Inter-National Salvus Ambientium Consultancy

Final Report

The Possibility of Alternative Applications for Stripped Ammonia in the Business Market:

A Nutrient Recovery Base Research

June 14th 2016

Final Report

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Abstract

The problem of waste from the agriculture industry is prevalent across the globe with risks that are linked to negative consequences in the environment and human health. The Netherlands is one of the countries that has to deal with this issue as well, with a production of around 1.2 million tons of waste produced by the poultry industry alone. Thus resulting in the following issues that have resulted in farmer paying a lot of money (€ 20/ ton) for treatment (incineration):

- Limitiations to the direct applicability of the poultry waste as fertilizer because of nutrient concentrations
- Limitations to the valorization (energy recovery) of the poultry
- Increase costs of transporatation because of pretreatment
- Unavailability of viable procesesses for treatment of the waste

Colsen Engineering, a leading engineering firm - situated in The Netherlands - in the field of sustainability, technology and environment- has come up with an innovative solution to tackle this problem through their newly developed **Poul-AR®** process which allows for the recovery nutrients from poultry waste. But the monetization of these recovered nutrients is difficult to manage in the Netherlands due to competition with the conventional fertilizer industry. Therefore, the company is looking into alternative ways to valorizing the end products from their poular-process (e.g. ammonia), one of which is **AUS32** (Adblue) – a urea-based diesel exhaust fluid utilized in the automotive emission control.

Together with Avans university and I.N.S.A consultancy the company has undergone the following research project in which alternative applications for ammonia, the production process of **AUS32** and the possible markets for **AUS32** were analyzed.

The research method was based on a quantitative approach in which information was gathered and analyzed from different sources (e.g internet, books, conference proceedings etc.). First, a literature review allowed for the identification of background information. The second part of the project included further analysis of the information gathered in the literature review. The final part of the project included the formation of a conclusion based on results from the information analyzed in the second part.

An analysis and sustainability assesment of two techniques used for urea production (**Snamprogetti™** and **Stamicarbon™**) concluded, that out of the two techniques; the **Snamprogetti™** process is the most viable option for urea synthesis (which is a pre-step for the production of **AUS32**). This process has lower emissions to the environment and also consumes around 0.2 GJ less energy than the **Stamicarbon™** process. The only downside is that the conversion rate of ammonia and carbondixide into urea is around 8-12% lower compared to that of the **Stamicarbon™** process. Also, the **Snamprogetti™** is costlier.

Next, it was found that there are alternative applications for ammonia as an alternative fuel source or internal combustion engines or fuel cell sysems which can be possibly utlized in rocket propulsion or as a stranded renewable energy source.

Finally, the market study revelealed that North America (e.g. the United States of America) has viable market opportunities for **AUS32** given the current legislative and economic situation in America - with regard to the production and consumption patterns of **AUS32**.

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1 Introduction

This introductory chapter serves to put emphasis on a broad sense the research at hand.

1.1 Background

In The Netherlands around 1.2 million tons of poultry manure is produced every year, the manure contains minerals (e.g. high concentrations of phosphate, nitrogen, and organic matter) that can be extracted and reused (1). However, the reuse and treatment of poultry waste brings with it many problems which include:

- According to the Dutch regulation, it cannot be directly used as fertilizer because of the very high concentrations of both nitrogen and phosphate
- It cannot be converted into biogas because of limitations in the digestion process
- It contains bird diseases which have as a consequence that the manure needs to be treated before it can be transported (increase of costs)
- Up until now there has been no viable process available to treat the chicken manure

These Issues have led to farmers paying high costs (€ 20/ ton) for treatment (incineration) which could otherwise be avoided if the manure was successfully valorised.

Colsen Engineering is an engineering firm, which specializes in the development of innovative environmentally sustainable technologies. Their focus is in the areas of **water treatment**, **energy (biogas) production, and nutrient recovery**. The company owns and employs state of the art technology for nutrient recovery (e.g. phosphorus, Nitrogen and Sulphur). Their newest **Poul-AR®** technology offers an alternative way for the extraction and conversion in chicken manure to valuable fertilizers (ammonium nitrate (l), ammonium sulfate (l), ammonium phosphate (s)) that can generate value ((€ 50/ton) for farmers. However, the products from the **Poul-AR®** process are secondary products, so instead of being mineral fertilizers, they are fertilizers created from manure, as a consequence, the following problems ensue:

- There is low acceptance of the products in the market: big fertilizer industries try to prevent that this kind of fertilizers come into the market because of competition
- The regulation is not fitted for the products: product derived from waste have no proper regulations assigned to them which allows for the facilitation use

These problems have resulted in the reduction of the price of a fertilizer that has much higher value. For this reason, Colsen has hired I.N.S.A. consultancy, in cooperation with the Avans University of applied sciences, to analyze alternative applications for ammonia as a raw material and research the market possibilities and production processes for one of these alternatives namely: **Adblue®**.

Adblue® is the registered trademark for Aqueous Urea Solution 32.5 % (**AUS32**), AUS32 is registered under different trademarks according to the region in which it is traded as the reader shall find out in chapter 3. For the purpose of uniformity, **AUS32** is primarily used throughout the report (2).

1.2 Project Objective

The main objectives of the project included: providing an analysis on processes for the production of **AUS32** and a market research on **AUS32** in an advice report within a time span of 20 weeks.

The sub-goals of this project include: Providing an analysis of possible “alternative” applications for ammonia as a raw material.

1.3 Boundaries

- The project will focus mostly on the alternative use of ammonia in ad-blue
- The technical part (how to make the product) need to be cover as the safety measurement
- Regulations related to the production and use of **AUS32**
- The market study will focus only on light- & heavy- duty vehicles
- This Research is limited to literature study and business case analysis
- Only two technologies will be researched

1.4 Reading Guide

In this report, the chapters are constructed as follows:

- ***Chapter 2*** - Describes the methodology the researchers used, to reach the goals also the process that the project undergoes.
- ***Chapter 3*** - Provides the contextual information on **AUS32** and *Urea* synthesis.
- ***Chapter 4*** - In this chapter different techniques (conventional, stamicarbon etc.) for the production of urea (**AUS32**) are analyzed. Also within this chapter the findings of the market research are conveyed can be found, it touches on themes like; drivers of **AUS32** consumption, market potential and the North-American market.
- ***Chapter 5*** - Provides the discussion on the research findings.
- ***Chapter 6*** – Describes the conclusions drawn from the findings that were discussed, also proving a recommendation for future aspect of this indented research in particular.

2 Methodology

The purpose of this chapter is to serve, in covering the method used to obtain results. (figure 1 and 2)

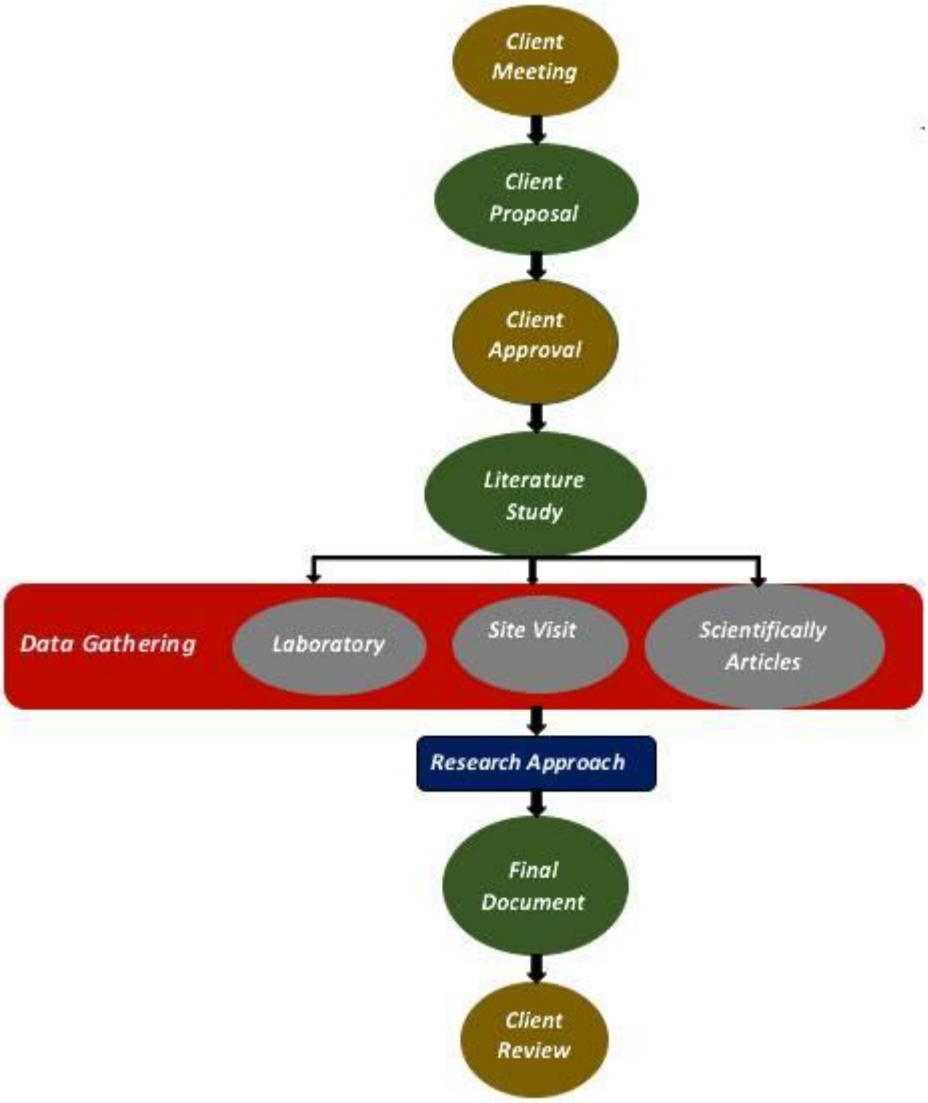

Figure 1 Project Process Scheme

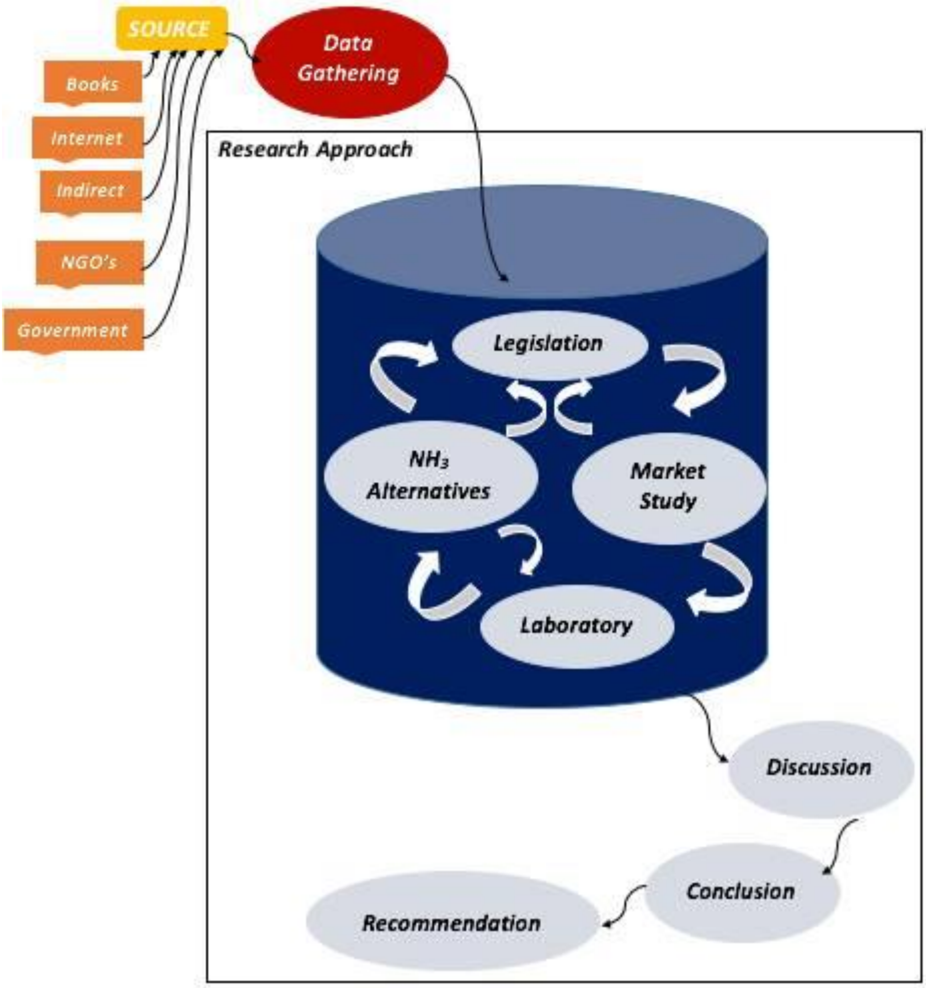

Figure 2 Research Approach Scheme

2.1 Research Approach

The completion of the main and sub-goals of this project requires a qualitative research approach which means that the research will be based on non-quantifiable data. The point is to understand the different phenomena behind the different concepts related to production processes of **AUS32** to understand how it's market works and finally to understand what the applicability of ammonia as a raw material is. To understand the above mentioned themes, data was gathered on the following topics:

- Legislation: processes related to **AUS32** production and its market application are bound to be governed by certain legislations. Therefore the legislations and regulations related to these topics where explored, an example for a research question was *what are the legislation that are related to **AUS32** production and consumption?*
- Urea synthesis: since **AUS32** is an aqueous solution of urea, it is important to understand the production process of urea. Therefore, information was gathered on the synthesis of urea, questions like exp. *How is urea synthesised?* was explored.
- NH_3 Alternative applications: for understanding this topic of the research, research questions like, *in what industry sectors is ammonia applied? how is it applied in this sector? What are possible future applications for ammonia?*

2.2 Data gathering

Obtaining reliable literature is vital, due to the specificity of each sub-research demands. Data was as previously mentioned by books on the subject of *urea production,* for the automotive purposes. The internet provided three different type of source information mainly being:

- Reliable indirect source of scientific article on the subject of urea production for further understanding the subject as well as information on different types of technologies applicable to the production of urea;
- The literature on legislations for a wide variety of Directive have been provided by both NGO's and Government, alongside a market study.

3 Theoretical Background

This chapter gives an overview of the data collected in the literature research.

3.1 Introduction to AUS32

AUS32 is a solution that is comprised of demineralized water (67.5%) and 32.5% of urea. It is colorless and is highly purified. It is trademarked in Europe as AdBlue®, but outside Europe, it is trademarked as Diesel Exhaust Fluid or **DEF** (US) or **Arla32** (Brazil) (3).

AUS32 is mainly formed by a chemical hydrolysis process of automotive urea, which resulted in ammonia as its main active component. It is usually used as a catalyst in a Selective Catalytic Reduction (SCR) system. **AUS32** is known to be a non-hazardous substance, which is safe to be handled by most consumers. It has to be stored in a container, away from heat and direct sunlight. If it's not stored correctly, the quality of the substance may decrease substantially. The composition and properties of **AUS32** can be found in the table 1 below (4).

Table 1 AUS32 Composition and Properties (5)

Composition	Demineralized water and Urea (31.8 – 33.2%)
Appearance	Colorless and clear liquid
Chemical Composition	$(NH_2)_2CO + H_2O$
ISO	ISO 22241: NOx Reduction Agent AUS32
Freezing Point	-11˚C
Evaporation Point	40 ˚C
Corrosive	Yes
Crystallization	Yes
Expiration Date	18 Months after production in a sealed, correctly stored package

3.1.1 Selective Catalytic Reduction (SCR)

Selective catalytic reduction (SCR) is an advanced active emissions control technology which is used in diesel engines. In the system, a liquid-reductant agent through a catalyst (ceramic) is injected into the exhaust stream of the diesel engine (*Fig. 3).*

First, the level of diesel exhaust emission is decreased through recirculation and filtration. Then the **AUS32** is injected into the exhaust stream, where it will decompose itself into ammonia and mix with the exhaust gasses. Next, a Ceramic catalyst will convert mixed ammonia and nitrogen oxides into nitrogen and water, thus reducing the amount of GHG emitted from the diesel exhaust at the end of the process. The successful application of **AUS32** requires a consumption rate of around 4-6% of the diesel fuel issued (6).

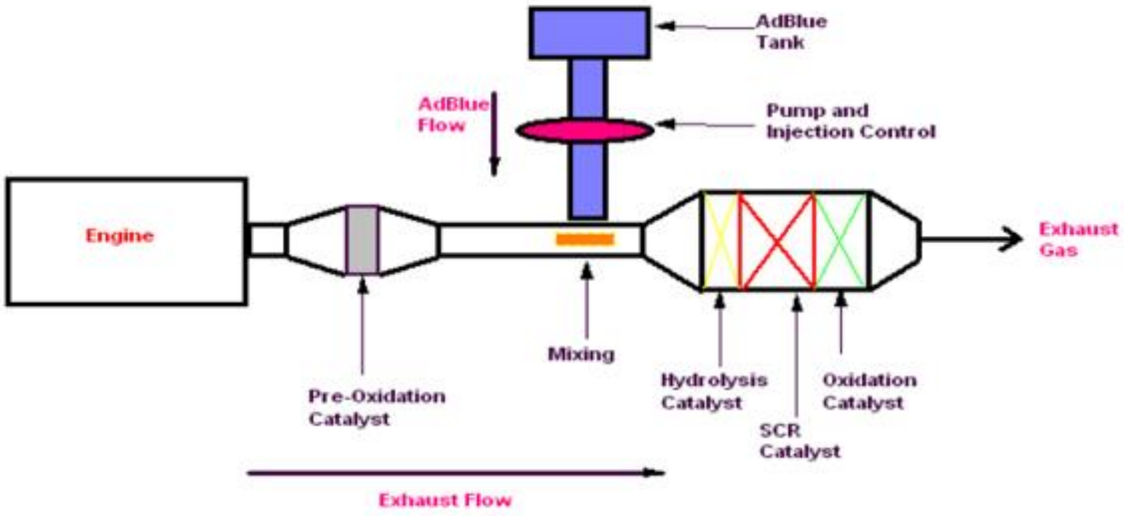

Figure 3 Detailed Schematic of an SCR System (6)

3.1.2 Legislation Related to SCR & AUS32

For the production of **AUS32** there are certain laws and regulations that need to be considered mainly the **ISO standards**. The use of SCR technology also falls under certain regulations mainly regulations that are related to air quality. The way these regulations are being implemented are through exhaust emission standards. The following subchapters will go a little deeper into legislative part of AUS32 and SCR.

3.1.2.1 *AUS32*

The legislation that concerns **AUS32** is strictly monitored following the ***ISO 22241*** *(7)*. There are five parts in the ***ISO 22241*** procedure which include: Quality requirements, Test methods, Handling, packaging transportation & storing and Refilling interface. Table 2 gives a specification on the and properties of **AUS32** according to the ***ISO 2224***.

Table 2 AUS32 Specifications as per ISO22241 (8)

Substance/Charachteristic	Content (Min)	Content (max)	Unit
Urea	31.8	33.2	% by weight
Density	1.0870	1.0930	g/cm^3
Refracting Index at 20°C	1.3814	1.3843	
Alkalinity as NH3		0.2	%
Biuret		0.3	%
Aldehyde		5	mg/kg
Insolubles		20	mg/kg
Phosphate (PO4)		0.5	mg/kg
Calcium		0.5	mg/kg
Iron		0.5	mg/kg
Copper		0.2	mg/kg
Zinc		0.2	mg/kg
Chromium		0.2	mg/kg
Nickel		0.2	mg/kg
Aluminium		0.5	mg/kg
Magnesium		0.5	mg/kg

Sodium		0.5	mg/kg
Potassium		0.5	mg/kg

3.1.2.2 *SCR*

In Europe, the legislation responsible for the reduction of the impact that air-born pollutants have on air quality is attained through the Directive 70/202/EEC. The Directive 70/202/EEC, was formulated on February 6^{th,} 1970, with the focus on the reduction of diesel greenhouse gasses emissions such as NOx, HC, PM, and CO. The directive and all its subsequent amending directives covered motor vehicles with progressive– ignition or compression—ignition engines. It leads to the development of several standards known emission standards or Euro standards (*Table 3*).

Table 3 European Exhaust Emission Standards (9)

Introduction dates			Petrol		Diesel		Petrol & Diesel
Euro standard	New approvals	All new registrations	NOx (g/km)	Mass of particles (g/km)	NOx (g/km)	Mass of particles (g/km)	Number of ultra-fine particles per km
Euro 1	1 July 1992	31 December 1992	0.97 (1)	-	0.97 (1)	0.14	-
Euro 2	1 January 1996	1 January 1997	0.5 (1)	-	0.9 (1)	0.1	-
Euro 3	1 January 2000	1 January 2001	0.15	-	0.5	0.05	-
Euro 4	1 January 2005	1 January 2006	0.08	-	0.25	0.025	-
Euro 5	1 September 2009	1 January 2011	0.06	0.0045 (2)	0.18	0.0045	6×10^{11} (3)
Euro 6	1 September 2014	1 September 2015	0.06	0.0045 (2)	0.08	0.0045	6×10^{11} (4) (5)

(1) Expressed as HC+NOx.
(2) Applicable to direct injection petrol engines.
(3) Applicable to diesel engines only.
(4) Limit of 6×10^{12} in the case of direct injection petrol engines.
(5) Common limit of 6×10^{11} for direct injection petrol engines and diesel engines from September 2017/September 2018.

The Euro 5 &6 Standards has replaced the Directive 70/202/EEC with the goal to set technical requirements for type-approval of motor vehicles. With the implementation of Euro 5 & 6 standards, a further reduction of most GHG's has gone underway (*Fig. 4*).

According to the International Council on Clean Transportation (ICCT), most countries in the world follow the pathway of the emission standards developed in the European Union, however, a lot of these countries are a decade or more behind. Table 4 gives an overview of all the countries that have either proposed, adopted or implemented emission standards with regard to legislation related to air quality. It is important to note that not all countries in Table 4 have implemented the emission standards to the extent that all new and old diesel engines are phased in. The emission standards merely point out the fact that the countries are looking into or have decided to either propose, adopt or implement the emission standard (10).

Recent regulatory developments have been recorded by the ICCT and are described in table 5. Accordingly, a 2014 ICCT report, noted that Brazil and Russia began type approvals for LDV standards based on Euro 5, Next, the EU and south Korea began type approval for HDV Euro VI standards, China also started to implement China IV standards (10).

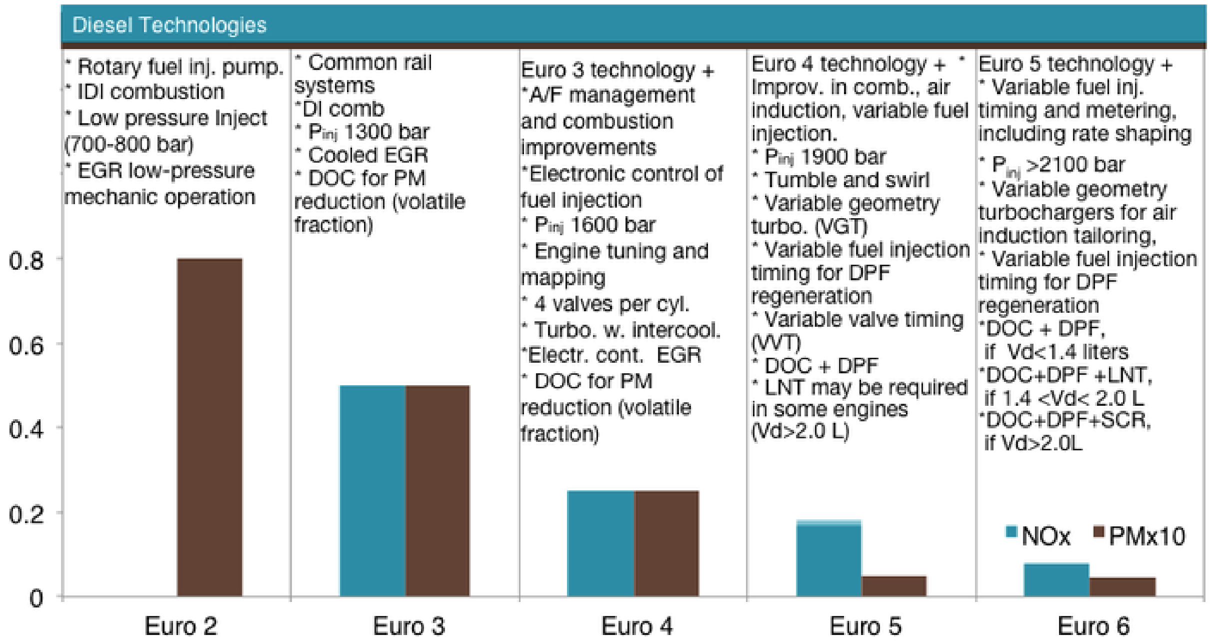

Figure 4 Progression on the Reduction of GHG's (11)

Table 4 list of proposed, adopted, implemented or current emission standards related to air quality legislation (12)

Region	*Country/administrative region*	*Name legislation/Reference Legislation*	
		HDVs	*LDVs*
Africa	*South Africa*	*Euro II/ US 98/ Japan 98/ ADR 80/00*	*Euro II*
Asia	*China*	*China IV***	*China V*
	Hong Kong	*Euro V*	*Euro 5*
	India	*Bharat IV*	*Bharat IV*
	Indonesia	*Euro II*	*Euro 2*
	Japan	*Post New Long-Term (PNLT)*	*Post New Long-Term (PNLT)*
	Malaysia	*Euro I*	*Euro 1*
	Philippines	*Euro II*	*Euro 4*
	Singapore	*Euro V*	*Euro 4*
	South Korea	*Euro V*	*Euro V*
	Taiwan	*Euro IV*	*Euro 5*
	Thailand	*Euro III*	*Euro 4*
	Vietnam	*Euro IV*	*Euro 4*
Australasia	*Australia*	*Euro V/US 07/JE 05*	*Euro VI*
	New Zealand	*ADR 80/03 & ADR 30/01/ Euro V/ EPA 2007/ Japan 05*	*ADR 79/01 & ADR 30/01/ Euro 4/ US 2004/ Japan 05*
Europe & Russia	*European Union*	*Euro VI*	*Euro VI*
	Russia	*Euro V*	*Euro V*
	Turkey	*Euro VI*	*Euro 5*
Middle East	*Israel*	*Euro VI*	*Euro V*
	Saudi Arabia	*Euro II*	*Euro III*
	United Arab Emirates (UAE)	--	--

North America	*U.S. EPA*	*2010 (EPA '10)*	*EPA Tier 3*
	U.S. CARB	*-*	*LEVIII*
	Canada	*EPA 2010*	*EPA Tier 2*
	Mexico	*EPA 04 / Euro IV*	*Tier 1/2 & Euro 3/4*
South America	*Argentina*	*Euro V*	*Euro 5*
	Bolivia	*Euro I*	*-*
	Brazil	*PROCONVE P7*	*PROCONVE L6*
	Chile	*Euro III/Euro IV or US 1998/US 2007 PM*	*Euro 5*
	Colombia	*Euro IV*	*Euro 4*
	Peru	*Euro III*	*Euro 3/Tier 1*

Table 5 Recent regulatory developments in diesel emission control standard (10)

Regulatory development	Percent reduction in emissions[a]	More information
Light-duty vehicles		
Brazil began type approvals for L-6 standards in January 2014. The standard will apply to all sales and registrations in January 2015. While based on Euro 5, L-6 does not include the particulate filter-forcing mass and number emission standards.	PM: **50%** NO_x: **50%**	Technical
Russia began type approvals for Euro 5 vehicles starting in 2014. The standard will apply to all sales and registrations in January 2016.	PM: **80%** NO_x: **25-28%**	Technical
US adopted Tier 3 emission standards, to be phased in from MY 2017 and fully implemented by 2025. The federal standards are largely harmonized with California's LEV III standards, which were adopted in 2012 and will be phased in starting MY 2015. Both Tier 3 and LEV III emission limits are significantly lower than those of Euro 6 (though LEV III requires a 90% reduction in PM, compared to 70% for Tier 3).	PM: **70%** NO_x: **80%**	Technical Policy update (German, 2014)
Heavy-duty vehicles		
China implemented China IV standards for all sales and registrations in July 2013. China IV standards are closely aligned with Euro IV requirements.	PM: **80%** NO_x: **30%**	Technical
EU implemented Euro VI standards for all sales and registrations in January 2014.	PM: **50%** NO_x: **80%**	Technical
South Korea began type approvals for Euro VI standards in January 2014. The standard will apply to all sales and registrations in January 2015.	PM: **50-65%** NO_x: **77-80%**	Technical
Russia began type approvals for Euro V standards in January 2014. The standard will apply to all sales and registrations in January 2016.	NO_x: **43%**	Technical

Implemented Adopted Proposed Delayed implementation

[a] Percent reductions in PM and NO_x emissions are estimated based on the limit values of the new standard compared to the previously implemented standard in that region.

3.2 Urea Synthesis

Urea can be produced from ammonia and carbon dioxide (*Fig 5).* First, ammonia and carbon dioxide react, forming ammonium carbamate. This reaction is very exothermic, and will keep reacting until heat is removed from the reaction. After that, ammonium carbamate will dehydrate, forming urea and water. This reaction is slightly endothermic, which is also slower than the previous reaction. The yield of urea may be limited by thermodynamics reaction, and no catalyst is known that can speed this reaction up. The urea formation reaction also only runs in the liquid phase. The typical conditions to synthesize urea are around 170-220 °C and 125-250 bar (13, 14).

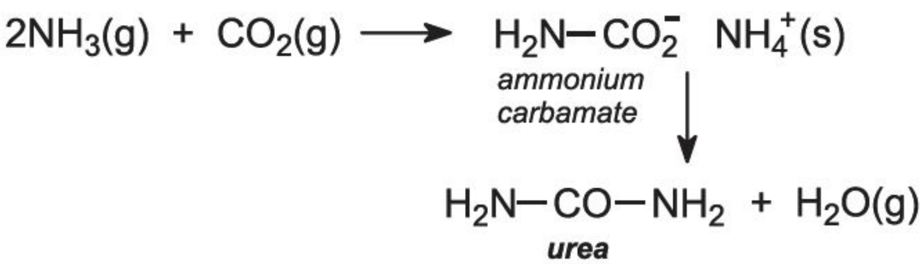

Figure 5 Chemical reactions in the process of urea synthesis (15)

3.2.1 Guidelines on Production of Urea

For the production of urea-based products several guidelines have been identified from which the most important element is presented in this chapter. The guidelines are more relevant to the production of urea-based product in a solid (fertilizer) form.

For the production of urea-based products in the form a fertilizer several guidelines have been found from, which it can be applied for urea.

3.2.1.1 *Emission for a Urea Plants*

Either a new or an existing plant should consider several emission levels (*Table 6, 7 and 8*). This applies for a steady-state production for stand-alone units.

Table 6 Emissions into Air (16)

	Source	Granulation Unit			Prilling Unit			Vents	
Unit		$Mg.Nm^{-3}$	ppmv	kg/ton	$Mg.Nm^{-3}$	ppmv	kg/ton	kg/h	kg/ton
New Plants	Urea	50	-	0.25	50	-	0.5	0	0
	NH_3	50	75	0.25	50	75	0.5	4	0.06
Existing Plants	Urea	70-80	-	0.35-0.4	100-150	-	1.0-1.5	0	0
	NH_3	130-165	200-250	0.65-0.83	65-100	100-150	0.65-1.0	30	0.75

Table 7 Emission into water from Waste Water Treatment Unit (16)

	Source	mg/l	kg/ton
New Plants	Urea	1	0.0005
	NH3	5	0.0025
Existing Plants	Urea	150	0.10
	NH3	150	0.10

Table 8 Total Emissions (16)

	Source	Granular Products	Prilled Product
New Plants	Urea	0.25 kg/ton	0.5 kg/ton
	NH_3	0.31 kg/ton	0.56 kg/ton
Existing Plants	Urea	0.45-0.50 kg/ton	1.1-1.6 kg/ton
	NH_3	1.5-1.7 kg/ton	1.5-1.8 kg/ton

3.2.1.2 *Urea-Ammonium Nitrate (UAN) Production*

For the production of Urea-ammonium nitrate (UAN) the basic feedstocks are ammonium nitrate and urea. The plant capacity can range between 200 and 2 000 tons/day. The typical UAN solution analysis N_2 content (16);

- 28-32% by weight
- pH 7 to 7.5
- Density 1,280-1,320kg.m-3,
- Salt-out temperature –18 to –2°C

3.2.1.3 *Ammonia Storage & Transfer Equipment*

The storage

The storage and transfer of ammonia or ammonia-based substances are usually stored three type of methods:

1. Stored in large full tank refrigeration with a typical capacity of 10.000 to 30.000 tonnes (even up to 50.000) at a temperature of about -33˚C
2. Stored in pressurized cylinders or spheres up to 1.700 tonnes
3. Semi-refrigerated tanks

The transfer equipment

For the transfer of liquid or gas, pipelines should be fitted with isolation valves. Whereas, the main isolation valves should be backed up by remotely operated valves. These remove systems should operate in such matter that closure automatic in case of any power failure (16).

3.2.1.4 *AUS32 Storage & Transfer*

The storage and transfer of AUS32 in this section are based on the Dutch regulatory requirements.

Storage

Due to its composition the **AUS32** is can pose risks to the soil. According to the Activities Arrangement on the Environment Article 4.18, the storage tank must be double-wall or above drip tray which must be placed. According to Activities Arrangement on the Environment Article 4.10 the packaging shall supply a soil protection that is impervious of drip tray to the floor with an incident management (17).

Transfer

AUS32 trademarked as AdBlue® is regularly delivered at gas stations that also sell liquid fuel. Activities scheme article 3.25, paragraph 12, Activities Arrangement on the Environment (*Activiteitenregeling Milieubeheer*); states that for the entire gas station the same soil protecting provisions. Small-scale delivery of liquid fuel (25,000 liter </year) with an incident management system. In large-scale delivery of liquid fuel (> 25,000 liters/year) is an impervious floor (18).

4 Results

This chapter describes the results of the research project, conveys what the researchers have found while after doing research on techniques for producing urea (urea synthesis), the **AUS32** market and the alternative applications for ammonia.

4.1 Urea synthesis techniques

There were several technologies for the synthesis of urea. However, during this project, these two techniques presented down below will be elaborated due to its popularity that these techniques have with European Member States. In Snamprogetti™ technology, the efficient ammonia stripping process can reduce size of equipment, avoid corrosion, and decompose unconverted carbamate into urea (19). In Stamicarbon™ technology, there is no need for a medium-pressure reactor because the ammonia and carbon conversion is high. This is why there is no recirculation of condensate within the technology. Around 230 urea plants have been using this technology. Stamicarbon™ is the oldest technology known to produce urea (around 60 years) (20). It is in constant evolution and this is the first technology that use the stripping technique (21).

4.1.1 Snamprogetti ™ Urea Technology

Snamprogetti ™ Urea process is one of the well-known processes to produce urea. Snamprogetti ™ process was first established in Milan, Italy at 1956. It was merged with Saipem S.p.A since 2006. It uses the concept of ammonia stripping to produce Urea. The process utilizes excess NH_3 that is not converted into urea by stripping it from Urea synthesis reactor and then recirculating it back into the reactor. This is done without using any additional reagent but using heat integration in the stripping plant. Total recycling processes can be achieved by Snamprogetti ™ Urea process. See figure x for complete process flow diagram of Snamprogetti ™ Urea process. There are six sections available within Snamprogetti ™ Urea process (*Fig. 6)* (22).

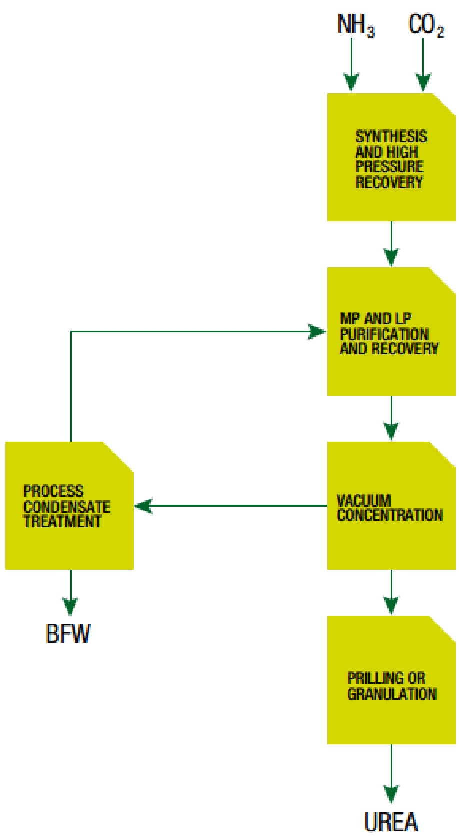

Figure 6 Process Block Diagram of Snamprogetti TM Urea Production (12)

4.1.1.1 *Synthesis and High-Pressure Recovery (Section 1)*

In this section, CO_2 and NH_3 are fed into the urea synthesis reactor, this reactor produces urea solution but not all CO_2 and NH_3 are converted into urea. The reactor is characterized by high NH_3/CO_2 ratio, which is 3.2 – 3.4 molar. A total of 62% - 64% of CO_2 entering the reactor is converted into urea. There is also a stripper present in this section which will strip out excess NH_3 and CO_2 vapors from the urea solution leaving the reaction. A Carbamate condenser condenses the vapors, which will result in ammonium carbamate solution, which will be recycled back into the synthesis reactor. The system requires high-pressure machinery to recycle the ammonium carbamate solution, as well as to feed NH_3 and CO_2 into the synthesis reactor. The parameters that are taken into account in this section are laid out in table 9.

Table 9 Parameters of synthesis and high-pressure recovery in Snamprogetti TM process.

	Temperature (°C)	Pressure (bar)
Reactor	188	150
Stripper	205	
Carbamate condenser	155	

4.1.1.2 *Medium Pressure Purification and Recovery (section 2)*

This section main purpose is to partially strip out NH_3, CO_2, and the reactant from urea solution formed from the previous section (*Fig. 7)*. This is achieved by using a distillation column, in which excess NH_3 is separated. After that, NH_3 and CO_2 are condensed partially in water, a shell of a preheater within the vacuum section is used for this condensation process, which is operated in pressure of 17 bar g. This results in energy recovery of approximately 200kg of steam per ton of urea.

Another feature that is present in this section is the availability of safe ammonia washing from "Inert" (CO, H_2 and CH4 and passivation[1] air). These inert are present in very small amounts which can be safely washed to recover NH_3 solution. Thanks to H_2/O_2 mixture that are fed into the washer, risk of explosion during washing can be avoided completely. This washing method has been implemented in several industrial plants.

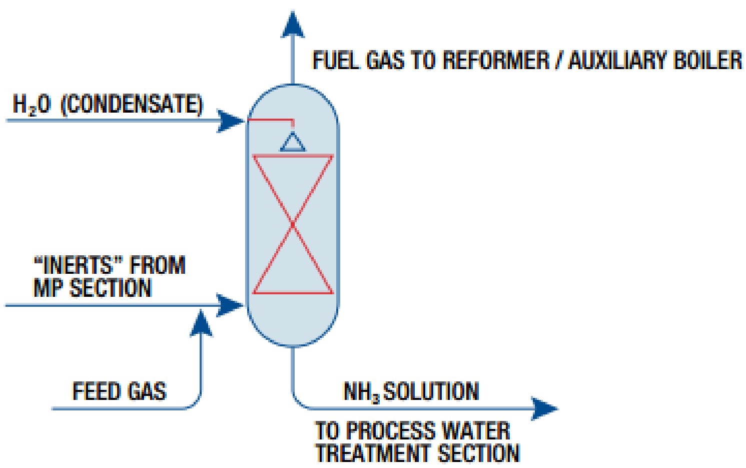

Figure 7 Diagram of ammonia washing from inerts

4.1.1.3 *Low-Pressure Purification and Recovery (Section 3)*

The main purpose of this section is to further strip NH_3 and CO_2. The strippers are operating at a pressure of 3.5 bar g. Vapors containing NH_3 and CO_2 that are condensed and recycled from the previous section recirculated to this section. A tank collects solution formed from previous sections to make sure that nothing is being discharged from the plant. It also acts as a storage when the plant is shut down for an extended period of time.

[1] Passivation refers to material becoming "passive" that it is less affected by the environment.

4.1.1.4 *Vacuum Concentration (Section 4)*

The urea solution that leaves the previous section has **70% b.w. (by weight)** and contains a small amount of NH_3 and CO_2. To finalize the concentration of urea solution, it is sent into 2 steps vacuum that operates in pressure of 0.3 and 0.03 bar g respectively. The result of this process is a **99.8% b.w. molten urea solution**. This final urea solution is then sent into the prilling tower where it is solidified into prills or a granular product, depending on the technology chosen for the process. The heat in this section is produced from partial condensation of NH_3 and CO_2 vapors from the medium pressure (MP) evaporator in section 2.

In the past, there is some problem concerning the formation of a lump in the vacuum separator, but a solution has been formulated to solve it: by wetting the internal walls of the vacuum separator. This can be done by performing small recycling process of molten urea solution.

4.1.1.5 *Process Condensate Treatment (Section 5)*

This section is focusing on the treatment of waste-water from the production process. Snamprogetti ™ process has achieved recognition for being able to discharge a large amount of process water containing 1 ppm of urea and 1 ppm of NH_3, which is the result of the condensate treatment. This makes the technology green since the state of the waste stream allows for improved treatment thus reducing pollution level. Energy recovery is also achieved at MP recovery section, which minimizes consumption of energy within the process.

4.1.1.6 *Prilling (Section 6)*

This section's main purpose is to transform final urea solution from previous sections into a solid product. Prilling is considered as the easiest technology to create solid urea product. The prilling tower has a height around 55-80 meters depending on the condition of climate in the production plant. Molten urea solution with 99.8% b.w. is sprayed at the top of the prilling tower. The liquid droplets (prills) will solidify due to a countercurrent flow of air that will cool the droplets that are falling to the bottom of the tower. These solid prills can be stored in a storage safely without any screening or coating.

According to Saipem, in the year 2001, the Snamprogetti ™ urea process was able to produce in average 3600 tons of urea per day. In this process, the conversion rate for ammonia and carbon dioxide transformation into urea is around 62-63% (see appendix 3). The expected required materials and electrical consumption of the Snamprogetti ™ process are described in table 10.

Table 10 Expected materials needed for production of 1 ton of Urea (23, 24)

Raw Materials and Power Consumption	Units	Prillling
NH_3	Kg	566
CO_2	Kg	733
High-pressure steam (110 bar g, 510 °C)	Kg	840
Cooling water (ΔT = 10°C)	m^3	95
Electric power	kWh	23
Steam (at 108 bar)	ton	0.76
Total energy consumption level	GJ	1.7

4.1.2 Stamicarbon ™ Urea Process

Another technique used for the production of urea is the Stamicarbon™ Urea 2000plus® CO_2 stripping concept. This technique is divided into three different processes that are not using the same technology: the pool condenser, the pool reactor, and the SS Concept. The only difference between the pool condenser and reactor is the combination of the reactor and the condenser in a vertical vessel for the second process. Then, in the advanced concept, it is using a new material (Safurex®) to reduce the corrosion, and it improves the synthesis section (13).

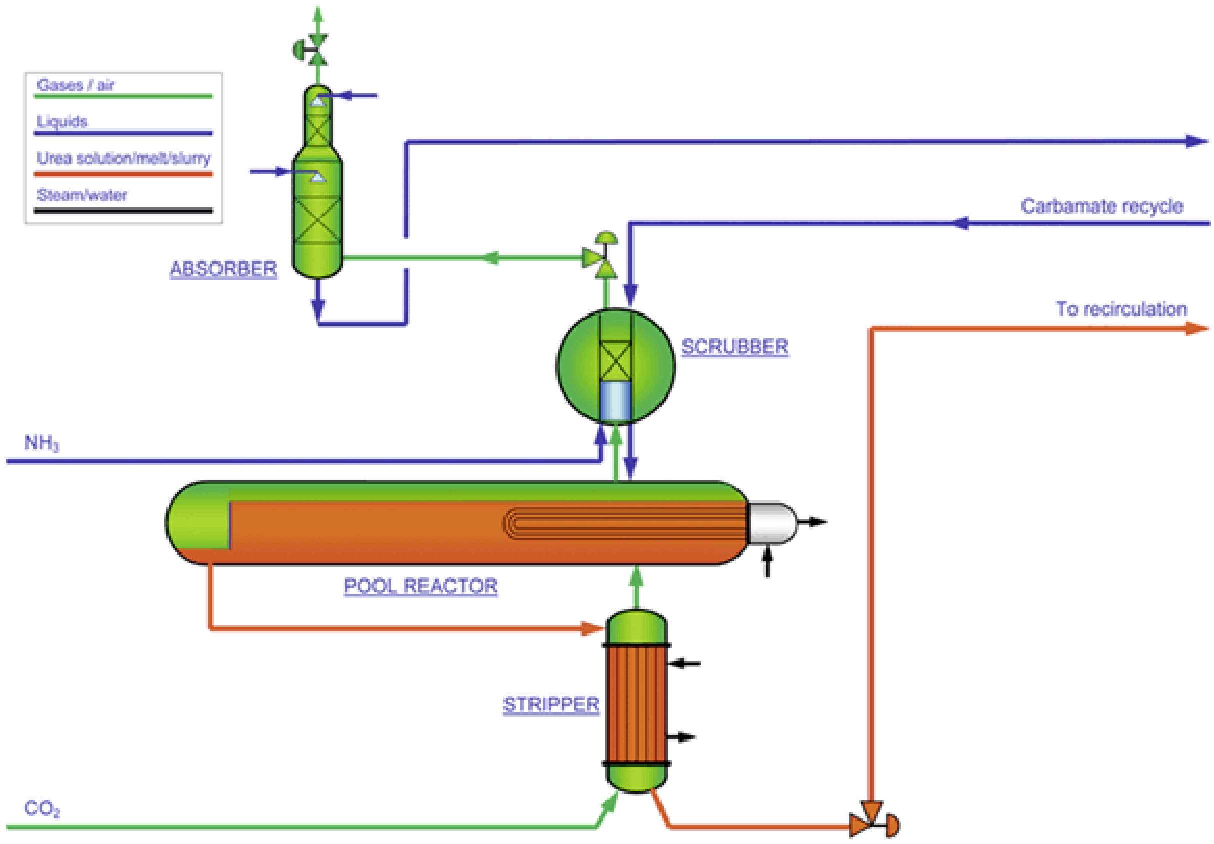

Figure 8 Stamicarbon Urea 2000plus® CO2 stripping process: pool reactor concept (13)

As the figure 8 displays, there is only one pool reactor that combines the condenser and the reactor to reduce the cost of equipment and the space used by this technology. It also reduces the electricity and maintenance costs, because there is no need of pumps or compressors moreover, the circulation is done by gravity. This process provides different conversion rates for ammonia and carbon dioxide transformation into urea, around 70-75% (see appendix 3).

The utilities, raw materials and estimated power consumption of the Stamicarbon™ process are described in table 11.

Table 11 Raw materials, Utilities and power consumption for the production of 1 ton of urea (25)

Raw material and power consumption	Amount	Unit
NH_3	567	kg
CO_2	733	kg
Cooling water	70	m^3
Steam (at 20-25 bar)	0.92	t
Electric power	58	kWH
Total Energy consumption	1.9	Gj

4.1.3 From Urea into AUS32

Urea that has been synthesized into prills can be mixed together with pure demineralized water to create AUS32. This process requires its own blending sites. The demineralized water has to be heated up to 40 to 50°C before it is mixed with the urea prills. This process can be done in approximately 30 minutes because urea dissolves quite fast in demineralized water.

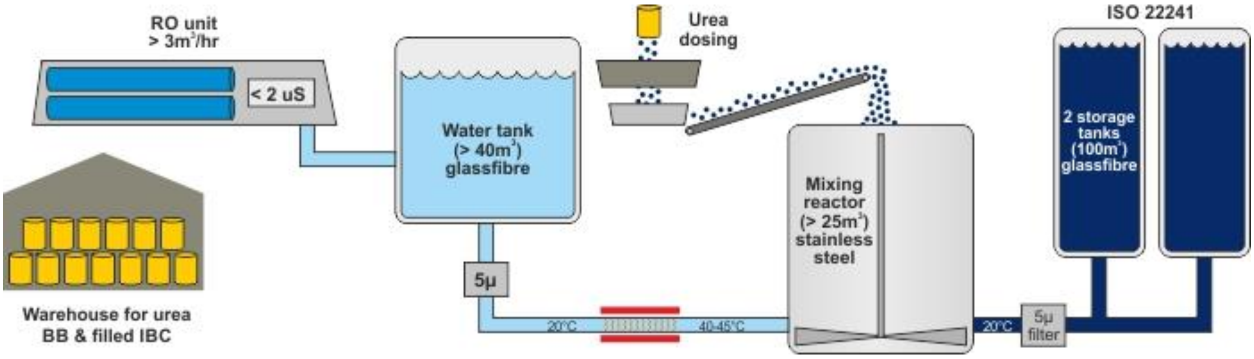

Figure 9 AUS32 Mixing Site Plan

There are 5 reactors and tanks (Figure 9) that are needed in order to mix urea into AUS32:

1. Reverse Osmosis **(RO) unit**
   This unit is utilized to purify water into demineralized water. Water that has not been purified contains salts and minerals which may cause deposits in the SCR system. By using reverse osmosis units, the unpurified water will be filtered using a membrane, resulting in pure demineralized water and removing any harmful and unwanted particles. This unit can process approximately more than 3 m^3 of water per hour.

2. Water tank
   This tank is utilized to store purified water until it is needed in the mixing reactor to create AdBlue. This water tank has a volume of approximately 40 m^3 or bigger.

3. Urea dosing system
   This system is used to add urea prills into the mixing reactor. The system also ensures that the right amount of urea prills are added.

4. Mixing reactor
   This reactor is utilized to mix urea prills and pure demineralized water. The pure water has to be heated into 40-45°C first before it enters the mixing reactor. This reactor has a size around 25 m^3 or bigger, making sure that the mix is happening constantly. Stainless steel is used as the material of this reactor to prevents corrosion or rust.

5. AUS32 storage tanks
   These storage tanks are used to store the final product of AUS32 before it is packaged and delivered to the clients. The final AUS32 solution will have a temperature of 20°C before entering the storage. The storage also abides ISO 22241 in its storing procedure. The tanks size is around 100 m^3, with two tanks usually constructed in a normal blending site plan.

4.2 Alternative Application for NH_3

4.2.1 Ammonia as fuel source for the production of electricity

According to the Space Propulsion Group, Inc. (SGP); there are opportunities for the utilization of ammonia as a source of clean energy and power generation exist and are very viable. Ammonia has the highest hydrogen density compared to other practical fuels like diesel and gasoline. Moreover, unlike other practical fuels (ex. diesel, gasoline etc.) combustion of ammonia does not result in CO_2 emissions since the ammonia molecule is free of any carbon atoms. Furthermore, the transition to ammonia as an alternative fuel will go smoothly since the substance is already a widely used commodity, which contains well-established distribution and handling procedures. See figure 10 for examples of the alternative use of ammonia (26).

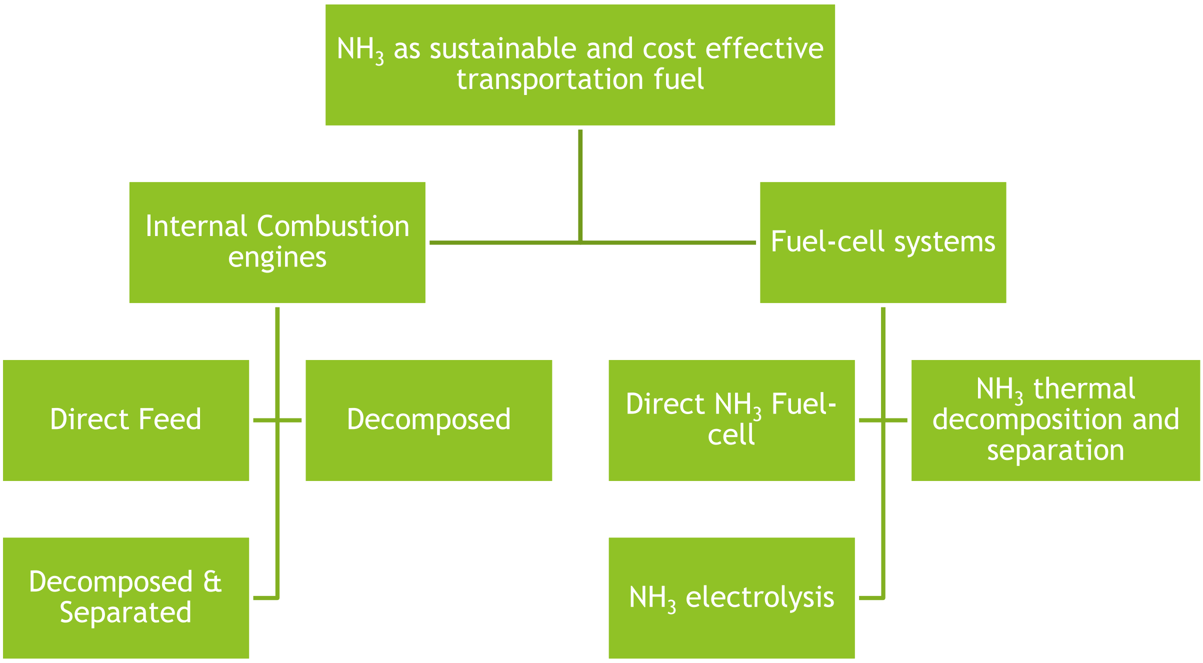

Figure 10 Flow scheme showing ammonia applied as fuel in internal combustion engines and fuel cell systems

Also, a study published in the journal of power sources, on the use of ammonia as a sustainable fuel concluded with similar statements as the ones mentioned but with addition of the following statements (27):

- Ammonia is the least expensive fuel in terms of $ Gj^{-1}
- There exists an advantage of by-product refrigeration, which reduces the costs and maintenance
- Ammonia is the cheapest fuel per 100 km driving range as a reasonable and practical assumption

However, there are also disadvantages associated with the use of ammonia as an alternative fuel mainly: its low energy density compared to hydrocarbon based fuels and its toxicity. However, these drawbacks have only hindered the development of ammonia as a fuel in transportation systems (e.g. small vehicles). When a car accident happens, the ammonia liquid can leak and harms the environment. This can be avoided by applying current storage and control technologies, such as using metal amines to embed ammonia into it. This differs from power generation systems, which pose little risks for its application of ammonia as a fuel. For power generation systems, the important parameters include the costs per BTU and emission levels. Ammonia can also be produced using renewable energy and also energy efficient method, making it competitive with fossil based fuels that have relatively low prices already. The toxicity can be minimized with current technology and handling procedures, with the support of perfect safety record until now.

The utility of ammonia as a fuel depends on two developments:

1. Efficient methods of synthesizing ammonia - using Solid State Ammonia Synthesis (SASS) technology
2. Technologies to burn it in power generation plants - using gas turbine systems that have been widely available in power generation application

Ammonia can also be utilized as an enabler of stranded renewable energy sources. Solar and geothermal as renewable energy sources are not accessible by electric grid system and also not economically beneficial when the grid needs to be expanded. Since ammonia can be used as a safe and good energy carrier, it has opened a lot of potentials for energy sources in remote places by just utilizing water and air. The produced ammonia can then be transported or used in a power plant to generate electricity.

4.3 Market Study

4.3.1 Drivers for the Demand of AUS32

4.3.1.1 *Legislation*

With the help of legislation and policies countries are able to control to a certain extent the human impact on the environment by regulating, for example, the impact on air quality through emission standards on greenhouse gasses and particulates. In turn legislation of this nature, can drive companies to change or update their products so they can adhere to the law, better their image and increase their potential for profits. This applies, particularly to the automotive industry.

In Europe this seems to be the case; with the advent of the Euro standards, the continent has been able to get trucks and buses as clean as possible, in terms of greenhouse gas (GHG) and particulate matter (PM) emissions *(Fig. 11)* (28).

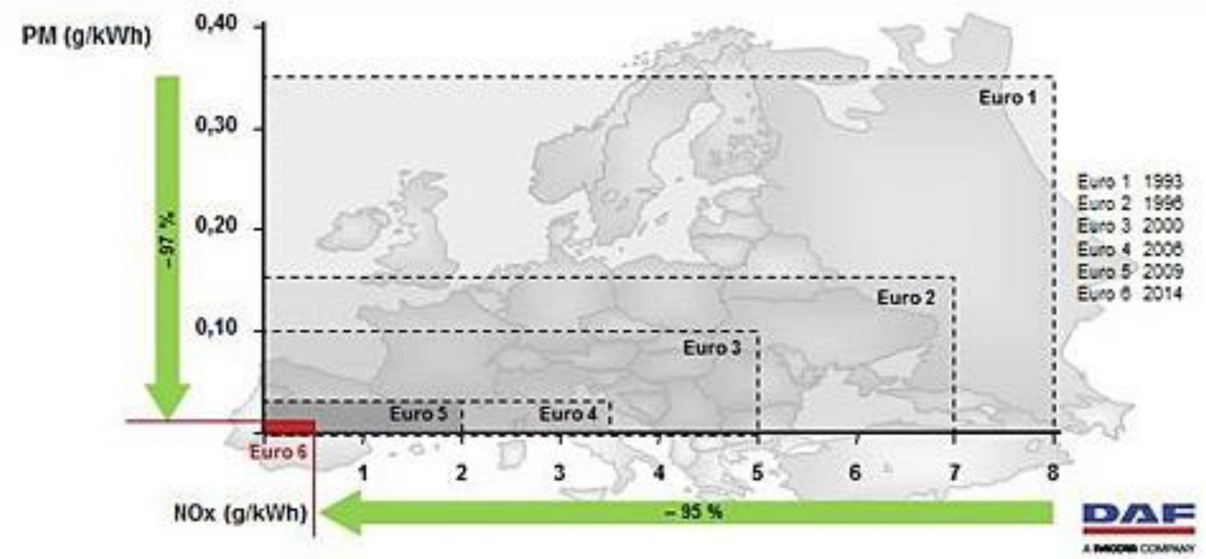

Figure 11 Progression of the European Emission standards (28)

When it comes to the consumption of **AUS32** it can be stated that the adoption of air quality legislation is the main driver. An example, which can prove this argument, is; a google trend search (*Fig. 12*) using the term; Adblue, shows an increasing trend in awareness, which has grown since 2004-2005. The region of interest was more concentrated in the European Union (*Fig.13)*. It is important to note that period of 2004-2005 marked the adaptation of greenhouse gas (GHG) emissions legislation such as **Directive 2005/55/EC** (**European Commission**) in EU, this legislation has paved the way to the adoption of emission control technologies (ex. SCR), required to meet the emission standards (28).

There exists a probable correlation between the increase in the demand of **AUS32 (AdBlue®)** and the adoption of regulation on GHG emissions. Because, the increase in awareness of **AUS32** (*Fig. 12)* in the EU (*Fig. 13)* and the increase in demand of **AUS32** in the EU (*Fig. 14),* happened around the same period that the GHG emission regulation (**Directive 2005/55/EC**) has been adopted. Thus, the countries in which a demand for **AUS32** will most likely exist, are countries that have implemented/adopted current (EU) air pollution legislation, with regard to the emissions of greenhouse gasses (e.g. NO_x).

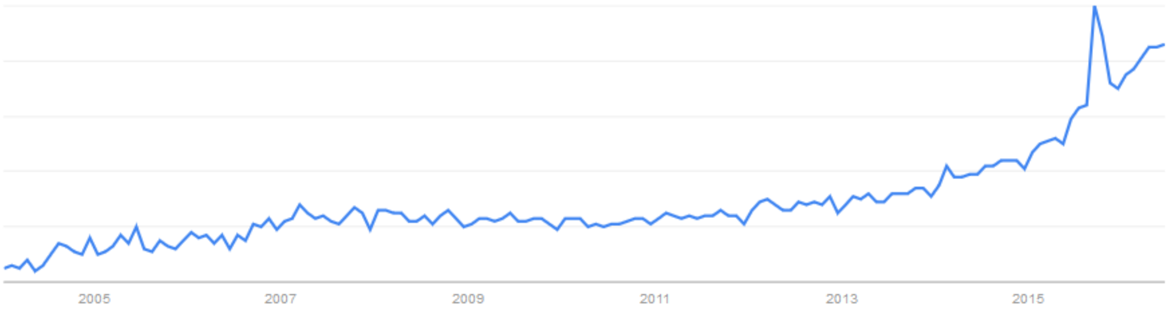

Figure 12 Google trend line showing the interes of the search term AdBlue in Europe (29)

Figure 13 Region interest for trendsearch using the term Adblue (29)

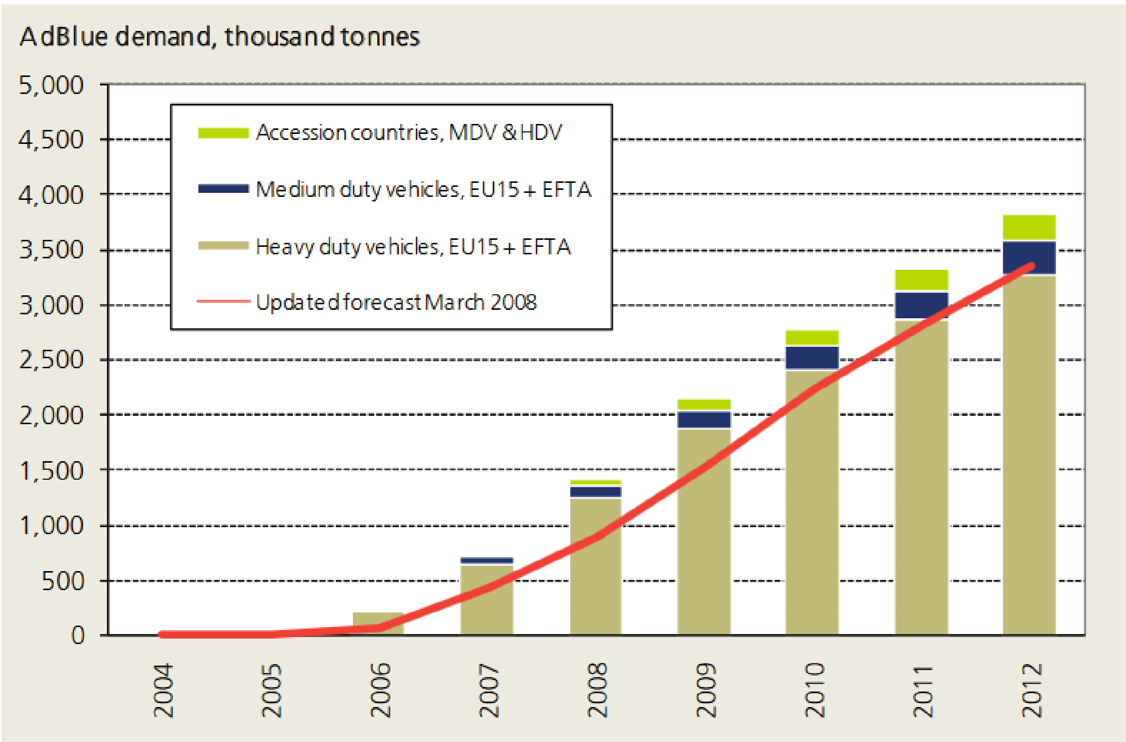

Figure 14 European Adblue Demand Forecast (30)

4.3.1.2 *Vehicle Market*

Another driver for the consumption of **AUS32** obviously is the availability of vehicles that utilize **SCR** technology, however, the availability of vehicles that use SCR technology is largely dependent on the countries adopting and implementing legislation that requires companies to adopt this sort of technology. Therefore, the most viable market opportunities for **AUS32** will be found in countries with strict air pollution legislation – with regard to NO_x emissions – and which at the same time have a big share of vehicle sales. It is important to note that since **AUS32** is only required in SCR vehicles, to get a true estimation of how big the market is, the number of registered SCR vehicles has to be taken into account as well. From figure 15 it can be concluded that China, the US, and EU have the biggest share global vehicle sales (10).

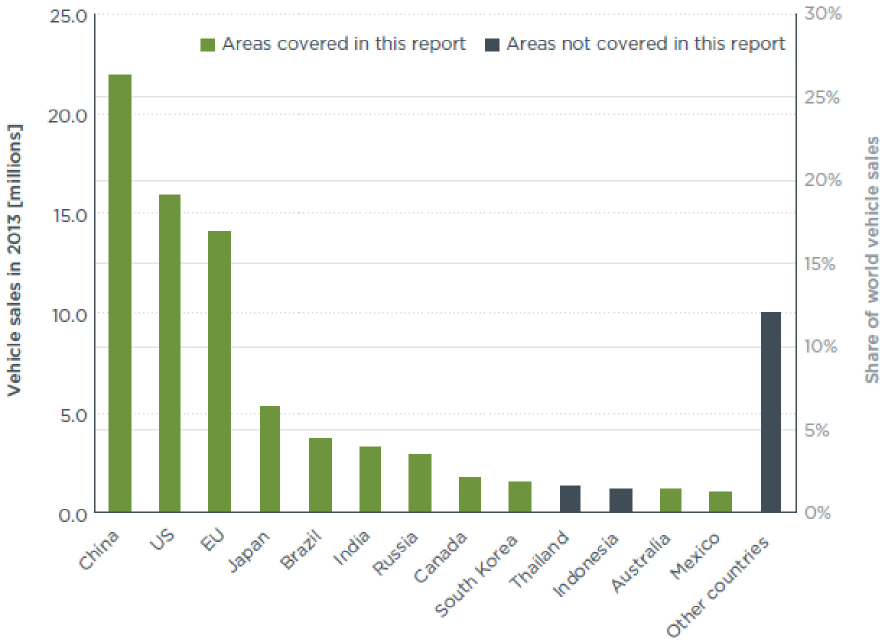

Figure 15 Sales of light and heavy-duty vehicles by country (10)

4.3.2 Potential Markets

Since GHG emission legislation (e.g. NO_x control) is one of the main drivers of the consumption of **AUS32** it can be concluded that countries with the strict implementation of GHG emission legislation are going to be the countries which provide possible market opportunities for **AUS32**.

Most of the countries in the world follow the pathway of emission standards developed in Europe, however, most of the countries are up to a decade or more behind. The most stringent emission standards currently in effect for **light duty vehicles** (LDV) are US **Tier 2**, Japan's **New Post Long-Term Standards** and **Euro 6.** The US EPA **Tier 3** require significant improvements from the **Tier 2** these could push for the next generation of emission controls.

The most stringent, already adopted, emissions standards for **Heavy-duty vehicles** (HDV) include; **Japan's New Post Long-Term Standards, US 2010** and **Euro VI**. Figure 16 gives an overview of the 2009 global HDV emission standards in terms of the Euro standards (10).

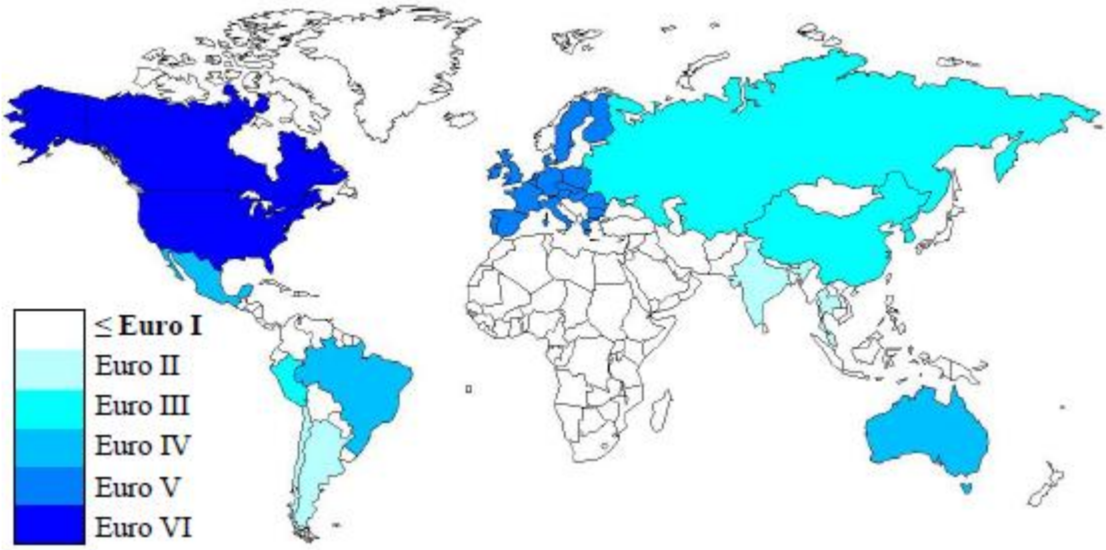

Figure 16 2009 global heavy vehicle emissions standards (3)

Figure 17 summarizes the emission and fuel sulfur standards currently in effect in 11 regions selected in a 2014 study (10) by the **ICCT (**The International Council on Clean Transportation). According to the ICCT, out of the 11 regions, 6 have yet to adopt Euro 6/VI-equivalent standards across LDVs, HDVs. China, US-Japan, and Europe are well on track with implementing the most current emission standards. Since the US, Japan and Canada have adopted the most stringent emission standards, and also are among the regions with the biggest share in vehicle sales, it can be concluded that the above-mentioned regions are the ones that will most likely provide the most opportunities for the **AUS32** market.

What is also important to consider is China, Brazil, and India. Even though compared to Europe and the US, they are lagging behind with the implementation of stringent emission standards; they are currently in the process of adopting the most current emission standards. However, these will only start to come in effect in the not too distant future, but considering the fact that these nations also have a huge percentage of global vehicle sales, they will probably also provide good market opportunities for **AUS32** (10).

Region	Percent of world vehicle sales 2013	Emission standards				Fuel sulfur standards			
		Light-duty		Heavy-duty		Gasoline		Diesel	
		Current[a]	Adopted	Current	Adopted	Current	Adopted	Current	Adopted
China	25%	China 4[b]	China 5	China IV		50 (10)[c]	10	350 (50, 10)	10
US	19%	Tier 2	Tier 3	US 2010		30	10	15	
EU	17%	Euro 5b	Euro 6	Euro VI		10		10	
Japan	6%	PNLT		PNLTES		10		10	
Brazil	4%	L-6		P-7		50		500 (10)	
India	4%	Bharat III	[d]	Bharat III		150		350 (50)	
Russia	3%	Euro 4	Euro 5	Euro IV	Euro V	150	10	350	10
Canada	2%	Tier 2	[e]	US 2010		30		15	
South Korea	2%	Euro 6		Euro V	Euro VI	10		10	
Australia	1%	'Core' Euro 5	Euro 6	Euro V / US07/JE05		150 (50)		10	
Mexico	1%	Tier 1 / Euro 3[f]		US 2004 / Euro IV		150 (30)		500 (15)	
Other countries	15%								

Euro-equivalent[g]

Euro 3/III | Euro 4/IV | Euro 5/V | Euro 6/VI | Post Euro 6/VI

[a] "Current" indicates standards apply to all vehicle sales and registrations. "Adopted" indicates standards that do not yet apply to all vehicle sales and registrations. Source: TransportPolicy.net.
[b] China 4 for light-duty vehicles applies to gasoline-fueled vehicles only. China 5 has been implemented in Beijing and Shanghai.
[c] Values in parentheses indicate higher quality fuel is available sub-nationally, but not required nationwide.
[d] As of April 2014, Bharat IV standards were in effect in 33 cities including the national capital region; however, a nationwide implementation date has yet to be formally adopted. In 2014, the Auto Fuel Policy Committee published recommendations for a nationwide roadmap to Bharat VI standards for vehicles and fuels; however, as of August 2014, these recommendations have yet to be officially notified as a government proposal.
[e] Canada has announced intention to harmonize with the US Tier 3 regulation; however, formal adoption had not occurred as of August 2014.
[f] Mexico is planning to revise its existing standards for diesel heavy-duty vehicles; however, as of August 2014, these revisions had yet to be officially notified as a government proposal.
[g] Euro-equivalent emission standards based on limit values.

Figure 17 Light- and heavy-duty vehicle emissions and fuel sulfur standards (10)

4.3.3 North American market

4.3.3.1 *Price*

The price of **AUS32** can vary depending on in what quantities it is bought, or the place it is bought from. According to Yara - a global firm specializing in agricultural products and environmental protection agents - the price of **AUS32** in general is estimated to be roughly half the price of diesel per gallon (3.8 liters) at the pump (5). According to DiscoverDEF - a free service that provides information on where to buy **AUS32** (DEF) and how to use it - the current **AUS32** price in America translates to around $ 0, 73/L (31).

Furthermore, **AUS32** can be purchased in packages of 1 – 2.5 gallons (3.8 L – 7.6 L), 55-gallon drums and 275 and 330 (1000 L – 1500 L) gallon intermediate bulk containers (totes). In addition, **AUS32** can be purchased in stillage's of about 4000 gallons (15000L), an example of how this might look like is presented in figure 18 and table 12.

Figure 18 Variety of volumes in which AUS32 (DEF) is sold (32)

Table 12 Price of AUS32 in a variety of volumes (32)

AUS32 Retail Containers	Container Volume	Price of AUS32 ($/L)
Stillage's	15000-L (3.963-gal) 3000-L (793-gal)	0.57 0.68
Totes	1000-L (24-gal)	0.73
Bottles	18-L (4.8-gal) 10-L (2.6-gal) 5-L (1.3-gal)	1.13 1.22 1.40

Since **AUS32** partly comprised of urea, urea is produced from ammonia which conventionally is constructed from natural gas, the price level of natural gas and ammonia can have a direct impact on the price of urea. An increase or decrease in the price of any of these raw materials will result in a direct increase or decrease in the price of the urea (33).

4.3.3.2 *Distribution Process*

Figure 19 gives an overview of the route that urea takes before it is distributed as **AUS32**. According to an executive summary report on SCR-Urea Implementation strategies, done by Tiax – lab-based technology company- the distribution process of **AUS32** goes as follows: urea is domestically produced or imported as dry urea, then it is transported to central distribution facility - where the urea is blended into **AUS32** - and then transported to the retailer.

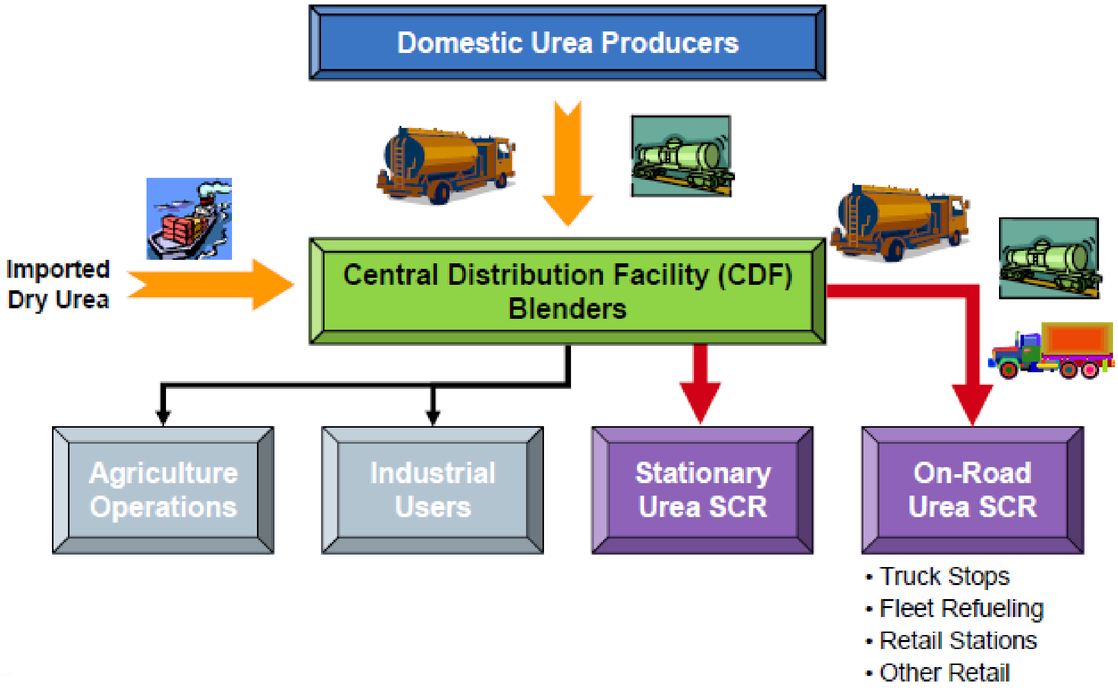

Figure 19 AUS32 (DEF) distribution process (32)

TIAX identified two pathways (*Fig.* 20) of distribution post the blending process, mainly; in pathway 1 the product **AUS32** directly loaded onto tankers from the CDF (usually in stillage's) and in pathway 2 the **AUS32** is packaged or bottled first and then sent off to the retailer (32).

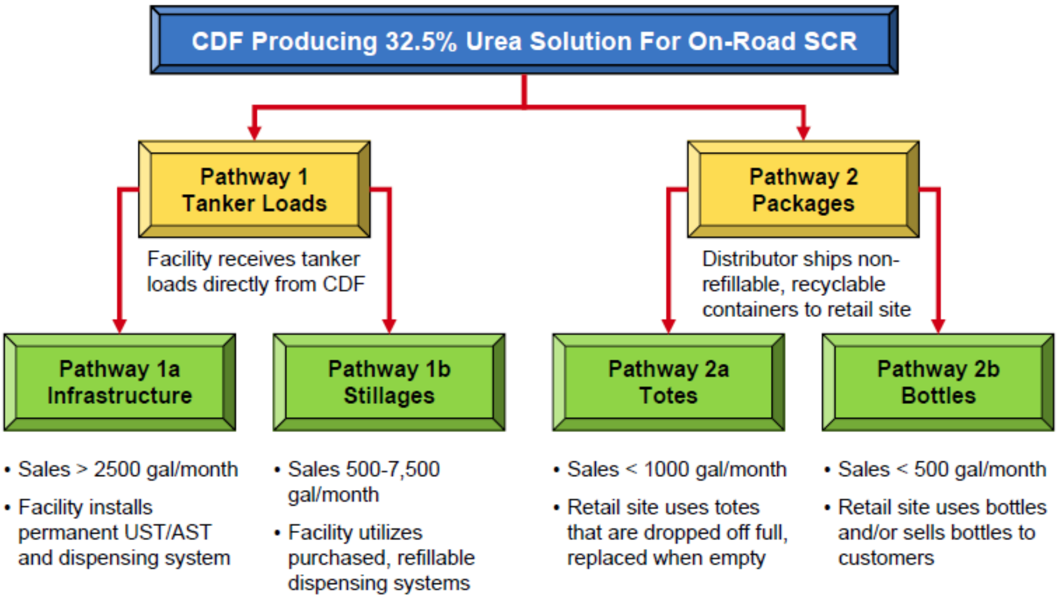

Figure 20 Main Pathways for urea distribution (32)

4.3.3.3 *Supply & Demand*

According to Integer – an independent provider of specialist market researches an analysis, conferences and events and consultancy services across industries of environment & emissions, fertilizer & chemicals and wire & cable - around half of all the urea-producing plants in North America are now producing **AUS32**. In addition, the research agency expects that this number will rise, thus positively influencing the supply of **AUS32** in America. Figure 21 gives an overview of how the volume of the projected increase of **AUS32** volume in North America (34).

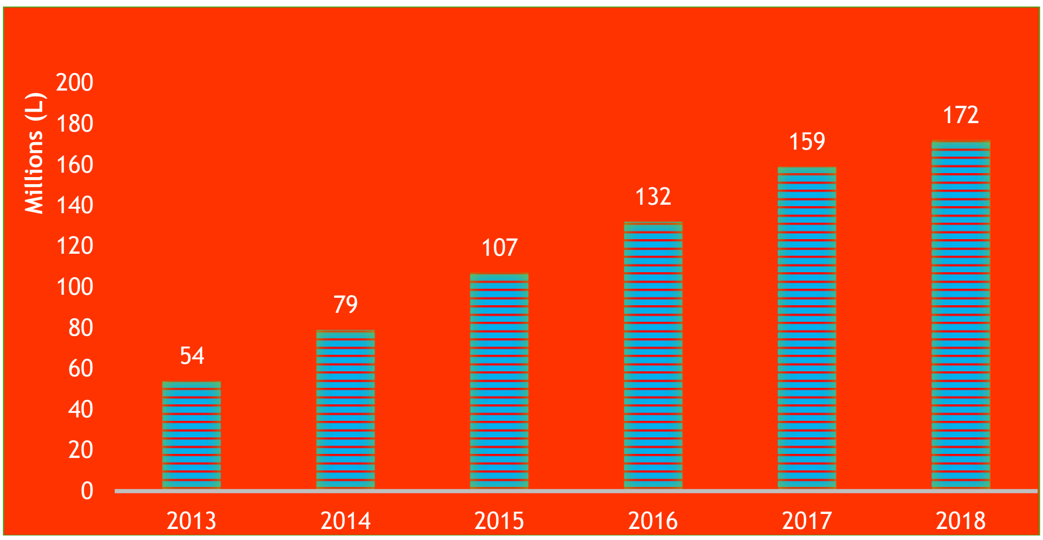

Figure 21 North American AUS32 (DEF) volume projections (35)

Furthermore, infrastructure for the supply of **AUS32** (e.g. retail pumps) is also on the rise, according to Integer, the pump locations have seen a 53 % increase between January 2014 and January 2015. Figure 22 gives an overview of the North American **AUS32** supply infrastructure in October 2012 (34, 35).

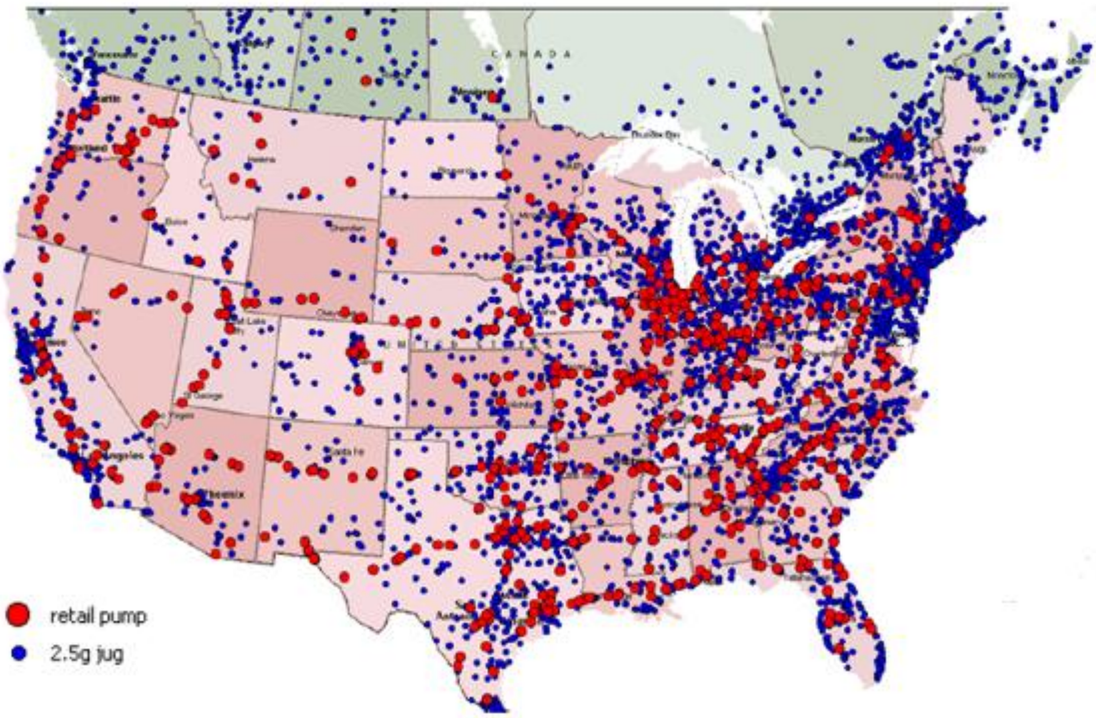

Figure 22 AUS32 (DEF) supply infrastructure in 2012 (36)

In addition, the demand of **AUS32** in the North American market is also projected to increase, integer reports that the consumption of **AUS32** will reach around 1.9 billion by the year 2019 *(Fig. 23)*, and this is an 826 % increase (35).

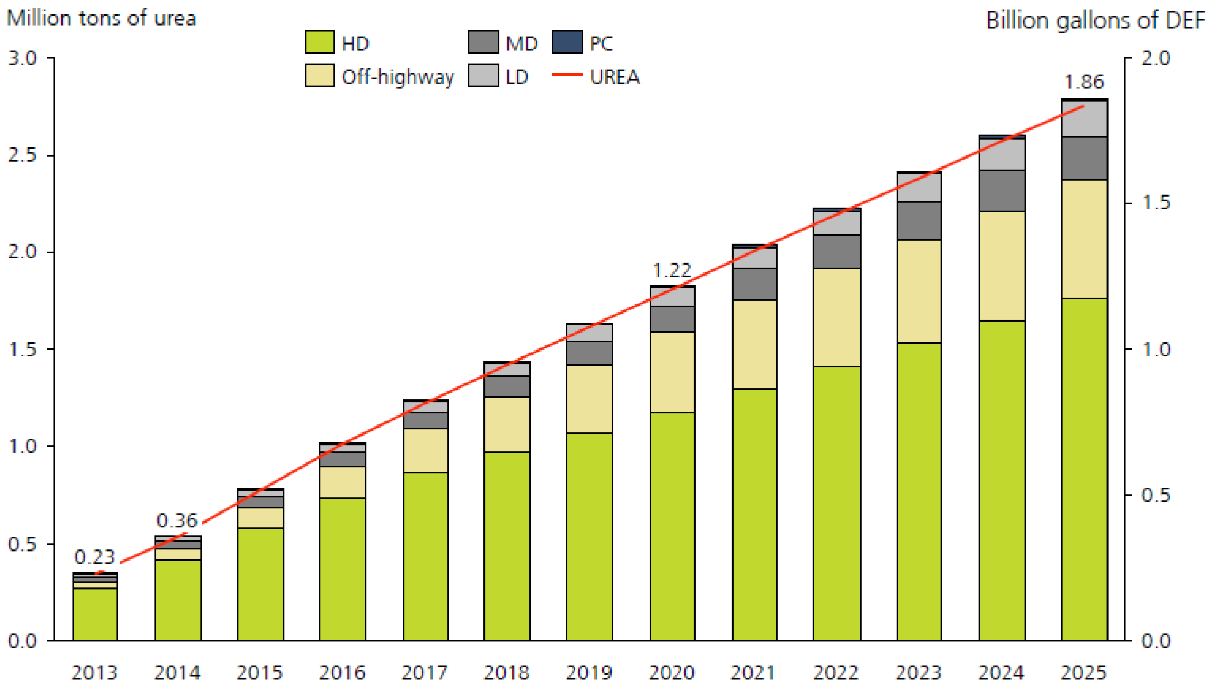

Figure 23 consumption of Urea and AUS32 (DEF) in North America (37)

What this means is that the demand for **AUS32** will increase in the coming years, this can also be seen in the 2012 projections on the demand of urea (*Fig. 24*). The demand of urea will continue to grow well into the year 2030 and since a percentage of the applications for urea is the automotive industry, an increase can also be expected in the demand for **AUS32**.

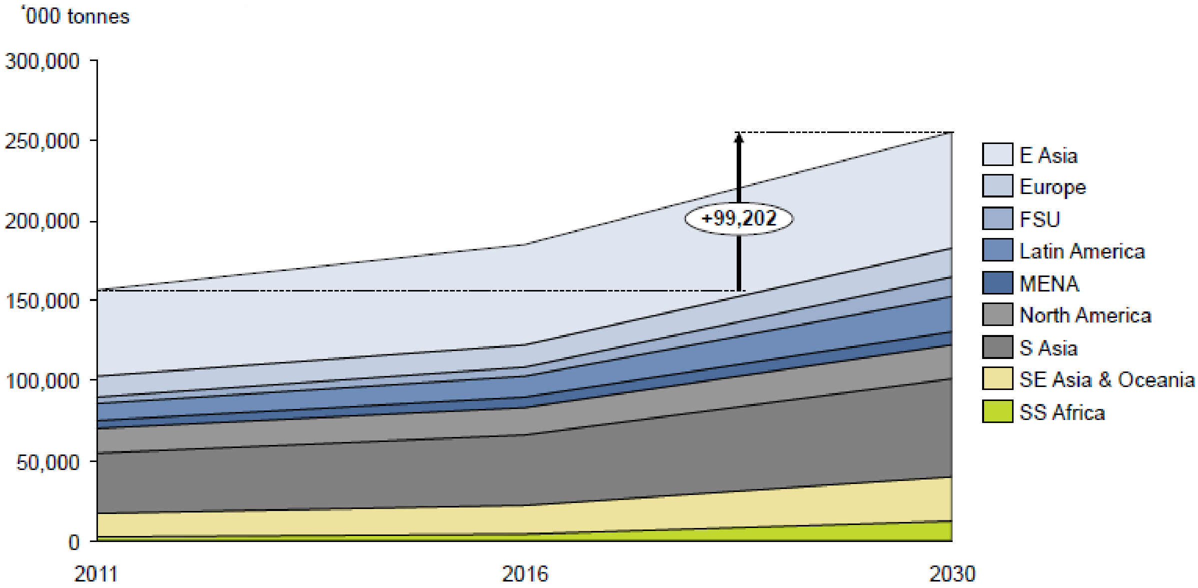

Figure 24 Projection of global urea demands 2011-2030 (36)

5 Discussion

During the research on techniques of urea synthesis, there were several problems that. Some of the literature was not available directly, and some of it required payment for access. Most of the literature that was utilized was from a book, a patent, and articles. These sources are quite reliable since it has been cited by several works and was acquired from the companies itself. Numbers related to the techniques are quite reliable, as similar numbers could be found in different literature sources. Both techniques numbers and figures were found within the same document, so the data can be compared together which can be found in the sustainability assessment in Appendix 3.

The assessment was done using the parameters that are considered important for the comparison between the techniques. Known numbers from the technique are compared together to determine which techniques is more sustainable. This assessment is not 100% correct, and can change depending on the design of the techniques. Some aspects of the technique can be removed or altered, thus providing different results each time. An assumption was made for the health impact and the cost of the equipment because it is not available in the literature. These parameters are then given a score and color to show which parameters within each technique is better than the other.

The difference between the score is not that high, and both processes showed a really good waste water pollution content, and even very little amount of process water generated after the production of urea. Health impact is considered in the assessment due to the presence of air pollution in the system that can affect local workers and inhabitants. Cost are very dependent on the techniques itself, it is assumed that Stamicarbon will have lower construction and operational cost, because condenser and pool ractor is combined.

The assessment showed that Snamprogetti™ process is more sustainable than Stamicarbon™ due to the availability to recover condensate in the process. Less air emission and wastewater pollution also support this results. The only downside to Snamprogetti process is the lower yield of Urea and the high construcion and operational costs, but this technique will be less harmful to the environment in the long run.

The research study has revealed alternative possibilities for ammonia as a raw material are possible. The data is based on up to date literature which is derived from well-established science therefore, the information is reliable.

With Regard to the market study, a global analysis of the regulations related to the air emission control showed that a few countries in which possibilities to market **AUS32** exists (e.g. the US, Canada, brazil etc.), out of these countries one has been analyzed (America). For the complete analysis of the American **AUS32** market, the majority of information has been drawn from conference proceedings. This might have a negative influence on the reliability of the Information in the scope of determining the actual market size since the conference proceedings don't provide actual up to date data to which access is otherwise limited. However, the data from the conference proceedings does help draw a reliable picture of the how the **AUS32** market works in the US and what the outlook is for this market.

6 Conclusions & Recommendations

After analysis of techniques related to producing urea, as well as sustainability assessment, it is recommended to use Snamprogetti™ process as a choice to create urea, which will be manufactured into **AUS32**. This process has lower emission to the environment and also require less energy consumption than Stamicarbon process. The only downside is slightly lower yield and also assumed costlier than the other process.

Next, this research concludes that ammonia can be used as an alternative fuel for the production of electricity. The ammonia can be utilized as a fuel in internal combustion engines and fuel cell systems. Furter research sould be done in order o locate already existing projects in which ammonia is utilized as fuel source for the generation of elecricity and power.

Furthermore, it is concluded that the possibilities for the **AUS32** market are very viable in the United States of America. The country is experiencing and expecting an increase in the supply & demand of **AUS32**. Also, the fact that this country is amongst the countries that have the most stringent laws on automotive greenhouse gas emissions compared to other countries in the world shows that the amount of vehicles that will be utilizing SCR is also going to increase.

Further study needs to be done to establish the exact figure and how big the North American **AUS32** market is. One approach that we suggest is to get in contact with the research firm (integer) who provides the most up to date data on the **AUS32** market globally (against payment). Furthermore, if the client starts producing **AUS32** it can get more acquainted in the market by attending any of the conferences organized by Integer, since all of the stakeholders (e.g. Auto manufacturing companies, Adblue producers, consumers etc.) attend these conferences. Upcoming relevant conferences include: *the 12th Integer Emissions Summit & Adblue® Forum Europe 2016 (Belgium)* and *the 9th Integer Emissions Summit & DEF Forum USA 2016 (Chicago)*.

Another point to take into consideration is the exploration of the **AUS32** market in the emerging economies e.g. China, India, and Brazil. Since these countries have just established "current" automotive greenhouse gas emissions. However, these countries are still in the process of the actual phase in the phase of technologies (SCR) required achieving the GHG emission standards related to these regulations. Thus looking the developmental process of these markets before allows for the client to have a competitive edge.

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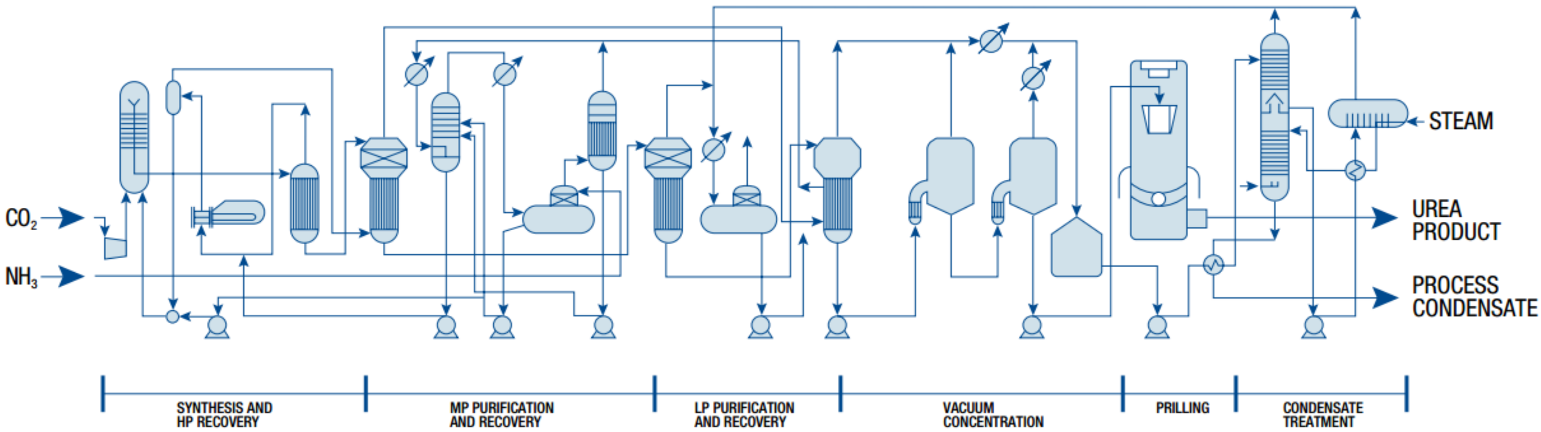
Appendix

Appendix 1 Complete Process Flow Diagram of Snamprogetti™ Urea Production

This figure shows the complete process flow diagram of Snamprogetti™ process to produce Urea from CO_2 and NH_3. There are six sections available within the process, and this information can be found in chapter 4.1.1.



Appendix 2 Snamprogetti™ Process Performance Data

This table shows the complete process performance data that can be expected from Snamprogetti™ technology. It can be seen the product quality that will be produced during the process, and also recoveries that are happening within the process. Effluent of the process can also be found here.

Expected Product Quality

Product Quality	Units	Prilling
Nitrogen	% b.w.	46.4
Biuret	% b.w.	0.85
Moisture	% b.w.	0.3
Prill size (average diameter)	mm	2
Crushing strength	kg	0.8 (on 2 mm)

Recoveries

LP steam export (3.5 bar g, 147°C)	kg	Injected into steam turbine
Total condensate export	kg	1100

Effluent

Process Condensate		
• Ammonia	ppm b.w.	<1
• Urea	ppm b.w.	<1
Air emission		
• Urea dust	mg/Nm	40
• NH_3	mg/Nm	20

Appendix 3 Sustainability Assessment of Urea synthesis techniques

This table shows the sustainability assessment that are done to see the sustainability of each technologies that are described in chapter 4.1. the scores can be found below the table, with each color representing the scores of each parameters. Detailed information about the assessment can be found in chapter 5.

Categories			Units	Techniques			
				Snamprogetti	Scores	Stamicarbon	Scores
Energy Consumption	Electricity		kWh	23	1	58	0
	Cooling water		m^3	95	-2	70	-1
	Steam		ton	1.6	1	0.92	2
	Total consumption		Gj	1.7	1	1.9	0
Reactant chemicals	Ammonia		kg	566	0	567	0
	Carbon dioxide		kg	733	0	733	0
Recovery	Condensate		kg	1100	2	0 (?)	0
Pollution	Health impact			(+)	1	(-)	-1
	Air	Ammonia	mg/m^3	20	2	2000	-2
		Dust	mg/m^3	40	-1	25-30	2
	Waste water	Process Water	m^3 / ton urea	0.65	0	0.46	0
		Ammonia	ppm	< 1	2	1	1
		Urea	ppm	< 1	2	1	1
Cost				(-)	-1	(+)	1
Yield				62-63%	-1	70-75%	1
Final Score				7		4	

Scores

2	1	0	-1	-2