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ENERGY CONSUMPTION AND GREENHOUSE GAS EMISSIONS IN FERTILIZER PRODUCTION¹

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SUMMARY

The fast growing population of the world needs food, and fertilizers are among the most important elements to secure sufficient food production. To-day, fertilizer production consumes approximately 1.2% of the world's energy and is responsible for approximately 1.2% of the total emission of the Greenhouse gases in the world, consisting of 0.3% of pure CO₂, 0.3% as N₂O and 0.6% as flue gas CO₂. Increased focus on energy issues during the last 25-30 years has already caused a positive downward trend both for energy consumption and Greenhouse gas emissions.

Theoretically, global energy consumption by the fertilizer industry can be reduced by almost 40% and the Greenhouse gas emissions by almost 60% through implementing new technology. This is positive in view of a ongoing replacement of old technology over the next decades. The specific energy consumption in the West European fertilizer industry is approximately 15% lower than the global average. In West Europe, the fertilizer industry consumes 0.9% of the total energy consumption and emits 1.8% of the CO₂/N₂O emissions. Lower energy consumption is mainly due to higher energy cost and higher emissions is due to different product ranges (more AN versus urea).

A product building block model has been developed. This model links energy consumption and Greenhouse gas emissions to the building block products. All kinds of fertilizers can be divided into these building blocks, and consequently energy consumption and Greenhouse gas emissions can easily be estimated for all kind of fertilizers. The main energy requirement for production of fertilizers is linked to the nitrogen component; 92.5% for N, 3% for P₂O₅ and 4.5% for the K₂O component on a global basis. Production of the most common phosphate fertilizers (DAP/MAP and SSP/TSP) with modern technology release excess energy due to the huge surplus energy formation in modern sulphuric acid processes.

RESUME

La formidable croissance démographique du monde nécessite beaucoup de nourriture. Les engrais sont un des éléments les plus importants pour garantir une production alimentaire suffisante. Aujourd'hui, la production d'engrais consomme environ 1,2 % de l'énergie mondiale et est responsable pour 1,4 % du total des émissions de gaz à effet de serre du monde (0,3 % CO₂ pur, 0,3 % N₂O, 0,6 % fumées de CO₂). L'attention croissante des questions posées sur l'énergie pendant les 25-30 dernières années apporte déjà une tendance descendante pour la consommation d'énergie et les émissions de gaz à effet de serre.

Théoriquement, la consommation mondiale d'énergie par l'industrie des engrais pourrait être réduite d'environ 40% et les émissions de gaz à effet de serre par presque 60 % par l'application de nouvelles technologies. Ceci est positif en vue des remplacements naturels des vieilles technologies dans les prochaines décennies. La consommation d'énergie de l'industrie des engrais de l'Europe de l'Ouest est environ 15 % inférieure à la moyenne mondiale. En Europe de l'Ouest, l'industrie des engrais consomme 0,9 % de la consommation totale et les émissions de CO₂/N₂O représentent 1,8 % du total Ouest Européen. La consommation d'énergie réduite s'explique principalement par les prix élevés de l'énergie et les émissions importantes sont dues aux différents types de produits (plus de AN que d'urée).

Un modèle de module produit a été développé. Ce modèle relie la consommation d'énergie et les émissions de gaz à effet de serre aux différents modules produits. Tous les types d'engrais peuvent être placés dans ces modules produits, et ainsi la consommation d'énergie et les émissions de gaz peuvent être facilement évaluées pour chaque sorte d'engrais. Le principal besoin en énergie dans la production d'engrais est lié au composant azote : 92,5 % pour N, 3 % pour P₂O₅ et 4,5 % pour K₂O sur la base mondiale. La production des engrais phosphatés ordinaires (DAP/MAP et SSP/TSP) à l'aide des technologies modernes libère un excès d'énergie, grâce aux importants surplus d'énergie du processus moderne d'acide sulfurique.



¹ Consommation d'énergie et émissions de gaz de serre dans la production des engrais

1. INTRODUCTION

Hydro has established a database covering energy and effluent data for its production plants, transportation systems and product application. The database is used for benchmarking and Life Cycle Analysis of the whole value chain from mining to grain production.

For ease of use and understanding of this data, it has been necessary to make simplified models giving general values for energy consumption and Greenhouse gas emissions related to fertilizer production. The Greenhouse gases from fertilizer production are CO₂ and N₂O. The N₂O emission will be converted to CO₂-equivalent (1 t. N₂O = 310 t. CO₂-equivalent).

Energy and Greenhouse gas emission depends on technology. In this paper numbers are given for:

- "Modern Technology": today's most efficient plants which correspond to Best Available Technology,
- "Average Europe": assumed to be the average in Europe based on several Hydro Agri plants and general information from EFMA and European manufacturers,
- "Old Technology": assumed energy utilisation for the most efficient plants operating 30 years ago. This gives us a good indication of energy consumption in 30-year-old plants that have not been upgraded.

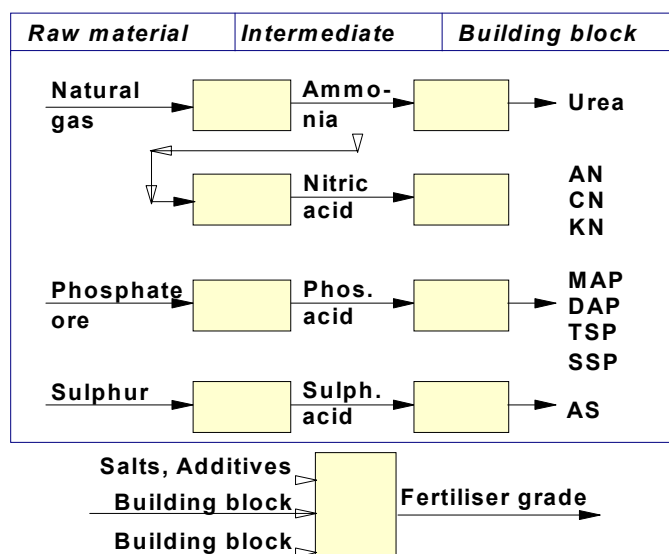
The final numbers include total energy required and total CO₂-equivalent emission from raw material production to fertilizer products.

2. THE BUILDING BLOCK MODEL

The accumulated energy consumption for fertilizer products can be simplified by using product building blocks as each fertilizer product grade can be split up into one or more building blocks. Exploration of raw materials and each process step between the different product building blocks represent a change in energy and Greenhouse gas emission. The accumulation of these changes gives the final energy number for the product building blocks.

The simplified model uses natural gas as source for ammonia production (corresponding to almost 80% of the ammonia production world wide). In the calculations, it is assumed that an average natural gas releases 0.057 t.CO₂/ GJ.

Figure 1 - The Building Block Structure



Natural gas, phosphate ore and sulphur are the raw materials for the main product building blocks produced in chemical reaction processes that pass through a liquid phase before ending up being solidified to fertilizers in a particulation unit (prilling or granulation).

For many fertilizers, more than one building block together with solid additives are fed to the particulation unit. In the building block model, the particulation energy is split on each product building block since most of these building blocks are also commercial fertilizers.

Some of the produced solid fertilizers may end up as additives for production of compound fertilizers in a second particulation unit; compaction unit or a bulk blend unit. Examples are MAP, TSP, AS and urea used for compound NPK production in granulation units, compaction units or as bulk blends. Materials passing twice such units must be charged for the additional energy consumption at the summation stage.

The same analogy will be applied for liquid fertilizers, by assuming that liquid melts are fed to a mixing tank with a cooler or heater.

The energy consumption for different fertilizer grades can, in this way, be estimated by summing up the energy allocated to the different product building blocks, which the fertilizer product can be split up into.

As fertilizer sites normally have a net import of energy, export of steam (from ammonia, nitric acid and sulphuric acid plants) will be given the full energy credit (2.5 GJ/t normal steam). The electric energy consumption is normally very small, thus the energy losses from the production of electric energy is not included in the product building blocks.

The same product building block principle will be used for calculation of the Greenhouse gases (CO₂, N₂O) related to production of different fertilizers.

3. FROM FERTILIZERS TO PRODUCT BUILDING BLOCK

To split any fertilizer grade up into product building blocks, the composition of the main building blocks must be known:

Table 1 - Nutrient Content in Fertilizer Building Blocks

Product	N	P ₂ O ₅	K ₂ O	SO ₃	
AP	11	49			Ammonium Phosphate
NITRO AP	8	52			Ammoniated Nitrophosphate acid
Urea	46				Urea
AN	35				Ammonium Nitrate
AS	21			59	Ammonium Sulphate
CN	16				Calcium Nitrate
KN	14		44		Potassium Nitrate
MAP	11	52			Mono Ammonium Phosphate
DAP	18	46			Di Ammonium Phosphate
TSP		48			Triple Superphosphate
SSP		21		25	Single Superphosphate
MOP			60		Potassium Chloride
SOP			50	46	Potassium Sulphate

AP (Ammonium Phosphate) is defined as the P₂O₅ component in phosphoric acid based NPK products. 95% of the P₂O₅ is MAP and DAP (90 - 10 distribution), while 5% are citrate soluble phosphates.

NITRO AP (Ammoniated Nitrophosphate acid) is defined as the P₂O₅ component in Nitrophosphate based fertilizers. 75% of the P₂O₅ is MAP and DAP (90 - 10 distribution), while 25% is citrate soluble phosphate (mainly dicalcium).

Except for AP and NITRO AP, all the other product building blocks are also commercial fertilizers.

Any fertilizer product can be composed by these main product building blocks and inert solid materials like:

- dolomite (15% MgO)
- gypsum (50% SO₃)
- kiserite (29% MgO, 58% SO₃)
- limestone
- additives
- Other inert salts.

Building block example for straight N fertilizers:

- CAN 26.5:
 - 75.6% AN [26.5*100/35] plus 24.4% inert (dolomite or limestone + additives).
- AN 33.5:
 - 95.7% AN [33.5*100/35] plus 4.3% inert (dolomite or limestone + additives).

Building block example for Superphosphate containing fertilizer:

- PK 22-22:
 - 45.8% TSP [22*100/48], 36.7% MOP [22*100/60] and 17.5% inert.

NPK grades are more difficult to split up into building blocks. We need to know the water soluble P_2O_5 content and if AS, Urea or AN are used to increase the N-content. If the nitrate content is analysed in the NPK grade, the AN content will be the double on N-basis [AN = $NO_3-N*2*100/35$].

Building block examples for NPK 15-15-15 based on:

- AN and phosphoric acid (95% water soluble P_2O_5) plus MOP:
 - 25% MOP [15*100/60], 30.6% AP [15*100/49], 33.2% AN [(15-30.6*11/100)*100/35] and 11.2% inert.
- Nitrophosphate (75% water soluble P_2O_5) plus MOP:
 - 25% MOP [15*100/60], 28.8% NITRO AP [15*100/52], 35.9% AN [(15-28.8*8.4/100)*100/35] and 10.3% inert.
- AS and DAP and MOP (in fact Triple 14.8):
 - 24.7% MOP [14.8*100/60], 32.4% DAP [14.9*100/46], 42.7% [(14.9-32.4*18/100)*100/21] and 0.2% inert.
- Urea, TSP and MOP:
 - 25% MOP [15*100/60], 31.2% TSP [15*100/48], 32.6% Urea [15*100/46] and 11.1% inert.

If a product contains sulphur, it is important to know the amount added as AS. AS can not be used in NS fertilizers if the AN content is above 45%.

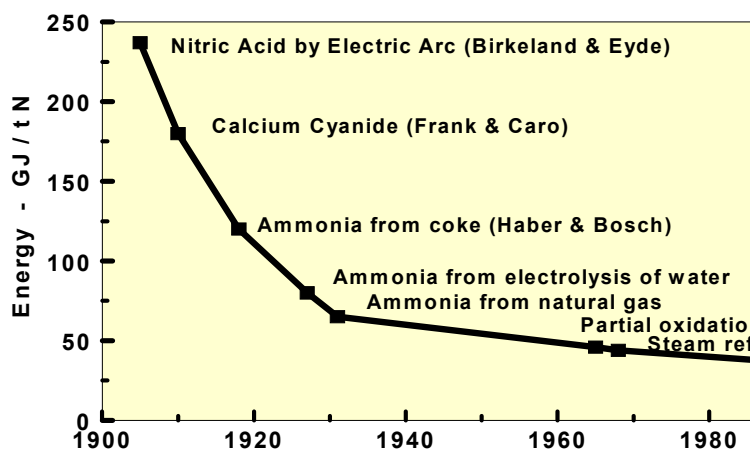
Building block example for sulphur containing products:

- ANS 26-0-0-35 SO_3 :
 - 59.3% AS [35*100/59], 38.7% AN [(26- 59.3*21/100)*100/35] and 2% inert.
- UREAS -40-0-0-14 SO_3 :
 - 24% AS [*100/59], 76% Urea [(40-24*21/100)*100/46].
- NS 24-0-0-12 SO_3 :
 - 69% AN [24*100/35], 24% Gypsum [12*100/50] and 7% inert (dolomite).

4. PRODUCTION OF INTERMEDIATES

4.1 N-fixation

Figure 2 - Historic Development of Energy for N-fixation



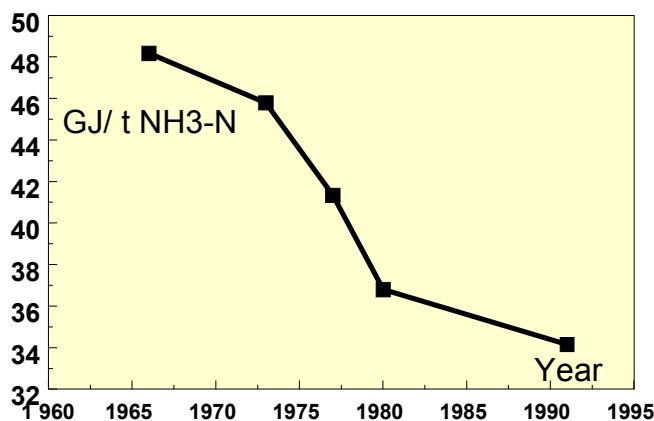
The chemical fixation of nitrogen requires the majority of energy in fertilizer production.

During the last 90 years significant improvements have been achieved by introducing new processes and continuously improving existing processes.

Today ammonia production is the only alternative for chemical fixation of nitrogen.

4.2 Production of Ammonia

Figure 3 - Net Energy Consumption for Ammonia Plants



During the last 30 years, significant energy savings have been achieved by improvement of the steam reforming ammonia process (BAT given by Max Apfel, 1997 - CRU Publishing Ltd., ISBN 1 873387 26 1).

As the graph shows, the first oil crisis in the early 1970s accelerated significant improvement in process design to improve energy consumption. This improvement has been mainly related to utilisation of fuel. The amount of natural gas as feed has in fact increased for the most optimised processes.

Early oil and coal based ammonia plants could consume in the order of 50 - 60 GJ/t N in total. Today a modern natural gas based ammonia plant operates with following energy balance:

Table 2 - Energy Balance for Modern Ammonia Plant

	GJ / t NH ₃	GJ / t N	t CO ₂ /t N
Feed	25	30.5	1.74
Fuel	5.6	6.8	0.39
Gas Consumption	30.6	37.3	2.13
Electricity	0.2	0.2	0.01
Steam export	-2.5	-3	-0.17
Net balance	28.3	34.5	1.97

Approximately 82% of the natural gas is used as feedstock, while 18% is used as fuel. Including the energy credit, 88% of the net energy consumption is used as feed. The energy loss for production of electrical energy is not included (50% for Combined Cycle and 65% for Steam Turbine).

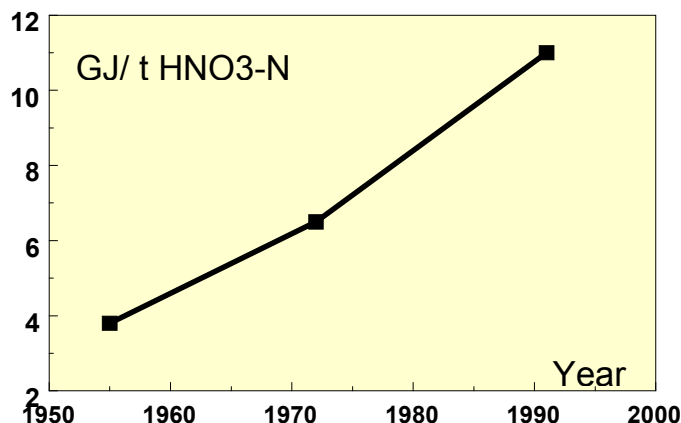
Average net consumption for European plants is assumed to be 39 GJ/t N (28 GJ/t N representing the feed and 11 GJ/t N as net fuel). 30 years ago, the best plants operated with approximately 47 GJ/t N (28 GJ/t N as feed and 19 GJ/t N as net fuel).

The energy improvement has consequently also reduced the total CO₂ emission. A modern ammonia plant, given credit for energy export should be charged by a net emission of ~2.0 t CO₂/t NH₃-N, of which ~1.75 t CO₂/t N is pure CO₂ gas generated from feedstock.

The average European CO₂ formation in ammonia plants is 2.2 t CO₂/t N, while 30 years ago the net CO₂ emission was around 2.7 t CO₂/t N.

4.3 Production of Nitric Acid

Figure 4 - Net Energy Export for Nitric Acid Plants



The Nitric Acid process has also undergone significant energy improvements during the last decades, from atmospheric combustion pressure, via mono medium pressure units to dual pressure plants operating with high absorption pressure.

The reaction from ammonia to 60% nitric acid theoretically releases 28.5 GJ/t HNO₃-N. However, the energy lost in gas compressors and cooling, reduces the net steam export.

Today a modern dual pressure nitric acid plant has a net energy export of 11.0 GJ/t HNO₃-N as high pressure steam (60 bar). The average net energy export for European plants is assumed to be 7 GJ/t N, while the best plants 30 years ago had a net export of 5 GJ/t N.

If all the released thermal energy is converted to electrical power in a steam turbine, the net energy export will be reduced by approximately 65%.

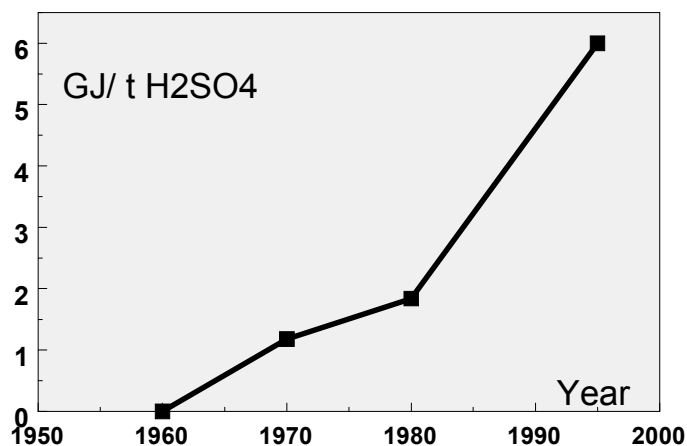
Oxidation of ammonia generates the Greenhouse gas nitrogen oxide (N₂O), giving around 700-1300 PPM in the tail gas. Increases in combustion pressure from 1 to 5 bar has slightly increased the N₂O emission. A good average for the European plants is 0.03 t N₂O/t N, corresponding to 9 t CO₂-eq./t N. 30 years ago, the best plants generated around 8 t CO₂-eq./tN.

Hydro Agri has developed a N₂O abatement process giving 70-85% N₂O reduction. This process, most suitable for new plants, was successfully installed in the latest nitric acid plant designed and built by Hydro Agri (2000 MTPD plant in Porsgrunn, Norway). A plant with modern technology (BAT) will therefore have an emission of 2.5 tCO₂-eq./t HNO₃-N.

For calculation of the accumulated numbers, an average efficiency of 94% for conversion of ammonia to nitric acid is assumed.

4.4 Production of Sulphuric Acid

Figure 5 - Net Energy Export from Sulphuric Acid Plants



Sulphuric acid is required for production of phosphoric acid. It is a key auxiliary chemical for production of 80% of the world's phosphate fertilizers.

The energy consumption for the production of 98% sulphuric acid (H₂SO₄) varies depending on process, sulphur form and origin. Due to improved equipment material and energy focus, the net energy export from the best plants has increased significantly.

Sulphur mining is energy intensive (corresponding to ~2 GJ/t acid), but as the majority of sulphur used is recovered from natural gas and fuel oil, no energy will be linked to the sulphur raw material.

The most modern sulphuric acid processes today generate steam equivalent to a net energy export of 6.0 GJ/t H₂SO₄. Some old plants can have net energy consumption, but the average energy export from European plants is assumed to be 3.0 GJ/t H₂SO₄. 30 years ago the best plants exported around 1.0 GJ/t H₂SO₄.

4.5 Production of Phosphoric Acid

Phosphate rock and Sulphuric Acid are the raw materials for producing phosphoric acid. Approximately 5 tonnes of phosphate ore must be mined and beneficiated to produce 1 tonne of commercial phosphate rock with average content of 32% P₂O₅ (50% CaO). The total energy requirement for production of dry sedimentary phosphate rock is as low as 0.1 GJ/t (0.3 GJ/t P₂O₅) for the easiest ore to be upgraded. This has slightly been improved during the last decades. Mining of apatite rock require higher energy consumption. As apatite rock is mined in Europe and several plants in Europe use it, the average number is assumed to be 0.9 GJ/t (2.8 GJ/t P₂O₅).

One of the main objectives for development of the phosphoric acid process during the last years has been to increase P₂O₅ efficiency and to minimise energy consumption. This has entailed improved agitator design and increases of acid concentration leaving the gypsum filter.

The hemihydrate process is by far the most energy efficient as the filter acid can be as high as 48-50% P₂O₅. The most energy efficient process design requires 1.5 GJ/t P₂O₅ for production of 48% P₂O₅ containing acid. However, due to filtration rate, most of the hemihydrate plants produce 42% P₂O₅. This give slightly higher energy consumption as concentration of the acid from 42% to 48% P₂O₅ requires around 1.0 GJ/t P₂O₅.

The dihydrate process requires ground rock, and yields ~28% P₂O₅ from the filter and lower P₂O₅ efficiency. Therefore the energy consumption is some 4 GJ/t P₂O₅ higher. Rational use of the energy export from the sulphuric acid process is the main reason for choosing the simple dihydrate process

The sulphuric acid requirement is 2.76 t H₂SO₄/t P₂O₅ for the given rock specification.

The given energy for the hemihydrate "BAT" process does not include upgrading or disposal of gypsum.

The data is based on 48% P₂O₅ to simplify the following calculations. However 54% P₂O₅ is the standard concentration for merchant acid, and thus require additional evaporation and increased energy consumption in the range of 1.0 GJ/t P₂O₅.

Table 3 - Energy Consumption for Sulphuric Acid and Phosphoric Acid

Product	Material input	BAT 30 yr. Ago	Average Europe	BAT today	
Sulphuric acid	S	-1.0	-3.0	-6.0	GJ/t H ₂ SO ₄
Sulphuric acid	S	-2.8	-8.3	-16.6	GJ/t P ₂ O ₅
Phosphate rock	Ore	1.0	2.8	0.3	GJ/t P ₂ O ₅
48% Phosph. Acid	Phosph. rock	8.0	6.0	1.5	GJ/t P ₂ O ₅
48% Phosph. Acid	Ore + S	6.2	0.5	-14.8	GJ/t P ₂ O ₅
54% Phosph. Acid	Ore + S	7.2	1.5	-13.8	GJ/t P ₂ O ₅

5. PARTICULATION AND BLENDING OF BUILDING BLOCKS

Primary particulation of product building blocks is carried out in prilling and granulation processes. These units can also be used for a second pass of product building blocks, in addition to compaction units and bulk blending units.

The prilling process requires almost water free melt as input (0.5% H₂O), while the granulation processes use between 0.5 and 15% water (standard 5%) in the melt depending on process and product grade. A 95% urea or AN melt can be used as basis for comparison of processes:

Table 4 - Energy Consumption for Various Particulation Processes

Numbers in GJ/t product	Prilling	Pan	Fluid bed	Drum *
Evaporation 95 to 99.5%	0.15	0.15	0	0
Particulation energy	0.1	0.2	0.45	0.5
Total energy	0.25	0.35	0.45	0.5

*) drum, pug-mill or spherodizer granulator.

The prilling process can not be chosen as the BAT for all products, as it is not suitable for many fertilizers. The most optimum particulation process is chosen for the different building blocks in the energy estimations.

Steam granulation of powder, compaction or blending is mostly used for the "second" pass of product building blocks.

Table 5 - Energy Consumption for Solid Mixing Processes

Numbers in GJ/t product	Steam Granulation	Solid Compaction	Bulk Blending
Total energy	1.1	0.7	~0

If solid additives must be ground before entering a particulation unit, the additional energy requirement will be ~0.4 GJ/t product.

6. PRODUCTION OF N-CONTAINING BUILDING BLOCKS

6.1 Production of Urea

The development of urea processes during the last decades has focused on reducing production costs and emission levels. Reduction of emission levels and introduction of "total recycling" has increased energy consumption, but the focus on heat recovery and reduction of utilities has overall reduced the energy consumption. Today different urea processes have almost the same energy requirement.

In a modern total "recycling" urea process, conversion of ammonia to a solid urea requires 7.2 GJ/t N (3.3 GJ/t urea). It is assumed that the average requirement for European plants is 9 GJ/t N, and that the best plants 30 years ago operated with 10 GJ/t N.

Production of urea is always linked to an ammonia plant due to the consumption of CO₂. The consumption is 0.733 t CO₂/t urea (1.6 tCO₂/t N). Urea production reduces therefore the emission of CO₂, corresponding to 1.6 tCO₂/t N as urea. In a Life Cycle Analysis for fertilizers, it is not correct to include this reduced emission, as the CO₂ will be released during usage of the fertilizer. However, in this paper it is included as only production of fertilizers is covered.

For calculation of the accumulated values, an overall efficiency of 100% for conversion of ammonia to urea (0.567 t NH₃/t urea) is assumed.

6.2 Production of Ammonium Nitrate

Neutralisation of nitric acid by ammonia to ammonium nitrate (AN) also releases energy. This energy is used to remove the water.

Introduction of pressure neutralisers with recycling and heat recovery has significantly improved the energy utilisation. A steam generator is installed in the neutraliser recycle loop. Today the most modern plants do not need additional heat to remove the water in the melt.

The energy consumption for modern AN plants is 0.15 GJ/t AN (0.43 GJ/t N). It is assumed that the average energy consumption in Europe today is 0.7 GJ/t AN (2.0 GJ/t N). 30 years ago atmospheric neutralisation in an agitated tank was the standard. The energy consumption for the best plants then is assumed to have been 1.4 GJ/t (4 GJ/tN).

For calculation of the accumulated values, an overall efficiency of 97% for conversion of ammonia to ammonium nitrate is assumed.

6.3 Production of Calcium Nitrate

Today most calcium nitrate (CN) is produced as by-product from nitric acid acidulation of phosphate rock (Nitrophosphate process). This gives the lowest energy consumption for production of CN melt, equal 5.2 GJ/t N (0.8 GJ/t product). Some 30 years ago however, the majority of calcium nitrate was produced by nitric acid acidulation of limestone which required approximately 27 GJ/t N (3.9 GJ/t CN). The average for Europe is assumed to be 6.5 GJ/t N.

6.4 Production of Potassium Nitrate

Except for the production in Chile, potassium nitrate (KN) is produced by ion exchange process based on nitric acid and muriate of potash. The main energy consumption for the ion exchange process is related to evaporation of the 20-25% KNO₃ solution produced. Total energy for an ion exchange process is 6 GJ/t KNO₃. To simplify the building block concept, all the energy will be linked to the N-content. This gives an energy requirement of 43 GJ/t N.

6.5 Production of Ammonium Phosphates

Ammonia neutralisation of phosphoric acid releases energy. To simplify the calculations, the neutralisation energy is assigned to the P_2O_5 nutrient (see the P_2O_5 chapter).

Ammonia conversion factor to N in ammonium phosphates is assumed to be 100%.

6.6 Production of Ammonium Sulphate

Most of the ammonium sulphate (AS) used in fertilizers is by-products from caprolactam production or gas scrubbing. However a small amount is produced synthetically or produced captive in fertilizer processes. The captive production requires negligible energy and the synthetic route requires around 0.8 GJ/t AS (1.3 GJ/t SO_3). Upgrading of the AS solution from a caprolactam plant requires in the order of 3 GJ/t AS (5 GJ/t SO_3).

From an energy viewpoint, the Best Available Technology is captive production from sulphuric acid and ammonia. The majority of AS used is by-product. As these processes are not included, it will in this analyses be correct not to charge any energy to the AS (allocate instead the energy to the process generating the AS by-product).

Table 6 - Energy Balance for Production of Ammonium Sulphate

	BAT 30 yr. Ago	Average Europe	BAT today	
AS process	0.0	0.0	0.0	GJ/t SO_3
Sulphuric Acid	-1.2	-3.7	-7.4	GJ/t SO_3
AS from S and NH_3	-1.2	-3.7	-7.4	GJ/t SO_3
AS from S and NH_3	-3.4	-10.3	-20.7	GJ/t N

In the last line of the table, the energy is referred to the nitrogen component in AS.

6.7 Liq. UAN (32% N)

Liquid UAN is produced by diluting melts of AN and urea in a tank with an agitator and cooler. Consequently, it is not necessary to carry out any final evaporation of the melt. Mixing, cooling and storage of the UAN is assumed to consume 0.7 GJ/t N (0.22 GJ/t liq. UAN).

When using the solid building blocks to calculate the accumulated energy consumption linked to liq. UAN, 0.2 and 0.4 GJ/t N must be deducted from the urea and AN building blocks respectively. This gives a net energy consumption for production of liq. UAN versus solid urea and AN of 0.40 GJ/t N [0.7 - 0.2*0.5 - 0.4*0.5].

No difference between the average and the best producer today and 30 years ago is assumed. Since 50% of the nitrogen in UAN is originated from urea, the net binding of CO_2 will be 0.8 t CO_2 /t N.

6.8 Summary of Nitrogen containing building blocks

Table 7 - Accumulated Energy Consumption for N-containing Building Blocks

Product Building Blocks	Material input	"Old" tech.	"Aver." Europe	Modern technology	
		GJ/t N	GJ/t N	GJ/t N	tCO ₂ /t N
Ammonia	Natural gas	50.0	39.0	34.5	2
Nitric Acid	NH ₃	-2.0	-7.0	-11.0	2.5
Urea	NH ₃	10.0	9.0	7.2	-1.6
AN	NH ₃ + HNO ₃	4.0	2.0	0.4	0
AS	NH ₃ + H ₂ SO ₄	-3.4	-10.3	-20.7	0
CN	HNO ₃ + Ca---	27.0	6.5	5.2	0
KN	HNO ₃ + KCl	50.0	46.0	43.0	0
*MAP/DAP/AP *	NH ₃ +H ₃ PO ₄	0.0	0.0	0.0	0
Liq. UAN	AN + Urea melts	0.4	0.4	0.4	-0.8
Accumulated numbers					
Urea	Natural gas	60.0	48.0	41.7	
AN	Natural gas	54.5	38.7	30.5	
AS	Natural gas + S	46.6	28.7	13.9	
CN	Natural gas	78.3	41.4	31.6	
KN	Natural gas	101.2	80.5	68.7	
MAP/DAP/AP *	Natural gas + ore	50.0	39.0	34.5	
Liq. UAN	Natural gas	57.7	43.8	36.5	

*) including NITRO AP

7. PHOSPHATE BASED PRODUCTION PROCESSES

7.1 Production of Ammonium Phosphates (MAP/DAP/AP)

Production of ammonium phosphates have developed through phases from atmospheric neutralisation in tanks with agitators, to pressure neutralisation and finally to pipe reactors in the granulator and/or the dryer. Today the most energy efficient processes utilise pipe reactors. There is no difference in energy requirement for MAP or DAP (or the mixture illustrated as AP).

By utilising 48% phosphoric acid and ammonia in a modern granulation unit with pipe reactor, the net energy consumption will be 0.35 GJ/t product, equal to 0.7 GJ/t P₂O₅. The energy consumption can be split in 55% natural gas, 30% electricity and 15% steam.

Most European plants are producing AP melts as the NPK base. The operation of old plants is partly compensated by using 54% merchant acid, thus the average energy requirement is assumed to be 0.9 GJ/t P₂O₅. This is also assumed to be the best energy requirement 30 years ago.

7.2 Production of Nitrophosphate (NITRO AP)

Nitrophosphate based complex fertilizers use nitric acid attack of phosphate rock instead of sulphuric acid. The process gives calcium nitrate as by product, which can be converted to AN.

The Nitrophosphate melt (NITRO AP) is comparable to the phosphoric acid based AP melt. The main difference is that NITRO AP melts contain approximately 25% P₂O₅ as dicalcium phosphate and are always mixed with AN.

The most energy efficient Nitrophosphate processes utilise pressure neutralisers and prilling. This process requires in the order of 4.6 GJ/t P₂O₅ to convert the rock to solid Nitrophosphate building blocks. It is assumed that the average in Europe is 6.3 GJ/t P₂O₅, and that the best plants 30 years ago operated with 6.6 GJ/t P₂O₅.

7.3 Production of Triple Superphosphate Melts

Triple Superphosphate (TSP) is produced from phosphoric acid and phosphate rock. 70% of the P₂O₅ feed is supplied as acid and 30 % as rock.

More than 75% of the TSP is produced in the two step process based on 54% merchant phosphoric acid. A powder is produced in the first step, where the main energy input is for rock grinding. The run of pile powder is granulated with steam in the second step. Muriate of potash is often added to the granulation unit to produce PK grades.

The total energy consumption based on 48% acid is 4.1 GJ/t P₂O₅. This corresponds to 2.0 GJ/t product of which 0.7 is used for evaporation, 0.3 for powder production and 1.0 for granulation.

A slurry process based on 42% acid has approximately 20% lower energy consumption. However, due to the need of a very soft rock and problems with unreacted rock in the product, this route is not the Best Available Technology.

Energy consumption for the two step process is therefore used. 4.0 GJ/t P₂O₅ is assumed as both the average in Europe and for the best plants 30 years ago.

7.4 Production of Single Superphosphate

Single superphosphate (SSP) is produced from sulphuric acid and phosphate rock. The two step process is very similar to the TSP process (often identical).

The total energy consumption is 6.7 GJ/t P₂O₅. This correspond to 1.4 GJ/t product, of which 0.4 is for powder production and 1.0 for granulation.

The overall feed is approximately 1.75 t H₂SO₄/t P₂O₅.

7.5 Summary of phosphate containing building blocks:

Table 8 - Accumulated Energy Consumption for P₂O₅-containing Building Blocks

Product Building Blocks	Material Input	"Old" tech.	"Aver." Europe	Modern technology
		GJ/P ₂ O ₅	GJ/P ₂ O ₅	GJ/P ₂ O ₅
Rock	Ore	1.0	2.8	0.3
48% Phosph. Acid	Ore + S	6.2	0.5	-14.8
MAP/DAP/AP	NH ₃ +H ₃ PO ₄	0.9	0.9	0.7
Nitro AP	NH ₃ + Rock	6.6	6.3	4.6
TSP	Rock + H ₃ PO ₄	4.1	4.1	4.1
SSP	Rock + H ₂ SO ₄	6.7	6.7	6.7
Accumulated numbers				
MAP/DAP/AP	Ore	7.1	1.4	-14.1
NITRO AP	Ore	7.6	9.1	4.9
TSP	Ore	8.8	5.3	-6.1
SSP	Ore	5.0	1.5	-3.8

8. ENERGY IN POTASH PRODUCTS AND INERT

8.1 Mining and Production of Potassium Chloride (MOP)

Production of potassium chloride (muriate of potash, 60 % K₂O) is mainly carried out by shaft mining and beneficiation. This gives also the lowest energy requirement. The most energy efficient potash processes based on a high quality sylvinite salt, require only 1.5 GJ/t MOP (2.5 GJ/t K₂O). The energy consumption vary however a lot, and numbers up to 6 GJ/t MOP is reported for mining of more mixed salts

The average energy consumption in Europe is roughly assumed to be 3 GJ/t MOP (5.0 GJ/t K₂O), while the best plants 30 years ago is assumed to be around 4 GJ/t (6.7 GJ/t K₂O).

8.2 Production of Potassium Sulphate (SOP)

Potassium sulphate is mined from mixed salts containing potassium and magnesium (Langbeinite, Kainite, Schoenite, etc.). The total energy consumption for mining and beneficiation of potassium sulphate is not given as the mining companies do not split the energy on the different products. 2.0 GJ/t SOP is a rough estimate.

Today most of the SOP is produced synthetically from sulphuric acid and MOP in the Mannheim process. This process requires that hydrochloric acid solution generated as by-product can be utilised (no energy is linked to this by-product).

An efficient two step process requires around 2.7 GJ/t SOP (5.4 GJ/t K₂O), split on 7% electrical energy and 93% fuel). The average energy consumption for the Mannheim process is assumed to be 3.1 GJ/t SOP (3.4 GJ/t SOP 30 years ago).

Since the production of 1 tonne requires 0.57 tonne sulphuric acid SOP in the Mannheim process, the accumulated energy requirement for the best plants will be very low. The sulphuric acid data from table 5 (-1.0, -3.0, -6.0 GJ/t H₂SO₄) combined with the Mannheim process data (3.4, 3.1, 2.7 GJ/t SOP) give 2.8 GJ/t SOP 30 years ago, 1.4 GJ/t SOP as average Europe and -0.7 GJ/t SOP as the best today. The data show that the Mannheim process is the most energy efficient process today if the energy generated in the sulphuric acid process can be utilised. 2.0 GJ/t K₂O (mining) will be used as the energy for the best process 30 years ago.

8.3 Energy Consumption for Inert Additives

The main inert additives are dolomite and limestone. Mining of these additives is assumed to require approximately 0.8 GJ/t product.

9. TOTAL ENERGY CONSUMPTION FOR THE PRODUCT BUILDING BLOCKS

All given data can now be used to calculate the energy content in the different building blocks and for all kinds of fertilizer grades. The data is based on accumulated energy from natural gas, different salts and rock ores and elementary sulphur.

Table 9 - Accumulated Energy Consumption for Building Blocks and Some Fertilizer Grades

Product building blocks		"Old" tech.	Av. Europe	Modern tech.	"Old" tech.	Av. Europe	Modern tech.	Feed energy	Feed CO ₂
		GJ/t	GJ/t	GJ/t	t CO ₂ /t*	t CO ₂ /t*	t CO ₂ /t*	GJ/t	t CO ₂ /t
NH ₄	82-0-0	41.0	32.0	28.3	2.51	1.91	1.66	23.37	1.33
AP	11-49-0	9.0	5.0	-3.1	0.57	0.30	-0.24	3.14	0.18
NITRO AP	8.4-52-0	7.5	7.2	5.1	0.48	0.45	0.31	2.57	0.15
Urea	46-0-0	27.6	22.1	19.2	0.98	0.61	0.42	13.11	0.75
AN	35-0-0	19.1	13.5	10.7	2.58	2.38	1.05	10.28	0.59
AS	21-0-0-23	9.8	6.0	2.9	0.60	0.34	0.14	5.99	0.34
CN	15.5-0-0	12.1	6.4	4.9	1.93	1.69	0.65	4.55	0.26
KN	14-0-44	19.1	11.3	9.6	2.36	1.97	0.95	4.24	0.24
MAP	11-52-0	9.2	5.0	-3.5	0.59	0.31	-0.27	3.14	0.18
DAP	18-46-0	12.3	7.7	-0.3	0.77	0.46	-0.07	5.13	0.29
TSP	0-48-0	4.2	2.5	-2.9	0.28	0.17	-0.20	0.00	0.00
SSP	0-21-0-23	1.0	0.3	-0.8	0.07	0.02	-0.05	0.00	0.00
MOP	0-0-60	6.7	5.0	2.5	0.45	0.34	0.17	0.00	0.00
SOP	0-0-50-46	2.0	1.4	-0.7	0.13	0.10	-0.04	0.00	0.00
Liq. UAN	32-0-0	28.8	21.9	18.2	1.53	1.31	0.64	9.12	0.52
Derived products									
CAN	26.5	14.8	10.6	8.4	2.0	1.82	0.80	7.87	0.45
AN	33.5	18.3	13.0	10.2	2.5	2.28	1.00	9.84	0.56
PK	22-22-0	4.5	3.1	-0.3	0.3	0.20	-0.03	0.00	0.00
NPK	15-15-15 Phosph. acid	10.9	7.4	3.3	1.1	0.97	0.32	4.37	0.25
NPK	15-15-15 Nitrophosphate	9.1	7.2	5.1	0.9	0.83	0.41	3.45	0.20
NPK	15-15-15 AS/TSP/MOP	10.1	6.5	1.5	0.6	0.39	0.06	4.13	0.24
NPK	15-15-15 Urea/TSP/MOP	12.1	9.3	6.0	0.5	0.34	0.12	4.27	0.24
ANS	26-0-0-35 AN+AS	13.2	8.8	5.9	1.3	1.12	0.49	7.53	0.43
UREAS	40-0-0-14 Urea + AS	23.3	18.2	15.3	0.9	0.55	0.35	11.40	0.65
NS	24-0-0-12, AN + gypsum	13.4	9.5	7.6	1.8	1.64	0.72	7.10	0.40

*) including N₂O

Example of the calculations for "Modern technology":

- DAP energy: $-0.3 \text{ GJ/t} = 34.5 \text{ GJ/t N} * (18\% \text{ N} / 100) + -14.1 \text{ GJ/t P}_2\text{O}_5 * (46\% \text{ P}_2\text{O}_5 / 100)$
 feed energy: $5.1 \text{ GJ/t} = 28.5 \text{ GJ/t N} * (18\% \text{ N} / 100)$
 fuel energy: $-1.1 \text{ GJ/t} = -0.3 - 5.1 \text{ GJ/t}$
 feed CO₂: $0.29 \text{ t CO}_2/\text{t} = 28.5 \text{ t CO}_2/\text{t N} * (18\% \text{ N} / 100)$
 fuel CO₂: $-0.36 \text{ t CO}_2/\text{t} = -5.4 * 0.067 \text{ GJ/t N}$
 total CO₂: $-0.07 \text{ t CO}_2/\text{t} = 0.29 - 0.36$
- ANS 26-0-0-35 (38.7% AN + 59.3% AS + 2% inert):
 energy: $6.7 \text{ GJ/t} = 0.387 * 10.7 + 0.593 * 2.9 + 0.02 * 0.8$
 feed energy $7.5 \text{ GJ/t} = 0.387 * 10.3 + 0.593 * 6.0$
 total CO₂: $0.49 \text{ GJ/t} = 0.387 * 1.05 + 0.593 * 0.14$

For calculation of the CO₂ generated from fuel, it is assumed 85% efficiency from natural gas since most of the generated energy is used as steam (90% efficiency for steam production). This gives: $0.067 \text{ t CO}_2/\text{GJ} = 0.057/0.85$.

10. ENERGY AND GREENHOUSE GAS EMISSION RELATED TO WORLD FERTILIZER CONSUMPTION

IFA monitor the world nutrient consumption by products, available on Internet. To be able to use this data, it has been necessary to split some of the IFA products on different product building blocks.

For N consumption:

- N-solutions: 100% UAN- based,
- NK compounds: 100% KN-based,
- NPK compounds: 45% AN-based, 25% urea-based, 20% AS-based, 10% MAP/DAP-based,
- Others: 70% NH₄-based (i.e. NH₃), 5% CN-based, 25% AS-based

For P₂O₅ consumption:

- PK compounds: 100% TSP-based,
- NPK compound: 60% AP-based, 30% NITRO-based, 10% TSP-based
- Others: 30% SSP-based, 70% TSP-based

For K₂O consumption:

- NK compounds: 100% MOP-based,
- PK compounds: 100% MOP-based,
- NPK compound: 80% MOP-based, 20% SOP,
- Others: 100% MOP-based

Table 10 - World Energy Consumption and CO₂-eq. Emission from Production of Fertilizers

Building block	World cons.	Specific energy		Total energy cons.		Total CO ₂ emission	
		World	"Best"	World	"Best"	World	"Best"
	mill. t N	GJ/t N		mill. GJ/yr.		mill. t CO ₂ /yr	
NH ₃ + NH ₄	12.6	44.5	34.5	563	436	34	26
Urea	38.1	54.0	41.7	2056	1588	66	35
AN	14.2	46.6	30.5	662	433	101	43
AS	37.6	13.9	225	225	83	13	4
CN	0.6	59.9	31.6	34	18	7	2
KN	0.04	90.8	68.7	4	3	1	0.3
MAP/DAP/AP	7.0	44.5	34.5	313	243	19	14
Liq. UAN	4.1	50.3	36.1	206	148	20	10
Total N:	82.7	49.2	35.7	4065	2953	260	133
	mill. t P ₂ O ₅	GJ/t P ₂ O ₅		mill. GJ/yr.		mill. t CO ₂ /yr.	
Rock	0.3	1.9	0.3	1	0	0.6	0.1
MAP/DAP/AP	17.2	4.3	-14.1	74	-242	4.9	-16.2
Nitro	2.0	8.4	4.9	17	10	1.1	0.7
TSP	4.5	7.0	-6.1	32	-28	2.1	-1.9
SSP	7.0	3.2	-3.8	22	-27	1.5	-1.8
Total P₂O₅	31.0	4.7	-9.2	145	-286	10	-19
	mill. t K ₂ O	GJ/t K ₂ O		mill. GJ/yr.		mill. t CO ₂ /yr.	
MOP	18.8	9.8	4.2	184	79	12.3	5.3
SOP	2.0	3.4	-1.3	7	-3	0.5	-0.2
Total K₂O	20.8	9.2	3.6	191	76	13	5
Total N+P₂O₅+K₂O	134	32.2	20.3	4400	2743	283	119

According to this analysis, the energy consumed for the world fertilizer production is 4400 mill. GJ/yr, of which 92.5% is used for production of the N component, 3% for the P₂O₅ component and 4.5% for the K₂O component. Approximately 53% (2350 mill. GJ/yr) of the energy consumption is supplied as feedstock to the ammonia plants, the remaining 47% (2000 mill. GJ/yr) is fuel energy.

By renewing the bulk of the plants with modern technology, it should theoretically be possible to reduce the total energy content by 37% to 2743 GJ/yr. The main potential is related to fuel for ammonia plants (10 GJ/t N, from 44.5 to 34.5). This will be achieved during the next 20-30 years. We have experienced that most of the European ammonia plants combine a small capacity revamp together with improvement of the energy efficiency.

A similar analysis as shown in Table 11 has been carried out with the specific energy numbers assumed to be the best 30 years ago (BAT1968) and with the average numbers for the European fertilizer industry:

Table 11 - Global Energy Consumption Today and for Different Scenarios

134 mill. t N+P₂O₅+K₂O	GJ/yr	% of today
BAT 1968	5040	115
World today	4400	100
European standard	3760	85
BAT 1998	2743	63

The table shows that the specific energy consumption has improved during the last 30 years, and that Europe has approximately 15% lower specific energy consumption than the world average today.

The world fertilizer production gives a gross emission of Greenhouse gases equivalent to 283 mill. t CO₂/yr. This is 134 mill. t CO₂/yr (48%) as flue gas from energy production, 74 mill. t CO₂-eq./yr (26%) as N₂O from production of approximately 70 mill. t/yr nitric acid and 75 mill. t CO₂/yr (26%) as pure CO₂. Around 12 mill. t/yr of pure CO₂ from the ammonia plants is used for technical applications (total global application of CO₂ is 13.5 mill. t CO₂/yr)

A reduction of energy consumption will also reduce the CO₂ emission. The theoretic reduction potential is 164 mill. t CO₂/yr, from 293 to 119 mill. t CO₂/yr. A fuel reduction of 10 GJ/t N in ammonia plants will reduce the CO₂ emission by 47 mill. t CO₂/yr. Introduction of new N₂O reduction technology, which Hydro Agri has developed (mainly for new plants) could also reduce the Greenhouse gas emission by 52 mill. t CO₂-eq./yr. The remaining gap of 65 mill. t CO₂/yr is related to several energy improvements achieved in process design during the last years.

11. ENERGY AND GREENHOUSE GAS EMISSION FOR EUROPEAN FERTILIZER PRODUCTION

A similar analysis is carried out for the European fertilizer production, based on data from IFA, EFMA and NITREX (NB: not the same split on building blocks as for the world):

Table 12 - Energy Consumption and CO₂-eq. Emission from the European Fertilizer Producers

	Europe cons.	Specific Energy		Total energy cons.		Total CO₂ emission	
	mill. t	Europe	"Best"	Europe	"Best"	Europe	"Best"
		GJ/t nutrient		mill. GJ/yr.		Mill. t CO ₂ /yr	
Total N:	10.7	40.3	32.2	431	344	56.6	26.2
Total P ₂ O ₅	2.7	3.4	-8.9	9	-24	0.6	-1.6
Total K ₂ O	5.4	7.3	3.2	40	17	2.6	1.1
Total N+P₂O₅+K₂O	18.8	25.5	18.0	480	337	60	26

The total energy consumption is 480 mill.GJ/yr, of which 305 mill.GJ/yr (65%) is feedstock to ammonia plants.

It is theoretically possible to reduce the energy consumption by 30% with new technology.

The emission of Greenhouse gases is 60 mill. t CO₂/yr, of which 9 mill. t CO₂/yr (15%) is flue gas, 34 mill. t CO₂-eq./yr (56%) is N₂O and 17 mill. t CO₂/yr (28%) is pure CO₂. Of the pure CO₂, around 2.8 mill. t CO₂/yr is used for technical application. It is possible to reduce the emissions by 57% introducing modern technology (25 mill. t CO₂/yr for N₂O reduction, 3 mill. t CO₂/yr as feedstock and 6 mill. t CO₂/yr as fuel reduction).

12. ENERGY AND EMISSION IN A GLOBAL PERSPECTIVE

The global energy consumption in 1997 was $360 \cdot 10^9$ GJ (40% oil, 23% natural gas, 27% coal, 7% nuclear, 3% hydro). The global production of fertilizers represents 1.2% of the consumed energy in the world ($0.44 \cdot 10^9$ GJ). By implementation of the most energy efficient process technology, the fertilizer industry could be reduced its energy utilisation by almost 40% to only 0.75% of the global energy consumption.

The global CO₂ emission is according to the OECD Environmental data for 1997, equal to $22 \cdot 10^9$ t CO₂. Based on the reported data, the global N₂O emission is estimated to be $2 \cdot 10^9$ tCO₂-eq./yr. The total is $24 \cdot 10^9$ t CO₂-eq./yr of CO₂ and N₂O.

The global production of fertilizers is responsible for 1.2% of the total emission of CO₂ and N₂O ($0.28 \cdot 10^9$ t CO₂-eq./yr). Technology renewal can reduce the CO₂+N₂O emissions by almost 60% to only 0.5% of the global emission.

West Europe (EU15) consumes approximately 14% of the world energy and release also 14% of the global emission of CO₂ and N₂O.

By a coincidence, West Europe produces also 14% of the world nutrients. The fertiliser production represent however, only 0.9% of the total energy consumption in West Europe. This low number is mainly a consequence of high energy cost in West Europe and upgrading of many plants. The energy consumption can be reduced by some 30% with the most energy efficient technology, to 0.66% of the West European consumption.

The West European fertiliser producers are responsible for 1.8% of the regional emissions of CO₂ and N₂O. This specific number is higher than the global due to relatively lower urea production and higher nitrate production. The Greenhouse gas emission from West European producers can however, be reduced by almost 60% (to 0.77% of the total emission) if modern technology is implied.

13. DISCUSSION

It has been very difficult to find relevant data for energy consumption related to fertilizers in the literature. A main reason may be that energy definitions are not clearly defined. It has therefore been necessary to make several assumptions based on reported data and data from Hydro Agri and other companies together with own fertilizer knowledge and judgement. These assumptions should however, not reduce the value of the final conclusions.

Data for transport has not been included in this study. Transport routes for the raw materials and intermediates could have been defined. Typical energy requirement for 1000 km transport is 0.1 GJ/t for bulk and liquid sea carriers, 0.4 GJ/t for pipeline, 0.7 GJ/t for rail and 1.9 GJ/t for truck (28t).

Full credit has been given to steam export from production units. This might be too optimistic when summing up the energy balance for some products based on "Modern Technology". The most energy efficient ammonia, nitric acid and sulphuric acid plants have today very high surplus of energy, especially the sulphuric acid plants. On the other hand, the most efficient phosphoric acid plants and the fertilizer plants require today very little supply of steam. This effect is especially seen for DAP/MAP and SSP/TSP products ending up with a negative accumulated energy requirement. The alternative had been to reduce the energy credit for steam export, but then the most energy efficient sites would not have been the reference.

Greenhouse gas emission is very closely linked to energy consumption and technology. EFMA has recently published booklets giving the Best Available Technology for different fertilizer processes. Surprisingly, all the booklets are lacking the energy consumption and the related Greenhouse gas emissions. Reduction of emissions very often requires an increased energy efficiency. Therefore Best Available Technology for energy utilisation must be linked to environmental requirements.

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