Fertilizers and Climate Change

Looking to the 2050

- Final -

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Elaborated by Ecofys

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1 Introduction

Mineral fertilizers are used to increase the yield from agriculture. The production of fertilizers is energy intensive. The large consumption of natural gas as both energy source and feedstock results into greenhouse gas emissions. Field application (use) of fertilizers leads to greenhouse gas emissions as well. The EU fertilizer industry endorses the need to globally reduce these emissions in the production phase and during field application.

Due to its greenhouse gas intensive nature, climate policies – such as the European Emission Trading System (EU ETS) – can have significant impacts on the profitability of production of fertilizers. Therefore, Fertilizers Europe has decided to prepare a future-oriented energy and climate roadmap for the European fertilizer industry, building further on the CEFIC Roadmap 2050 [CEFIC, 2013] prepared with the assistance of Ecofys. Fertilizers Europe has assigned Ecofys to support them in the preparation of this Roadmap by jointly developing a storyline and by supporting them in drafting the text, based on information provided by them. Given the energy intensive production of nitrogen (N) fertilizers, this Roadmap focuses on two of the most important N-fertilizers in Europe: ammonium nitrate (AN) and urea.

Figure 1[1] visualizes the production routes to these two fertilizers (both indicated in orange). The figure illustrates:

- The central role of **ammonia** (NH_3): It is needed for the production of urea, as well as for the production of ammonium nitrate; in the latter case, it is used to produce **nitric acid** (HNO_3), which subsequently reacts with more ammonia to form ammonium nitrate;
- CO_2 formed during the production of ammonia reacts in the next reaction step(s) with ammonia to form urea.

[1] The reaction equations in the picture are simplifications. In reality, many more reactions take place subsequently and in parallel, and many by-products are formed.

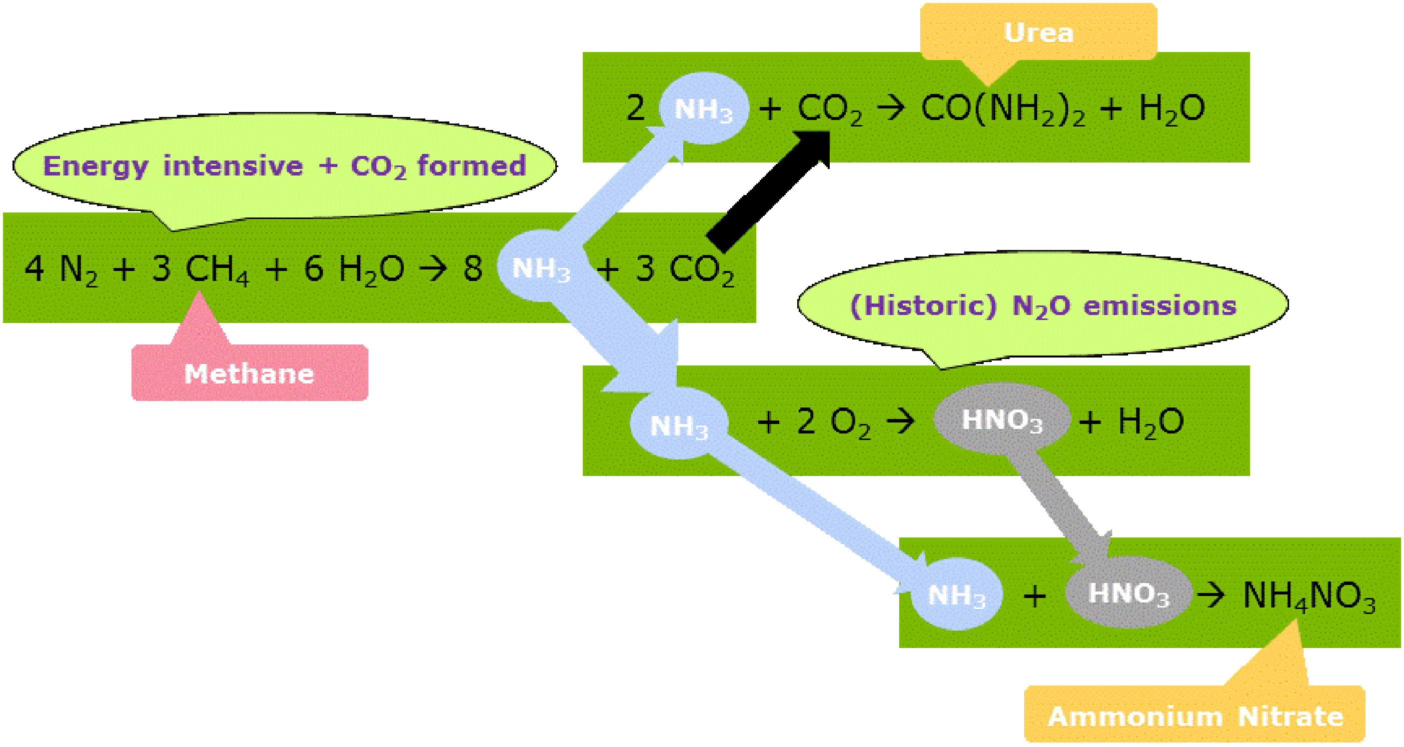

Figure 1: Simplified reaction equations for the production of urea and ammonium nitrate[2].

This Roadmap will elaborate:

- The production of ammonia (chapter 2);
- The current energy and greenhouse gas intensity of the production of building blocks[3] for ammonium nitrate and urea, key sources of greenhouse gas emissions during their use, and benefits of their use (chapter 3);
- Possibilities to reduce the energy and greenhouse gas intensity of production and use of these (chapter 4);
- Conclusions and recommendations (chapter 5);

[2] Methane is natural gas. Burning of methane to produce the required heat (Figure 2) is not taken into account.
[3] Ammonia and nitric acid.

2 Manufacture of Ammonia

The production of ammonia (NH_3) is the first step to produce ammonium nitrate and urea. This production step has the biggest impact on the total emissions related to the production of urea and ammonium nitrate[4]. Ammonia is produced by combining nitrogen from air with hydrogen ($N_2 + 3\ H_2 \rightarrow NH_3$). The hydrogen ($H_2$) is – in Europe - mostly produced by Steam Methane Reforming[5] ($CH_4 + 2\ H_2O \rightarrow CO_2 + 4\ H_2$). The heat required for this reaction is obtained by burning methane. So, part of the methane is used as raw material for hydrogen and part of the methane is burned to generate the temperature required for the reaction. Carbon dioxide (CO_2) is formed in both steps. Figure 2 illustrates the production process of ammonia.

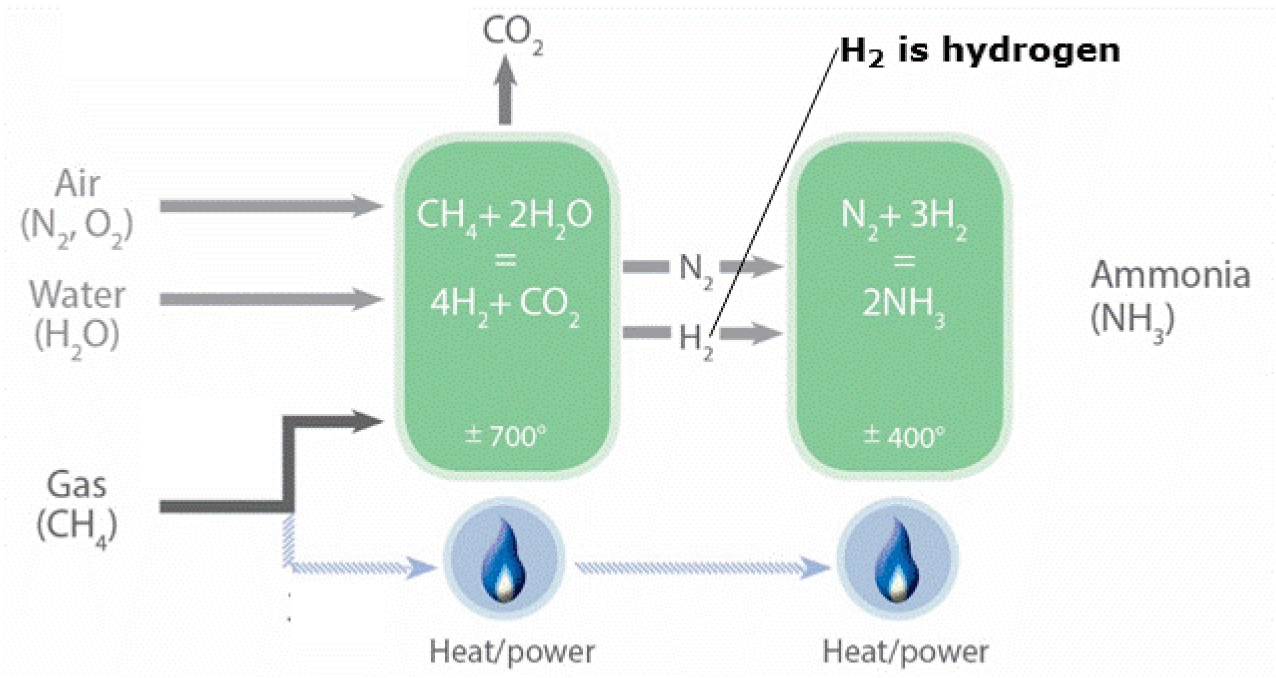

Figure 2: Simplified ammonia production process [adjusted from figure received from Fertilizers Europe]

[4] Later in this Roadmap, we will elaborate that the GHG emissions of nitric acid manufacture have decreased steeply over the past decade, and therefore are now much smaller than the GHG emissions of ammonia production.

5 In the EU, more than 90% of the hydrogen for ammonia production is made by steam reforming with natural gas as feedstock [Ecofys, 2009].

European production:

European production of ammonia has stayed relatively constant over the past 20 years, while its market share in the world decreased (Figure 3); in 2014/15, the import of N-fertilizers as share of EU-28 consumption was 28% [Fertilizers Europe]. Taking export into account as well, the net import[6] of N-fertilizers as share of EU-28 consumption was 13% [Fertilizers Europe].

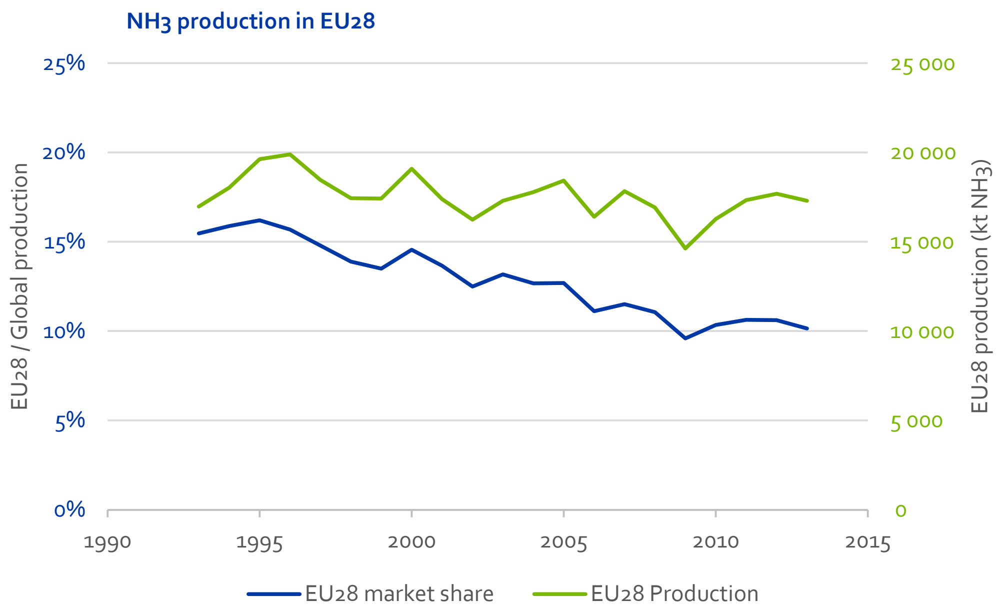

Figure 3: Ammonia production in EU28 (in kt NH_3), and the EU28 market share in the world [information provided by Fertilizers Europe].

Fertilizers Europe further indicates that:

- The average age of the European ammonia plants is 37 years;
- Almost halve of the European ammonia plants have been built between 1970-1979;
- The newest ammonia plant in Europe has been built in 2007;
- Hardly any new plants are foreseen[7].

Despite their age, the European ammonia plants are on average the most energy efficient in the world (see chapter 3); this can be attributed to the efforts to improve and upgrade existing ammonia plants. These investments have been driven by the high gas price. Increasing energy efficiency of ammonia plants automatically results in reduction of GHG emissions.

[6] Net import is defined here as (Import-Export) / Total Consumption.

[7] According to Fertilizer Europe, the only publicly announced new plant is in Slovakia (with government subsidies).

3 Energy use and GHG emissions now

In this chapter, we will discuss the energy use and emissions related to the **manufacture** of ammonium nitrate and urea. We will also indicatively address key sources of greenhouse gas emissions during the **use** (transport and application in the field) of these fertilizers. At the end of this chapter we will show that emissions related to the use of fertilizers exceed the emissions during manufacture and address their benefits in the use phase (additional yield of crops).

Manufacturing of ammonium nitrate and urea

The energy use and greenhouse gas emissions during the production of ammonia dominate the total energy use and greenhouse gas emissions for the production of ammonium nitrate and urea. Until recently, the greenhouse gases emitted during the production of nitric acid contributed very significantly to the total greenhouse gas emissions for the production of ammonium nitrate. This chapter focuses on the energy use and greenhouse gas emissions of manufacture of ammonia, and greenhouse gas emissions of manufacture of nitric acid.

Ammonia

Currently, European ammonia plants consume 35 GJ/tonne [CEFIC, 2013]. This has been relatively stable over the past 3 years (from 35.5 GJ/tonne in 2010 to 35.2 GJ/tonne in 2013 [Fertilizers Europe]). Figure 4 shows that the average energy use to produce ammonia is lower in EU than in many other key regions; [Saygin, 2012] confirms that Europe is the most energy efficient region for ammonia production.

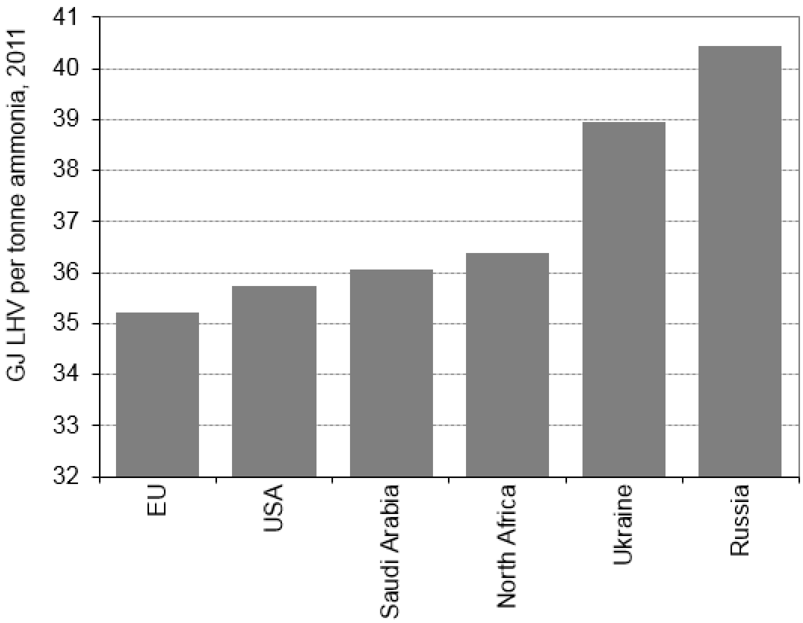

Figure 4: Average energy use to produce a tonne of ammonia [Fertilizers Europe, 2013, based on Integer Research][8].

Figure 5 illustrates that the potential for improvement of existing plants is relatively limited. In line with this figure, [CEFIC, 2013] projects an average energy efficiency improvement of ~3 GJ/tonne to be realized in 2030 in all its scenarios. Further improvements of the energy efficiency are expensive to build in existing plants, but could be viable for new plants.

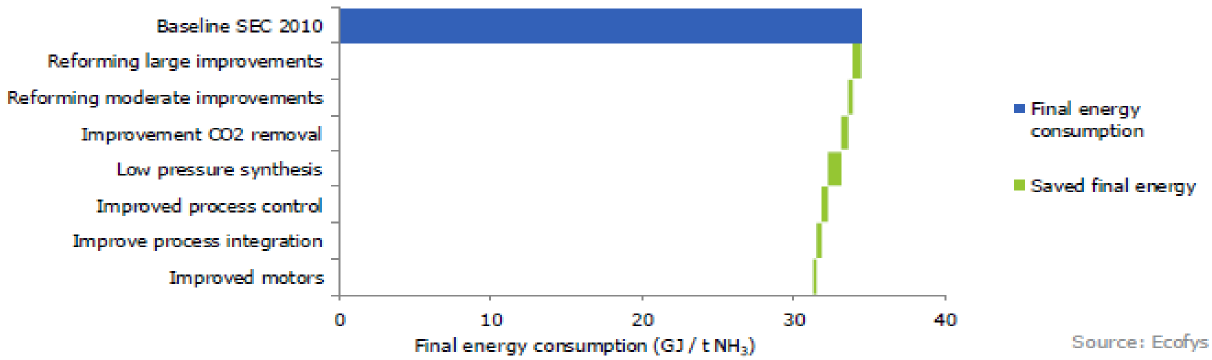

Figure 5: Technical potential for energy efficiency improvements in existing ammonia plants in 2050[9] [CEFIC, 2013]

New ammonia plants, heavily integrated in a production site can already achieve an energy demand of 27 GJ / tonne NH_3 [Hoxha, 2013]. Fertilizer Europe has provided an indication on the investment costs of a new ammonia plant (in Russia: US$1000 per tonne ammonia yearly design capacity[10]).

[8] Integer Research: market intelligence and expert evaluation.
[9] The economic feasibility of these measures is taken into account in this figure.
[10] Based on one source, one plant.

The average European emissions are 1.95 tonne CO_2 per tonne of ammonia [information received from Fertilizers Europe, based on their ammonia energy efficiency survey[11]]. The product benchmark - average emission intensity of the top10% plants - in EU's emissions trading system is 1,619 tonne CO_2 per tonne of ammonia [European Commission, 2011].

Nitric acid

Nitric acid is only used in the production of ammonium nitrate (not in the production of urea). The main greenhouse gas emissions during production of nitric acid are caused by the emissions of N_2O. These emissions have been reduced drastically over the past decade (an 87% decrease in N_2O emissions per tonne of nitric acid in 11 years, corresponding to 17% per year; see Figure 8 in chapter 4). This also means[12] that – in the production of ammonium nitrate - the remaining N_2O emissions[13] from the production of nitric acid are now almost 5 times lower than the CO_2 emissions from the manufacturing of ammonia.

Use of fertilizers

Application of fertilizers:

As has been discussed before, manufacturing of fertilizers leads to emissions. During application ("use"), fertilizers cause further emissions. To illustrate this, a few key emission sources during the "use phase" are shown in Figure 6.

[11] To which Fertilizer Europe did calculations / with assumptions.

[12] Assuming ideal reactions (100% conversion and selectivity).

[13] Expressed as CO_2equivalent.

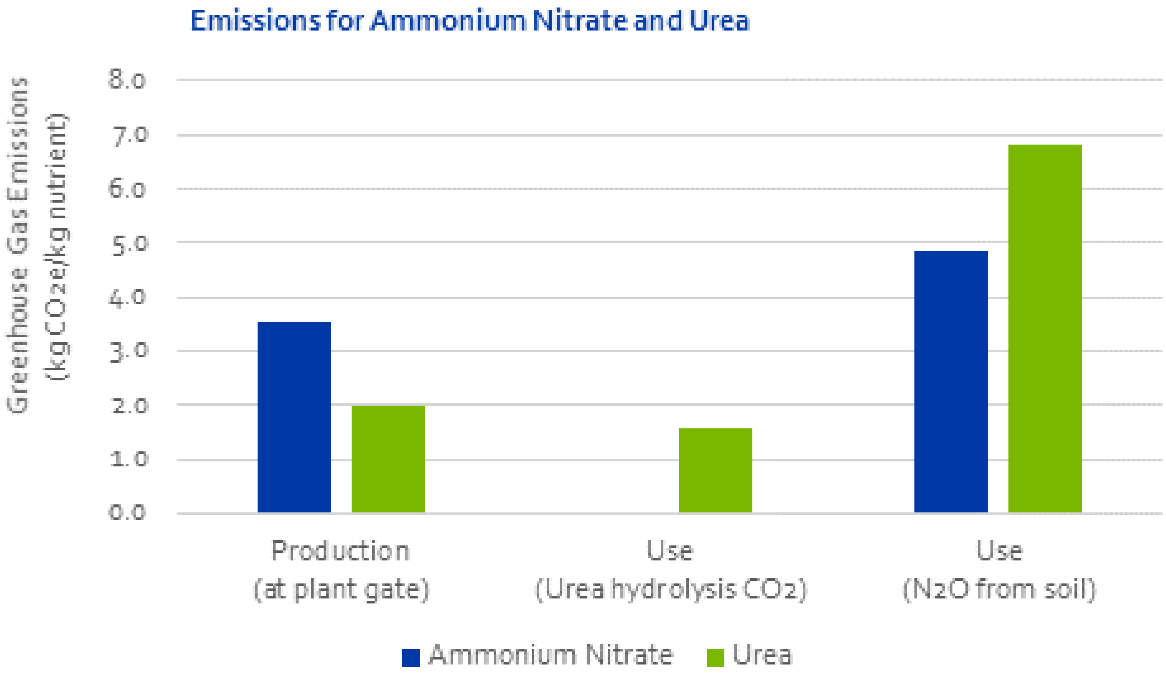

Figure 6 Fertilizers Europe Carbon footprint reference values for European mineral fertilizer production and use, 2011[14] (not covering all emission sources).

Figure 6 shows that the CO_2 "captured" in the urea in its manufacturing (reducing the greenhouse gas emissions during manufacturing), is released during its use. The dominant emissions during use of fertilizers are however N_2O emissions. N_2O is produced by bacteria in all soils. In agriculture, N_2O is emitted mainly from fertilized soils and animal wastes – wherever nitrogen (N) is readily available.

[14] A Global Warming Potential conversion factor of 298 has been used in the cited reference. Production emissions in this figure are based on EU average data, come from the Carbon Footprint Calculator – which has been verified by DNV [info obtained from Fertilizer Europe]. The "use phase" numbers [info below from Frank Brentrup, Yara] are based on different literature sources:

- For the direct N2O emissions the 2002 Bouwman model is used to determine average emissions from the field related to fertilizer use. This empirical model is based on an extensive literature review; the resulting emission factors reflect the average global soil and climate conditions under which the fertilizers have been applied;
- For the indirect N2O emissions (emissions caused by volatilization of ammonia or leaching of nitrates from the field to other areas, where a small part of it is converted into N2O which is emitted), default factors from EMEP/UNECE (for ammonia) and IPCC (for nitrate) have been used, including a uniform 30% loss by leaching (assuming excess fertilizer dosage).

The uncertainty in the use phase numbers is significant.

Nitrogen applied in excess of crop needs is particularly susceptible to loss. Though the amounts of carbon and oxygen available in soil also affect microbial N_2O production, the presence of inorganic N usually matters most [Millar, 2014]. This makes N fertilizer management (right N-application rate, formulation (fertilizer type), timing of application, …) very important [Millar, 2014]. The European fertilizer industry has been moving over the past years from a volume driven industry ("aiming at producing and selling as many tonnes as possible") towards a functionality driven industry ("aiming at delivering an optimal increase of agricultural yields"), by – for example:

- Producing fertilizer products that are increasingly tailor-made to meet specific crop requirements and cater for different locations and soil types, as well as for the different weather conditions encountered in Europe;
- Optimize nutrient efficiency (satellite technology such as GPS soil and biomass mapping, which can define nutrient demand down to within a few metres on a particular field);
- Improving crop productivity and greatly reducing nutrient losses with smart sensors enabling highly targeted application patterns;
- Developing practical tools[15], including mobile applications for smart phones, for improving on-farm nutrient management;
- Building up a comprehensive range of information for farmers that address the issues of productivity, energy efficiency, and the management of emissions;
- Developing fertilizers with nitrification inhibitors to reduce N_2O emissions in the field.

Fertilizer Europe reports that – with the availability of new fertilizers that limit soil emissions - the main focus of current greenhouse gas mitigation efforts is on the promotion of nitrogen-use efficiency. This has increased by 45% in Europe since 1985, but there still is further scope for improvement [Fertilizers Europe, 2013].

Fertilizers' dominant application is to increase the yield of agriculture. [Küsters, 1999] reports that – for example – for the production of winter wheat and sugar beet in Europe –the amount of energy obtained through the increase in harvested biomass due to N fertilizer exceeds at least five times the energy input through N fertilizer application[16]. The perspective here is the yield per hectare. Fertilizers Europe has – based on this work – found that the CO_2 harvested additionally due to the use of fertilizers in the grain + straw is also a factor five larger than the greenhouse gases emitted due to the production and use of these fertilizers[17]. The CO_2 binding is not permanent, but helps to reduce fossil CO_2 emissions if the biomass is used to substitute fossil fuels in heat and electricity generation, or used in the transport sector as biofuel. (…) To what extent fossil energy is saved and CO_2 is mitigated depends on the kind of crop used, and the conversion technology that converts the feedstock into bio-energy."

[15] Fertilizer Europe is a partner in the Cool Farm Tool (a tool for farmers to estimate the carbon footprint of agricultural products).

[16] Alternative manners (like organic fertilizers, such as manure) to increase the yield of agricultural land have not been assessed here.

[17] Assuming fertilizers lead to an increase in grain + straw production from 9.4 to 16.4 t biomass (straw + grain) / ha, 1.6 t CO_2 /t dry matter (the average CO_2 fixation in cereal biomass), and 2.2 t CO_2 eq/ha additional greenhouse gas emissions due to the use of fertilizer.

4 How can the European Fertilizer Industry reduce its energy use and GHG emissions?

In this chapter, the improvement of the carbon footprint of fertilizers is explored, first by assessing the potential to improve the emissions during their manufacturing, and then by assessing improvement of key greenhouse gas emissions in the use phase.

Manufacturing of fertilizers

Again we focus here on the production of ammonia and nitric acid. Obviously, energy use in other reactions shown in Figure 1 can be optimized as well, including further heat integration of various plants. As these processes require little energy, this potential has not been assessed.

Ammonia

Currently, the average energy use of European ammonia plants is 35 GJ / tonne ammonia. The average energy use of existing plants could be improved to 32 GJ / tonne ammonia by improvements in the reformer section, the CO_2 removal, application of low pressure synthesis, improved process control, process integration and motors [CEFIC, 2013].

European ammonia plants are predominantly based on gas-fed Steam Methane Reforming. Ammonia can be produced through “Partial Oxidation” as well (mainly outside Europe). This process route uses heavy hydrocarbon fractions and coke/coal as feed [IPPC, 2007]. [Ecofys, 2009] says: “The CO_2 emissions emerging from the partial oxidation process are always higher than those from steam reforming. The same is valid for the energy consumption.” No further focus is put on this technology in this Roadmap.

The energy efficiency of new plants (baseline based on Steam Methane Reforming) is expected to be significantly lower than for the currently existing plants, from 27 GJ / tonne ammonia that is now attainable, to - in future and with innovation (membrane, catalyst, integration) – an estimated 24-25 GJ/tonne ammonia.

The production of ammonia requires energy. The lower heating value of ammonia[18], which is 18.6 GJ/tonne ammonia [CEFIC, 2013], gives a good impression of the minimum energy required to produce ammonia; this is the theoretic minimum, which can in practice never be achieved (as a driving force is always needed to drive processes). This value is often considered the feedstock energy.

This is summarized in Figure 7.

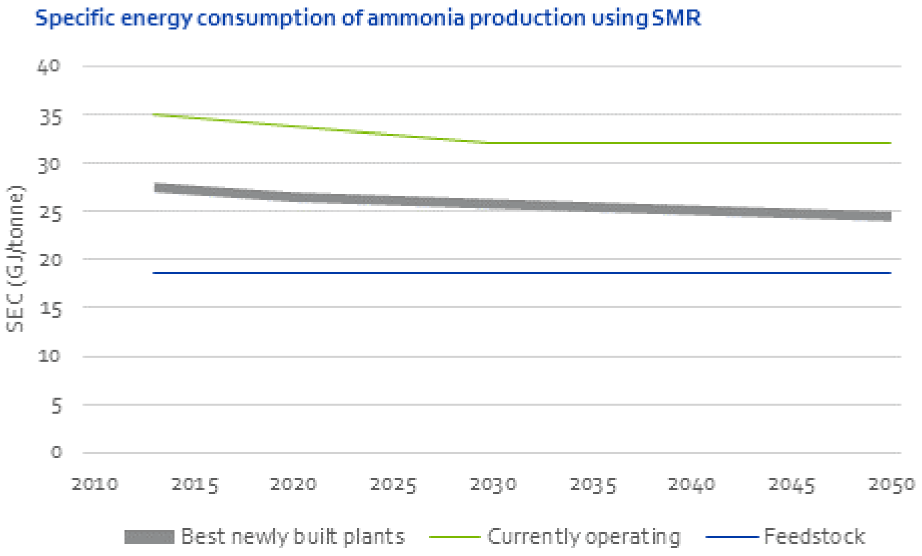

Figure 7: Future specific energy consumption of ammonia production (with SMR).

This raises the question whether other – game-changing – technologies would be able to reduce carbon emissions during the production of ammonia deeper. This question typically boils down to alternative routes to manufacture hydrogen; these are discussed in Table 1.

[18] The lower heating value represents the heat released when burning ammonia: NH_3 (g) + O_2 (g) → N_2 (g) + H_2O (g). Alternative ways of expressing the minimum energy required to produce ammonia include:

- Its exergy (19,8 GJ/tonne NH_3 [de Beer, 1998]);
- The heat of reaction (3/8 CH_4 (g) + 6/8 H_2O (g) + 4/8 N_2 (g) → 3/8 CO_2 (g) + NH_3 (g)) is 0.9 GJ/tonne (based on [Kirova – Yordanova, 2012]). Adding the LHV of reactant methane (17.7) this yields 18.6 GJ / tonne ammonia. Methane reacting with oxygen is ignored in these considerations, and could be taken into consideration as well. Likewise for evaporation of water prior to reaction.

Technology:	Large scale implementation expected before 2050[19]:	Reason:
Syngas produced from biomass	No	Energy use is higher than for SMR[20] route and option is not economically viable. In case sufficient competitively priced biogas with constant quality would be supplied by the grid, there would be no problem to use it. The availability of sufficient sustainable biomass, and its price, will depend on competing uses of biomass, notably for energy, and on research to ensure sustainable levels of harvesting.
Electrolysis	No	Energy use is more or less comparable than for SMR route, but power is not economically viable.
Nuclear High Temperature Electrolysis	No	Energy use is more or less comparable than for SMR route, but power is not economically viable.
Solid State	No	Energy use is more or less comparable than for SMR route, but power is not economically viable; first commercial scale plant scheduled [NHthree, 2015].

Table 1 Potential of other technologies to produce ammonia

The key message from Table 1 is that steam methane reforming is expected to remain the dominant technology to produce ammonia [CEFIC, 2013].

Demand side management:
Rapid development of the hydrogen economy – with availability of competitive hydrogen – could change this picture. Furthermore, the power dependent options (rows 2-4 in Table 1) potentially become attractive in case of abundant renewable and cheap power, and lead to significantly lower emissions in case the power would be (partly) renewable. Such options could potentially also be combined with Demand Side Management (increasing ammonia production – thus energy use – during periods of abundant and thus cheap generation of (renewable) energy[21]).

[19] Based on [CEFIC, 2013], and the scenarios used there.
[20] Steam Methane Reforming
[21] While respecting limits of fluctuations that an ammonia plant can cope with (not regularly starting-stopping, but limited variations in production rate).

The attractiveness of such options depends on:

- (Future development of) investment costs for the power-driven processes;
- Future gas prices, and carbon costs;
- The total time that cheap / free power would be available, depending amongst others on:
  - o Whether other power consumers will increase their demand for power at such moments;
  - o Export to neighbouring regions (requires additional transmission lines – which could well take long);
  - o Power market policies that raise minimum prices for electricity and/or decrease volatility of prices;
  - o The design of renewable energy subsidy schemes;
  - o Grid fees, taxes and levies for industry on power;

In case conditions would – regionally – be favourable, the ammonia industry could contribute to balancing supply variations by adjusting power demand, thus stabilizing the power system.

These are factors to be taken into account when deciding on the fourth phase of the European ETS (refer to the chapter with the recommendations later on).

Carbon Capture and Storage & Utilization:

With Steam Methane Reforming as the remaining dominant process to produce ammonia, with its limited potential to improve the energy efficiency further, the next question would be whether the produced CO_2 could be captured. Part of this CO_2 is produced in concentrated – almost pure - form[22]:

- In some fertilizer complexes this CO_2 is used (as feed for the urea process), and not emitted from the fertilizer complex (in case it is fed to the urea process, it will later be emitted in the use phase; refer to chapter 3);
- In other fertilizer complexes this CO_2 is emitted ("process emissions"); as CO_2 is already concentrated in these emission sources, application of CCS to these streams will become cost-effective before capturing CO_2 from combustion streams[23]. Nevertheless, this still comes at significant costs. To illustrate these costs: investment costs would be around € 120 / tonne CO_2 (capacity to yearly capture and transport 1 tonne of CO_2)[24]. Operational and all storage costs are to be added to these costs.

Costs to apply CCS to combustion of CO_2 are significantly higher.

[22] This is the CO_2 that is generated during the reaction in which ammonia is formed. Next to this pure stream, diluted CO_2 – formed during the burning of methane to provide the required heat to the process - is emitted to the atmosphere as well.

[23] Actually, there is no need to "capture" this pure CO_2, as it is already available in concentrated form. It should 'just' be compressed and stored. As many other factors determine the business case for CCS and CCU (distance to transport network, possibilities to use / store the CO_2, …) this remark should not be interpreted as "all ammonia plants should be the first to install CCS".

[24] Number in 2010€ and assume investment in the period to 2020, and are for a typical ammonia plant (0.8 Mtonne CO_2 process emissions). These numbers have a large uncertainty; these costs are expected to decrease in time.

Therefore, application of CCS would require much more policy stimuli than the current carbon price in EU ETS (€ 8 / tonne CO_2 [EEX, 2015]):

- A higher carbon price in EU ETS would increase the economic attractiveness of implementation of CCS; this measure could be very effective in case this would be applied on a global scale, establishing a level playing field. As this has not yet been established, increasing the carbon price 'just in Europe' (unilaterally) could go at the expense of the European industries' competitiveness and could lead to carbon leakage;
- Subsidies for the implementation of CCS.

The attractiveness of capturing CO_2 would also increase in case:

- Costs decrease, due to learning in demonstration projects;
- The CO_2 would be used, and therefore get a value (Carbon Capture & Utilization). Research is ongoing into a variety of applications of CO_2[25].

Even if the business case for CCS would be acceptable, important factors to take into consideration would be:

- Need for CO_2 transport facilities (pipeline grid, ship) close by: this would be a very important factor in the total costs, and will vary between plants;
- CCS technologies could improve significantly in time; learning would be significantly accelerated by implementation of CCS in a few large scale pilots;
- There are, for EU Member States, public acceptance and legal issues to be overcome.

Once CCS becomes economically attractive, the European ammonia producers are well positioned to supply pure CO_2.

Other route

N2 Applied claims to be able to use plasma technology to produce NO, which would flow in the processes of the Fertilizer Industry, thereby circumventing (part of) the ammonia. This might open routes towards fertilizers with reduced energy use. As this technology still seems to be in the research phase [N2 Applied, 2015], this has not been assessed further.

[25] This research is done outside the European Fertilizer Industry; the European Fertilizer Industry could be the CO_2 supplier.

Nitric acid

In correspondence with Figure 6, the N_2O emissions, when producing nitric acid, were in 2013 on average (Europe) 0.23 CO_2eq/tonne nitric acid. [CEFIC, 2013] projects a further decrease in future to ~0.09 ton CO_2eq / tonne nitric acid[26]. This is reflected in Figure 8.

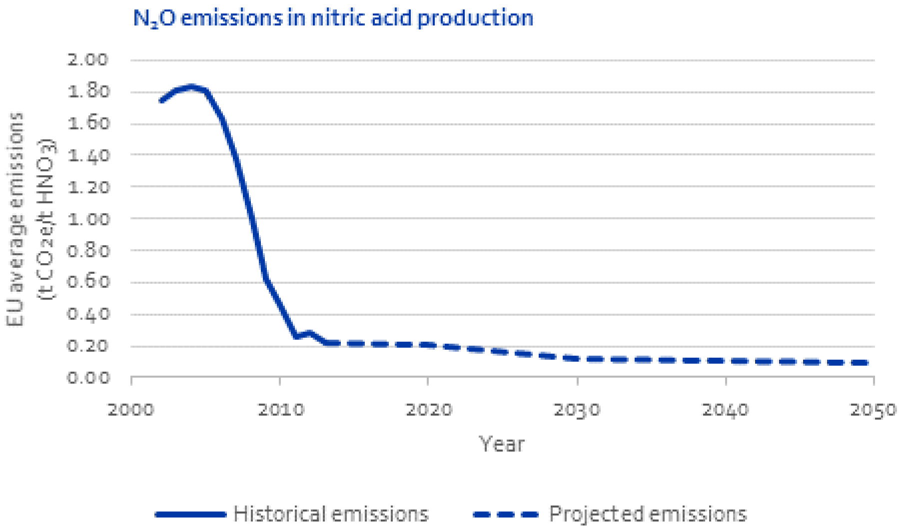

Figure 8: Decline of N_2O emissions in nitric acid production [data received from Fertilizers Europe][27]

During the production of nitric acid, heat is formed (6.3 GJ/tonne 100% nitric acid, [IPPC, 2007]), which is only partly used[28]. Increasing the use of this heat in other places contributes to lower greenhouse gas emissions[29].

[26] Again using the Global Warming Potential of 298 t/t [IPCC, 2007].
[27] A Global Warming Potential of 0.298 tonne/kg has been used to convert N_2O emissions into CO_2equivalents [European Commission, 2014].
[28] On average 1,75 GJ/tonne 100% nitric acid [estimated by Fertilizer Europe] modern plant in / before 1998/2001: 2,4 GJ/tonne 100% nitric acid [IPPC, 2007].
[29] The underlying mechanism is: The use of heat from nitric acid production in other places reduces the need to generate heat in these other places; in case this heat would alternatively have been generated on the basis of fossil fuels, the replacement of this heat generation reduces overall greenhouse gas emissions.

Use of fertilizers

The previous chapter lists measures to improve the efficiency and reduce the emissions associated to using fertilizers. These efforts continue, and there is scope for further improvement. On top of that, recent attention has focussed on “closing the fertilizer loop” through more efficient use of on-farm waste and nutrient recycling strategies. These primarily involve recycling waste through composting, anaerobic digestion of manure for energy or fuel generation, and its more efficient use within the overall fertilization strategy.

Research continues into the viable nutrient recycling schemes. Combined with better nutrient-use efficiency, these can lead to major improvements in overall resource use [Fertilizers Europe, 2013].

5 Conclusions & Recommendations

Conclusions

The European fertilizer industry is an energy and greenhouse gas intensive industry. The production of key building block ammonia requires by far most energy, and European ammonia plants are the most energy efficient in the world. Production of nitric acid historically lead to significant amounts of N_2O emissions, thereby making it the chemical process with highest greenhouse gas emissions in Europe [Ecofys, 2009]; these emissions have been reduced with 87% between 2002 and 2013. Therefore, the European fertilizer industry can be considered a frontrunner in limiting greenhouse gas emissions from the manufacturing of fertilizers. Apart from that, manufacturing fertilizers in Europe contributes to European control on the yield of European agricultural yield, and thus to Europe's security of food supply and to European jobs.

Most European fertilizer plants use natural gas as feedstock. This Roadmap has elaborated that neither biomass nor electric power are foreseen to become a dominant feedstock / energy source in the decades to come. Rapid development of the hydrogen economy – with availability of cheap renewable power (competitive hydrogen) – could change this picture. In case conditions would – regionally – be favourable, the ammonia industry could contribute to balancing supply variations by adjusting power demand, thus stabilizing the power system.
In some other regions of the world, production of ammonia is to a larger extent than in Europe based on heavier feedstocks; for example, in China around 85% of the ammonia production capacity is coal-based [IFA, Ammonia Statistics]. Without Carbon Capture & Storage, a shift to such heavier feedstocks will lead to an increase of greenhouse gas emissions.

In the manufacture of ammonia, some energy efficiency gains (from 35 GJ/tonne NH_3 to 32 GJ/tonne NH_3) can still be achieved in existing plants. New plants could have a higher energy efficiency (up to 24-25 GJ/tonne NH_3), but the ultimate maximum improvement potential is limited by the feedstock related energy of ammonia (18.6 GJ/tonne NH_3), which can in practice never be fully exploited. The biggest further reduction from industries greenhouse gas emissions would be delivered by carbon capture and storage (or utilization). In the future, if cost-efficient CCS and logistics systems would become available, nearly all CO_2 generated in ammonia plants could be dealt with. In practice, if the CO_2 from combustion processes could be cleaned in a cost-efficient manner, the European Fertilizer industry has the potential to come close to zero emissions[30]. For this to happen, significant investments would be needed, and therefore a regulatory framework facilitating these is required and economic viability would need to improve.

[30] In that case, CCS could be applied to both process emissions and combustion emissions.

Recommendations

Therefore, in the absence of a global climate change agreement, the design of the carbon market and further climate policies for the period after 2020 is key. Unilateral carbon costs could reduce the competitiveness of the European fertilizer industry; this can be prevented with stable and predictable measures to support the European fertilizer industry. These measures should be coordinated throughout Europe. Key choices to be made include:

- Will Europe apply a cross sectoral correction factor, implicating that even installations producing ammonia at the European product benchmark (Europe already being the most energy efficient producer of ammonia) will need to buy allowances?
- Will the European Emission Trading System impact growth of European production (new ammonia plants would further reduce the average energy use of European ammonia production)?

Another key area where policy makers can make the difference would be in stimulating actual implementation of Demand Side Management (linked to the development of hydrogen economy based on cheap renew cheap renewable power able power) and Carbon Capture & Storage. [CEFIC, 2013] shows that significant costs reductions are to be expected; "learning by doing" is expected to be an important factor here. Therefore, the European Union could stimulate quick implementation of CCS at short notice.

The main impact from fertilizers comes from its use though – not from its manufacturing. Therefore, it is key to focus on functionality, not on tonnes. Application of modern farming and best fertilizing practices have the potential to significantly reduce the emission of greenhouse gases, by as much as 30% compared to present conventional farming practices without loss of yield [Fertilizer Europe]. In the use phase various regulations already impact use patterns and stimulate efficient and prudent use – including the use of waste streams. Regulations should stimulate farmers in adopting best fertilizer practices when using fertilizers to increase their yields.

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