Nutrien, and CF Industries.

These state-backed enterprises fundamentally exist as a value-adding component to the geological comparative advantage that comes with low-cost oil and gas reserves. Whilst globalisation has lowered the costs of production for some, firms such as Incitec Pivot and CSBP face pressures of scale and increasing competition for natural gas as export demand increases, considerable import competition from new global entrants that use newer, more productive manufacturing facilities, preferential pricing on petroleum inputs due to common government ownership, and newer plants of greater scale.

Currently there is no large-scale application of zero-carbon fertiliser production, with many of the present initiatives small scale and with low rates of production. Thus, there is likely greater long term natural resource rents to be made from the production of nitrogen fertilisers.

Figure 7. UAE, Saudi Arabia, and Qatar aggregate exports (Australia's largest nitrogen fertiliser import-export partners)



Source: UN Comtrade (2021)

Product differentiation

The six most prominent nitrogen fertiliser products shown in Table 1 are widely traded commodities. The commodities have World Trade Organisation trade codes and well-known production processes, are they are produced in hundreds of plants across the world and traded with little product differentiation on the world market. As a commodity, there are relatively small rents derived from production as a consumer can easily substitute nitrogen fertilisers from one producer for that of another.

This competitive pressure is evident in how the major nitrogen fertiliser retailers in Australia offer a range of differentiated products to their customers. Looking at the available products from the major nitrogen fertiliser retailers in Australia, it is evident that the lead firms offer a range of value-add products that are suitable for a range of a customer's needs. The major Australian distributers have specific labels for fertiliser products for a range of agronomic conditions, largely aimed towards higher gross value production such as horticulture. This is done through integrating macro and micronutrients into singular products.

Enhanced efficiency fertilisers

Enhanced efficiency fertilisers are a class of fertilisers which have been treated with additives and coatings to slow the release of the fertiliser or increase the utilisation efficiency of the nitrogen by either mitigating nitrogen loss pathways and/or increasing plant uptake (Li *et al.*, 2018). Generally, there are three major types of EEFs, slow-release coating-based fertilisers, nitrification inhibitors and urease inhibitors[1].

[1] Though often marketed as a slow-release fertiliser, urea ammonium nitrate is not included. Similarly, sulphur coated products are marketed as slow release coated fertilisers in the United States but due to their general lack of availability in the Australian market, they are not included either.

Table 1. The six most prominent nitrogen fertiliser types

Fertiliser type	Chemical composition	Percentage fertiliser content	Marketed forms
Urea	CH_4N_2O	46% Nitrogen (N)	Liquid, Prilled (1-2mm) and Granular (2-4mm)
Ammonia	NH_3	82% N	Anhydrous Gas
Monoammonium Phosphate	$NH_4H_2PO_4$	12% N 27% Phosphorus (P)	Granular
Diammonium Phosphate	$(NH_4)2HPO_4$	21% N 23% P	Granular
Ammonium Nitrate	NH_4NO_3	35% N	Granular and Prilled
Ammonium Sulphate	$(NH_4)_2SO_4$	21% N 35% Sulphur (S)	Liquid and Granular

Source: UNIDO (1998)

Data collection by the ABS about the use of EEFs began in the 2013-14 *Land Management and Farming* report with the addition of slow-release fertiliser categories. In prior ABS information fertiliser types were not differentiated beyond general fertiliser categories, and information surrounding EEF use before this report is difficult to ascertain.

Polymer coatings

Polymer-coated nitrogen fertilisers fall under a broader category of products termed controlled-release fertilisers (CRF) and slow-release fertilisers (SRF). These products consist of either a conventional prilled or granulated fertiliser encapsulated within a thin semi-permeable membrane polymer coating, or a blending matrix of polymer and fertiliser components. There has been a trend towards bio-polymer research in recent years. Synthetic polymer coatings are not regarded as biodegradable and may contribute to wider plastic pollution, but their effect is unresearched (Lawrencia *et al.*, 2021).

The product catalogues of members of Fertiliser Australia indicate that there is little polymer-coated nitrogen fertilisers available in the broader Australian nitrogen fertiliser market. The polymer-coated nitrogen fertilisers that are available are aimed at turf, garden, and niche horticultural activities. A product labelled POLYON was marketed by a number of smaller garden supply stores as well as by Nutrien Ag in 2014, but the product did not show up on their more recent product catalogues.

Urease inhibitors

Urea is not directly available to plant roots, but instead goes through two steps: hydrolysis into ammonium ions which can be taken up by roots, and nitrification into nitrates. The first step is what urease inhibitors seek to delay. Urea is hydrolysed by the urease enzyme which involves urease in the presence of water unbinding the two component ammonium ions from the central oxygen group forming carbonic acid. The increased concentration of ammonium in the soil solution thereby increases the localised soil pH, causing ammonium to be transformed further into gaseous ammonia and lost via ammonia volatilisation. Urease inhibitors work via blocking the action of urease enzyme and slowing the overall time in which hydrolysis occurs and thereby decreasing gaseous ammonia losses from volatilisation. Slowing the hydrolysis of urea allows greater time (~14 days) for urea to be incorporated into the soil.

There are a considerable number of urease inhibitors that have been trialled worldwide and have shown efficacy in reducing ammonia losses. Currently only a single product is present on Australian markets - N-(n-Butyl) thiophosphoric triamide (NBPT). NBPT can reduce ammonia losses to volatilisation by 53 per cent and increase yields by 5-12 per cent (Cantarella *et al.*, 2018). This low correlation between nitrogen savings from NBPT and the yield gains is attributable to limits on plant nitrogen uptake but provides the benefit of increased mineralised soil nitrogen.

Incitec Pivot Fertilisers currently markets NBPT under their Green Urea NV label, supplying the chemical at primary distribution centres around Australia (*Charlie Walker, pers. comm, 2022*). IPF does not publish information about individual product consumption. CSBP is seeking to introduce a NBPT product in 2023 (*Justin Mercy, pers. comm, 2022*) named Urea Sustain. Koch Fertilisers Australia also markets NPBT under their Agrotain label and NEXEN as a finished fertiliser product.

Other researched urease inhibitors which are not presently available on the Australian market include ammonium thiosulfate (ATS), N-(n-propyl) thiophosphoric triamide (NPPT) and phenyl phosphonodiamidite (PPDA). The firm CSBP sells one product containing ATS as part of their Flexi-NS Boost range, but is not marketed as an EEF. Products containing ATS alone can be used as a suitable fertiliser for production systems which require added sulphur, but as an EEF it is less efficient compared to NBPT in inhibiting urease enzymes, and requires levels of application that have adverse effects on seed germination (McCarty *et al.*, 1990).

Nitrification inhibitors

Nitrates are added to the soil in two ways: via the nitrification of ammonia by *Nitrosomonas* and *Nitrobacter* bacteria and the addition of nitrate fertilisers by salt ion nitrates (sodium, potassium, and ammonium nitrates). Nitrates can be lost in two ways, via soil leaching or denitrification into nitrogen gas and nitrous oxides. Fertiliser losses via nitrous oxide (N_2O) and nitric oxide (NO_x) pathways similar to those of carbon emissions in their additive greenhouse effect, and as well they oxidise in the atmosphere into nitric acid and increasing acid rain. Agriculture accounts for about 80 per cent of Australia's nitrous oxide emissions (Edwards, 2021).

Nitrate leeching is also a major problem caused by nitrification. This process occurs when nitrate is lost from the soil solution through soil water drainage, entering localised water bodies such as water tables and rivers. The Australian Drinking Water Guidelines (NHMRC, 2011) recommend that nitrate levels remain below 100mg/L for bodies of water used for drinking, with levels above 50mg/L regarded as unsafe for infants under three months.

In evaluating the available EEF products in Australia, two major nitrification inhibitors were found: 3,4-Dimethylpyrazole phosphate (DMPP) and Dicyandiamide (DCD). DCD was first introduced in the early 1980s and predominately used in European agriculture (Solansky, 1982), being able to decrease overall emissions by 35-46 per cent (Gilsanz *et al.*, 2016). DCD has several limitations due to it requiring relatively high levels of application (15-30kg/ha) increasing the probability of chemical run-off, as well as being phytotoxic under certain agronomic conditions (Zerulla *et al.*, 2001). Concerns were raised in New Zealand in 2013 surrounding DCD contamination in milk products, which led to a temporary voluntary suspension of its use (Danaher and Jordan, 2013). Concerns were also raised due to DCD being a chemical precursor for melamine, recalling consumer fears from the 2008 Chinese milk scandal in which powdered milk was found to contain the substance. Currently there is no established link between DCD intake and any non-communicable disease.

The nitrification inhibitor DMPP was developed during the late 1990s by the chemical company BASF in collaboration with European universities to alleviate much of the limitations associated with DCD.

The inhibitor DMPP is applied at substantially lower volumes (20-30 times less) compared to DCD to achieve similar effects, and benefits from increased chemical stability over time (Zerulla *et al.*, 2001). It is estimated that DMPP reduces N_2O emissions by at least 65 per cent in Australian vertosols under laboratory conditions (Chen *et al.*, 2010).

Incitec Pivot Fertiliser currently markets two products based on DMPP: eNpower and ENTEC. ENTEC is a licensed brand name from EuroChem Agro in which ENTEC is used as an additive coating on multiple standard nitrogen fertilisers. eNpower is a DMP-G coated mono-ammonium phosphate product, specifically designed to alleviate the chemical incompatibility of nitrogen phosphates and standard DMPP coatings. Incitec Pivot does note on their product website that eNpower is only available through company accredited advisors. Impact Fertilisers markets a DCD product under the N-Protect label. Impact Fertilisers claims that DCD is the most effective nitrification inhibitor presently available, but this claim was difficult to verify with available evidence.

The ABS collects use data on nitrification inhibitors but only since 2016-17. The latest release of the ABS's *Land Management and Farming* data from 2016-17 estimates approximately 51kt and 4 million litres of fertilisers containing nitrification inhibitors were used that financial year in Australia. The growing use of both bulk and liquid fertiliser has continued since then, albeit with closer attention being paid to expected costs and benefits during the recent significant rises in cost.

A summary of the major forms of EEFs is provided in Table 2, while a listing of the major EEF products offered by the major manufacturers is provided in Table 3.

Value Chain Mapping

Combining the data and information provided above, two depictions of the Australian nitrogen fertiliser value chain are shown in Table 4 and Figure 8. In Table 4, the role of each of the major lead firms is outlined in relation to the value chain functions performed, while in Figure 8 the movement of product through the chain is shown. In Figure 8, the product flows are for 2020.

As noted previously, the purpose of this description of the Australian nitrogen fertiliser value chain is to set the scene for a performance analysis that pinpoints the gaps, deficiencies, or opportunities in the value chain so that better EEF integration can occur. That is the task of the companion paper (Wirtz *et al*., 2023).

Conclusions

In summary, Australia's nitrogen fertiliser value chain accomplishes its core goals of supplying a wide range of fertiliser products, most times meeting the needs of farmers in the quantities and qualities of nitrogen fertiliser they need. The shift over the last 40 years towards imports over domestic production has meant that availability and reliability of supply has for the most part not been a constraint on production. Along the value chain, the retail end of the value chain has a large number of participants in both national and local markets, suggesting keen competition is likely. Though distribution is concentrated within a few firms in Australia's two domestic markets, East and West, concentration alone tells nothing about degree of competition: contestability of markets and the floor of global prices, along with anti-competitive legal frameworks, are *prima facie* conditions for competition to apply. Assuredly trade liberalisation and increasing contestability enhances the keenness of competition domestic distributors face.

Table 2. Major EEF categories

Category	**Major forms**	**Fertiliser use category**	**Action**	**Select available products**	**Efficacy**
Coatings	Sulphur Polymers	Granulated / prilled fertilisers	Slows or controls the release of nitrogen	Broadly prevalent	
Urease inhibitors	NBPT CHPT PPDA	Urea UAN Separate application	Disrupts ammonia volatilization	Koch Agrotain IPF Green Urea NV	20-88% decrease in ammonia volatilization in Australian conditions (Suter *et al.*, 2016)
Nitrification inhibitors	DCD DMPP TPTA	Ammonium nitrate UAN Separate application	Disrupts nitrifying bacteria	IPF eNpower and ENTEC	0-48% decrease in nitrate leaching

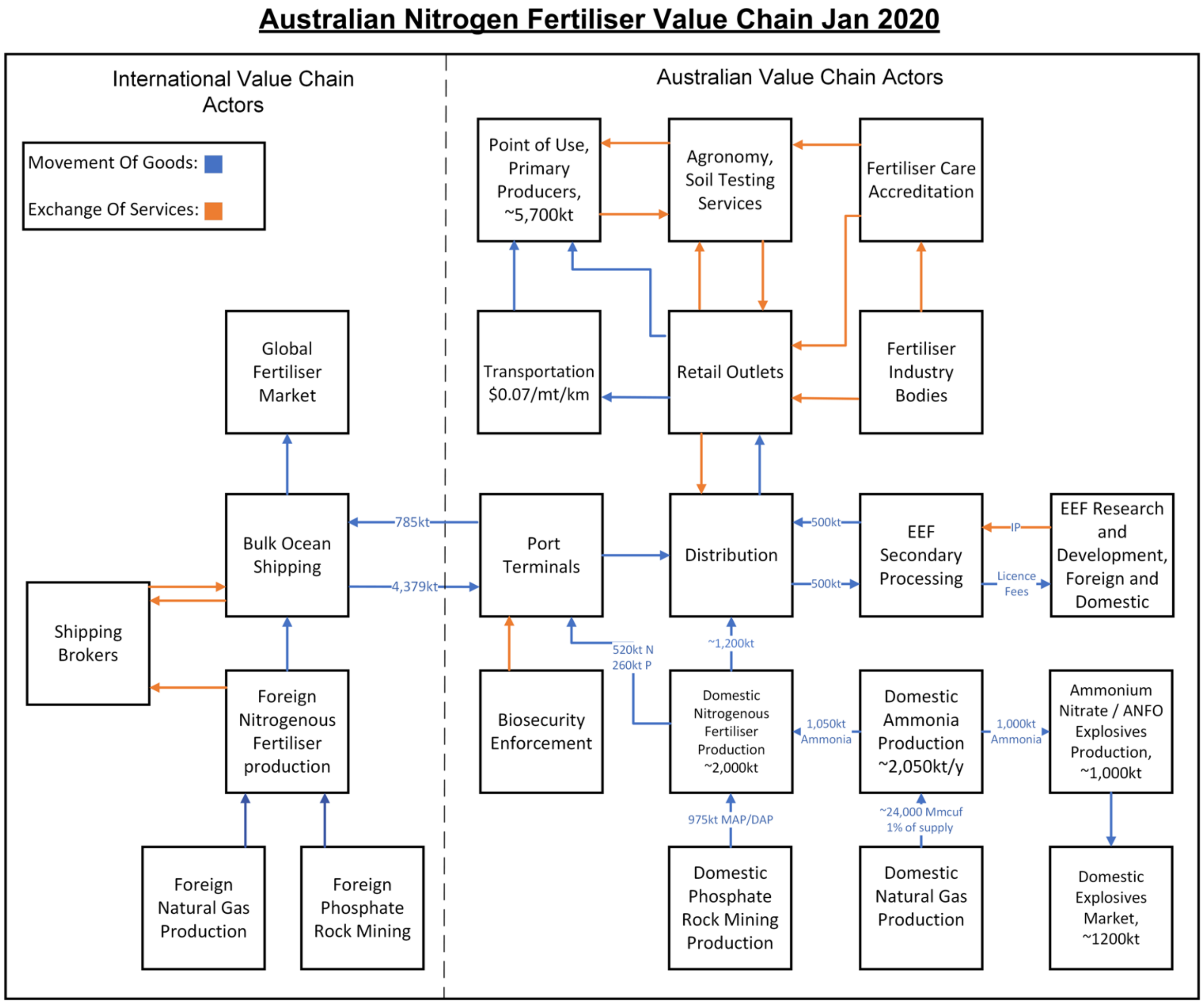
Table 3. Currently available enhanced efficiency fertiliser products containing nitrogen from Fertiliser Australia member organisations

	Product	Chemical composition	EEF applied	Marketed Applications
Incitec Pivot	eNpower[vi] ENTEC[vii]	Additive	DMPP	Marketed towards cane and various horticultural crops Specifically designed for combination with MAP/DAP
Incitec Pivot	Green Urea NV[viii]	Urea	NBPT	Marketed claim to reduce volatilisation by ~70% Top-dress application For warm to hot conditions/days
Koch Fertilisers Australia	Agrotain[ix]	Additive	NBPT	
Koch Fertilisers Australia	NEXEN[x]	Urea	NBPT	Marketed as towards places with variable and unpredictable rainfall, high levels of crop residue Top dress application
CSBP	Urea Sustain[xi]	Urea	DMPP + NBPT	Dual urease and nitrification inhibitor urea product
Impact Fertilisers	N-Protect[xii]	Urea	DCD	Marketed towards cane farming to reduce leeching and nitrification

Table 4. Australian nitrogen fertiliser value chain, select major participants by function

Activity	**Incitec Pivot Limited**	**CSBP**	**Yara**	**Orica**	**Nutrien Ag**	**Elders**	**Combined Rural Traders**	**Koch Fertiliser Australia**
Manufacture	2 sites, Gibson Island, Phosphate Hill	1 site, Kwinana	1 plant, Pilbara	1 plant, Kooragang Island				Offshore manufacturing
Distribution	16 Primary Distribution centres, 9 regional supply centres, 3 Liquid fertiliser mixing plants	5 Distribution centres, 5 Depots	Yara Nipro assets sold to IPF in August of 2022					7 distribution centres
Retail			8 sales offices		400+ locations	400+ locations	~300 member locations	
Soil testing	1 lab, Werribee	1 Lab, Perth						
Transport								
EEF Development	Onshore RandD		Offshore R&D					Offshore R&D
EEF integration	Integrated at PDCs	Integrated at Distribution centres						
Governance and aggregate value chain	Between captive and hierarchical value chain Lead firm	Between relational and captive value chain lead firm	Modular / relational lead firm	Modular components and material supplier	Relational retailer	Relational retailer	Turnkey / relational retailer	Modular components and materials suppliers

Figure 8. The Australian nitrogen fertiliser value chain visualised, 2020



Compared to other highly developed nations, Australia uses relatively little nitrogen fertiliser per hectare, making the problems of nitrogen fertiliser pollution less acute. The adoption of enhanced efficiency fertilisers is generally low. In the companion paper (Wirtz *et al*., 2023), the information provided here leads to a performance analysis that pinpoints the gaps, deficiencies, or opportunities in the value chain so that better EEF integration can occur.

Appendix. The Chemistry of Fertiliser Production

The production of the key nitrogen fertilisers shown in below has been largely standardised to the Haber Bosch process since the middle of the 20th century. Urea production can be summarised into two chemical reactions, the Haber-Bosch process, and the Bosch–Meiser urea process.

Haber Bosch Ammonia Process overall reaction:

$$CH_4 + 10H_2O + 8N_2 + 2O_2 \rightarrow 2O_2 + 16NH_3 + 7CO_2$$

Bosch-Meiser Urea Process overall reaction:

$$2NH_3 + CO_2 \rightarrow CO(NH_2)_2 + H_2O$$

The first converts hydrogen and nitrogen into ammonia, using a petroleum feedstock such as natural gas (methane)/LPG (liquified butane and propane) or naphtha. Coal has been historically used in some cases but has largely been phased out outside of China. Fossil fuels serve as a generally cheap source of hydrogen due to their relative abundance. As seen in the equation above, the Haber Bosch ammonia process produces 7 units of CO2 for every 16 units of ammonia, which can be dealt with in a variety of ways. In combined ammonia-urea plants, that CO2 can be reused for during the Bosch-Meiser urea process requiring 1 unit of CO2 and 2 units of ammonia to produce ammonia, effectively negating emissions. Another way is that CO2 is retained is via it being saved sold as an input for soft-drink carbonation, generating extra revenue for a plant. CO_2 from ammonia plants has the benefit of being relatively pure compared to the emissions of fossil fuel plants.

Ammonia is also used to produce a variety of other synthetic nitrogen fertilisers. Ammonium nitrate is a combination of ammonia and nitric acid, which itself is a product of ammonia as seen in 4 chemical reactions below.

Industrial Nitric Acid reaction production pathway:

$$4\,NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$$
$$2\text{NO} + O_2 \rightarrow 2\text{N}O_2$$
$$3NOO_2 + H_2O \rightarrow 2\,HNO_3 + NO$$

Industrial Ammonium Nitrate production reaction:

$$HNO_3 + NH_3 \rightarrow NH_4NO_3$$

Mono/di-ammonium phosphate (MAP/DAP) are products of the reaction between ammonia and phosphoric acid. The phosphoric acid used in this reaction is sourced from various forms of phosphate rock and produced at industrial scale via the wet process in which phosphate rate is dissolved in the presence of sulphuric acid through the reactions shown below.

Phosphoric Acid via the wet process from hydroxyapatite:

$$Ca5(PO4)3OH + 5\,H2SO4 \rightarrow 3\,H3PO4 + 5\,CaSO4 + H2O$$

Mono-Ammonium Phosphate (MAP) production process:

$$NH_3 + H_3PO_4 \rightarrow NH_6PO_4$$

Di-Ammonium Phosphate (DAP) production process from MAP:

$$NH_6PO_4 + NH_3 \rightleftharpoons (NH_4)_2HPO_4$$

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