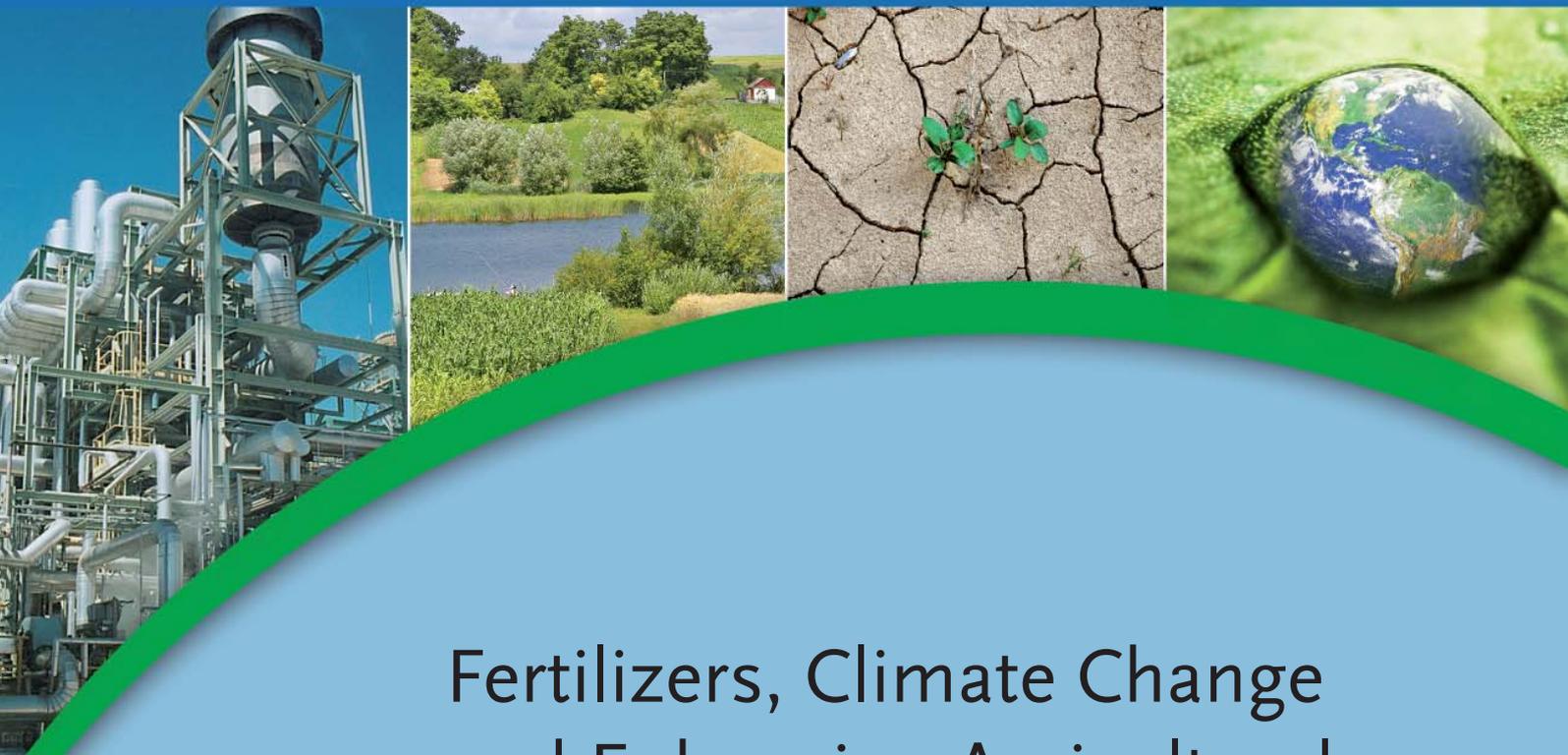




International
Fertilizer Industry
Association



Fertilizers, Climate Change and Enhancing Agricultural Productivity Sustainably

International Fertilizer Industry Association

Acknowledgments

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Note on the units used in this document

The global fertilizer industry generally refers to metric tonnes (t), millions of metric tonnes (Mt) and billions of metric tonnes (Bt).

The scientific community and policymakers working on climate change tend to use teragrams (Tg) and petagrams (Pg).

In order to facilitate dialogue with the scientific and policy communities, we have used Tg and Pg throughout this report.

1 Tg = 1 Mt

1 Pg = 1 Bt = 1000 Tg = 1000 Mt.

Fertilizers, Climate Change and Enhancing Agricultural Productivity Sustainably

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Abbreviations

ABC	Ammonium bicarbonate
AN	Ammonium nitrate
BMP	Best Management Practice
BAT	Best Available Technique
BPT	Best Practice Technology
C	Carbon
CAN	Calcium ammonium nitrate
CCS	Carbon Capture and Storage
CH ₄	Methane
CO ₂	Carbon dioxide
CO ₂ -eq	Carbon dioxide equivalent
CO(NH ₂) ₂	Urea
DAP	Diammonium phosphate
dwt	Dead weight tonnage
EFMA	European Fertilizer Manufacturers Association
FAO	Food and Agriculture of the United Nations
FAOSTAT	Online, multilingual statistical databases of the Food and Agriculture Organization of the United Nations (FAO)
FBMPs	Fertilizer Best Management Practices
GHG	Greenhouse gas
GJ	Gigajoule
HNO ₃	Nitric acid
IEA	International Energy Agency
IFA	International Fertilizer Industry Association
IFADATA	Online fertilizer production, trade and consumption statistics of the International Fertilizer Industry Association (IFA)
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
IPNI	International Plant Nutrition Institute
ISFM	Integrated Soil Fertility Management
LCA	Life-cycle assessment
MAP	Monoammonium phosphate
N	Nitrogen
N ₂	Dinitrogen
N ₂ O	Nitrous oxide
NH ₃	Ammonia
NO ₃ ⁻	Nitrate
NO _x	Nitrogen oxides
(N)SCR	(Non-)Selective Catalytic Reduction
NUE	Nitrogen use efficiency
Pg	Petagram
Pj	Petajoule
SSP	Single Superphosphate
t	Metric tonne
Tg	Teragram
TSP	Triple superphosphate
UNFCCC	United Nations Framework Convention on Climate Change

Executive Summary

The primary objective of agriculture is to feed the world. It has been estimated that almost half the people on the Earth (around 48%) are currently fed as a result of manufactured nitrogen fertilizer use (Erismann *et al.* 2008). Yet the share of total global GHG emissions directly related to the production, distribution and use of fertilizers is between 2 and 3% (Table 1). As the population continues to grow and progress is made in achieving food and nutrition security for all, fertilizer use will increase before eventually reaching a plateau towards the middle of the century. (Section 1)

The significant risks and opportunities that climate change presents for agriculture, food supplies and the global fertilizer industry create an imperative for the International Fertilizer Industry Association (IFA) and its member companies to contribute to mitigation and adaptation in the context of achieving a more sustainable path to global food security.

Fertilizers are an essential tool to limit additional emissions related to greater agricultural production

In the context of projected population growth and improving incomes, it is estimated that agricultural demand by 2050 will range from 50 to 80% above today's level of production (Müller 2009, FAO 2006). The expected increase in arable land area is estimated to be much lower, implying a need to further increase land productivity (FAO 2003). Because any reduction in production intensity at one location would need to be compensated by additional production elsewhere, it is imperative to optimize agricultural production per unit of land in order to meet future demand.

Many good agricultural practices that increase productivity also moderate agricultural GHG emissions and have other sustainable development benefits, including greater food security, poverty alleviation, moisture retention in soils and soil conservation. Good agricultural practices also help prevent unwanted environmental impacts related to poorly managed fertilizer use, such as eutrophication of aquatic ecosystems and acidification.

According to the agricultural chapter of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), direct agricultural emissions made up 10-12% of total anthropogenic GHG emissions in 2005 (5.1-6.2 Pg CO₂-eq) (Smith *et*

al. 2007). GHG emissions from deforestation, mainly in tropical countries, contributed an additional 5.9 Pg CO₂-eq per year (with an uncertainty range of ±2.9 Pg CO₂-eq), thus equalling or exceeding emissions from all other agricultural sources combined.

Enhanced yields are particularly important in helping to prevent further deforestation, and fertilizers are essential to increase production on existing agricultural land.

The overall level of agricultural greenhouse gas emissions will continue to rise for the foreseeable future as agricultural production expands to keep pace with growing food, feed, fibre and bioenergy demand. Increasing agricultural efficiency is critical to keep overall emissions as low as possible and to reduce the level of emissions per unit of agricultural output. Efficient and responsible production, distribution and use of fertilizers are central to achieving these goals.

The fertilizer industry can help to reduce global greenhouse gas emissions

The fertilizer industry recognizes that it contributes directly and indirectly to emissions of greenhouse gases (GHGs), particularly carbon dioxide (CO₂) and nitrous oxide (N₂O), through the production, distribution and use of fertilizers. (Section 2)

- **Fertilizer production**

IFA estimates that the fertilizer industry's activities in 2007 generated some 465 Tg CO₂-eq (Annex 3). This represents about **0.93% of global GHG emissions**. A significant share (about 20%) of the products manufactured are destined for industrial uses. Implementing Best Practice Technologies (BPTs) in natural gas-based ammonia production and nitric acid production together could reduce these emissions by about 119 Tg CO₂-eq per year in the medium term, or about 26%.

- **Fertilizer distribution**

IFA estimates that emissions associated with fertilizer distribution amounted to about 37 Tg CO₂-eq in 2007. This is only **0.07% of total global GHG emissions**.

- **Fertilizer use**

Nitrous oxide (N₂O) emissions from soils related to the use of mineral nitrogen fertilizers in 2006 are estimated at 605 Tg CO₂-eq. This represents less than one-third of N₂O emissions from agricultural soils. CO₂ emissions related to the use of urea and

ammonium bicarbonate (ABC) are about 105.6 Tg and 17.9 Tg per year respectively.¹ Altogether, emissions from fertilizer use equal about 1.5% of global GHG emissions.

IFA encourages its members to minimize their direct emissions, to foster the reduction of emissions related to the use of fertilizers and, where possible, to contribute to the creation or expansion of carbon sinks. (Section 4)

Future natural gas-based ammonia production will use Best Available Techniques (BATs) because of competitiveness and energy efficiency imperatives, thus reducing related greenhouse gas emissions. Clean-coal technologies like Carbon Capture and Storage (CCS) will help address GHG emissions from new coal-based ammonia production capacity. However, it will take decades to bring this new technology online.

In the meantime, wider uptake of Best Practice Technologies (BPTs) can help improve the average performance of existing production sites. For example, new catalytic technology for the nitric acid sector provides significant potential for reducing the fertilizer industry's N₂O emissions in the medium term.

In addition to improvements in production technology, the industry provides stewardship through its marketing, R&D, and application and advisory services. These efforts encourage nutrient management that:

- Minimizes agricultural greenhouse gas emissions;

- Maximizes carbon storage;
- Prevents additional deforestation;
- Optimizes the production of agricultural products, including those that can be substituted for some fossil fuels and products derived from fossil fuels.

To help farmers adapt to climate change, the fertilizer industry is intensifying its efforts to develop and share its knowledge, products and technologies.

Appropriate and timely policy decisions are critical to ensure desired emissions reductions (Section 3)

Fertilizer production and agriculture are both truly global businesses. Policy decisions related to climate change need to take into account local conditions and the possibility of trade substitution (which could lead to “carbon leakage”). Otherwise, competitiveness could be distorted and emissions reduction targets could be undermined.

Policies should recognize early adopters and providers of improved technologies in order to encourage appropriate investments in the near term. Policy makers should provide timely and transparent signals to foster the implementation of better-performing technologies at the earliest possible opportunity.

Financing mechanisms need to address barriers to technology adoption. They also need to take into account the specific needs of agriculture.

Efforts by the fertilizer industry to take responsibility for its greenhouse gas emissions can only be fully effective if policy makers and other partners, such as farmers, also play their parts.

¹ Equal to the amount of CO₂ fixed during production.

1. How Agriculture, Climate Change and Fertilizers Interrelate

The primary objective of agriculture is to feed the world. In the context of projected population growth and improving incomes, agricultural demand by 2050 is estimated to range from 50 to 80% above today's level of production (Müller 2009, FAO 2006). However, the increase in arable land area is expected to be much lower (FAO 2003), implying a need to continue improving land productivity (Figure 1).

Because a reduction in production intensity at any one location would need to be compensated by additional production elsewhere, **it is imperative to optimize agricultural production per unit of land in order to meet future demand**; this should be done using techniques that minimize unwanted impacts such as greenhouse gas emissions, eutrophication and acidification. Efficient and responsible production, distribution and use of fertilizers are central to achieving these goals.

It has been estimated that almost half the people on the Earth (around 48%) are currently fed as a result of manufactured nitrogen fertilizer use (Erisman *et al.* 2008). Agriculture also supplies fibre, energy and raw materials for a growing number of industrial processes. Yet according to data published by Bellarby *et al.*, fertilizer production, transport and use only represent about one-tenth of total agricultural emissions (including direct and indirect emissions and related land-use change) (Bellarby *et al.* 2008). As the population continues to grow and progress is made in achieving food and nutrition security for all,

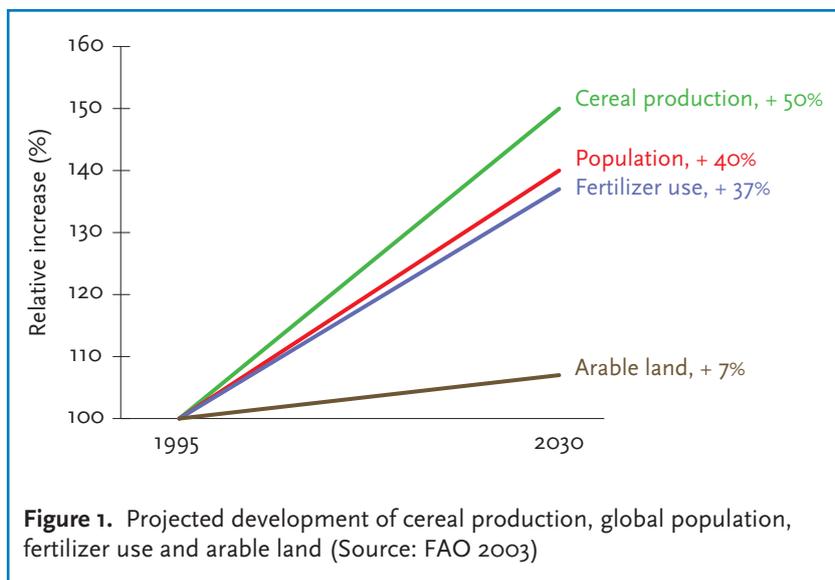
fertilizer use will increase for the foreseeable future – before eventually reaching a plateau.

It is widely accepted that human activities, including agriculture, have significant impacts on the world's climate. The Intergovernmental Panel on Climate Change (IPCC) regularly issues reports to assess the situation. The latest report (the fourth) affirms that a variety of changes have been unequivocally observed at regional and global levels. *The Climate Change 2007 Synthesis Report: Summary for Policymakers* states that “Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic GHG concentrations.” The predicted consequences of climate change are wide-ranging, and agriculture will be especially vulnerable (IPCC 2007).

The fertilizer industry recognizes that the production, distribution and use of fertilizers contribute directly and indirectly to emissions of greenhouse gases (GHGs), notably carbon dioxide (CO₂) and nitrous oxide (N₂O). At the same time, fertilizers help increase agricultural productivity, reducing greenhouse gas emissions per unit of agricultural output. **Enhanced yields are particularly important in helping to prevent deforestation (Figure 2), which is the most important contribution of GHGs related to agriculture.**

The overall level of agricultural greenhouse gas emissions is expected to continue to rise for the foreseeable future as food production expands to keep pace with growing food demand. It is therefore critical to increase agricultural efficiency to keep additional GHG emissions as low as possible, and to minimize the level of emissions per unit of agricultural output.

Many good agricultural practices that increase productivity also moderate agricultural GHG emissions and have other sustainable development benefits, including greater food security, poverty alleviation, moisture retention in soils and soil conservation. Good agricultural practices also help prevent unwanted environmental impacts related to



poorly managed fertilizer use, such as eutrophication of aquatic ecosystems and acidification.

IFA encourages its members to minimize their direct emissions, to foster the reduction of emissions related to the use of fertilizers and, where possible, to contribute to the creation or expansion of carbon sinks.

- **Fertilizer production**

Based on the results of IFA's latest benchmarking exercise and global fertilizer production statistics for 2007, the fertilizer industry's manufacturing activities generated about 465 Tg CO₂-eq in 2007. This represents about 0.93% of global GHG emissions. In comparison, the emissions assigned to the industry in the IPCC Fourth Assessment Report were 410 Tg CO₂-eq. About 20% of the products manufactured by the fertilizer industry in 2007 were destined for industrial uses. (Bellarby *et al.* 2008 and IFA production statistics for 2007).

- **Fertilizer distribution**

Estimating the global greenhouse gas emissions associated with fertilizer distribution is difficult because of continuously shifting trade and transport patterns and because trade accounts for only a minority of fertilizer movements. Using life-cycle analysis methodology, IFA has estimated that these emissions amount to about 37 Tg CO₂-eq per year. This represents about 3% of total emissions associated with the fertilizer life cycle and only 0.07% of total global GHG emissions.

- **Fertilizer use**

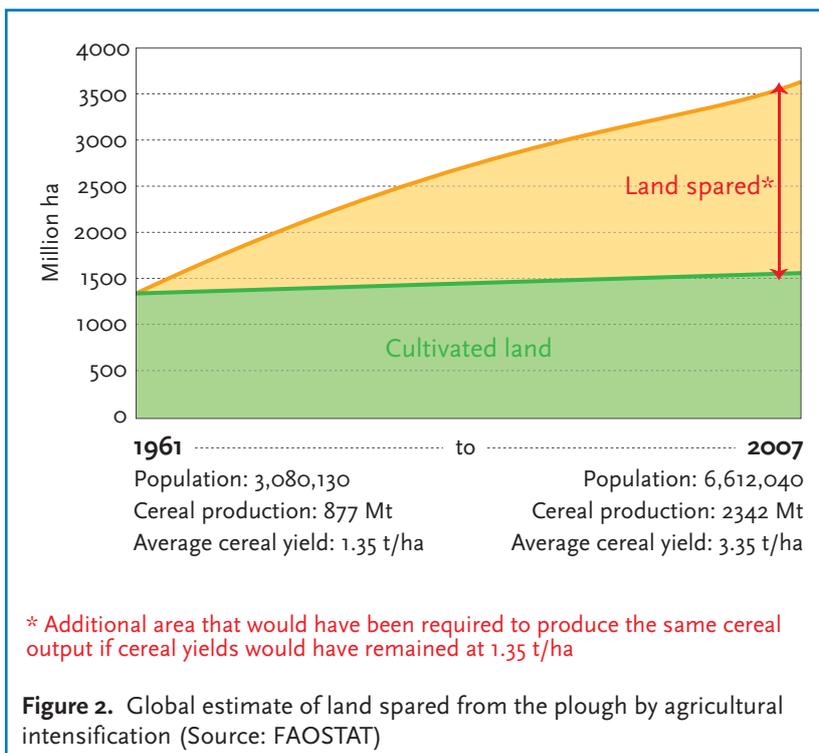
Nitrous oxide (N₂O) emissions from soils directly or indirectly related to the use of nitrogen fertilizers are estimated at 605 Tg CO₂-eq per year (calculated using the IPCC methodology and IFADATA consumption figures for 2006). This represents less than one-third of N₂O emissions from agricultural soils. CO₂ emissions related to the use of urea are about 106 Tg per year; those related to ammonium bicarbonate applications are about 18 Tg per year. Altogether, emissions from fertilizer use are about 1.5% of total global GHG emissions.

- According to the agricultural chapter of the IPCC Fourth Assessment Report, agriculture accounted directly for 10-12% of anthropogenic GHG emissions in 2005 (Smith *et al.* 2007). The total share related to the production, distribution and use of fertilizers is between 2 and 3% of total global GHG emissions.

The fertilizer industry has direct control over efforts to minimize GHG emissions during fertilizer production. Moving from production further down the fertilizer life cycle, the industry's direct responsibility decreases. Nonetheless, IFA embraces a stewardship role that extends to the use of fertilizers in the field.

During fertilizer use, farmers' choices ultimately determine the extent to which the impacts of climate change can be mitigated, but the fertilizer industry provides stewardship to encourage appropriate nutrient management (Figure 3). These practices can help to achieve the following:

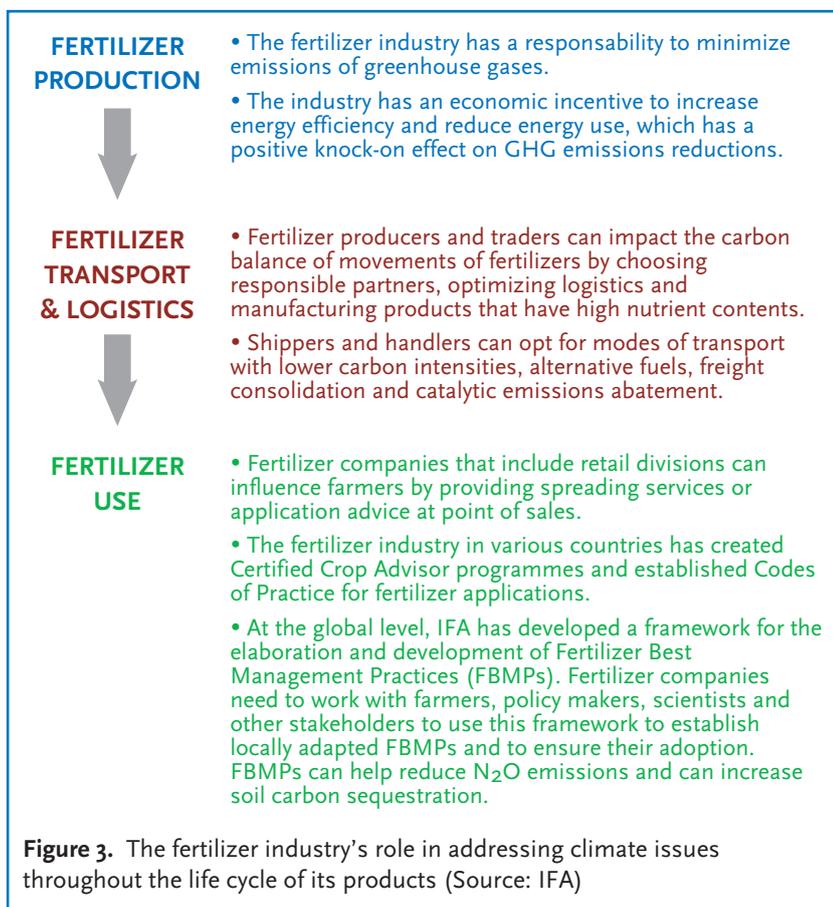
- Preventing the conversion of new land to agriculture, which is agriculture's greatest contribution to greenhouse gas emissions;
- Optimizing agricultural productivity (i.e. enhancing the efficiency of production), which reduces emissions per unit of food produced;
- Increasing carbon sequestration in perennial biomass and in agricultural soils;
- Reconverting marginal farmland to grassland or forests (both of which store more carbon than cropland);
- Providing agricultural products that can be substituted for a certain proportion of fossil fuels or products derived from fossil fuels (such as bioplastics and biofuels).



To help farmers adapt to climate change, the fertilizer industry is intensifying its efforts to develop and share its knowledge, products and technologies.

Many leading fertilizer companies are also motivated by broader sustainability commitments. These companies aim to operate with a long-term perspective that is in harmony with the environment and consistent with the expectations of society. In this context, climate change is emerging as a critical issue to be addressed directly and embraced fully by companies, so that they can carry out their activities in a financially, environmentally and socially responsible and sustainable manner.

Specific company initiatives to address climate change include installing more efficient production technologies, commercializing innovative products and helping to develop and disseminate management approaches (including management of both fertilizer production sites and agricultural systems). The fertilizer industry's associations bolster these efforts and provide platforms for collective action, including benchmarking exercises and stewardship programmes. The industry also supports several institutes that conduct research on plant nutrition and on enhancing fertilizer use efficiency through better management.



2. Current Climate Change Impacts across the Fertilizer Life Cycle

The fertilizer industry's greenhouse gas emissions and related actions are associated primarily with the point of production or with crop applications. However, transport and logistics should not be overlooked when considering ways to improve the overall carbon balance of the product life cycle.

According to Bellarby *et al.* (2008), fertilizer production and distribution together account for about 410 Tg of CO₂-eq per year. IFA's most recent estimate is 465 Tg for 2007. Applying the IPCC estimation methodology to a global consumption of 97 Tg mineral N (IFADATA 2006), the combined direct and indirect soil N₂O emissions related to

fertilizer use 605 Tg CO₂-eq per year. This represents less than one-third of total N₂O emissions from soils. CO₂ emissions related to the use of urea fertilizers and ammonium bicarbonate (ABC) were about 106 Tg and 18 Tg respectively in 2006. Altogether, emissions related to fertilizer use are about 738 Tg CO₂-eq per year or 1.5% of global GHG emissions (Table 1).

2.1 Fertilizer production

Greenhouse gases are produced as a result of numerous industrial processes. In the fertilizer industry, greenhouse gas emissions are primarily

Table 1. Sources of fertilizer related GHG emissions

Sources	Tg CO ₂ -eq	% of total global GHG emissions ^a
Total global GHG emissions (2005)	50,000	100%
<i>Bellarby et al. 2008</i>		
1. All N, P and K manufacturing by the fertilizer industry (2007) ^b	464.8	0.93
Of which industrial uses	82.0	0.16
Of which fertilizers only	382.8	0.77
<i>Calculated using methodology from Kongshaug 1998, Prince 2007's estimate of the GHG index of each ammonia production process (BAT) and IFA 2008a. See annexes 1-3 for details.</i>		
2. Fertilizer use in agriculture (2006)	738.1	1.48
Nitrous oxide (N ₂ O) from soils ^c	604.6	1.21
CO ₂ from applied urea	105.6	0.21
CO ₂ from applied ABC	17.9	0.04
Farm machinery ^d	10	0.02
<i>Calculated using Bellarby et al. 2008, Brentrup 2008, methodology from Kongshaug 1998, IFA 2008a and IFADATA consumption statistics for 2006.</i>		
3. Fertilizer transport and distribution ^e	37.2	0.07
<i>Estimated using IFA 2008a, data from Bellarby et al. 2008 and LCA methodology.</i>		
Total estimated emissions related to the fertilizer life cycle	1240.1	2.48%

^a As global emissions are likely to have been higher in 2006 and 2007, the actual percentages may be slightly lower. The latest available data have been used for each activity.

^b No global benchmark exists for greenhouse gas emissions related to ammonia production using other fuel sources than natural gas. In order to estimate global emissions for any fuel sources except natural gas. We have therefore multiplied the GHG index for BAT coal-based production (Prince 2007) by the industry benchmark for natural gas-based production (IFA 2008b).

^c The value for N₂O emissions related to fertilizer use is calculated using the IPCC methodology for national emissions inventories (IPCC 2006). The data obtained using this methodology are subject to considerable uncertainty.

^d Only a portion of farm machinery use can be attributed to spreading fertilizers, so we have included one-third of 30, which is the average 3-57 Tg reported by Bellarby *et al.*

^e Emissions related to the transport of raw materials are not included in this table.

associated with three industrial processes: ammonia production, phosphoric acid production and nitric acid production.

2.1.1 Ammonia production

The industry's main energy requirement is the fuel and feedstock² used in manufacturing ammonia. Virtually all nitrogen fertilizers are derived from ammonia, and ammonia production accounts for 87% of the industry's total energy consumption. The manufacture of all N fertilizers together accounts for about 94% of the sector's energy use. About 20% of the ammonia manufactured is destined for industrial uses and is therefore not part of the agricultural life cycle.

On average, one-third of emissions from natural gas-based ammonia production are associated with the burning of fuel and two-thirds with the use of fossil fuel feedstock to obtain the hydrogen needed to synthesize ammonia. In coal-based production, the proportions are 25% and 75% respectively. CO₂ emissions related to the consumption of feedstock are subject to the laws of chemistry, and efficient producers today are very close to the theoretical minimum emissions. However, this "process" CO₂ is clean and can be captured fairly easily. In contrast, flue gas (resulting from fuel combustion) must be cleaned before that CO₂ can be captured and stored or re-used, which entails additional costs.

For ammonia production, natural gas is the dominant feedstock globally although a significant portion (27%) is coal-based (Figure 4). Natural gas has the highest hydrogen content of any existing energy source, which makes it highly desirable as a source of hydrogen for ammonia synthesis. Moreover,

among current energy sources, natural gas has the lowest CO₂ emissions per energy unit.

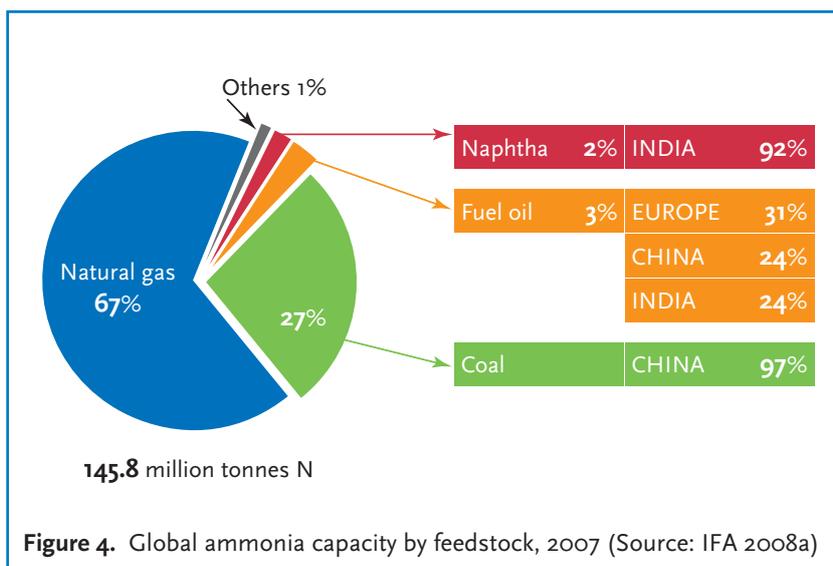
According to the most recent IFA report on *Energy Efficiency and CO₂ Emissions in Ammonia Production* (IFA 2008b), **some 36% of the CO₂ produced in 2008 was recovered**. About one-third of the CO₂ generated globally was captured for production of urea – which has the chemical formula CO(NH₂)₂. The remaining CO₂ captured by the fertilizer industry (2.2%) was sold into other value chains, e.g. to the oil and gas industry (for injection into wells) or to the beverage industry. Enhanced oil and gas recovery is the only current downstream use of the ammonia sector's CO₂ that qualifies under the term "Carbon Capture and Storage" as used in climate change policy discussions. CO₂ captured for urea production, or for use in beverages and other downstream products, is released to the atmosphere later in the value chain. When more CO₂ is produced than can be reused on-site or sold, the balance is vented to the atmosphere.

2.1.2 Nitric acid production

Nitric acid (HNO₃) is required as an intermediate in the production of nitrate fertilizers (and several other industrial chemicals). In an average medium-pressure plant, the nitric acid process creates 6-8 kg nitrous oxide (N₂O)/tonne HNO₃. A Non-Selective Catalytic Reduction (NSCR) process, which has existed for several decades to abate NO_x emissions, also reduces N₂O emissions (unlike Selective Catalytic Reduction). Tertiary systems have become available to destroy N₂O; although they are very effective, they affect energy efficiency and CO₂ emissions and are often expensive to retrofit in existing plants. **A recently developed secondary catalyst has significantly improved the economics of nitrous oxide abatement** (see section 4.1.3 for more information).

2.1.3 Production of phosphate and potash fertilizers

Phosphate rock releases some CO₂ when reacted with sulphuric acid in the phosphate fertilizer manufacturing process. Additionally, some CO₂ is emitted from fuel combustion during this process. **The production of phosphate fertilizers has become to a significant extent energy and greenhouse gas neutral, largely due to energy**



² "Feedstock" refers to the raw materials required for an industrial process.

cogeneration during sulphuric acid production. There are nonetheless emissions related to the production of raw materials and intermediates, as well as to the transport of inputs and final products.

The energy requirement for potash mining and beneficiation varies according to mining processes and ore quality. In the context of overall fertilizer production, this sub-sector's energy consumption and greenhouse gas emissions are low. Beyond the plant gate, emissions related to transport should not be overlooked.

2.1.4 Product portfolio

The products manufactured by a fertilizer company influence downstream greenhouse gas emissions.

Nutrients in higher-analysis products (products with a higher nutrient concentration) are more efficient to transport because a smaller overall volume of product contains the same amount of nutrients as lower-concentration products.

Slow-release and controlled-release fertilizers and stabilized fertilizers can also contribute to increasing nutrient use efficiency in the field, limiting agricultural emissions.

2.2 Fertilizer transport and logistics

Transport of fertilizers contributes to the emission of greenhouse gases, but at a much lower level than does fertilizer production.

Fertilizers and their intermediates and raw materials, which are bulky and heavy, are shipped within countries and around the world in large quantities because the distribution of raw materials is uneven. During the past ten years, trade in fertilizers and related raw materials has expanded by an overall 25%.

The structure of fertilizer trade has changed significantly. For example, given the decline in domestic production, many products consumed in North America and in Europe now travel greater distances to their final markets. On the other hand, more production is occurring in or nearer the regions that account for the largest share of current and future fertilizer consumption, which shortens the distances those products travel. In addition, a greater proportion of mineral ore is being processed near the point of extraction, increasing the relative nutrient

content and thus reducing emissions per unit of nutrient transported.

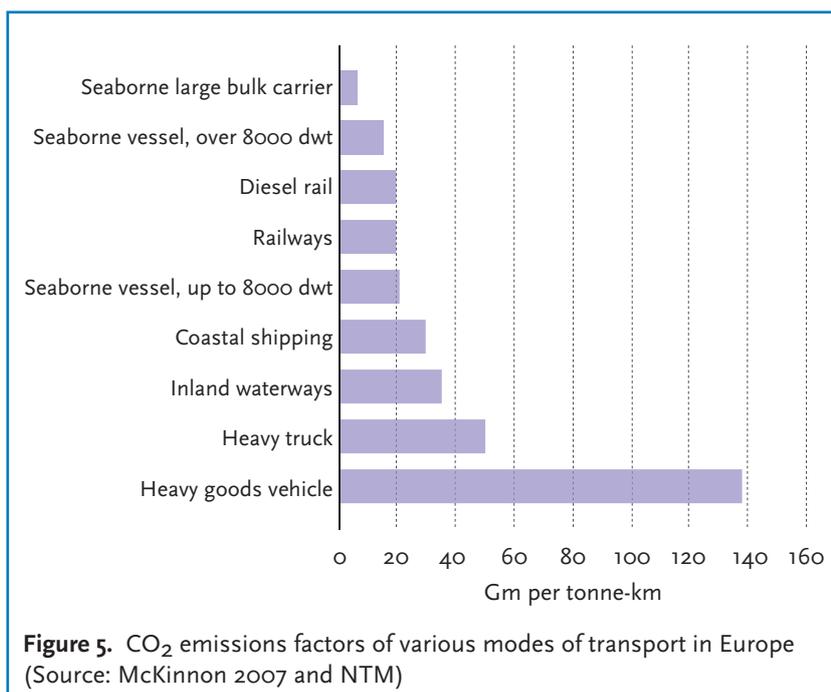
On the global scale, it is difficult to determine emissions related to domestic distribution of fertilizers since quantities, routes and modes of transport are continuously changing. Companies can estimate the emissions related to the transport of their products by multiplying the number of tonnes by the number of kilometres and the coefficient for the appropriate form of transport (after obtaining locally adjusted coefficients). This step should then be repeated for each form of transport used. Cooperation with logistical partners can help minimize the emissions related to fertilizer distribution.

The efficiency of road transport depends on load factor, vehicle efficiency (design, maintenance and operation) and cargo type. There seems to be some regional variation with regard to whether transport by rail or inland waterway has the least environmental impact. (Highway H₂O 2009, Krohn *et al.* 2009, National Marine and Industrial Council Secretariat 2004). (Figure 5)

Using life-cycle analysis methodology, IFA has estimated the emissions related to the transport of fertilizer materials in 2007 to be around 37 Tg CO₂-eq.

2.3 Fertilizer use and emissions in agriculture

Agriculture is a significant emitter of greenhouse gases, but agricultural soils are also an important carbon sink. Emissions of greenhouse gases are mostly related to the following activities:



- **CO₂ emissions**
CO₂ from the applied urea and ABC, land conversion to cropping, use of agricultural machinery, livestock production;³
- **N₂O emissions**
Use of nitrogen fertilizers, manures and nitrogen-fixing legumes, as well as microbial conversion of other nitrogen sources in agricultural soils;
- **Methane (CH₄) emissions**
Livestock and irrigated rice production.

With regard to climate change, inappropriate nitrogen management may increase the atmospheric concentration of N₂O, a greenhouse gas considered 296 times⁴ more potent than CO₂. The Intergovernmental Panel on Climate Change (IPCC) estimates all N₂O emissions from soils at some 2.1 Pg CO₂-eq per year (of which about 605 Tg CO₂-eq per year related to mineral fertilizer use), an increase of 17% between 1990 and 2005. The IPCC projects a further 35-60% increase by 2030, driven by growing agricultural demand. However, the IPCC reports uncertainty concerning these previsions since improved management practices may partially offset increased emissions (Smith *et al.* 2007).

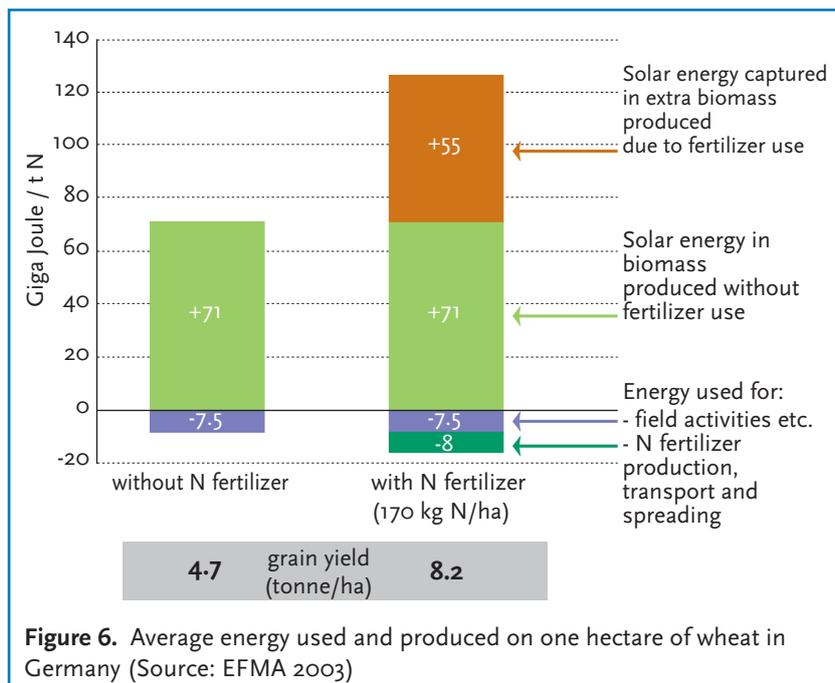
It is important to manage all sources of agricultural nitrogen in an integrated manner because the nitrogen from manure and nitrogen-fixing legumes

also contributes to N₂O emissions. Reduction of N₂O losses should not result in increased losses of other N compounds (e.g. NH₃, NO₃⁻) to the environment.

The conversion of forest or natural land to cropping results in an estimated 5.9 Pg CO₂-eq emissions annually. This is nearly three times the annual N₂O emissions from soil, underscoring **the importance of preventing land conversion from forests to crops.**

2.4 When managed properly, fertilizer use fosters carbon capture

To obtain a more complete idea of the greenhouse gas emissions performance of the fertilizer industry throughout its products' life cycles, **it is important to weigh emissions against the energy and carbon capture that fertilizer use promotes** (Figure 6). When fertilizers are used properly, they help plants to produce more energy than is consumed during the production, transport and application of fertilizers. They also encourage the conversion of carbon dioxide to biomass through photosynthesis, although the length of time during which the carbon is bound will depend on whether the biomass is used immediately, ploughed into the soil, part of a perennial plant or used for bioenergy/biomaterials.



³ Although the manufacture and shipping of fertilizers and agro-chemicals are part of the agricultural life cycle, they are counted under the industrial and transport sectors according to the IPCC methodology.

⁴ This coefficient has been used by the IPCC since its Fourth Assessment Report.

3. Business Implications of Climate Change for the Fertilizer Industry

All industrial sectors are facing expectations to contribute to global efforts to reduce greenhouse gas emissions, but energy-intensive activities (like the manufacture of nitrogen fertilizers) are subject to particular scrutiny.

Climate change has emerged as a major issue with implications for the markets, operations, logistical systems and stewardship of fertilizer companies. Many fertilizer companies are responding to these challenges by taking steps to understand the risks and other implications. They are adopting targets and strategies to reduce their emissions and to take advantage of new opportunities.

Among the most significant challenges of integrating climate change considerations into their operations are the twin imperatives of identifying the relevant issues for the company and establishing priorities for the deployment of limited resources.

3.1 Managing complex risks and balancing competing priorities

For fertilizer companies, long-term and short-term goals need to be reconciled, as do global concerns with local objectives, and all without losing sight of the basic goals of profitability and increasing shareholder value. In this context, there is a trend for companies to orient their risk management toward broader categories of risk, with targets and measures extending over longer time frames than were customary in the past.

Any approach to climate change must keep in mind other key sustainability issues, such as achieving food and nutrition security for all and managing natural resources sustainably. Strategies should seek to obtain the greatest net gain across all of these objectives.

3.2 New product and service opportunities

The fertilizer industry's efforts to reduce its greenhouse gas emissions go beyond modification of existing production processes. Companies are also exploring new market opportunities created by concerns over climate change.

Some companies have developed slow-release and controlled-release fertilizers and stabilized products

that help to reduce N₂O emissions and to increase crop yields by providing greater control over nutrient release rates and timing.

Specialized software, chlorophyll sensors, satellite mapping and other tools improve the precision of fertilizer applications, thus increasing fertilizer use efficiency and reducing emissions from agricultural soils.

Other companies are helping the livestock sector to address its emissions through the application of nitrification inhibitors to pasturelands.

3.3 Adopting goals and strategies and reporting achievements

Some companies have adopted specific goals and strategies to reduce their direct and indirect greenhouse gas emissions. These include setting targets to reduce emissions per tonne of product by a specific amount over the full range of a company's fertilizer production within a defined time frame.

Dialogue between the industry and policy makers is important in order to give due consideration to the fertilizer industry's diversity. For example, early adopters of Best Practice Technologies have little room to make further emissions reductions in their operations. Their sites already operate so efficiently that, given the current state of technology, further capital expenditure would yield few additional emissions reductions.

The Kyoto Protocol's Clean Development Mechanism and Joint Implementation projects have provided companies with opportunities to help reduce emissions at other companies' production facilities.

Companies demonstrate their commitment and accountability by reporting on their performance in reducing and mitigating direct and indirect emissions of greenhouse gases. Such reporting takes place against established standards, including the Global Reporting Initiative, the Carbon Disclosure Project and the Greenhouse Gas Protocol.

In some jurisdictions, fertilizer companies are subject to regulatory compliance with regard to greenhouse gas emissions and are providing audited reports on their emissions and on initiatives to reduce them.

3.4 Planning for an unpredictable agricultural landscape...

One challenge is the high degree of uncertainty that accompanies projections about climate change and its repercussions on the agricultural economy, including the nature and amplitude of impacts that farmers will face and the resilience of existing agricultural systems.

Forecasts provide little or no indication of what agricultural producers can expect locally. They are therefore unsure about the risks they face with regard to the frequency, severity and extent of extreme events (e.g. extended droughts and heavy rain) and increased variability. Some current agricultural practices will prove to be poorly adapted to changing growing seasons and rainfall patterns. Agricultural conditions will become less favourable in many places, while growing seasons are expected to lengthen in some cooler regions.

Climate change also presents some opportunities. Farmers can foster carbon capture in increased biomass, which helps prevent deforestation, makes it possible to increase carbon stored in the form of soil organic matter and provides the raw material for biofuels that displace some fossil fuels.

These factors together could affect fertilizer demand, both in terms of volume and product choices.

3.5 ...in an evolving regulatory context

Measures that raise the price of carbon – such as taxes or caps – are likely to raise the price of natural gas and other fossil fuels that serve as a major feedstock and source of fuel for fertilizer production. Natural gas prices could rise as a result of fuel-switching triggered by the relatively lower carbon content of natural gas compared to other fossil fuels.

Emissions of nitrous oxide and carbon dioxide associated with inefficient fertilizer production and use could result in more stringent regulation of fertilizers.

While it is difficult to be precise about legislative outcomes or the impact on markets in light of current and projected climate risks, fertilizer producers need to be aware of the range of possibilities, so as to make appropriate and effective choices.

Differing regulations from one market to another will also affect competitiveness. **The fertilizer industry is truly global, with a large volume of international trade.** Stricter regulations in one jurisdiction could drive up production costs, thus making it difficult for the domestic industry to compete on world markets. Shifting production to countries that are less strictly regulated could lead to “carbon leakage”. Such carbon leakage has implications for national economies, environmental protection and national food security.

It is also unclear what regulatory and market-based measures governments will put in place for the post-2012 period (while the fertilizer industry is making long-term investments in new production capacity today).

4. Climate Change Challenges and Opportunities for the Fertilizer Industry

The fertilizer industry strongly advocates the need to take a life-cycle approach to reducing greenhouse gas emissions associated with fertilizers. This means that fertilizer production is just one part of the picture.

Greater adoption of state-of-the-art technologies, especially with regard to improved efficiencies in ammonia production, future possibilities for permanent Carbon Capture and Storage of CO₂ from ammonia plants and N₂O destruction in nitric acid (HNO₃) production, could decrease the sector's carbon footprint significantly. The fertilizer industry can also play an active role in ensuring widespread use of Fertilizer Best Management Practices (FBMPs) in order to scale back N₂O emissions from fertilized soils and to improve the carbon storage potential of cropland (IFA 2007a).

Fertilizers contribute to enhanced production on existing cropland, helping to avoid further destruction of forest and other natural land. The use of FBMPs improves crop yield per unit of fertilizer applied; when properly managed this results in fewer nutrient losses to the environment, including greenhouse gas emissions, for the same quantity of food produced. Fertilizers can promote forest growth and increase the production of the biomass that is incorporated in soils to sequester carbon. Fertilizers also support new cropping patterns that help farmers adapt to changing agricultural conditions.

4.1. Promoting widespread adoption of Best Practice Technologies (BPTs) in fertilizer production

Energy efficiency in the production of nitrogen fertilizers has improved significantly since industrial-scale production began in the early 20th century. Continuous improvements in energy efficiency are driven by companies' efforts to achieve enhanced competitiveness through cost efficiency. The most efficient ammonia production facilities approach the minimum energy consumption possible according to the laws of chemistry. Nonetheless, many fertilizer production plants are not yet equipped with the most advanced technologies.

Possible improvements relate to greater energy efficiency in ammonia production plants, the introduction of new nitrous oxide (N₂O) emission reduction technologies in nitric acid (HNO₃) production, and general energy-saving measures in manufacturing.

The scope for improvements varies dramatically, as many production sites are already performing at or near optimal levels. Therefore, these global averages provide valuable information on the potential for achieving greater energy efficiency and trends in industry efforts but they are not appropriate for setting local targets, which need to consider historical performance and site-appropriate technology

Table 2. Potential GHG emissions reductions through the adoption of Best Practice Technologies in fertilizer production

	Tg CO ₂ -eq/year	% of the sector's current GHG emissions
Natural gas-based ammonia production	27	5.8
N ₂ O abatement in nitric acid production	73	15.7
All other processes	19	4.1
TOTAL	119	25.6
BPTs and CCS in coal-based ammonia production*	100	–

* This figure for reductions related to coal-based production has not been included in the total of Table 2 because the available information about the current deployment of technologies used in coal-based ammonia production only allows us to make an extremely rough estimate for indicative purposes. As mentioned in Table 1, no credible benchmark has been established for the coal-based processes.

Source: Calculated using IFA production statistics for 2007, Kongshaug 1998 and IEA 2006.

options. A Best Practice Technology (BPT) defines the improvement that is achievable for existing plants. This definition implies that a BPT is economically viable. In contrast, a Best Available Technique (BAT) generally uses more advanced technology and is typically the reference when building new plants.

Based on experience with the industry's existing BPTs, IFA has calculated the sector's potential GHG reductions (Table 2).

- The potential energy savings on a global basis at natural gas-based ammonia facilities could reach around 15%;
- The overall potential for reducing greenhouse gas emissions – largely due to implementation of the recently rolled out secondary abatement processes for N₂O in nitric acid production – could reach more than 25% (and possibly as much as 40% if BATs become the norm);
- Improved performance in other manufacturing processes would be about 20 Tg CO₂-eq per year;
- Taken together, these initiatives have an emissions reduction potential of up to about 120 Tg CO₂-eq per year;
- In addition, future Carbon Capture and Storage (CCS) could reach some 100 Tg CO₂-eq per year, depending on production capacity, feedstock and processes, although this estimate is subject to significant uncertainty.

It is important to note the appropriate time frame for emissions reductions. While some technologies could achieve important reductions in the medium term, it will be decades before costly technology revamps are widely integrated into older plants as part of capacity upgrades. **Policy makers should be cognizant of the fact that raising global performance averages could entail closing some of the least efficient production units, which could negatively impact other sustainability objectives, including national efforts to achieve food security and local employment.**

Measures aimed at bringing about additional energy efficiency and reduced emissions – whether they are regulatory or market-based mechanisms like carbon trading – need to take into account the truly global nature of the fertilizer industry to prevent the creation of market distortions or the simple displacement of emissions from one jurisdiction to another. IFA surveys of global ammonia capacity in 2008 indicate that some **two-thirds of world ammonia production currently occurs in countries that are not subject to greenhouse gas reduction targets** under the United Nations Framework Convention on Climate Change (“non-Annex I countries”). The proportion of ammonia production in non-Annex I countries has been growing rapidly over the past ten years and is expected to continue increasing for the foreseeable future. With regard to products that require nitric

acid, **some 74% of ammonium nitrate (AN) and 90% of calcium ammonium nitrate (CAN) were produced in Annex I countries** during that same year (IFA 2008a).

4.1.1 Improving energy efficiency in ammonia production

Overall, an ammonia plant built today uses some 30% less energy per tonne of ammonia produced than one built 40 years ago. Technical advances have accompanied economic changes. Restructuring has rewarded more efficient producers. Average energy consumption in Europe and North America has been reduced through revamping and closing of plants with high energy costs. Energy costs have also led to new state-of-the-art units being built in regions like North Africa and the Middle East with abundant sources of affordable natural gas. The move towards higher-capacity plants has helped implement more efficient technologies. Capacity upgrades offer a cost-effective opportunity to install better performing technology.

Comparisons of current performance against Best Practice Technologies (BPT) indicate that there is still room for improvement.

The BPT energy requirement for the top ten percentile natural gas-based ammonia production facilities operating today is 32 GJ per tonne of ammonia in net energy consumption. In contrast, the 2008 IFA report on *Energy Efficiency and CO₂ Emissions in Ammonia Production* (which only covers natural gas-based production) indicates an average energy requirement of 36.7 GJ/tonne ammonia. This suggests that revamping less efficient existing plants would increase energy efficiency and decrease CO₂ emissions by some 10%. However, the cost would be significant (sometimes exceeding USD 20 million per site).

Shifting production from poorly performing plants to new production sites with BAT technology would improve the overall energy efficiency by up to 25%, with a corresponding decrease in GHG emissions of about 30%. However, this is a long-term scenario, stretching over decades.

As shown in Table 3, the energy requirement in coal-based plants is significantly higher per tonne of ammonia. These plants also produce some 2.4 times more CO₂ per tonne of ammonia than natural gas plants. In view of availability and the relative costs of energy sources in different regions, and the policy imperative in China to achieve food security through ensuring domestic fertilizer supply, **coal-based ammonia synthesis is expected to increase in coming years.** Carbon Capture and Storage (CCS) could be an important way to minimize emissions related to coal-based production.

Table 3: Comparison of Best Available Technology processes for ammonia production

Energy source	Process	Energy GJ/t ammonia	CO ₂ emissions t/t ammonia	GHG index*
Natural gas	Steam reforming	28	1.6	100
Naphtha	Steam reforming	35	2.5	153
Heavy fuel oil	Partial oxidation	38	3.0	188
Coal	Partial oxidation	42	3.8	238

* Using natural gas as the reference, this index shows the relative carbon intensity of different energy sources.

Source: Prince 2007

4.1.2 Carbon Capture and Storage (CCS)

As mentioned above, “process” CO₂ is currently captured at a number of ammonia production sites for use in the manufacture of urea or in other industrial value chains. This CO₂ is released to the atmosphere in later stages of the value chain, except when it is used in enhanced oil or gas recovery. The future development of carbon capture for disposal (as opposed to being sold into another value chain) will depend on the economics and possibilities at specific ammonia production sites.

The expansion of CCS in ammonia production could be supported by appropriate policy decisions, including eligibility for the Clean Development Mechanism and Joint Implementation.

4.1.3 Reducing nitrous oxide emissions in nitric acid production

Nitric acid (HNO₃) production is often a component of integrated fertilizer and chemical manufacturing plants. The nitric acid process creates nitrous oxide (N₂O), which is 296 times more potent than CO₂ as a greenhouse gas when released to the atmosphere (IPCC 2007).

New secondary catalytic processes deployed in the past five years now make it possible to convert 70-95% of N₂O related to nitric acid production into dinitrogen (N₂) and water without any additional energy use. The level of N₂O reduction depends on the nitric acid process design and operational conditions. The new technologies are more cost-effective and have been installed at a number of sites worldwide. Financing through the Clean Development Mechanism has been instrumental in the uptake of this technology so far. Its use in developed countries has also been promoted through Joint Implementation financing.

The mitigation potential of widespread implementation of this catalytic process ranges between 73 Tg CO₂-eq per year (BPT level) and 96 Tg CO₂-eq per year (BAT level).

4.2 Reducing GHG emissions related to transport and logistics

In operational terms, methods to reduce greenhouse gas emissions include shifting transport modes, using energy efficient-fuels, consolidating freight, optimizing warehouse and logistics systems, and installing vehicle catalysts to capture exhaust emissions and improve fuel efficiency.

As a general rule of thumb, seaborne transport has the lowest emissions factor and truck transport the highest, with rail and inland waterway falling in the middle. **Future growth in fertilizer consumption is expected to occur mainly in Asia, South America and Africa, where trucking is the primary means of domestic fertilizer distribution.**

Indirect methods of reducing emissions associated with freight also exist. In the case of fertilizers, these methods include changing the nutrient concentration of the product and improving the efficiency of its use, which moderate the overall volume of fertilizers transported (with a positive knock-on effect regarding the reduction of transport-related emissions).

4.3 Using Fertilizer Best Management Practices (FBMPs) to improve agricultural GHG balances

The IPCC has identified three ways to make agriculture’s overall carbon balance more positive. Appropriate fertilizer use can contribute to all three.

- **Reducing emissions of greenhouse gases**

Agricultural releases of CO₂, N₂O and methane (CH₄) can be reduced through better management of carbon and nitrogen flows in agricultural ecosystems. Improving nutrient use efficiency is key to achieve these reductions. The fertilizer industry promotes Fertilizer Best Management Practices (FBMPs) in many countries to help farmers reduce emissions from fertilizer use. In Canada, the industry is working with government officials to develop a protocol through which

improved fertilizer management can be translated into carbon credits for farmers.

- **Enhancing CO₂ removals from the atmosphere**

The net flux of CO₂ between agricultural land and the atmosphere is currently estimated to be more or less in balance, with net CO₂ emissions at around 40 Tg CO₂ per year (IPCC 2007). Concerning future mitigation, the IPCC estimates that some 89% of agriculture's future mitigation potential is based on soil carbon sequestration, 9% on reducing CH₄ emissions, and only 2% on reducing N₂O emissions from soils (UNFCCC 2008). **Judicious fertilizer use helps increase cultivated soil carbon reserves by increasing the photosynthetic conversion of CO₂ to biomass that is subsequently converted, in part, to soil organic carbon.** The potential gain could be very large in the case of degraded soils, as in much of Sub-Saharan Africa, with positive knock-on effects for other sustainable development priorities, including land rehabilitation, food security and, ultimately, poverty alleviation.

- **Avoiding (or displacing) emissions**

There are two techniques for avoiding emissions. The first is to increase productivity and thus prevent conversion of additional land to cropping and the significant emissions that result. The second consists of using agricultural products as

bioenergy sources or as raw materials for industrial processes that would otherwise use fossil fuels as feedstock.

“An effective way to reduce emissions associated with the conversion of land to agriculture is by intensifying agriculture, that is, producing more crops on land already in production” (UNFCCC 2008). In this scenario, the overall use of agricultural inputs such as fertilizers would increase, but improved management practices would make it possible for overall GHG emissions per unit of agricultural output to be lower than if the additional crops were produced on land newly brought under cultivation (Figure 7).

A corollary of increasing food production per area of land is the use of agricultural crops as feedstock for bioplastics, pharmaceuticals and other industrial processes. Biofuels are one of the best-known examples. The overall implications for greenhouse gas emissions will depend on knock-on effects for food production and land-use change, whether transport distances increase and several other factors.

Fertilizer Best Management Practices (FBMPs) are essential in order to minimize unwanted impacts of intensified agriculture. They also increase the resilience of agricultural systems to the expected impacts of climate change. For example, higher levels

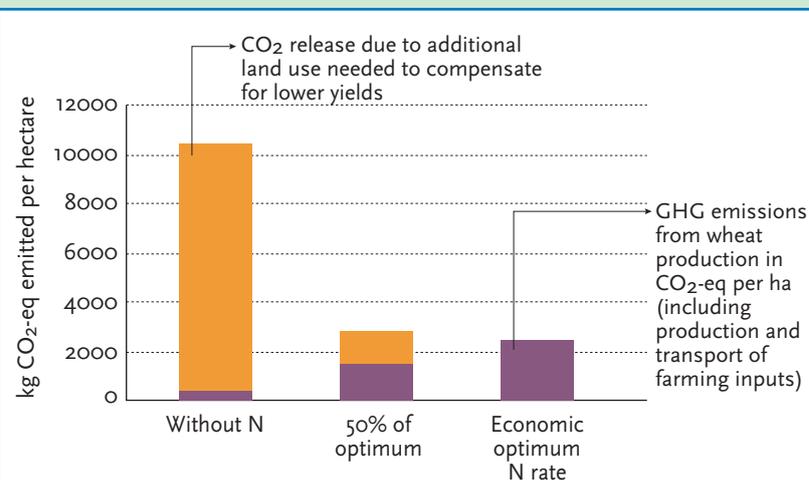


Figure 7. To achieve the same yield, less productive agriculture increases overall GHG emissions (Source: Brentrup et Pallière 2009)

Simply looking at greenhouse gas emissions per hectare gives the impression that applying nitrogen (whether fertilizers or an organic source of nutrients) at the economic rate (which generally corresponds to recommended good agricultural practices) leads to a greater carbon footprint than applying half as much or no nitrogen at all (see the purple bars).

However, in order to achieve stable or increased yields, using less than the economic optimum level of N would require expanding production to a greater land area because of lower yields. This land conversion would mean the release of additional carbon (the orange bars) and would lead to a greater overall carbon footprint. Thus it can be concluded that **intensive crop production aiming to use resources, including agricultural land, as efficiently as possible reduces global GHG emissions.**

In order to analyze which option is the most sustainable solution in the long term, the carbon dioxide release from land use change has been evenly spread over 100 years in these calculations.

of soil organic matter (carbon) enhance the ability of soils to retain moisture.

IFA has developed a global framework⁵ for the elaboration and adoption of site- and crop-specific FBMPs that can result in lower N₂O emissions during crop production, and in greater carbon sequestration in agricultural soils, among other positive outcomes. This framework is built around the principle of using the right nutrient source at the right rate at the right time and at the right place⁶. FBMPs should be integrated into farmwide good agricultural practices and must be adapted to local specificities in consultation with relevant stakeholders, in order to take into account soil, climate and cropping system diversity as well as wider societal expectations. (Figure 8)

The FBMP framework is designed to address the need to manage all nutrients and different nutrient sources for the greatest net benefit. The framework emphasizes the importance of managing nitrogen, phosphate and potash and other essential plant nutrients in a balanced manner. Nonetheless, nitrogen management is particularly important in the context of GHG emissions.

FBMPs and other existing techniques could greatly reduce agricultural emissions if they were used more widely. **Effectively transferring knowledge and technology to farmers is the most critical and most challenging part of FBMPs.** This is particularly true in developing countries because of the multitude of small-scale farmers and the lack of resources for extension services. The fertilizer industry was one of the leading proponents behind the creation of

Certified Crop Advisor services, which exist in some developed countries. Fertilizer companies and their related associations and research institutes support the provision of advice and training to farmers in developing countries, including Argentina, Brazil, China, India and Pakistan, among others.

The fertilizer industry in several countries has also developed Codes of Practice for using fertilizers in ways that comply with government-set environmental targets.

4.3.1 Improving the efficiency of nitrogen use

Low nitrogen use efficiency correlates with high losses of N₂O and other N compounds from the agricultural system. **On a global basis, it is estimated that only about 40-50% of applied fertilizer nitrogen is recovered by the cropping system in the year of application,** although recovery may be much higher or lower than this locally, mainly depending on nutrient management and climatic conditions (Figure 9).

Simultaneous improvements in productivity and in nitrogen use efficiency have been recorded for more than two decades in a number of intensive cropping systems, such as maize production in the United States, wheat production in Western Europe and rice production in Japan. Such productive and resource-efficient systems result in fewer losses of reactive nitrogen, such as N₂O, to the environment per unit of agricultural output. Between 1990 and 2005, agricultural emissions in the developed countries decreased by about 12% (UNFCCC 2008). However, it should be noted that a portion of this decrease can be attributed to collapse in agricultural production in the transitional economies of eastern Europe.

Nutrient deficiencies, excess applications and poorly timed use are major factors that influence how efficiently plants use available nutrients. It is also important to complement nutrient use efficiency measures for a single crop with measures that entail a wider timeframe. Where soils are depleted, nutrients not taken up by plants may help replenish soil nutrient levels. **It is critical to note that all nutrients – including phosphorus, potassium, secondary and micronutrients – must be managed together to achieve optimal nitrogen use efficiency.**

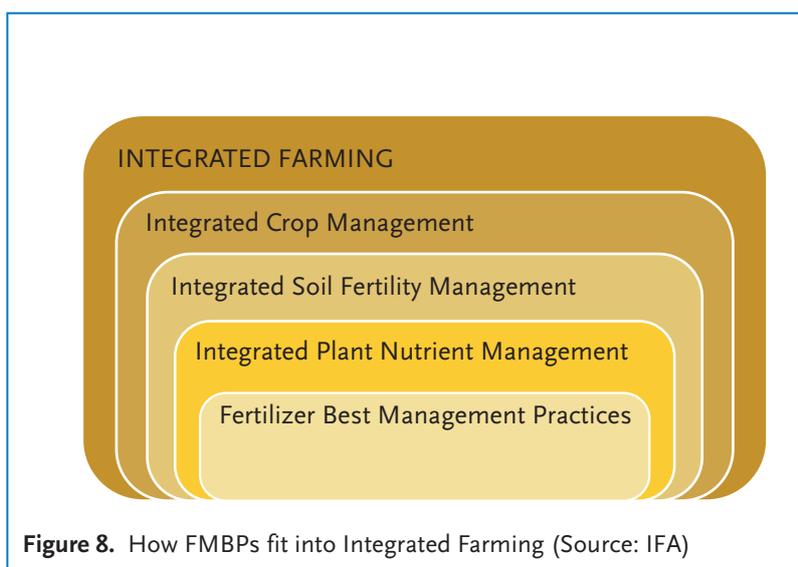


Figure 8. How FBMPs fit into Integrated Farming (Source: IFA)

⁵ The Global “4R” Nutrient Stewardship Framework.

⁶ The 4R framework (“Right Product @ Right Rate, Right Time, Right Place”) is a trademark registered by the Canadian Fertilizer Institute on behalf of the global industry to describe its stewardship approach.

Fertilizer application rates also vary widely by country and region. If not adapted to actual crop requirements, high application rates are usually associated with increased GHG emissions, as well as with nitrate leaching, eutrophication of surface water and other environmental impacts.

In contrast, the amount of fertilizer used by small-scale African farmers is usually far below recommended levels for the maintenance of soil fertility, resulting in nutrient depletion and land degradation (including erosion that could be prevented by ensuring robust crop cover).

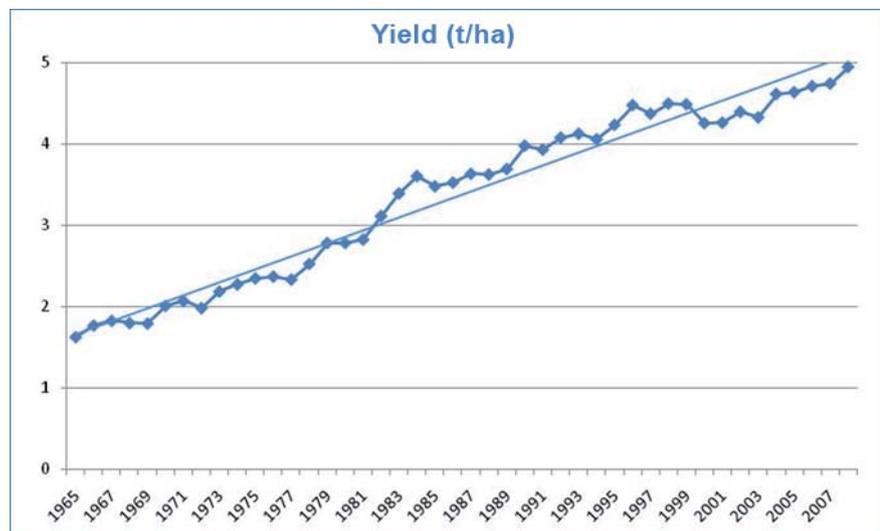
Insufficient plant-available nitrogen in the agricultural ecosystem can have significant implications for climate change. Insufficient

application of nitrogen leads to low crop yields, fewer crop residues and the depletion of soil organic matter, which could otherwise act as an important carbon sink. In addition, low-yielding agriculture leads to the conversion of additional forest into arable or grassland, reducing the level of stored carbon.

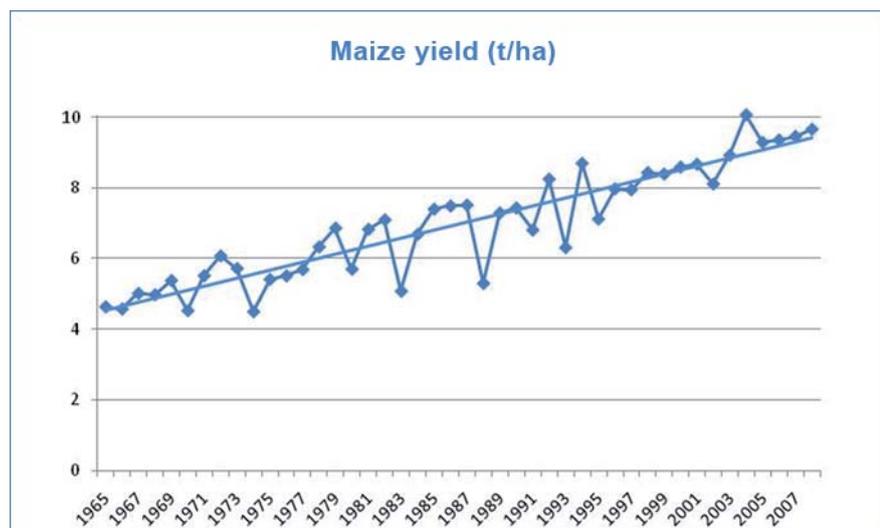
The fertilizer industry helps to foster improved nitrogen use efficiency in the following ways (IFA 2007b):

- Developing and promoting fertilizer recommendations that balance soil nutrient supply and mineral fertilizer applications with actual crop needs;
- Developing products with improved physical characteristics;

9a. Evolution of cereal, oilseed and potato yields in China

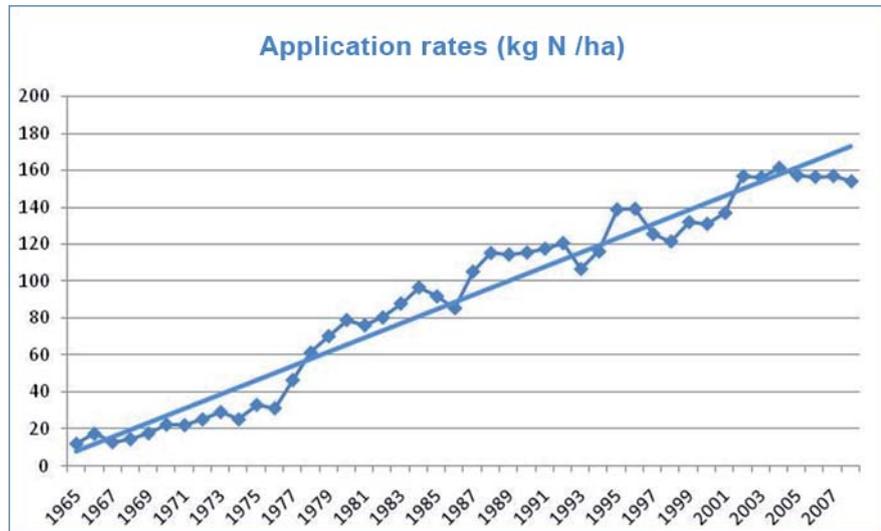


9b. Evolution of maize yields in the United States

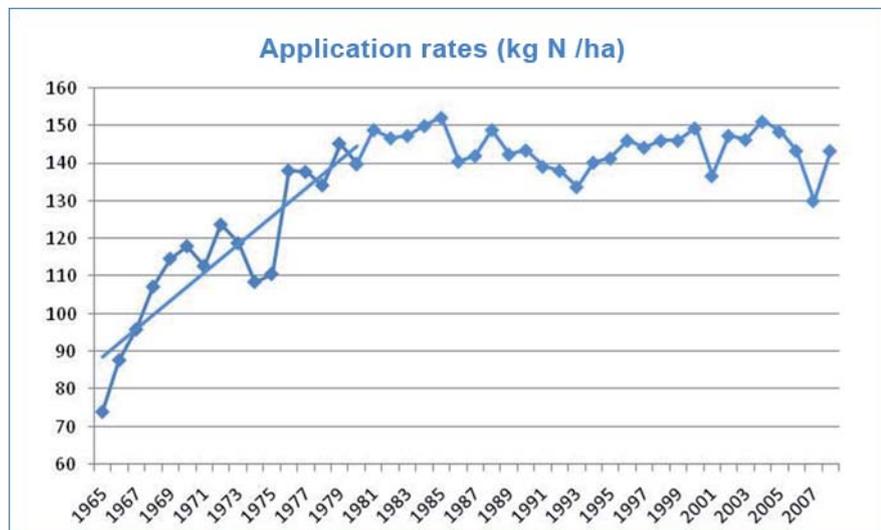


In both cases, yields have been climbing steadily over the past 40 years.

9c. Evolution of nitrogen fertilizer application rates on cereal, oilseed and potato crops in China

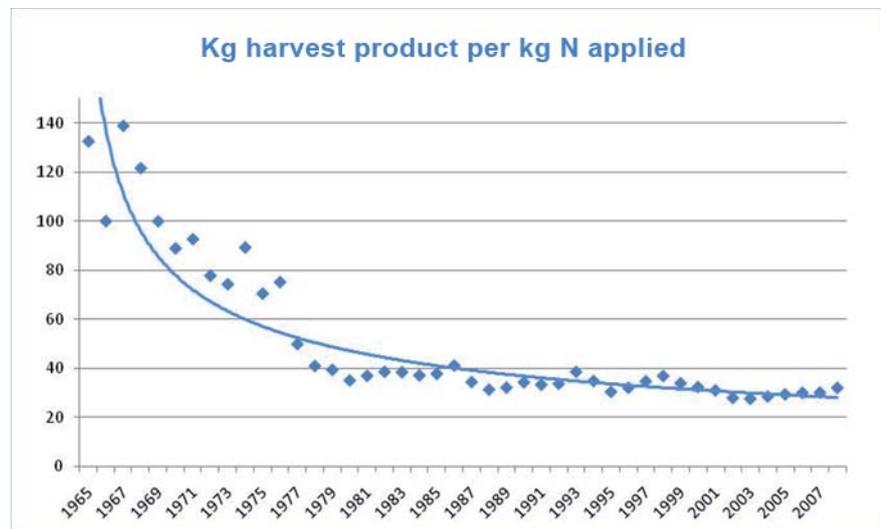


9b. Evolution of nitrogen fertilizer application rates on maize in the United States

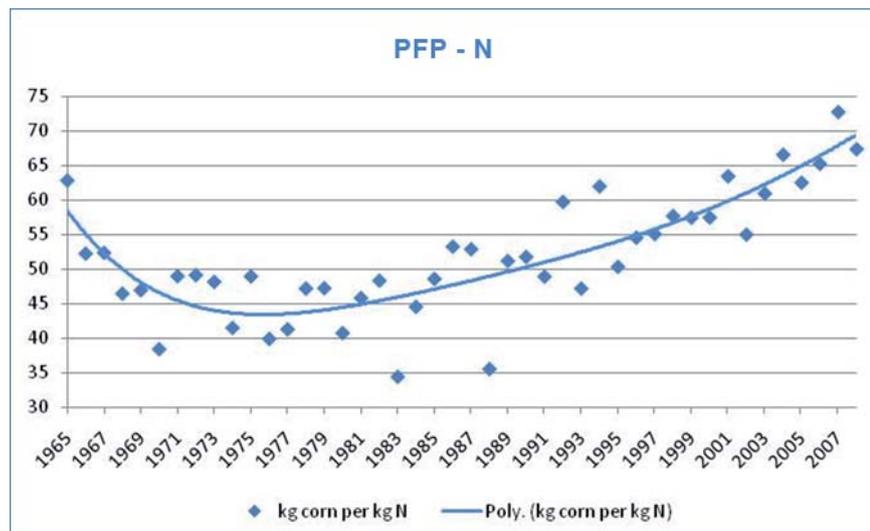


In China, over the past 40 years, increasing rates of fertilizer use have driven yield growth. In contrast, maize yields in the United States have continued to grow as fertilizer application rates have levelled off. This reflects, in large part, improved nutrient management in the United States.

9e. Evolution of nitrogen use efficiency of cereal, oilseed and potato crops in China



9f. Evolution of nitrogen use efficiency of maize in the United States



An initial decline in nitrogen use efficiency (NUE), measured as kg harvest product per kg nitrogen applied, is normal when farmers begin applying fertilizers since deficient nutrients are generally used very efficiently by plants. However, some countries – such as the United States and several other industrialized countries where farmers have access to appropriate knowledge and technology – have demonstrated significant recoveries in NUE while most developing countries that use significant amounts of fertilizer continue to show either declining NUE or persistently low but stable NUE. This demonstrates clearly that applying site-specific nutrient management could significantly reduce nitrogen losses from agriculture in countries such as China, with an important positive knock-on effect for the mitigation of agricultural greenhouse gas emissions. Adequate resources for farmer training and access to appropriate technologies are imperative to effect this change.

Figure 9. Evolution of yields, nitrogen fertilizer use and nitrogen use efficiency in China and the United States (Source: Zhang 2007 and Snyder 2009)

- Developing products with chemical compositions that meet the variable nutrient requirements of crops and improve nitrogen use efficiency;
- Making a wide range of fertilizer products available to farmers;
- Improving the supply chain;
- Developing and promoting nutrient/fertilizer best management practices;
- Measuring the performance of the recommended products and practices;
- Working with stakeholders and strategic partners.

A concerted effort among researchers, farmers and the fertilizer industry is needed in order to improve our understanding of the mechanisms related to nitrogen losses to the environment and the management practices that minimize these risks. This research should extend beyond N_2O to other nitrogen compounds, notably ammonia, nitrate and NO_x , as they may be transformed into N_2O in the N cycle.

4.3.2 Increasing carbon sequestration

Agriculture has significant capacity for carbon sequestration, which could transform the sector from the one of the largest greenhouse gas emitters to a net carbon sink (Bellarby *et al.* 2008). The fertilizer

industry has an important role to play in promoting this goal and working in partnership with others to ensure that it is realized.

Key direct and indirect sequestration opportunities include restoring the carbon storage potential of degraded land and promoting tree growth for carbon storage in forests and in wood products, as well as avoiding deforestation.

4.3.2.1 Restoring the carbon storage potential of cultivated and degraded land

The greatest opportunity to improve agriculture's carbon balance is to increase carbon sequestration in soil, primarily through measures to restore the carbon content in existing cropland and to prevent additional deforestation (UNFCCC 2008). **The low average carbon concentration in cropland means that there is great potential to increase carbon content through beneficial management practices, including the efficient use of fertilizers.**

In agriculture, a large share of the organic matter produced by plants is located in the roots, which remain in the soil after harvest. If not burned, aboveground crop residues can also contribute to enriching the organic matter content of agricultural

soils. Increasing crop productivity through judicious use of fertilizers makes it possible to simultaneously increase agricultural production and carbon sequestration in soil organic matter, provided crop residues are left in the field. This should be combined with other farm management practices that limit releases of N_2O and CH_4 to the atmosphere, in order to achieve a meaningful reduction in greenhouse gas emissions and greater carbon sequestration in plants and soils

In parts of the world where the amount of fertilizer used by small-scale farmers is far below recommended levels for the maintenance of soil fertility, nutrient depletion and loss of soil organic matter (carbon stored in the soil) are common. Increasing the availability and affordability of mineral fertilizers could contribute significantly to restoring the soil's carbon storage and soil productivity. Ideally, fertilizer use would be combined with the recycling of organic sources of nutrients within the framework

of Integrated Soil Fertility Management (ISFM) and would be adapted to local conditions.

4.3.2.2 Promoting the role of fertilizers in restoring forests

The amount of land available for cultivation cannot be increased substantially without further destruction of tropical forests. Such land use change results in emissions of an estimated 5.9 Pg of CO_2 -eq per year (Smith *et al.* 2007). A better option would be to enhance production from existing cropland through more efficient farming. High-yield agriculture, including application of mineral fertilizers, can make an important contribution. **Enhanced productivity entails additional emissions; however, the net result is lower CO_2 -eq emissions per unit of output than if more land were converted since emissions related to land conversion are nearly three times greater than direct N_2O emissions from fertilized soils.**

5. Looking Forward

The fertilizer industry will continue to reduce its CO₂-eq emissions balances throughout the life cycles of its products. This means:

- Continuing to install state-of-the-art technology, as well as improving the management of operations, in order to reduce both energy consumption and direct greenhouse gas emissions;
- Working with partners in the distribution chain to improve logistics and reduce per unit emissions associated with fertilizer transport;
- Deploying the global framework for Fertilizer Best Management Practices, in partnership with policy makers, scientists, extension agents and farmers, to ensure that an ever-growing number of farmers uses the Right Product @ Right Rate, Right Time, Right Place® approach to reduce agricultural emissions and increase opportunities for carbon sequestration in agriculture and forestry;
- Studying specific crop case studies to identify practices that result in reduced greenhouse gas emissions, as well as to track progress in the adoption of Fertilizer Best Management Practices;

- Exploring and embracing new opportunities to market innovative products and services that reduce emissions from fertilizer use and other sources.

These steps need to be supported by a regulatory framework that fosters a level playing field for fertilizer producers from all countries and does not introduce market distortions.

Technological improvements should be encouraged through financing mechanisms that address the high costs related to introducing new mitigation technologies, particularly in the case of retrofits (when new technologies are integrated into existing facilities).

Today's investments in new production capacity will be guided by the regulatory signals provided by policy decisions. These should promote transparency and predictability and reward the early adopters of better performing technologies for their leadership. At the same time, regulations should be flexible enough to accommodate the diversity of situations faced by different members of this truly global industry (Table 4).

Table 4. Overview of how the fertilizer industry's efforts to address climate change interact with policy instruments and other actors' initiatives

Fertilizer industry	Partners	Policy
Optimize the efficiency of fertilizer production by implementing Best Practice Technologies and good management	Provide innovative technologies	Instruments that reward responsible production and early adopters; policies that prevent "carbon leakage" from regulated countries/regions to others
Implement Best Available Techniques at new production sites	Provide innovative technologies	Incentives for the implementation of better performing technology when cost differentials exist
Install N ₂ O abatement in relevant production facilities	Provide innovative technologies	Enabling financing mechanisms, such as the UNFCCC's Clean Development Mechanism and Joint Implementation
Conduct Carbon Capture and Storage at appropriate ammonia production sites (especially key for coal-based production)	Provide economical solutions for storage near production sites	Enabling financing mechanisms, such as the UNFCCC's Clean Development Mechanism and Joint Implementation
Opt for transport and logistical solutions that minimize emissions	Provide transport and logistical solutions that minimize emissions	Development of appropriate infrastructure
Develop Fertilizer Best Management Practices	Researchers and others to adapt global FBMP framework to local conditions; farmers to adopt FBMPs within an Integrated Soil Fertility Management framework	Provide knowledge and technology transfer programmes and funding to support partnerships to extend best practices to a wide number of farmers

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Annexes

Annex 1. Energy consumption in selected fertilizer processes and products⁷

Product	Energy input (GJ/tonne product)				CO ₂ -eq (tonne/tonne)			
	BAT 40 years ago	World today	BPT today for all plants	BAT today for new plants	BAT 40 years ago	World today	BPT today for all plants	BAT today for new plants
Process								
Ammonia - natural gas-based	41.0	36.7	32.0	27.0	2.3	2.1	1.8	1.5
Ammonia - coal, oil, naphtha based	50.0	45.0	45.0	42.0	4.5	4.1	4.1	3.8
Captured CO ₂ for non fertilizer					-0.05	-0.05	-0.05	-0.05
Urea	4.6	4.1	3.7	3.2	0.26	0.23	0.21	0.18
Captured CO ₂ in urea					-0.733	-0.733	-0.733	-0.733
Nitric acid (100%)	-0.44	-1.56	-2.30	-3.11	-0.02	-0.09	-0.13	-0.17
Nitric acid (100%) - N ₂ O	7.0 kg N ₂ O/t	6.0 kg N ₂ O/t	1.85 kg N ₂ O/t	0.5 kg N ₂ O/t	2.07	1.78	0.55	0.15
Ammonium nitrate	1.4	0.7	0.5	0.0	0.08	0.04	0.03	0.00
Sulphuric acid	-1.0	-3.0	-4.0	-5.0	-0.06	-0.17	-0.22	-0.28
Phosphoric acid (P ₂ O ₅)	8.0	6.0	4.0	1.5	0.45	0.34	0.22	0.08
Phosphate rock	0.5	0.3	0.3	0.2	0.03	0.02	0.02	0.01
Potash	4.0	3.0	3.0	3.0	0.22	0.17	0.17	0.17
Inerts (limestone, dolomite)	0.8	0.8	0.8	0.8	0.04	0.04	0.04	0.04
Melt granulation/ compaction	0.5	0.5	0.5	0.5	0.03	0.03	0.03	0.03
Drum solid granulation	1.1	1.1	1.1	1.1	0.06	0.06	0.06	0.06
Accumulated in products								
Urea (46-0-0)	29.5	26.5	24.3	21.3	1.2	1.01	0.88	0.70
Ammonium nitrate (35-0-0)	20.6	17.1	14.9	11.9	3.0	2.55	1.46	0.97
Calcium ammonium nitrate (26.5-0-0)	15.9	13.2	11.6	9.3	2.3	1.95	1.13	0.75
Ammonium sulphate (21-0-0, 24S)	11.0	8.3	6.8	4.9	0.7	0.58	0.50	0.38
MAP (11-52-0)	10.0	5.1	2.2	-1.3	0.6	0.35	0.19	-0.01
DAP (18-46-0)	13.3	8.5	5.7	2.2	0.9	0.58	0.42	0.21
TSP (0-46-0)	3.7	0.8	-0.9	-2.8	0.21	0.04	-0.05	-0.16
SSP (0-18-0)	1.0	0.1	-0.3	-0.7	0.06	0.01	-0.02	-0.04
Other fertilizers containing N, P or K								
- as ammonical nitrogen	54.8	49.3	45.5	40.2	3.7	3.31	3.10	2.76
- as nitrate nitrogen	59.5	47.1	39.3	29.0	13.3	11.21	5.25	2.83
- as phosacid P ₂ O ₅	8.4	0.3	-4.5	-10.1	0.47	0.01	-0.25	-0.56
- as phosphate P ₂ O ₅	3.7	3.1	3.1	2.7	0.21	0.17	0.17	0.15
- as potash K ₂ O	7.5	5.8	5.8	5.8	0.42	0.33	0.33	0.33

Sources:

Ammonia accumulated in products is based on the world average fuel mix as estimated in IFA 2008a. BPT and "World today" are derived from IFA 2008b. N₂O from nitric acid production is converted to CO₂ equivalents using the factor 296. Other data are from Kongshaug 1998.

⁷ Excluding energy and GHG emissions from power and steam generation and transport of raw materials. For certain products (which are not dominated by ammonia synthesis) this is significant. Estimates that take these factors into account will therefore be higher.

Annex 2. World fertilizer production in 2007

Product	Product volume Tg/year	N Tg/year	P ₂ O ₅ Tg/year	K ₂ O Tg/year	Data source
Primary materials					
Ammonia - Total	154.3	126.9			IFA 2007
- natural gas based	103.4	85.0			IFA 2007
- coal, fuel oil, naphtha based	50.9	41.9			IFA 2007
Phosphate rock	176.1		54.4		IFA 2007
Potash	54.1			33.4	IFA 2007
Intermediates					
Phosphoric acid	36.2		36.2		IFA 2007
Nitric acid	59.0	13.1			Kongshaug 1998
End user products					
Urea (46-0-0)	128.9	59.3			IFA 2007
Ammonium nitrate (35-0-0)	31.7	10.6			IFA 2007
Calcium ammonium nitrate (26.5-0-0)	13.7	3.7			IFA 2007
Ammonium sulphate (21-0-0, 24S)	20.4	4.3			IFA 2007
MAP (11-52-0)	18.9	2.1	9.8		IFA 2007
DAP (18-46-0)	27.2	4.9	12.5		IFA 2007
TSP (0-46-0)	5.8		2.6		IFA 2007
SSP (0-18-0)	38.2		6.3		IFA 2007
Other fertilizers containing N, P or K	170.2	20.0	23.2	33.4	Calculated
- as ammonical nitrogen	16.0	16.0			Calculated
- as nitrate nitrogen	4.0	4.0			Calculated
- as phosphoric acid P ₂ O ₅	12.0		12.0		Calculated
- as phosphate P ₂ O ₅	11.3		11.3		Calculated
- as potash K ₂ O	33.4			33.4	Calculated
Products for industrial use					
- ammonia	13.4	11.0			IFA 2007
- ammonium nitrate	11.9	4.0			IFA 2007
- urea	15.2	7.0			IFA 2007
Total end products	495.5	126.9	54.4	33.4	

As indicated in the lower portion of the table, the entire tonnage produced by fertilizer manufacturers is included here although not all of this tonnage is destined for use as fertilizers. Some products serve as intermediates for other industrial value chains and should not be counted in calculations of agricultural life cycles.

Small amounts of phosphoric acid and potash are also used for industrial purposes, but their impact on the fertilizer industry's greenhouse gas emissions is marginal, and they have not been included in this table.

Source: IFA 2008a

Annex 3. World energy consumption and GHG emissions in 2007 from all of the fertilizer industry's production (including products destined for industrial uses)

Product	World production Tg/year	Energy input (PJ/year)				CO ₂ -eq (Tg/year)			
		BAT 40 years ago	World today	BPT today for all plants	BAT today for new plants	BAT 40 years ago	World today	BPT today for all plants	BAT today for new plants
Urea (46-0-0)	128.9	3806.0	3410.5	3128.8	2747.2	156.0	129.8	114.0	90.2
Ammonium nitrate (35-0-0)	31.7	652.5	540.5	472.4	376.8	95.2	80.8	46.4	30.6
Calcium ammonium nitrate (26.5-0-0)	13.7	218.2	181.5	159.2	127.8	31.4	26.7	15.4	10.3
Ammonium sulphate (21-0-0, 24S)	20.4	223.7	169.8	138.2	100.4	15.2	11.9	10.1	7.8
MAP (11-52-0)	18.9	188.5	96.8	42.1	-23.7	11.8	6.6	3.5	-0.3
DAP (18-46-0)	27.2	361.7	232.5	154.3	58.7	23.3	15.7	11.3	5.8
TSP (0-46-0)	5.8	21.4	4.6	-4.9	-16.3	1.2	0.3	-0.3	-0.9
SSP (0-18-0)	38.2	39.0	4.4	-10.5	-27.7	2.2	0.2	-0.6	-1.6
Other fertilizers containing N, P or K	170.2								
- as ammonical nitrogen	16.0	877.6	789.5	728.3	643.9	59.1	53.1	49.6	44.2
- as nitrate nitrogen	4.0	237.8	188.3	157.1	115.8	53.2	44.8	21.0	11.3
- as phosacid P ₂ O ₅	12.0	100.6	3.0	-53.7	-120.5	5.6	0.2	-3.0	-6.7
- as phosphate P ₂ O ₅	11.3	41.7	34.3	34.3	30.7	2.3	1.9	1.9	1.7
- as potash K ₂ O	33.4	250.5	194.8	194.8	194.8	14.0	10.9	10.9	10.9
Fertilizer: Energy and GHG emissions		7019.2	5850.5	5140.4	4207.8	470.6	382.8	280.3	203.3
Industrial products									
ammonia, ammonium nitrate and urea	40.5	1282.8	1133.3	1032.3	893.2	94.7	82.0	64.8	52.4
Total energy and GHG emissions		8302.0	6983.8	6172.7	5101.1	565.4	464.8	345.1	255.7

Sources:

Ammonia accumulated in products is based on the world average fuel mix as estimated in IFA 2008a and IFA 2008b.

N₂O from nitric acid production is converted to CO₂ equivalents using the factor 296.

Other data: Kongshaug 1998.