EXPLORING THE POSSIBILITIES FOR FERTILIZER PRODUCTION BASED ON THE CIRCULAR ECONOMY IDEA

Master thesis

Monday, 14 March 2016

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SUEZ

UNIVERSITEIT TWENTE.

Colophon

General information

Document type:	Master thesis
Date:	Monday, March 14, 2016
Version:	1.1

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Management summary

In 2015 SUEZ started with the transformation of their business and organization. This transformation, named "Ready for the resource revolution", aims to develop the activities and innovations of SUEZ day after day. Delivering concrete solutions to its customers and partners should help SUEZ to cope with the new challenges of resource management. In the context of these new developments SUEZ aims to reuse residues by transforming them into raw materials. Because SUEZ receives residual streams that contain valuable nutrients for the fertilizer industry, the ReFertilizer project has been launched. However, due to the daily tasks of the employees, the project did not yet receive enough attention to define all possibilities and limitations. This report aims to create insights on the legal, qualitative, production, storage and financial aspects of the project by answering the following central research question:

"What is required for SUEZ Almelo to successfully start with the production of 'green' inorganic fertilizers?"

We conducted our research by analyzing the available literature, interviewing the employees involved, analyzing the laboratory results and contacting potential customers.

Our findings on the various aspects are consicely described below, where recommendations and follow-ups have been drafted in a roadmap.

Legal

This report outlines all relevant general information on the incoming material streams. However, there are a few legal subjects that require additional attention. The first subject is the end-of-waste legislation, the legislation that is related to the transformation of waste streams into 'new' raw materials. For SUEZ Almelo there are two ways to apply this end-of-waste legislation, it can be applied to all the incoming waste material streams separately (before formulation) or it can be applied to just the final inorganic fertilizer product (after formulation). Based on the criteria that should be met to comply with the end-of-waste legislation, the application of the legislation after formulation to the final inorganic fertilizer product is recommended. Another legislation that is important for the ReFertilizer project is the REACH legislation. The European legislation that engages in the registration, evaluation and authorization of chemicals. The formulation of the inorganic fertilizer is considered to be a process that creates a mixture of the incoming substances and no new substance is formulated. Therefore, all incoming substances should be registered at REACH. An accredited laboratory should measure all incoming substances and define whether or not these substances have been registered at REACH before. When already registered, SUEZ can use these substances. When a substance has not been registered before, it should be registered at REACH by SUEZ. Besides measurements on the REACH regulation it is important to measure the substances on the maximum levels of heavy metals, level of nutrients, micro-organic pollutions, viruses and bacteria.

Follow-ups regarding this legal part are therefore to obtain the end-of-waste status on the inorganic fertilizer and to find an accredited laboratory that can test all related substances on the level of heavy metals, level of micronutrients, micro-organic pollution and viruses or bacteria. Based on this information it is possible to define and decide what materials can legally and safely be used in the ReFertilizer project.

Qualitative

The qualitative part summarizes all relevant aspects that are related to the incoming materials and the produced fertilizer material. It starts with outlining all relevant nutrient and fertilizer types. It reveals an increasing worldwide demand for fertilizers. However, the relatively large local Dutch market seems to stagnate. Based on the available waste material streams that SUEZ handles, the most useful fertilizer type is ammonium sulfate (containing nitrogen and sulfur). However, based on the available material streams it is possible to produce these fertilizers in various compositions. Table 0-1 shows all different combinations possible. All combinations contain urea and ammonia. The other substances that can be used are the ammonium sulfate from farms, the ammonium sulfate from the semiconductor industry, ammonium bisulfate from the pharmaceutical industry, sulfuric acid from the semiconductor industry and virgin sulfuric acid.

Ranking mixed substances				Costs per ton (€)
Water	AS from semiconductor industry	Urea	Ammonia	€ 134.87
AS from farms	AS from semiconductor industry	Urea	Ammonia	€ 139.64
AS from farms	ABS from pharmaceutical industry	Urea	Ammonia	€ 152.17
AS from farms	SA from semiconductor industry	Urea	Ammonia	€ 152.90
AS from farms	SA (virgin)	Urea	Ammonia	€ 157.34

Table 0-1: Cost tanking mixed substances (AS=Ammonium sulfate, ABS=Ammonium bisulfate, SA=Sulfuric acid)

Table 0-1 shows the possible combinations based on a ton of fertilizer output. It can be concluded that the ammonium sulfate from the semiconductor industry diluted with water and complemented with urea and ammonia can be formulated at the lowest cost. The second option of the cost ranking is the combination of the ammonium sulfate from farms with the ammonium sulfate from the semiconductor industry. The third option is considered to be inapplicable because the bisulfate is available in small quantities.

Follow-up for this chapter will be to look for more high-quality ammonium sulfate and waste streams that can be used as a substitute for the expensive urea.

Production process

Internal discussions revealed that the production of 2,000 ton of inorganic fertilizer during the first years of the production should be achievable. Calculations on both storage options and production options are based on this number of fertilizer output. Because not only the cost of the material is

Total material amounts required	Monthly volume (m^3)
Ammonium sulfate from farms	75.57
Ammonium sulfate from semiconductor industry	8.63
Sulfuric acid from semiconductor industry	1.81
Sulfuric acid (virgin)	0.00
Urea	88.71
Ammonia	5.50
Fertilizer	142.51

Table 0-2: Required monthly volumes

important, there are other factors that define what combinations are the best option to produce (availability, origin). Including all relevant factors reveals that ammonium sulfate from farms combined with the ammonium sulfate from the semiconductor industry should be produced first. This option, combined with the cheapest option (ammonium sulfate from the semiconductor diluted with water) is currently available in such large quantities that 2,000 ton of inorganic fertilizer can be produced. Therefore the other options (see table 0-1) are considered to be unnecessary during the starting years of the ReFertilizer project.

Producing 2,000 ton of inorganic fertilizer requires the monthly amounts of materials that are shown in table 0-2. Because of the large required amounts of ammonium sulfate from farms and urea, the best storage equipment for these materials is a tank and a silo, respectively. The ammonium sulfate and the sulfuric acid from the semiconductor industry can be stored in intermediate bulk containers (IBC) of one cubic meter and the ammonia can be stored in the barrels in which it is delivered to SUEZ. The production process itself is relatively simple, consisting of a few production steps. For this production process there are two production plant options considered to be relevant for the ReFertilizer project. The first option is to update the outdated spent catalyst installation, the other option is to build a new installation for this project. For the production of 2,000 ton of fertilizer the current capacity of the spent catalyst installation (6 m^3) is sufficient, but increasing the production requires a larger reactor vessel. A reactor vessel should be isolated, double walled and contain a pump and heat exchanger. For the storage of the final product there are several options. However, storage of the fertilizer in an external warehouse or a (new to build) storage location in Almelo is considered to be too costly. The most suitable option is store the fertilizer product in a bag tank, this option is cheaper than the other options and has a large storage capacity.

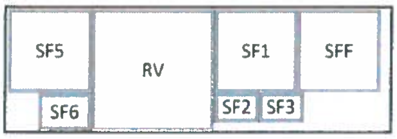

Figure 0-2: Proposed layout spent catalyst installation

In order to start the production, a plant layout has been designed for both production options. For this plant layout the theory of Muther (Muther, 1961) has been applied. Where relationships and space requirements are taken into account. Applying the theory resulted in the proposed layouts shown in figure 0-1 and 0-2.

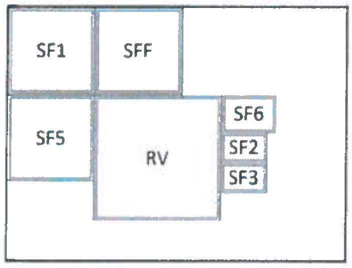

Figure 0-1: Proposed layout new production plant

The major follow-ups for this chapter will be to define what amount of products will be produced on a yearly basis by SUEZ, where the production will take place and to which extent the fertilizer product can be stored in a bag tank during the winter period.

Financial

The financial aspects revealed the costs of the materials, the revenues, required investments and a valuation of the overall project. Material costs are calculated based on the currently available material costs per combination (see table 0-1). Based on the two combinations required to produce 2,000 ton of fertilizer and their availability the average material costs per ton fertilizer are €148.40. Revenues are based on a price per ton of €260. Investments that are required for the production facilities differ per option. The updating of the spent catalyst installation requires an investment of roughly €45,000. Where the second option of building a new installation requires a larger investment, roughly €100,000. Based on the revenues per ton fertilizer, all involved cost categories and a number of cost indexation and valuation assumptions, the net present value (NPV) of both production facility options are calculated. This shows that updating the spent catalyst installation (option 1) is, over the project length, more profitable than building a new installation (option 2). These values are summarized in table 0-3.

	Option 1	Option 2
NPV	€ 30,678.38	€ 1,926.31

Table 0-3: NPV of the two production facility options

Follow-up for the financial chapter will be to gain more insight on the investment costs and the revenues over the long-term. Based on an extensive financial analysis it will be possible to make a go/no-go decision on the ReFertilizer project.

Roadmap

This roadmap indicates what follow-up actions will have to be taken by SUEZ Almelo in order to successfully continue with the ReFertilizer project. The roadmap outlines different phases. Phases follow one another, or overlap. For each phase the action that should be taken is described and the related dates (quartile and year) are given. Next to the action and date, the actor responsible for the action is listed in table 0-4. The actors are introduced in the current situation description, section 2.2. The actions defined in this roadmap are described in detail within chapter 7, conclusions and recommendations.

Phase	Action	Date	Actor
1	Achieve end-of-waste status	Q3 – 2016	HSE manager
2	Find company to investigate product	Q2 – 2016	Head of laboratory
3	Define amount to produce	Q2 – 2016	Director treatment and manager hazardous waste
4	Define where to produce	Q2 – 2016	Director treatment
5	Extensive financial analysis	Q3 – 2016	Manager hazardous waste
6	Look for new high-quality waste flows	2016	Waste manager
7	Make Go / No-Go decision	Q4 – 2016	*All actors*

Table 0-4: Roadmap ReFertilizer project

Preface

After nearly six months of hard work I can proudly present you my master thesis. Presenting this thesis implies finalizing my master Industrial Engineering and Management at the University of Twente. This means the end of my student life, moving forward to the next phase in my life. I had a great time during my years at the University, but I am ready for the next step and face the future with confidence.

It would have been impossible to perform and complete this master thesis without the input and support of many people. First of all, I would like to thank SUEZ for providing me the opportunity to graduate at such an interesting multinational. Within SUEZ I would like to thank all involved employees, everyone I contacted within different departments and locations was willing to cooperate and provide me with useful information. I would like to thank my supervisor, Marc van der Kemp, in particular. He provided me with input, support and useful feedback on my report. Besides the interesting project I could perform within SUEZ, the department I could work was a very pleasant working environment where time flew by so fast.

Besides everyone involved from SUEZ, I would like to thank both my supervisors at the University. Peter Schuur and Henk Kroon provided me with useful feedback and support. This resulted in me getting the most out of my graduation project and therefore I am able to present this report.

Last but not least, I would like to thank my family and friends for their support during the execution of my master thesis.

Thijs Nijhuis
Almelo, March 2016

Contents

List of figures and tables

List of abbreviations

ADR	Accord européen relative au transport international des marchandises Dangereuses par Route
BAT	Best Available Techniques/Technologies
BRZO	Bedrijfs Risico Zwaar Ongeval
COGS	Costs Of Goods Sold
EBIT	Earnings Before Interest and Taxes
EBITDA	Earnings Before Interest, Taxes, Depreciation and Amortization
ECHA	European CHemicals Agency
EOW	End Of Waste
FLS	Formulation of Liquids and Solids
IBC	Intermediate Bulk Container
IPPC	Integrated Pollution Prevention and Control
MSDS	Material Safety Data Sheet
NA	Not Applicable
NPV	Net Present Value
ONO	Ontgiften Neutraliseren Ontwateren
REACH	Registration Evaluation and Authorization of CHemicals
SGA	Selling, General and Administrative
SVHC	Substances of Very High Concern
SLP	Systematic Layout Planning
TPA	Ton Per Annum
XRF	X-Ray Fluorescence

1. Introduction

1.1 SUEZ

In the framework of completing my Master studies Industrial Engineering and Management I performed research at SUEZ in Almelo into the ReFertilizer project. SUEZ is specialized in the field of durable waste management. SUEZ collects, transports, separates, processes and recycles regular (industrial) waste and hazardous[1] waste. Besides this they do the maintenance and management of sewerage and soil remediation. The company started in France as SITA and the name SITA originally came from the Société Industrielle des Transports Automobiles. This is named after the first motorized garbage trucks that started collecting waste in the large cities in France around 1919 and arose out of the need for more hygiene and rapid treatment of waste. Nowadays SUEZ operates in over 24 countries and the company SUEZ belongs to the world's largest waste management companies. Together with the other Dutch SUEZ companies SUEZ Almelo is part of the large multinational SUEZ. The SUEZ Group is also French based and operates in over 70 countries, besides the waste management sector SUEZ operates in the water treatment sector. The name SITA has been replaced by SUEZ during my internship (SITA, SITA Nederland, 2015).

SUEZ Nederland consists of 40 different locations where about 2,200 people are employed, the headquarters is currently situated in Arnhem. SUEZ Nederland has over 70,000 customers, consisting of governmental departments and all sorts of companies. Waste is collected and processed in various locations in the Netherlands, always in the most environmental friendly way (SITA, SITA Nederland, 2015). A specific part of SUEZ is responsible for all hazardous waste services in the Netherlands. The graduation assignment is performed within the location of SUEZ in Almelo. The department of SUEZ Nederland has locations in Maastricht, Gorinchem, Veendam and Almelo. Hazardous waste is collected at the customer and transported to one of the storage locations (Maastricht, Gorinchem or Veendam) or to the processing location in Almelo. The customer base for the department consists of large multinational firms, SMEs, institutions and governments. After collecting the hazardous waste, the mono-flows are categorized and transported to waste processing facilities. These facilities are a range of specific (niche) processes within the SUEZ group (like the treatment department in Almelo) or specific partners like chemical incineration plants in several European countries. Because of the wide diversity of hazardous waste streams, SUEZ cooperates with more than hundred different partners. Within the treatment location of Almelo two main activities can be recognized. These are the distillation and the metal recovery activities. Besides these main activities several customer specific installations are operated. The majority of the waste products within SUEZ are on the EURAL[2] list and marked with an asterisk, these types of wastes are defined as hazardous waste (SITA, Onze operatie, 2014).

[1] Hazardous waste includes all goods or waste mentioned in the EURAL list (European waste list) categorized by EURAL code including an asterisk

[2] EURAl is the European waste list that contains all waste products described by a six digits code

1.2 Research motivation

SUEZ has implemented a new strategy, this new strategy strives to protect the natural resources that are essential for our future. The idea of the new strategy is based on 3C's. These three 3C's are, circularly, concrete and collaborative. Circularly has to do with the aim to generate raw materials that are essential for our life and future, based on the principles of a circular economy. Concrete supports the tangible and innovative actions that are used to protect the natural resources. The last C, collaborative, connects everyone who contributes to better managing and securing natural raw materials for the future (SITA, Strategie, 2014). Based on this strategy SUEZ strives for new circular business models, within these models the materials that are previously considered as waste will be sustainably reused either as raw materials for the same industry or as input for processes in other industries. These new projects will be started to expand their current base of materials and to improve their revenues and their corporate image. SUEZ already started with some innovative project. These projects result in a decrease in the amount of residual waste, as can be seen in figure 1-1.Projects based on this innovative circular environment that have been started are the RePaint, ReEnergy and the ReCyper project (SITA, Circulaire Economie, 2014). By starting these projects, SUEZ is on the one hand able to increase their revenues because the incoming waste materials can be transformed to and sold as new raw materials. On the other hand SUEZ will be able to build a green image because it decreases the environmental impact of hazardous waste by transforming hazardous waste into the sustainable reuse of incoming waste materials.

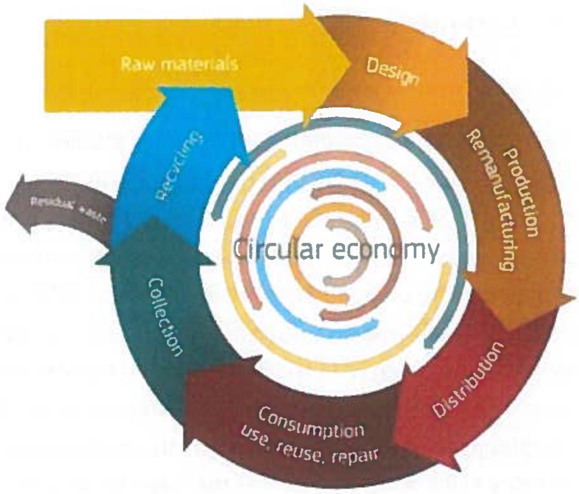

Figure 1-1: Circular economy

Based on this circular economy principle SUEZ would like to start a ReFertilizer project. This project implies that current waste streams can, by performing a few chemical steps, be transformed into an inorganic liquid fertilizer[3]. For this ReFertilizer project SUEZ would like to investigate the possibilities to produce fertilizers out of waste materials. SUEZ could produce fertilizers out of new raw materials, but this is considered of low economic value and does not satisfy the circular economy principle. For the input materials there are different possibilities to start with the production of fertilizers. A valuable input material can be the liquid substance ammonium sulfate. The collection of this substance could be achieved by collecting washing fluids[4] from (pig)farms, where these washing fluids are the output of air washers that are used to reduce the emission of the harmful gas ammonia. Besides the reduction of the emission, the air washer will reduce the spreading of odor and dust. Next to using the ammonium

[3] Fertilizer is any material of natural or synthetic origin that is applied to soil or to plant tissues to supply one or more plant nutrients essential to the growth of plants.
[4] Washing fluids are the output of air washers that are used to reduce the emission of the harmful gas ammonia. The ammonium containing air is lead through or along a solution of sulfuric acid.

sulfate of the farming industry there is the possibility to use another waste stream, this is the waste stream from a company that produces semi-conductors. Producing these conductors results in the formation of ammonium sulfate, this substance is considered as waste by the semi-conductor producer but can be used by SUEZ as input for the production of fertilizers.

For the incoming ammonium sulfate stream there are different possibilities, however two of the considered input streams (farm and computer industry) have different compositions. Besides the ammonium sulfate the computer industry also delivers a sulfuric acid stream that can be useful for the ReFertilizer project. Another possible input material is the waste stream of another customer, operating in the chemical production industry, that delivers the waste stream ammonium hydrogen sulfate. This results in different requirements for the production process, all compositions require different production steps. The different possibilities for the production are outlined in table 1-1 below.

Supplier input material	Additional material #1	Additional material #2
Farm	Sulfuric acid	Urea
Computer	Water	Urea
Farm and computer (mix)	Urea	-
Farm	Sulfuric acid	Nitrogenous waste
Computer	Water	Nitrogenous waste
Farm and computer (mix)	Nitrogenous waste	-

Table 1-1: Possible combinations fertilizer production

Fertilizers can be produced out of different elements, see table 1-2, with these elements different combinations of fertilizers can be produced. The main elements within the waste streams that SUEZ receives are nitrogen and sulfur. With these elements the NS (Nitrogen & Sulfur) fertilizer can be produced. If the concentration of sulfur in the input material is too low, the substance requires the addition of sulfuric acid. If the concentration of sulfur is too high, the substance will have to be diluted with water. If the concentration of nitrogen is too low, the substance requires the addition of urea or the addition of another waste stream that contains nitrogen.

Element abbreviation	Element name
N	Nitrogen
S	Sulfur
P	Phosphorus
K	Potassium

Table 1-2: Fertilizer elements

The current ReFertilizer project within SUEZ has focused on the production of NS fertilizers. However, besides the production of the NS fertilizer it is possible to produce other types of fertilizers by adding the phosphorus element and/or the potassium element. With this addition(s) it is possible to produce NPS/NPK/NPKS fertilizers. Based on external demands and internal possibilities it is important to analyze what fertilizers are demanded in the market and what opportunities are there within SUEZ to produce other type of fertilizers. This assignment will research and define what the relevant possibilities are and focus on the fertilizers that are demanded and producible within SUEZ . The research on the possibilities and the qualitative aspects of the fertilizer is described in chapter 4.

The location in Almelo contacted suppliers and customers for this new ReFertilizer project and performed tests with the new waste material. Both suppliers and customers are interested and willing to cooperate in this new production process. The first tests have been executed and showed positive results. However, additional tests are required to define what the best mix of input materials is. Besides this, tests will have to prove that the fertilizers do not contain any harmful substances for the customers. The output of the new production process, the inorganic[5] fertilizers, can be used within the agricultural sector.

This new ReFertilizer project has been introduced within SUEZ but has not been documented or completely worked out. Therefore SUEZ would like to better investigate and develop the major steps that are necessary to start this new production process. The major blocks necessary to start with this process are defined within SUEZ as :

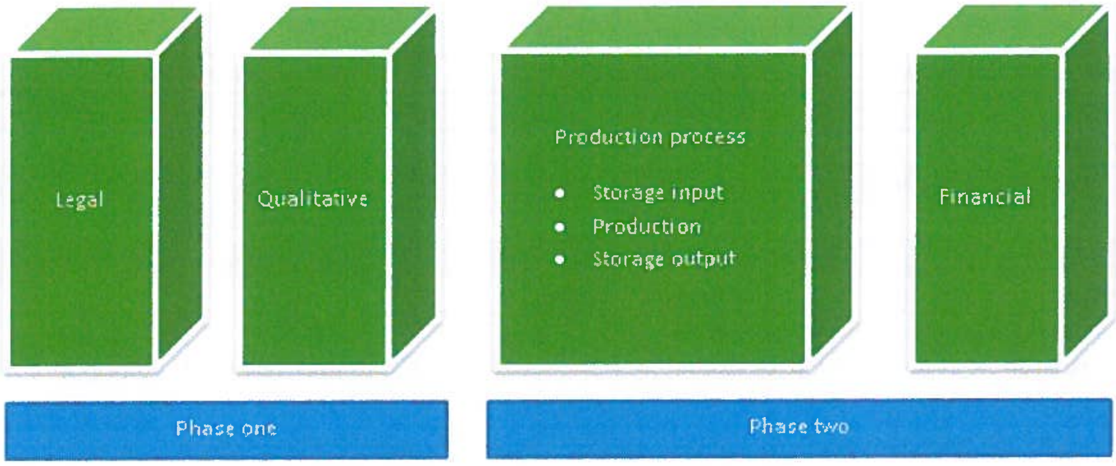

Figure 1-2: Blocks ReFertilizer report

The legal aspect addresses all issues that might influence the ReFertilizer project. The qualitative research will be necessary to define what the actual chemical process will look like and what (additional) materials are required. The production process will describe what storage and production equipment will be required to store and produce the (end-)product and what a production line might look like when SUEZ decides to start producing Fertilizers in large quantities. This production process will be designed taking into account the location constraints and possible storage locations. A market research will have to be conducted to create an image of what the market for these liquid fertilizers will look like, what customers there are, what quantities of fertilizers they would like to buy and what prices they are willing to pay for this new product.

1.3 Report outline

This report is divided into different blocks (see figure 1.2). After this introduction chapter, all blocks are assigned to a separate chapter. Each chapter will start with an introduction on the subject of the block, outline the most important subjects of the block and at the end of each chapter there is a summary. The last chapter is a summary of the report, where conclusions are drawn and recommendations are made.

[5] Inorganic fertilizers are fertilizers that usually not plant- or animal derived. Various chemical treatments are required to manufacture inorganic fertilizers.

1.4 Research plan

1.4.1 Problem description

The new idea of the production line has been discussed and concisely described within SUEZ. However, before starting with producing Fertilizers SUEZ would like to better document and investigate the possibilities for setting up this new production line. To create better insights in the possibilities and risks of the new production line it is necessary to investigate the described steps as described in the research motivation (legal, qualitative, production process, market). This graduation assignment will focus on the setting up of this new production line, where research will divided into two phases, the first phase will focus on the gathering of information on the new product. This phase will address the legal aspects and the qualitative aspects of the production process. The second phase will focus on the design of the production process and related market segment.

Phase one

The start of phase one will be to better investigate and document what is necessary to purchase, transport and store input materials for the production of fertilizers (ammonium sulfate, urea, sulfuric acid, etc.) and to produce, store and transport the inorganic fertilizers. Because the ReFertilizer project is new for SUEZ and chemical waste streams are used as input for the production of fertilizers it is important to map what the possibilities and barriers are with respect to the legislations. Another important aspect is the documentation of the qualitative process. There are different possibilities with respect to the production of fertilizers. Different input materials can be used, different production steps might be necessary and there is the possibility to produce different types of fertilizers. A study with respect to the different possibilities has to show what are, or what is the main fertilizer that SUEZ should focus on. The chemical engineers within SUEZ have performed tests and will perform new tests with these materials to gain knowledge on what will be necessary to perform this production process. The gathered information within this qualitative aspect will be used to do recommendations on what are the required materials and what are the required production steps to produce fertilizers in the best way.

Phase two

The second phase will comprise the design of a new production line for the ReFertilizer project. The information that has been collected and documented in the first phase will be used as input for this phase. With this information and with the information from other producers of fertilizers, suppliers and market data a new design can be made for the production of liquid fertilizers. Recommendations will have to be made on what equipment, production materials and production capacity will be necessary to produce the fertilizers. Production capacity will have to take into account the seasonality of the fertilizer product. An analysis will define what the market demands are in the months that the product can be used. Besides this, a suitable layout is required for the production process. This layout describes the steps necessary to produce the product and their optimal location. This includes the storage of raw materials, processed and end products. Before taking any of these decisions it is important to analyze and investigate the possibilities, taking into account the current location constraints. Constraints can be the availability of resources, available space within the location, traffic on and around the location and safety issues and regulations.

1.4.2 Research objective(s)

To successfully complete this research it is important to complete the two phases described above. The objective for the first part of this research is to describe all legal barriers and opportunities for SUEZ to start with the production of inorganic fertilizers. Besides this it is important to document and describe in what way and with what required (additional) materials SUEZ is able to produce the required inorganic fertilizers.

The objective of the last part will be to come up with an advice on how the production of fertilizers can be performed on the location of SUEZ in Almelo. The advice takes into account the current location with the location constraints, required storage locations, required production equipment and production layouts.

1.4.3 Research (sub)questions

To perform a descent graduation assignment it is important to draft good research questions. Sub-questions will be composed to answer the smaller divided parts of the research. These sub-questions will be used to answer the main research question of this graduation assignment. The sub-questions and the main research question can be found in the tables 1-2 and 1-3 below.

Research sub-question
What legal issues influence the ReFertilizer project?
What is the best option to produce inorganic fertilizers and what materials are required to produce these inorganic fertilizers?
What are required equipment and capacities for SUEZ to produce inorganic fertilizers?
What is a suitable layout, taking into account all relevant constraints, for the production of inorganic fertilizers by SUEZ in Almelo?
What are possible storage locations and storage options for the input and output products?

Table 1-3: Research sub-question

Research question
What is required for SUEZ Almelo to successfully start with the production of 'green' inorganic fertilizers?

Table 1-4: Research question

1.4.4 Project planning

Project week	Week number	Year	Activities
1-2	41-42	2015	Introduction, starting research, gathering info
3-6	43-46	2015	P1 – Legal
7-10	47-50	2015	P1 – Qualitative
11-14	51-4	2015/2016	P2 – Production
15-18	5-8	2016	Process results
19-21	9-11	2016	Solution design
22-23	12-13	2016	Conclusions and recommendations
24	14	2016	Finalizing master thesis and final presentation

Table 1-5: Project planning graduation assignment

2. Context analysis

2.1 Literature review

This section will describe and summarize the available literature and general information on this subject, including the research that has been done on the subjects of this project. Information has been gathered on the general circular economy idea (that is the rationale behind this project), general information on the chemical process and elements in the production of different fertilizers, the history and future of fertilizer and the demands of these products throughout the year. This information will help to increase the background knowledge and create a better image on the situation and will summarize what has been done on this subject within other companies and research institutes.

2.2.1 Circular economy

The underlying idea behind this ReFertilizer project can be placed in a large and topical worldwide problem. Although the twentieth century was a century of large surpluses in the food industry the world has currently reached a period of structural food scarcity. Food can be seen as the new oil and land as the new gold. The demands are growing because of the growth in world population and the economic growth, but on the other side the extreme soil erosions, increasing water shortages and changing environments cause a discrepancy. Expectations on the increases in demands can be seen in figure 2-1, food demands are expected to be increased with 50% in 2030, where water and energy demands are expected to increase with 30% (Beddington, 2009). If these shortages will not be reversed the scarcity and the hunger over the world will increase. Farmers are more and more in trouble to comply with the worldwide demands, the world enters a period of permanent food scarcity which will result in a growing competition for natural resources (Brown, 2013).

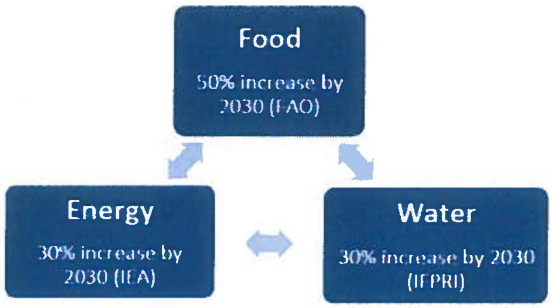

Figure 2-1: 'Food, energy, water and the climate: a perfect storm of global events?'

These large scarcity problems are not new and history showed that previous civilizations had similar problems. These civilizations unsustainably managed their agricultural resources which resulted in the end of these civilizations. Examples are the Sumerians and the Maya's. The Sumerians disappeared because of salinization, an effect of the misuse of their irrigation system. The Maya's are extinct because of the , among other things, soil erosion (Brown, 2013).

In order to prevent the history to repeat itself, the challenges of a growing population and a finite resource base could be countered by the circular economy idea. The circular economy idea has deep-rooted concepts and cannot be traced back to one single author or date. The concept has gained momentum since the late '70s of the twentieth century, where it has been developed and refined by a small number of academics, thought-leaders and businesses. The schools of thought on the circular economy are summarized in table 2-1 below (MacArthur, Schools of thought, 2015).

Circular economy concept	Author
Cradle to cradle	M. Braungart & B. McDonough
Performance economy	W. Stahel
Biomimicry	J. Benyus
Industrial ecology	R. Frosch & N.E. Gallopoulos
Blue economy	G. Pauli
Regenerative design	J.T. Lyle

Table 2-1: Circular economy concept

The circular economy principle is based around a simple set of principles: using less and eliminating waste, maximizing value at each step in the process, deepening cooperation in the supply chain and managing the resources. The model is particularly useful in the global food and agribusiness sector, offering a new way in organizing economic activity to enable growth. Implementation of these ideas requires a shift from a linear 'take-make-dispose' model to a circular model which aims to reduce waste (Sherrard, Bosch, & Elst, 2012).

Several ideas have been introduced on this circular economy principle which can be applied in several industries. For example land restoration, where the ability to restore the land, promote soil fertility and increase harvests. Alternative nutrients sources have been used before for the production of fertilizers. Food waste (alcoholic fermentation of sugar beet or fish waste generated from restaurants), animal manure and sewage are examples of these alternatives (Thingoc & Kyun, 2011). These alternatives can be sufficient to cover the entire fertilizer need in today's production system and stop the dependence on foreign minerals. However these new ideas require both changes in the legislative frameworks and technical innovations (MacArthur, Towards the circular economy, 2013).

2.2.2 Fertilizers

Fertilizers are the main output product of the ReFertilizer project and the re-use of products such as a fertilizer is a circular economy idea, as introduced before in the previous section. However, the idea behind the ReFertilizer project, as described within the introduction is relatively new. To gain more knowledge on the background of the fertilizer industry this section will outline the usefulness and necessity of fertilizers and the different ways of producing different fertilizer types.

Humans, animals and plants all need nutrients to survive. The scope of this project is on the provision of nutrients to plants. The enhancement of growth of these plants by nutrients is generally accomplished by fertilizers. Different types of fertilizers exist, they can be classified based on the nutrients they provide or on the organic or inorganic nature of the fertilizer (Benton Jones, 2012).

When classifying a fertilizer, based on the nutrients they provide , differentiations are made between the 'macronutrients' and the 'micronutrients'. The macronutrients are nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), sulfur (S) and magnesium (Mg). The micronutrients are zinc (Zn), copper (Cu), iron (Fe), boron (B), and molybdenum (Mo). Macronutrients are called 'macro' because they are needed in greater quantities than the 'micro'- nutrients (IFIA, 2015). Within the macronutrients differentiations are made between primary and secondary nutrients, primary nutrients are only the elements nitrogen, phosphorus and potassium. The secondary nutrients are calcium, magnesium, sodium and sulfur (Europees Parlement, 2004). Based on these nutrients different types of fertilizers can be distinguished. There are single (straight) nutrients that contain only a single nutrient and there are multi-nutrient fertilizers. These fertilizers contain more than one (two or three) nutrient components. The focus within the ReFertilizer project at SUEZ will be on the two nutrient fertilizers, containing nitrogen and sulfur. The focus is placed on this fertilizer type because the waste streams that are transported to SUEZ and considered to be relevant for the formulation of fertilizers contain (small) levels of nitrogen and/or sulfur. This decision will be described in more detail within chapter 4.

The difference between the organic and inorganic (or synthetic) fertilizers is that the organic fertilizer usually consists of plant or animal derived substances where inorganic fertilizers require chemical treatments to produce (Benton Jones, 2012). The ReFertilizer project is based on the production of inorganic fertilizers because the production requires a few chemical treatment/formulation steps. The focus on the inorganic fertilizer instead of the organic fertilizer requires other regulations that apply and will require different production steps but these differences will be explained in the next chapter (chapter 3) of this graduation assignment.

Besides differences based on the materials and origin of the fertilizer there is a difference between the state of the substance. Fertilizers can be applied in a solid form or in a liquid form. The advantage of liquid fertilizers is that the effects of the application of fertilizers can be recognized faster and it has easier coverage (Dittmar, 2009). The relevant output of the ReFertilizer project is a fertilizer that will be a liquid substance, the form of the ingoing and outgoing streams will be described in the chapters on the qualitative aspects and the production process (chapter 4 and 5).

Short-term Forecasts for World Fertilizer Demand (Mt nutrients)

	N	P_2O_5	K_2O	Total
12/13	108.1	41.6	29.1	178.8
13/14	110.4	40.3	30.2	180.9
14/15 (e)	111.8	41.3	31.5	184.6
Change	*+1.3%*	*+2.5%*	*+4.2%*	*+2.0%*
15/16 (f)	112.9	41.8	31.8	186.5
Change	*+1.0%*	*+1.1%*	*+0.8%*	*+1.0%*

(e): estimate; (f): forecast

Source: P. Heffer, IFA, June 2015

Table 2-2: Short-term fertilizer forecast

Once the inorganic fertilizer, containing nitrogen and sulfur, is produced it will have to be sold to the fertilizer industry. The fertilizer industry has grown during the last years. It is also expected and forecasted to increase in the coming years, see table 2-2. The growth in the industry can also be seen in the investments made and the people employed. In the coming years, up to 2019, the industry will invest close to USD 25 billion worldwide, increasing global capacity to 165 million tonnes of fertilizer products. The international fertilizer industry association (IFIA) estimates that worldwide, close to 1.4 million people are currently employed in the fertilizer sector. Over the next years this number is expected to increase with a 45,000 direct and 95,000 indirect jobs (Heffer & Prud'homme, 2015). However, the production and use of fertilizer is also under pressure because of the environmental issues regarding the emissions of the fertilizers when produced or used.

2.2 Current situation description

Within SUEZ the ideas of new innovative projects, based on the circular economy (figure 1-1), have been introduced during the last few years. Some of these projects are operational, e.g. the RePaint, ReEnergy and the ReCyper project, and some have not been developed sufficiently enough to be implemented. The ReFertilizer idea is in the latter category. Within the SUEZ location in Almelo there have been discussions and meetings, and there are idea's, documents and presentations on this subject. However, due to the everyday tasks of the employees, the project did not have enough attention yet and has not been worked out. Before this project can be started there has to be a study on the production of fertilizers. As described within the research motivation there are a few building blocks, major subjects that have to be investigated before a clear view arises on what the strengths, weaknesses, opportunities and threats are for this innovative idea. For each of these subjects this section will describe, based on the gathered internal information, what steps have been made and what research has been done before the start of this graduation assignment. Based on this information a clear idea arises on what remains to be done before SUEZ can successfully start with the production of fertilizers. To gather information, the available documents within SUEZ have been consulted and relevant SUEZ employees have been interviewed. Marc van der Kemp (manager hazardous waste), Gert Godeke (waste manager), Herman Lugtenberg (director treatment business unit), Henk Jan Wesseler (head of laboratory), Jan van Zon (manager health, safety and environment) and Roy Kobes (head of treatment business unit) provided information on the work that has been done and what still has to be done within this project.

2.1.1 Legal

Investigating the legal aspects of the project made clear that this subject is not yet fully investigated. Because the project involves (hazardous) waste streams it is important to map what the requirements are to work with those chemicals. Executing this production process can require several licenses and regulations or there can be specific laws that will apply to this situation. For the incoming streams there is a lot of internal knowledge because the majority of the input materials arrived in Almelo before. The only new incoming waste stream is the ammonium sulfate from the air washers out of the farming industry. This fluid has been tested in the laboratory before, but has not yet been transported to Almelo in large quantities. It is yet unclear what statements or licenses for the incoming waste streams are mandatory in order to be transported and stored at SUEZ Almelo.

For the production of fertilizers it is necessary to install and use a new production line because there does not yet exist a facility where fertilizers can be produced in large quantities. There exists an older installation at the plant in Almelo that might be suitable for the production of fertilizers. This installation is currently out of order and has not been used for several years. However, it is not yet clear if it can be transformed into a suitable production facility. To make sure that the facility can be used, if it turns out to be suitable, the facility has been made part of the submitted licence that has been submitted to the municipality. This license will be analyzed and expected to be approved in 2016.

When the product has been produced there arise new legal problems for the finished products. There are uncertainties about the storage and transportation of the final product. The expectation within SUEZ, based on previous tests, is that the final product cannot be stored in a location with low temperatures. Storage of the product in the outdoors is therefore considered to be undesirable. Tests showed that the dissolving process (that will be described in chapter 5) will be reversed and one of the input materials will crystallize and become a solid substance again at lower temperatures. For the transportation and delivery of the product it is important that the final product satisfies the governmental requirements regarding fertilizers and also satisfies the requirements of the customer.

2.1.2 Product

Fertilizers can consist of many different elements (see table 1-2), research during this assignment should clarify what the best fertilizer option for SUEZ is. The research already performed on this project has focused on the production of fertilizers containing nitrogen and sulfur. This product can be produced in various different ways, and a few of these possibilities have been tested in the laboratory of SUEZ. A summary of the tested combinations, that result in a NS fertilizer, can be found in table 2-3. The summary of the tests results can be found in table 2-4.

Combination no.	Tested combination (all include urea and ammonia)
1	Ammonium sulfate from farms combined with sulfuric acid
2	Ammonium sulfate from farms combined with ammonium sulfate from the semi-conductor industry
3	Ammonium sulfate from farms combined with ammonium bisulfate from the chemical production industry
4	Ammonium sulfate from the semi-conductor industry

Table 2-3: Possibilities fertilizer production

Combination no.	Substance	Sulfur (% m/m)	Nitrogen (% m/m)	Weight (kg)
1	Washing fluids	2.42	1.02	100
	Sulfuric acid	81.88	0	9.77
	Urea	0.00	48.66	85.90
	Ammonia	0	20.66	17.81
	Fertilizer	**2.57**	**20.96**	**213.48**
2	Washing fluids	2.42	1.02	100
	Ammonium sulfate	7.76	7.59	75
	Urea	0	46.65	117.20
	Ammonia	0	20.56	1.58
	Fertilizer	**2.80**	**21.0**	**293.78**
3	Washing fluids	2.42	1.02	100
	Ammonium bisulfate	17.04	4.56	25.06
	Urea	0	46.65	94.55
	Ammonia	0	20.56	17.73
	Fertilizer	**2.82**	**21.03**	**237.34**
4	Water	0	0	100
	Ammonium sulfate	7.43	6.47	203.40
	Urea	0	46.65	197.30
	Ammonia	0	20.56	1.00
	Fertilizer	**3.01**	**21.01**	**501.70**

Table 2-4: Tested fertilizer combinations

The summary in table 2-4 provides an overview of the tested combinations. Each combination in the table is identified by a combination number, this combination number is the combination that has been described in table 2-3. The substance column provides information on what materials have been used to produce the fertilizer. In all cases urea and ammonia have been added, but the other two components differ. The first three combinations all contain the washing fluids from farms, these washing fluids consist of ammonium sulfate. For the first combination the washing fluids are combined with sulfuric acid that has been bought by SUEZ Almelo. The second combination consists of the washing fluids combined with the ammonium sulfate out of a waste stream. A waste stream from a SUEZ customer out of the computer industry. The third combination is the mixture of the washing fluids from farms combined with the ammonium bisulfate from another SUEZ customer. The last combination consists of water and the ammonium sulfate from the computer industry. The sulfur and nitrogen column show the percentage of both elements present in the substances. The last column shows the weight in kilogram of each element.

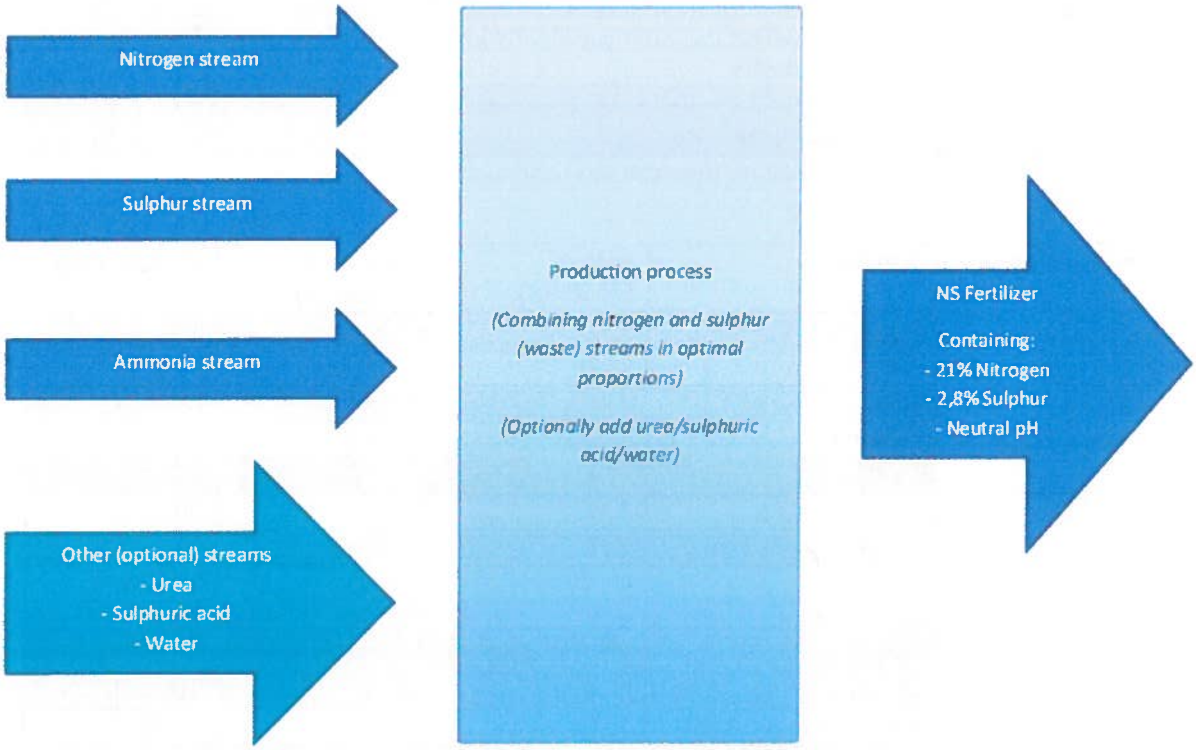

Figure 2-2: Production NS fertilizer

Discussions with potential customers revealed that the Dutch farming industry requires different levels of sulfur and nitrogen. For the sulfur component, the fertilizer industry demands a standard level of sulfur trioxide. The optimal level of sulfur trioxide turned out to be 7%. When this sulfur trioxide is converted into a level of sulfur, the demanded sulfur level is 2,8%. The demanded ratio of sulfur trioxide to nitrogen is 1:3, which implies that the required level of nitrogen will be 21%. When taking into account a certain allowed range, the market demands a sulfur percentage between 2 and 3 percent. The pH value should be between 4.5 and 6. Based on these laboratory tests table 2-4 shows nitrogen and sulfur levels around the demanded market levels. Sulfur levels fluctuate around the 2-3 per cent and the nitrogen level around the 21 per cent.

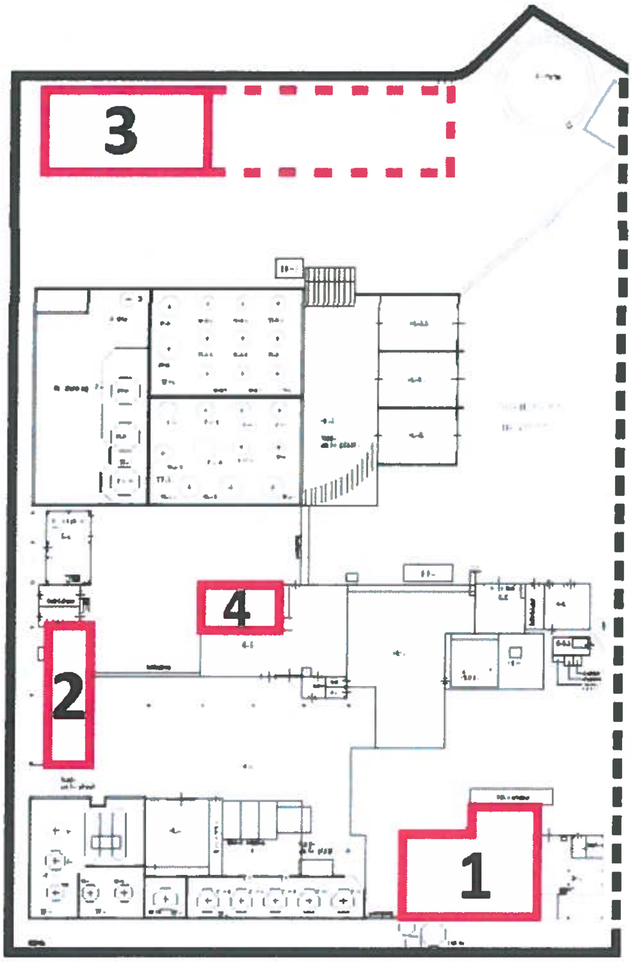

Figure 2-3: Site plan SITA

2.1.3 Production

Production of the fertilizers have been tested but only in the compositions of table 2-4 and within the laboratory of the SUEZ in Almelo. It is possible to do a test batch on the SUEZ plant in Almelo to experiment with the production process in a large quantity. This location can be found within figure 2-3, the facility highlighted in red with the number 1 is the ONO installation. However, this ONO installation is originally designed for the detoxification, neutralizing and the dehydration of several acidic and alkaline liquids. The ONO installation will be described in chapter 5.3.1. This facility has a high occupation rate and for tests it will have to be emptied and cleaned before it can be used for any other production process. This production facility can, occasionally, be used to do large quantity batches. With these large batches it can be tested what the optimal propositions are for fertilizers. Besides the existing operational production facility there are other possibilities for the production of fertilizers. A possibility is to build a completely new production line on the plant in Almelo. The possible location for doing this is circled in red and numbered three in figure 2-3. The other possibility is to transform an existing, older production facility. This older production facility is outdated and will have to be audited and upgraded to be sufficient for the production of fertilizers. The location of this option is circled in red within figure 2-3 and marked with number 2.

2.1.4 Storage

To produce fertilizers it will be required to store different incoming (waste) streams, there are different possibilities for these streams to store within SUEZ. After producing the fertilizers it will also be necessary to store the final product. There are currently no idea's on the final product storage. Problems with the storage can occur because, as already mentioned in the legal part and will be described in chapter 5, the product should be stored in a location that does not cool down to a low temperature. A location that can be heated and might be usable for the storage of final products is the building highlighted in red and numbered 4 within figure 2-3. However other options, other buildings, external storage, etc., have not yet been considered and should be analyzed before a decent storage location can be designated. Another problem for the fertilizer storage is that the incoming waste streams arrive equally during the year while the demand for the final product only occurs when the fertilizers can be applied within the farming industry. The highest demands are expected within the months February, March and April but these demands have to be investigated and substantiated. These storage aspects will be described in more detail in chapter 5.4.

2.1.5 Market

Within SUEZ there has been put some effort in the draft of a business case. The data used in the business case are obsolete and some of the considered production options for the ReFertilizer project are out of consideration. The data that is still applicable is kept in the business case and has to be updated with more up-to-date information. When considering the current market conditions and market information available within SUEZ the cost calculation within table 2-5 below can be made. Within the current situation there will be costs involved for the purchase of washing fluids and ammonium sulfate, this is considered to be waste for other companies but can be used within SUEZ for the ReFertilizer project. The additional materials that are required with those combinations of input materials are the purchase of sulfuric acid, urea and ammonia. Research within this assignment will have to clarify if these prices are the actual prices. Another important aspect for the ReFertilizer project is the market where the fertilizer product can be sold to. There has been contact with a potential buyers, N-xt fertilizers and Triferto, who would like to purchase the product. Important is to gather information on what terms they would like to purchase the product and what prices they are willing to pay for these products.

Combination no.	Substance	Costs per ton (€)	Costs per ton Fertilizer (€)
1	Washing fluids	€ -	€ -
	Sulfuric acid (96%)	€ 120.00	€ 5.49
	Urea	€ 340.00	€ 136.81
	Ammonia (25%)	€ 330.00	€ 27.53
	Fertilizer		**€ 169.83**
2	Washing fluids	€ -	€ -
	Ammonium sulfate	€ -	€ -
	Urea	€ 340.00	€ 135.64
	Ammonia	€ 330.00	€ 1.77
	Fertilizer		**€ 137.41**
3	Washing fluids	€ -	€ -
	Ammonium bisulfate	€ -	€ -
	Urea	€ 340.00	€ 135.45
	Ammonia	€ 330.00	€ 24.65
	Fertilizer		**€ 160.10**
4	Water	€ 2.50	€ 0.50
	Ammonium sulfate	€ -	€ -
	Urea	€ 340.00	€ 133.71
	Ammonia	€ 330.00	€ 0.66
	Fertilizer		**€ 134.87**

Table 2-5: Costs per ton Fertilizer

3. Legal

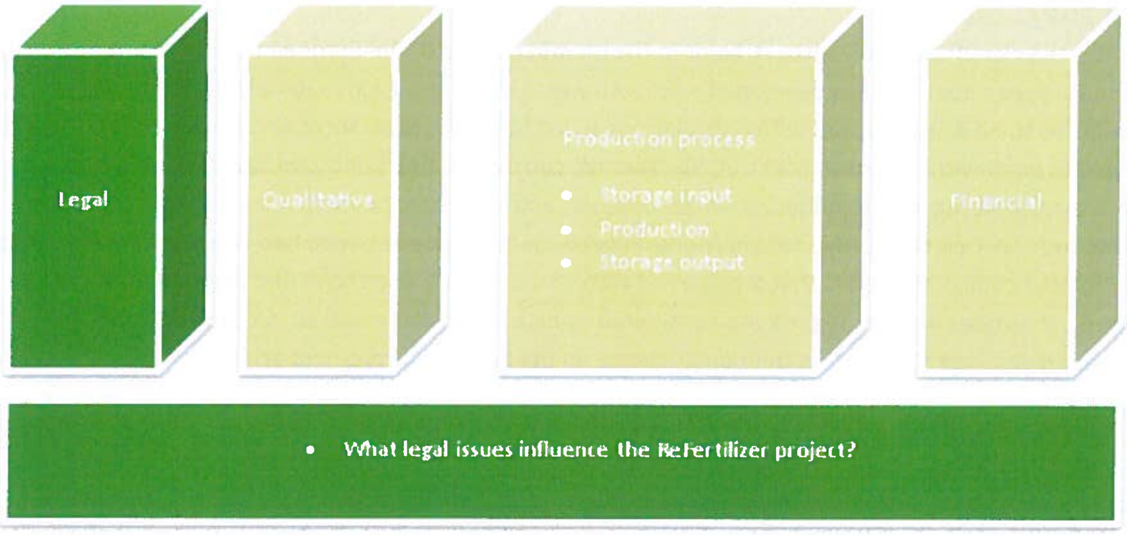

Figure 3-1: First block of the ReFertilizer project

For the legal part of the ReFertilizer project there are different steps that will have to be performed in order to create a sufficient knowledge level on the legal barriers and possibilities of the project. The ReFertilizer project involves the process of transforming different available waste streams into an inorganic fertilizer product (as described in chapter 2). Before starting with this project it is important to gain knowledge on the transport and storage of all ingoing waste streams, the production process and the storage plus transport of all the involved outgoing streams. This chapter describes all relevant legal aspects for the ingoing material streams, the production process and the final product.

Within the (inter)national legislation on the transport, storage or production/formulation of products there are specific codes, number and classes that classify the materials. Classifications are made based on the characteristics of the product, the requirements necessary for transport or the possible dangers when materials are used in production. The concepts that are relevant within this ReFertilizer project are the EURAL code, UN number, ADR class, EC number and CAS number. These concepts will be introduced in the next sections and the substances that are considered to be relevant for this project will be described in the relevant sections. If a material stream is not considered to be waste or hazardous there will be no codes or classes attached to the substance and the classifications will be not applicable.

Differentiations are made within the production of fertilizers based on the type and input materials of the fertilizer. Within the legal aspects there are different legislations that apply for different types of fertilizers and therefore the different types of fertilizers are introduced to create insights on what the major categories of fertilizers are. The relevant fertilizer types that are relevant for this ReFertilizer project are described.

3.1 Introduction

3.1.1 EURAL code

To unify the classification of waste streams in the member states of the European Union the commission of the European communities developed a list with waste materials. Each material stream that is considered to be waste is listed within this European list for waste substances and each member state is obliged to work with this list (InfoMil, 2010). This list, consisting of 800 different waste materials, is called the EURAL list and describes all waste materials and each specific waste material has an unique EURAL code. Within the EURAL classifications distinctions are made between two categories of materials (and related codes), the codes that are marked with an asterisk (*) and those that are listed without an asterisk. The codes with an asterisk are considered to be a hazardous material. All codes consist of 6 different digits, partly ranked on their origin based on the industry or business activity.

For the allocation of the waste substance to a EURAL code it is important to define what the substance consists of and what process or industry it comes from. Classification of the six digits code is based on the division in three groups. The first two number are related to the chapters (a process), the next two numbers are related to the subchapter (a sub-process) and the last two number are related to the waste category (a waste material from a sub-process). The first part consist of twenty different chapters. To allocate these EURAL codes to a chapter there are several European Union members that designed a stepwise approach, the Dutch stepwise approach is concisely described below. It is important to assign the right EURAL codes to the relevant material streams. Based on the step-wise approach the most suitable EURAL code can be assigned. It is strongly recommended and advised to use the stepwise approach and assign the most suitable EURAL code. In several cases it could be beneficial and tempting to assign a similar, comparable EURAL code because there are e.g. fewer or different laws and regulations that apply than when the perfect EURAL code is assigned. However, assigning the wrong EURAL code is not advised because this is not allowed and can cause major problems for SUEZ . For the ReFertilizer project all relevant material streams have been mapped and assigned, based on the Dutch stepwise approach, to the EURAL code that best suited the material and its origin. The Dutch stepwise approach for assigning EURAL codes is (VROM, 2001):

1) Define the chapter
    a. The waste material will be searched within the chapters 1 to 12 and chapter 17 to 20 and the related subchapters. The EURAL codes that end with '99' will be left out of consideration;
    b. If the waste material cannot be divided into one of the chapters in 1) the chapters 13, 14 and 15 should be searched. These chapters do not represent the origin of the material but describe different sorts of waste materials;
    c. If the chapters in 1) and 2) do neither contain a useful waste material than chapter 16 should be searched. This chapter describes waste materials not elsewhere mentioned including discarded materials, substances and products;
2) Define the subchapter
    a. Based on the allocation of a waste material to a chapter of origin: search the related subchapter (a sub-process) and the related waste category with six numbers;

b. If the waste material within the sub-category cannot be assigned to a six digit waste code than use the code '99' for the last two digits of the code.

3.1.2 UN number

United Nation (UN) numbers are the numbers that identify hazardous chemicals or classes of hazardous materials. The numbers are assigned by the United Nations Committee of Experts on the Transport of Dangerous Goods. Together with specialist groups they set down recommendations. These recommendations are applied as the basic rules for various modes of transport and national governments. The UN number consists of a four digit number and is used world-wide, the four digit number can be preceded by the letters UN to avoid confusion with other number codes, the numbers generally range from 0000 to 3500. Each hazardous waste stream, as identified within the United Nations, is classified and received an UN number. The UN number is also related to the ADR class, described in section 3.1.3.

3.1.3 ADR class

The ADR (Accord européen relatif au transport international des marchandises Dangereuses par Route) is the treaty that is drafted by the United Nations in 1957 and which governs the transnational transport of hazardous materials. The ADR classifies nine different hazardous categories. A four digit UN number is assigned to each entry in the class, but it is usually not possible to deduce the hazardous classifications of a substance from its UN number. The only exception on this is the class 1 in the ADR, the explosive substances and articles. Those substances will always begin with a 0. For each ADR class there are pictograms designed that reflect the dangers of the ADR classes. Each class describes the transport requirements that are applicable for the related substances.

3.1.4 Fertilizer type

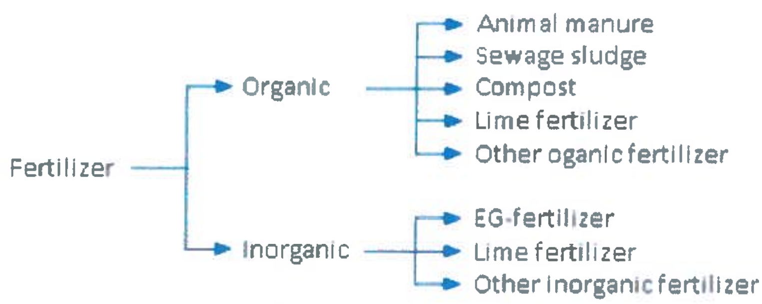

Figure 3-2: fertilizer types

Within the Dutch legislation on fertilizers there are different categories of fertilizers defined. For each category there are different laws and requirements that apply. The different types of fertilizers can be found in figure 3-2. Legislation distinguishes organic and inorganic fertilizers. As mentioned in section 2.2.2, there is a difference between the organic and inorganic fertilizers. The difference is that the organic fertilizers are derived directly from plant or animal sources. The inorganic fertilizers are also called the synthetic fertilizers because they go through a manufacturing process. With the production of inorganic fertilizers it is possible to decouple the animal production and the crop production and producing inorganic fertilizers provides the opportunity for the production facility to set their own nutrients levels. Within the organic fertilizers there are five types of fertilizers described, these are the animal manure, sewage sludge, compost, lime fertilizer and the other organic fertilizers. Within the inorganic fertilizers differentiations are made between the EG-fertilizers, lime fertilizers and other inorganic fertilizers. The categories that are relevant for the ReFertilizer project are the other inorganic fertilizer group (e.g. ammonium sulfate from farms) and the EG-fertilizer (e.g. urea). The project focuses on the transformation of several waste streams, optionally added with virgin material to create an inorganic fertilizer with high quality that will meet all demanded fertilizer requirements. Laws and legislation that apply to the use of the other inorganic fertilizers will be described in the relevant parts of the ingoing and outgoing sections in the next subchapter.

3.1.5 End-of-Waste criteria

When a material is considered to be waste there are certain regulations plus financial and administrative obligations that apply. When a material is not considered to be waste there are other, product related regulations and obligations, that should be met. Those materials that will no longer be categorized as waste and can be seen as (secondary) raw material again. The end-of-waste declaration is important when someone wants to market a product that used to be a waste material. In these cases it is necessary to define upfront whether it can be seen as end-of-waste. End-of-waste is important when:

1) The material is sold to someone
2) The material will be transported within the Netherlands
3) Imported/exported
4) Bought from someone or used by the company itself

The European Commission designed specific End-of-Waste criteria that should be met to transfer products from the waste category to the raw material category. End-of-Waste criteria are a certain set of criteria that define, when all criteria have been met, that a material can no longer be considered as waste. The waste ceases to be waste and obtains the status of a (secondary) raw material or product. (European Commision, 2015). The framework for waste materials is designed to increase and stimulate the recycling of raw materials. Besides this, the framework of criteria should decrease the amount of administrative regulations that apply to waste management. The criteria will also contain limits for the pollution and will take into account all possible negative effects for the environment (RIVM, 2014). The base criteria for the End-of-Waste are listed below (European Parliament, 2008).

a) The substance or object is commonly used for specific purposes;
b) A market or demand exists for such a substance or object;
c) The substance or object fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products; and
d) The use of the substance or object will not lead to overall adverse environmental or human health impacts.

The European Commission is currently busy with the design and draft of new regulations that are based on these criteria and that apply to waste materials. Just a few regulations have been designed that can be applied to waste materials. The European Commission has designed regulations for the iron, steel and aluminum scrap, cullet and copper scrap. These End-of-waste criteria are generally applicable to the whole European Union. When a European Union member would like to have an end-of-waste declaration it should comply to all the criteria described above. However, the criteria can be interpreted in different ways and the review for end-of-waste declarations can be performed in different ways. For waste streams other than the iron, steel & aluminium scrap and cullet & copper scrap the European members can design their own regulations with associated End-of-Waste criteria. The Dutch government designed one specific regulation for End-of-Waste criteria. The regulation applies to the recycled granules from stony waste. However, also for other waste streams it is possible to achieve an end-of-waste declaration and companies can perform a test to define whether they comply to the Dutch implementation of the end-of-waste laws. This test can be performed by filling out an online question form. Answering these questions results in the positive or negative outcome of the end-of-waste declaration. To make sure that the end-of-waste declaration is valid, a definitive examination is required and legal acceptance of the end-of-waste declaration has to be confirmed by the government.

For the ReFertilizer project the end-of-waste directive is an important regulation. The production within the project is about transforming waste materials (mixed with the required virgin materials) into a new marketable product. Therefore, somewhere in between the input and output of the process the waste streams transformed to a new product stream. This means that somewhere in the process the end-of-waste directive should be applied. For SUEZ there are two different ways that the end-of-waste directive can be applied. These different approaches will be outlined below.

Option 1: End-of-waste before formulation

The first option of the application of the end-of-waste directive is to use the directive for all the incoming waste streams. The ReFertilizer project transforms one or more waste stream materials into a new product. This option is about the application of the end-of-waste directive at the beginning of the process, when all (waste) materials are received. For all different incoming waste streams it will be necessary to apply the end-of-waste criteria and test whether or not the waste material can be considered to be classified as non-waste. When all incoming waste streams receive an end-of-waste declaration the production process is allowed, based on the end-of-waste directive. The situation is displayed below in figure 3-3, all incoming products are considered to be non-waste products before the formulation is started.

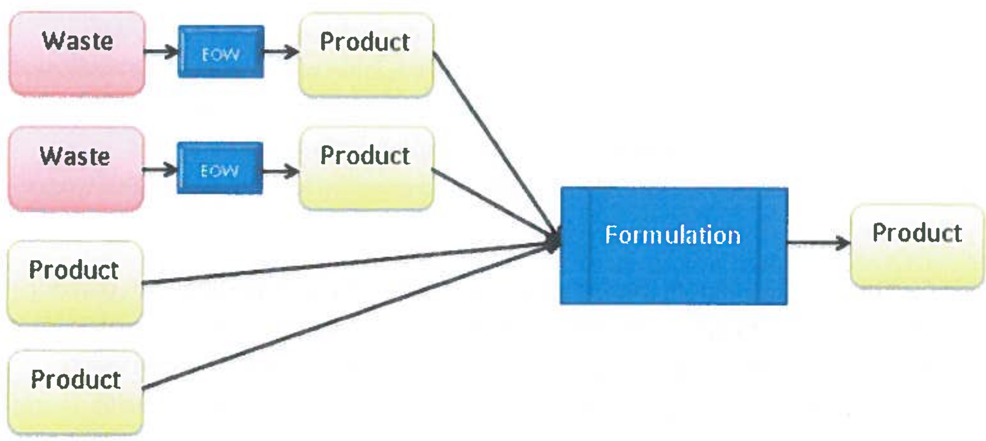

Figure 3-3: Option 1 End-of-waste

Option 2: End-of-waste after formulation

The second option of applying the end-of-waste directive is to use the directive for the product after formulation. Because SUEZ is legally considered to be a waste treatment company, SUEZ is allowed to receive and (for certain waste streams) treat or transform the streams into other streams or substances. This option is therefore about the formulation of an end product out of the waste streams and the virgin product streams. The end-of-waste directive only applies to the product after the formulation, this is the difference with the first situation where the end-of-waste directives had to be applied before the formulation process. In this situation there will only be one end-of-waste declaration necessary because it is only required for the end product, see figure 3-4. When all criteria for the end-of-waste directive will be met for the final product it can be considered to be non-waste and can be sold to customers.

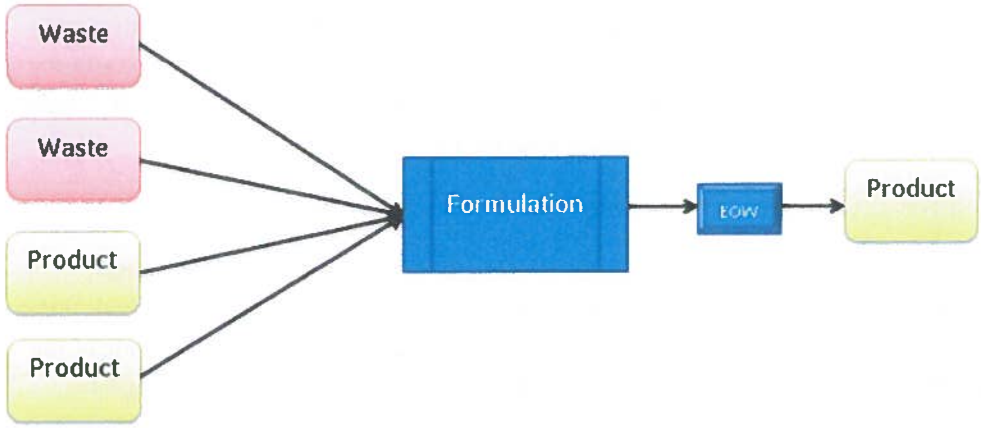

Figure 3-4: Option 2 End-of-waste

Comparing both situations reveals advantages for the application of the end-of-waste directive with regard to the second option, where an end-of-waste declaration is only required after the formulation process. The second option has two major advantages for SUEZ compared to the first option. One of the major advantages is that for the second option there is only one end-of-waste declaration required where in the first option there can be more than one end-of-waste declaration required. This will depend on the number of waste streams that will be used in the production process of the ReFertilizer project. For each waste stream that will be used an end-of-waste declaration will be necessary. The other advantage is that the obtaining of the end-of-waste declaration for the second option is considered to be easier, based on available internal knowledge and experiences with the end-of-waste legislation.

The criteria relevant for obtaining the end-of-waste declaration are described above and each criterion will be outlined and discussed for both options below. The discussions are based on the internal SUEZ experiences of employees with end-of-waste declarations. SUEZ has already issued an end-of-waste declaration (phosphoric acid) and are in the process of issuing another declaration (sulfuric acid).

a) The substance or object is commonly used for specific purposes;

For the first option it can be demonstrated that the waste material streams will be commonly used for specific purposes. These purposes will be the transformation of these waste streams, in combination with other virgin material streams, into a new inorganic fertilizer product.

Proving that the end product, the inorganic fertilizer, will be used for specific purposes is considered to be possible. It is possible because it has a specific purpose in the application within the farmland of the agricultural sector where it will be used for the enhancement of the growth of crops.

b) A market or demand exists for such a substance or object;

Existence of a market or demand for the first option can be a problem. For the waste streams SUEZ will be the only customer and no contracts or tenders can be used in order to show the existence of a market or demand. Besides this it is unknown whether all amounts of all incoming streams will be used for the formulation process. It could be that all waste material A is required for production but not all waste material B is required for the production process. These remainders might be useless and there is no market or demand for these remainders.

Analysing the second criterion for the second option reveals that it can be shown that there exists a market or demand for the substance. The substance will be the inorganic fertilizer and contacts with possible customers showed that they would like to purchase the product. When these customers keep word and will sign a contract, SUEZ will be able to prove the existence of a demand. However, experience with end-of-waste declarations in the past for other waste streams showed that the existence of more than one customer can be demanded by the authorities.

c) The substance or object fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products;

The substances of both options fulfil the technical requirements for the specific purposes and meet the existing legislations and standards that are applicable to the product. However, the first option considers waste streams from different SUEZ customers, these customers can offer different forms of material that have different compositions. Therefore it might be possible that there are fluctuations in the offered material which results in problems for the technical requirements and standards applicable to the product.

Complying to this criterion for the second option will be easier. The fulfilment of technical requirements and meeting existing legislations or standards can be easier because changes in the transformation process will have influence on the outcomes. Therefore requirements can be met by adapting the transformation process to these requirements.

d) The use of the substance or object will not lead to overall adverse environmental or human health impacts.

Adverse environmental or human health impacts cannot be excluded within the first option because there are waste streams that are considered to be hazardous waste (EURAL code with an asterisk). These substances can only be used under strict safety and usage measures, otherwise it will have impact on the environment or human health.

End-of-waste	Option 1	Option 2
Criterion a		
Criterion b		
Criterion c		
Criterion d		

Table 3-1: End-of-waste

The second option is considered to be non-hazardous waste and will have no or very small environmental or human impacts. Summarizing the criteria for the two options showed that the second option, where an end-of-waste declaration is only required at the end of the formulation process, has advantages over the first option. Due to all legislations and involved authorities it might be hard to receive an end-of-waste declaration for the ReFertilizer project but the chances of acquiring an end-of-waste declaration will be higher when option two will be applied. The outcomes are summarized in table 3-1, where green options represent a positive outcome, red a negative outcome and the orange color represents a doubtful outcome with regard to meeting the criteria.

Based on this analysis the best option for SUEZ will be the second option, where only after the formulation of a new inorganic fertilizer the end-of-waste directive applies. However, this is a brief analysis based on the currently available information. The best way to follow-up here is to use the web tool that has been designed to define whether or not a waste stream can be classified as new product (http://www.ishetafval.nl). This online tool has been developed by the Dutch authority Rijkswaterstaat and can, after answering a selection of question, indicate if the substance can receive an end-of-waste declaration. To make sure that SUEZ can use the end-of-waste classification it should be verified by an authorized employee of the Dutch Rijkswaterstaat.

3.1.6 REACH

Reach is a regulation made by the European Union to better protect the health of the human and the environment against the risks of chemical substances. REACH is the abbreviation of **R**egistration, **E**valuation and **A**uthorization of **Ch**emicals. Besides this the regulation should enhance the competitiveness of the chemical industry in the European Union. The REACH regulation is, in principle, applicable on all chemical substances. Also those substances that are used in the daily life of people. Therefore the REACH regulation is applicable to almost all companies (ECHA, 2015). REACH brings the onus to the companies, REACH classifies those procedures to collect and judge the information about the properties and dangerous effects of substances. Companies should register their materials and are expected to cooperate with other companies who register the same substances. The agencies can prohibit the use of certain hazardous substances if the risks of using these substances is unmanageable. They can also decide to limit the use of substances or require authorization for certain substances. As mentioned before, the REACH regulation is applicable on many different companies, even those companies that do not directly seem to work with hazardous substances. REACH came into force in June 2007, from this day on the pre-registration of substances started. Phase 1 of reach started in June 2010, where substances supplied in more than 1000 ton per annum (tpa) or substances classified as toxic should be registered. In June 2013 the second phase started where each substance that is supplied at more than 100 tpa should be registered. The last deadline is June 2018 where registration is required for all substances supplied at more than 1 tpa (HSE, 2015).

Within the REACH regulation different roles are defined and each role has different duties and obligations. The roles that can be defined under REACH are manufacturer, importer and downstream user. There is another role, the formulator, but this role can be classified as downstream user. The roles that are applicable for the REACH regulations can be seen in figure 3-5. SUEZ is a downstream user because it does receive (hazardous) waste materials from their customers and it is a recycler (of mainly solvents). However, when waste is being recycled into a secondary raw material (complying to the waste framework directive[6]) the recycler will be classified as a producer/manufacturer. Considering the ReFertilizer project, SUEZ will be a downstream user for the incoming waste or virgin materials and will be a producer/manufacturer with respect to the outgoing material, the inorganic fertilizer.

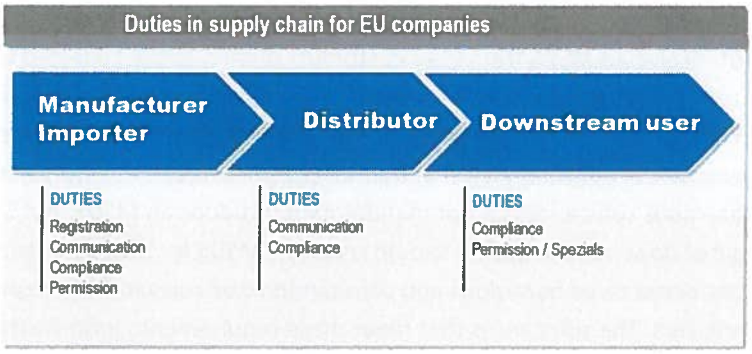

Figure 3-5: Roles REACH regulation

Producer/manufacturer

REACH is not about the recycling of waste materials and the moment when waste, after recycling, transforms to raw materials. The waste framework directive is leading in this. However, REACH does define that when a recycler (as producer of secondary raw materials) can prove that the materials that he will sell to the market as secondary raw material have been registered in REACH by the primary producer, the recycler does not have to register the product. Decisive in the not registering of the secondary raw materials is the prove of the sameness of the primary and secondary materials. SUEZ does have special equipment to define if the secondary raw materials are equal to the primary raw materials (according to the registered primary raw materials at ECHA). Although the possibilities for exclusion of some new raw materials is not applicable for the ReFertilizer project, because the material streams will not be put on the market under the sameness as it was primarily produced. Therefore SUEZ will have to define whether the new substance, the inorganic fertilizer, has been previously registered at REACH or not. If the new substance has not been registered within REACH SUEZ will have to register the new substance.

Material Safety Data Sheet

The MSDS (Material Safety Data Sheet) plays an important role in the REACH registration. An MSDS is an important document to make sure that the producers and importers in the supply chain provide and

[6] Waste Framework Directive (WFD) is a European Union directive of 2008. Aim of the WFD is to lay the basis to turn the European Union into a recycling society (http://ec.europa.eu/environment/waste/framework/)

receive enough information to safely use their substances. MSDS contains information on the properties and dangers of a substance, the instructions for treatment, removing and transport, first aid measures, firefighting and exposure controls (ECHA, 2015). An important aspect of the MSDS with respect to SUEZ is the fact that 'recycling' is not the same as a 'downstream user' in REACH. This implies that SUEZ does not receive an MSDS from their customers related to the collected waste stream because waste substances are exempted from the REACH regulation. But SUEZ is expected to, after recycling, provide a MSDS for each hazardous substance for the purchaser of the secondary raw materials. However, because the output material of the ReFertilizer project, the inorganic fertilizer, is not considered to be a hazardous substance it is not mandatory to produce an MSDS. But SUEZ should receive a MSDS in the role of downstream user. It should receive a MSDS for those incoming material streams that are considered to be hazardous and considered to be relevant for the production process of the inorganic fertilizers. The substances that meet these requirements (non-waste and hazardous) are the virgin sulfuric acid, urea and ammonia, this will be described in the next section.

Downstream user

SUEZ is, according to the REACH regulations, a downstream user when it purchases raw materials. To define what has to be done when a new material is purchased SUEZ developed a flowchart that describes the tasks and obligations with respect to their role as downstream user under REACH. The first part of the flowchart defines whether the material is considered to be a hazardous material or not, when this is not the case there is no MSDS required and the material can be used. When it is considered to be hazardous, according to the REACH regulation, SUEZ will define in a few steps if it is allowed to use the material within SUEZ or not. If the material is not allowed the flowchart defines what could be done in order to be able to use the material within SUEZ. SUEZ is required to ensure that the use of the materials is in line with the related MSDS. For hazardous materials SUEZ is required to receive the complete and correct MSDS. All information will be shared with the concerned employees. The material streams that are considered to be hazardous and non-waste for the ReFertilizer project are mentioned in the previous section on Material Safety Data Sheet.

Within the registration process of REACH, companies are expected to investigate and describe the chemicals that they distribute or produce. Registration is required to prevent the society from being surprised in the future by the negative effects of a substance. In the registration of the chemicals the abovementioned MSDS (Material Safety Data Sheet) plays an important role. This data sheet is relevant for all the hazardous materials as outlined above. Besides these data sheets and the different roles that apply, REACH is based on two major subjects. The first important subject is the list with substances that are considered to be of high concern, also known as the Substances of Very High Concern (SVHC). The second subject that is considered to be important for REACH is the registration of substances. Each substance should be registered within REACH, except a small list of partly exempted materials and a list of completely exempted materials. These lists will be introduced in the registration section.

Substance of Very High Concern

For a number of substances the REACH regulation requires special authorizations. These substances with high risks for people and environment are considered to be Substances of Very High Concern (SVHC). The REACH regulation requires these substances to be substituted by other (less dangerous) substances. The European Chemicals Agency (ECHA) developed a list with substances that are considered to be SVHC and need authorization. There are no substances on this list that are related to the ReFertilizer project and therefore this list and substances are considered to be irrelevant.

Registration

Companies that want to import substances to Europe or transport or sell substances within Europe should make sure that the chemical substances are registered at ECHA. A registration dossier should be provided to ECHA with related hazard information and, if applicable, an assessment of the risks of using the substance and the way in which these risks should be managed. When the substance that is used has been registered before (by any company) it will not be necessary to register the substance again and the related information of the concerning substance is freely available for a company (ECHA, 2015).

Besides those chemicals that require registration, evaluation or authorization there are chemicals that are partly or completely exempted from the REACH regulations. The chemicals that are partly exempted from REACH are those where e.g. other equivalent legislations apply. However, the chemicals that are partly exempted are not considered to be relevant for the ReFertilizer project and will therefore not be mentioned. The complete exemptions are related to the ReFertilizer project because the ReFertilizer project is (partly) based on the input of waste materials. The chemicals that are completely exempted from REACH are (REACH Helpdesk, 2015):

- Radioactive substances
- Substances under customs supervision
- Substances used in the interest of defence
- Non-isolated intermediates
- Transport of hazardous goods
- Waste materials

The chemicals can be exempted from the REACH titles II (registration requirement), V (downstream user) and VI (judgement) (RIVM, 2015). The reason for the exemptions differ per chemical category and will be shortly outlined below (REACH-Serv, 2009).

Radioactive substances
Radioactive substances are exempted from REACH because there is a specific legislation that applies to the radioactive substances.

Substances under customs supervision
Substances which are 'passing through' the European Union and are not processed in any way are exempted from REACH. The exemptions includes repackaging.

Substances used in the interest of defence
The REACH regulation allow the EU members to apply exemptions to substances that are in the interest of defence. Those exemptions are only applicable within the boundaries of the member state.

Non-isolated intermediates
These intermediates are the substances that are synthesized and consumed within the same continuous or batch process. The substances can only be removed from the plant for sampling. As the substances do not exist outside the processing plant REACH does not apply.

Transport of hazardous goods
Carriage of dangerous substances by air, sea, inland waterway, rail or road are exempted from REACH because there are other rules that apply. This means that any company that acts solely as a transport agent and does not alter the goods in any way is exempted from the obligations under REACH.

Waste materials
The REACH regulation regarding waste does not apply to the treatment, storage, separation, or the prevention of the genesis of these substances. Waste has within REACH been classified as (ECHA, 2015):

> "Waste is defined in the Waste Framework Directive 2008/98/EC as any substance or object which the holder discards, or intends or is required to discard."

The waste streams that are considered to be waste within this ReFertilizer project can be classified as waste because the supplier of the waste stream discards, or intends, or is required to discard the material. However, the REACH classifications can in several cases be applicable if the waste material is used in another substance mixture or article:

> "It is important to remark that once waste is recovered and in this recovery process another substance, mixture or article is produced, the REACH requirements will apply to the recovered substance in the same way as to any other substance, mixture or article manufactured, produced in or imported to the EU."

According to this description the waste materials that are used within the ReFertilizer project should apply to the REACH regulation because the project focuses on the use of waste materials to be recovered and used in the process for another mixture, the inorganic fertilizer. This implies that the substance should apply to the REACH requirements, but there is another part of the waste description that describes the situation for specific cases of waste materials:

> "In specific cases, where a substance recovered in the EU is the same as a substance which has already been registered, an exemption from the registration obligation may apply."

This will not apply to the SUEZ project because the recovered substance will be the inorganic fertilizer, which is a mixture of various material streams and for mixtures of materials there are specific parts of REACH that will apply. To further explicate how REACH applies to the fertilizer end-product it is important to define what REACH defines as a product or mixture. REACH states that it is important to define whether a product or a mixture is formed, the difference between a mixture and a substance that consists of multi constituents is defined within REACH as (ECHA, 2011):

> "The difference between mixture and multi-constituent substance is that a mixture is obtained by the blending of two or more substances without chemical reaction. A multi-constituent substance is the result of a chemical reaction."

Based on this definition within REACH the output of the ReFertilizer project can be considered to be a mixture because there is no chemical reaction that occurs. The inorganic fertilizer product is the output of the mixing of a few important substances. It is important to indicate whether it is a mixture or a substance consisting of multi constituent substance because according to REACH there are different obligations. When a multi-constituent substance is produced there is an obligation to register the product. For mixtures REACH applies different rules (ECHA, 2014):

> "A mixture consists of several substances. Each individual components substance in a mixture needs to be identified, registered according to REACH and, when required, notified according to CLP either by the substance manufacturer or by the importer of the mixture."

These requirements and obligations of the REACH regulations imply that for the output of the ReFertilizer project it is required to register all individual component substances within the inorganic fertilizer. It depends on what materials will be used for the formulation of inorganic fertilizers for which substances REACH registration is required. But the waste materials that are included in the production will have to comply to the REACH regulation as well. Because the waste streams that are considered to be relevant are common substances it is likely that those substances will be registered within ECHA. To make sure that these materials are registered it is necessary for SUEZ to test the incoming substances and define whether it is a common substance and is registered at REACH.

Evaluation

Once the information for the registration has been submitted the information will be evaluated by the ECHA and the member states to examine the quality of the registration dossiers and the testing proposals to define if a given substance constitutes a risk to the environment or human health. The evaluation consists of three different aspects. The examination of testing proposals submitted by registrants, the compliance check of the dossiers that have been submitted by the registrants and the substance evaluation. Once the evaluation has been done, registrants may be required to submit further information on the substance (ECHA, 2015).

Authorization

The authorization procedure is introduced to assure that the risks from Substances of Very High Concern are properly controlled and that these substances will be progressively replaced by suitable alternatives, while guaranteeing a proper functioning European Union internal market (ECHA, 2015). Because the ReFertilizer project does not involve any SVHC substances the authorization part is considered to be irrelevant.

3.1.7 RoHS

The Restriction of Hazardous Substances is an European guideline that aims to reduce the usage of six hazardous substances within the electronic industry. The substances that are related to this guideline are (European Parliament, 2003):

- Lead
- Mercury
- Cadmium
- Hexavalent chromium
- Polybrominated biphenyls
- Polybrominated diphenyl ether

These substances, and therefore the guidelines, are not considered to be relevant for this ReFertilizer project because the substances are not related to any of the substances used in the formulation process of the ReFertilizer project.

The next sections describe all relevant material streams. For each stream, if applicable, it will be defined if the REACH regulations apply.

3.2 Ingoing material streams

Part of the legal knowledge is already available within SUEZ and will have to be gathered and summarized in this section. This concerns the part on the incoming waste streams that have been transported to and stored at SUEZ before. Other unknown streams will have to be analyzed and information on these streams will have to be gathered from outside the company. Tables 3-4 and 3-5 below summarize all incoming streams that are currently considered relevant for the ReFertilizer project. For each incoming stream it has been defined if it is considered to be waste by the provider of the stream or if it is a virgin stream. Besides the label that the provider of the stream attaches to the product there is a difference between those ingoing streams that are known within SUEZ and those that are unknown within SUEZ. The streams that are considered to be known by SUEZ are those streams that have been transported and stored – in large quantities - at SUEZ before. The related EURAL codes, UN numbers, ADR classes, EC number, CAS numbers and the molecular formulas are (if available) listed in the tables below.

Ingoing stream	Waste/virgin	(Un)known	EURAL	UN Number	ADR Class
Ammonium sulfate from farms (spuiloog)	Waste	Unknown	16.10.02	N.A.	N.A.
Ammonium sulfate from computer industry (80%)	Waste	Known	19.02.99	N.A.	N.A.
Ammonium bisulfate from semiconductor industry	Waste	Known	06.02.03*	2506	8, II
Sulfuric acid from computer industry(80%)	Waste	Known	06.01.01*	1830/1832	8, II
Sulfuric acid (96%)	Virgin	Known	06.01.01*	1830	8, II
Urea	Virgin	Known	16.05.08*	N.A.	N.A.
Ammonia (25%)	Virgin	Known	06.02.03*	2672	8, III
Water	Virgin	Known	N.A.	N.A.	N.A.

Table 3-3: Ingoing material streams

Ingoing stream	EC number	CAS number	Molecular formula	REACH
Ammonium sulfate from farms (spuiloog)	231-984-1	7783-20-2	H3N.1/2H2O4S	No
Ammonium sulfate from computer industry (80%)	231-984-1	7783-20-2	H3N.1/2H2O4S	No
Ammonium bisulfate from semiconductor industry	232-265-5	7803-63-6	H3N.H2O4S	No
Sulfuric acid from computer industry(80%)	231-639-5	7664-93-9	H2O4S	No
Sulfuric acid (96%)	231-639-5	7664-93-9	H2O4S	Yes
Urea	200-315-5	57-13-6	CH4N2O	Yes
Ammonia (25%)	215-647-6	1336-21-6	H5NO	Yes
Water	231-791-2	7732-18-5	H2O	Yes

Table 3-2: Ingoing material streams

Each ingoing stream will be shortly introduced below and the legal issues will be addressed for each stream.

3.2.1 Ammonium sulfate from farms

This section will describe the incoming waste water from the air scrubbers that are used within farms and contain ammonium sulfate. Because this stream is relatively new in the industry, it is important for SUEZ to map the relevant issues regarding this new opportunity. Therefore there will be an extensive research on this material stream. This section will describe the position of washing fluids on the European list of waste materials (EURAL), the position of the washing fluids regarding the ADR regulations, the regulations and requirements that apply when selling, transporting or storing the washing fluids and the possible dangerous side effects of the product.

Ammonium sulfate	
Supplier	Farm
Molecular formula	$(NH_4)_2SO_4$
Waste/virgin	Waste
Known/unknown	Unknown
EURAL code	16.10.02
UN number	N.A.
ADR class	N.A.
EC number	231-984-1
CAS number	7783-20-2

Table 3-4: Ammonium sulfate (waste)

Washing fluids are a by-product from air scrub systems and could be the new fertilizer on the rise, some people call it the nitrogen fertilizer of the 21st century. This new fertilizer product has many advantages: there are many suppliers, it is a circular economy idea, it reduces the CO2 footprint, the product barely leaches and there is sulfur present in the product. However there are disadvantages as well, the product causes acidification, and an excess amount of sulfur may limit the application. Underexposed is the regulation around the washing fluids within the manure laws. The washing fluids are within the EURAL waste list included under the rubric 16.10, the aqueous liquid wastes. Within this rubric distinctions are made between (InfoMil, 2013):

- Aqueous liquid waste containing dangerous substances (16.10.11*)
- Other aqueous liquid waste (16.10.02).

The first category (waste numbers with an asterisk) is considered to be hazardous. Waste is categorized as hazardous when the level of dangerous content present in the waste (in weight percentages) has one or more hazardous properties. The washing fluids of a chemical air scrubber consist mainly of ammonium sulfate and a little remainder of sulfuric acid. There are no risk codes assigned to ammonium sulfate which means that there are no concentration limits for this substance. This means that ammonium sulfate has no hazardous properties. For the sulfuric acid there are risk codes assigned, for this substance there is a concentration limit that should be equal to or smaller than one per cent. The level of sulfuric acid in the washing fluids is generally lower than one per cent which implies that the washing fluids are not considered to be hazardous waste (InfoMil, 2013).

Because the output from the air scrubbers has such a low concentration of the hazardous substance sulfuric acid, it is not considered to be a hazardous substance itself. Because of the absence of these hazardous properties there is no UN number or ADR class assigned to this waste stream. Therefore there are no hard restrictions on the transport of the product, however SUEZ might decide to require additional actions to transport this substance because it involves (although in small substances) hazardous materials with corrosive properties.

Since January 1, 2011 the washing fluids from air scrubbers are annexed in the appendix aa, category II of the implementation manure-law (in Dutch: uitvoeringsregeling meststoffenwet). Therefore the washing fluids may be sold and used as fertilizer (Overheid, 2015). Legislation on fertilizers distinguishes these substances (within the category of waste and residues) as (EZ, 2015):

1) Residues released after the chemical cleaning of stable air of farms by the washing of stable air with ammonia in a diluted solution of sulfuric acid and consists of ammonium sulfate in water (chemical wash)
2) Residues released after the biological cleaning of stable air of farms by washing the air with water and guided over material in a spatial structure in which the nitrifying bacteria convert ammonia into nitrite and then in nitrate. The material consists of a very highly diluted pH neutral sulfur and nitrogen containing liquid dissolved in water (biological wash)
3) Residues released after the cleaning of stable air of farms by washing the air with water (water wash)

Discussions within SUEZ resulted in the focus on the first option, described under 1) above, this is considered to be the most promising and best option for the production of fertilizers by SUEZ. This option contains the valuable substance ammonium sulfate which the second (2) and third (3) option lack. Besides this the first option has a very small chance of the presence of bacteria or legionella, which is more likely to be present in the second option (RIVM, 2013). The problem with bacteria and legionella will be further discussed in the section on sampling and analysis.

Those who want to sell or transport the washing fluids out of chemical air scrubbers should comply to certain requirements. The washing fluids from the air scrubbers described above are within the manure laws described as other inorganic fertilizers. This means that – according to the regulations – the product is comparable with fertilizers. However, when someone transports or sells the washing fluids there are specific regulations that apply and those who want to sell or transport the washing fluids should meet these requirements. The requirements are categorized and listed below, where all requirements are derived from the document "Regels voor handel en vervoer van overige anorganische meststoffen" (RVO, 2015). When all requirements below are met the product can be sold and transported.

General requirements

- Producers and transporters of washing fluids should be registered at the RVO (Rijksdienst voor Ondernemend Nederland)
- The fertilizer is in a usable state and is uniform in composition
- The fertilizer provides food for plants or parts of plants in the form of primary, secondary or micro-nutrients and performs the operation which the fertilizer is mainly intended to do in an effective way

- The fertilizer has, under normal conditions of use, no harmful effects on human health, animal, plant or the environment
- The washing fluids of air scrubbers are included in appendix Aa, category II of the implementation manure-law.

Mixing requirements

It is allowed to mix fertilizers with other sorts of fertilizers. However, the mixing of the ammonium sulfate from farms is not allowed with all other fertilizers. The ammonium sulfate from farms is classified as an other inorganic fertilizer that is within the fertilizer law part of the appendix aa section I and II of the Dutch 'Uitvoeringsregeling Meststoffenwet'. Mixing of the ammonium sulfate from farms with animal manure is strictly forbidden and can be dangerous. The mixing of washing fluids and animal manure is dangerous according to the RVO (Rijksdienst voor Ondernemend Nederland) (RVO, 2015). This can lead to the hydrogen sulfide gas, which is toxic. Besides this, copperas can be formed which will be transformed within the soil to sulfuric acid. The sulfuric acid acidifies the soil and this will have negative effects on the crops.

Agronomic requirements

- Other inorganic fertilizer that mainly supply primary nutrients: the fertilizer should contain at least 5% nitrogen, or 5% phosphate or 5% potassium of the dry matter.

Environmental requirements

- Other inorganic fertilizers that mainly supply primary-, secondary macronutrients or micro-nutrients, do not exceed the maximum values for heavy metals as described in the table below (for washing fluids the N column applies, because nitrogen is the main macronutrient)

Heavy metal	**Maximum value in milligrams per kilogram of the respective value-giving ingredient (mm/kg)**				
	PO4	N	K	Neutralizing value	Organic substance
Cd	31.3	25	16.7	6.3	0.8
Cr	1875	1500	1000	375	50
Cu	1875	1500	1000	375	50
Hg	18.8	15	10	3.8	0.5
Ni	750	600	400	150	20
Pb	2500	2000	1333	500	67
Zn	7500	6000	4000	1500	200
As	375	300	200	75	10

Table 3-5: Maximum value's heavy metals

This implies that SUEZ will have to sample every load of washing fluids to make sure that the washing fluids do not exceed the maximum amount of heavy metals. The rest of information that is required from sampling and analysis and the way this should be done is explained in the next section on sampling and analysis.

- Other inorganic fertilizers that do not only supply the primary or secondary nutrients, but also the micronutrients copper and zinc may exceed the maximum values for copper and zinc
    - Provided that:
        a. The fertilizer is equipped with data on the levels of copper and zinc (label) and
        b. The amounts of primary and secondary nutrients and the amount of copper and zinc that are intended to be applied with the fertilizer fits into the total fertilizer advice

Sampling and analysis

- By sampling and analysis the following information of the fertilizer will be determined:
    - The amounts of nitrogen and sulfur
    - The dry matter content
    - The valuable ingredients
    - The amount of heavy metals
    - The amount of organic micro-pollutants
- A sample is taken according to the generally applicable principle of sampling
- The sampling and analysis other fertilizers should be performed based on strict rules
    - The laboratory should be accredited by the board of accreditation
    - The laboratory should meet the NEN-N-ISO/IEC17025 standard
    - The analysis should be performed based on the protocol of individual fertilizers as described within the appendix ac
- The results of the sampling and analysis should be electronically submitted to the RVO (Rijksdienst voor Ondernemend Nederland), containing the data on nitrogen, phosphate (not applicable for ReFertilizer project), dry matter and heavy metals

Because SUEZ does have a laboratory but not and accredited laboratory, the analysis will have to be performed by another laboratory. SUEZ can perform many sorts of tests but for the tests to be legally approved they should be performed by an accredited laboratory. SUEZ normally cooperates with Eurofins Analytico to do sampling and analysis.

The use of ammonium sulfate from the air scrubbers has some disadvantages. The first disadvantage is that the output of the air scrubbers is a substance with a relatively low pH value which implies negative side effects. Another disadvantage is that it is not allowed to discharge the ammonium sulfate in the manure pit of the farm or to mix the ammonium sulfate with animal manure. Another disadvantage of the application of air scrubbers is that there exists a possibility that – under certain conditions - legionella could grow in biological or acid air scrubbers. The parameters that are responsible for this growth are the temperature and the acidity of the liquids present in the air scrubber. These type of air scrubbers are the type of scrubbers that provide input materials for SUEZ to start producing fertilizers. Because there have been a lot of uncertainties and questions on this subject the Dutch national institute for public health and environment (RIVM) investigated the risks of legionella in and around the locations where air scrubbers are used. The outcomes of the research showed that the majority, about 90 per cent, of the air scrubbers used are of the acidic type. These type of air scrubbers have a pH value of 4 or less. Sometimes the pH value increases for several days up to the pH value of 7, but afterwards a shot dosage of sulfuric acid will be injected which results in the decline of the pH value.

The researchers concluded that, when the pH value is no longer than a few days around 6-7, there is a very small change that the legionella bacteria will survive. However, the researchers of the RIVM cannot guarantee that legionella will never survive within the air scrubbers and the waste materials of the scrubbers (RIVM, 2013).

Although there are small chances of legionella being present in the washing fluids, there should be additional tests performed to exclude the presence of legionella in the washing fluids. Besides the legionella also other microbiological problems should be excluded. Contacts with potential customers revealed that there are concerns about the use of waste water from farms. The microbiological problems that could occur should be removed by the execution of additional tests on bacteria and legionella. Because SUEZ is not able to do this on their own they should use the available external opportunities to test the ingoing ammonium sulfate from farms.

3.2.2 Ammonium sulfate from semiconductor industry

This incoming waste stream is an existing waste stream that is transported to SUEZ on a regular basis. The output is the result of processes of NXP, a customer that operates in the computer industry. The general output of the NXP location is an ammonium sulfate with a concentration between the 85 and 95 per cent. It is a waste stream that has been transported to SUEZ in the past and the company does have enough internal knowledge on this stream to transport and store the product.

Ammonium sulfate	
Supplier	NXP
Molecular formula	$(NH_4)_2SO_4$
Waste/virgin	Waste
Known/unknown	Known
EURAL code	11.01.05*
UN number	N.A.
ADR class	N.A.
EC number	231-984-1
CAS number	7783-20-2

Table 3-6: Ammonium sulfate (waste)

The assigned EURAL code for this waste stream is 11.01.05*. This is waste classified in chapter 11, wastes from the waste management facilities, off-site waste water treatment plants and the preparation of water intended for human consumption and water for industrial use. The sub category it is assigned to is the waste from physico/chemical treatments of waste (including dechromatation, decynidation and neutralization). Within this sub-category it is defined as wastes not otherwise specified.

The material is not considered as hazardous by the EURAL list and not classified as dangerous by the ADR classes, there is no class assigned to this material and the material does not have a UN number.

3.2.3 Ammonium bisulfate from pharmaceutical industry

The ammonium bisulfate (also known as ammonium hydrogen sulfate) is the product that is considered to be waste by the pharmaceutical company. This waste stream has been transported to SUEZ before and the EURAL code of this waste stream is 06.02.03*. Because the stream is marked with an asterisk (*) it is considered to be a hazardous waste stream, this EURAL code assigned to this waste stream is linked to the chapter of wastes from inorganic chemical processes. The ammonium hydrogen sulfate is assigned to the subcategory of wastes from the MFSU (manufacture, formulation, supply and use) of bases and belongs to the ammonium hydroxide category.

This stream is considered to be hazardous and is therefore assigned to an ADR class. The ADR class that is applicable to this waste stream is class 8. Within this class the package category is II. Class 8 category substances are those substances that have corrosive properties. Within the ADR these substances are described as: "substances of this Class which by chemical action attack epithelial tissue - of skin or mucous membranes – with which they are in contact, or which in the event of leakage are capable of damaging or destroying other goods, or means of transport, and may also cause other hazards. The heading of this class also covers other substances which form a corrosive liquid only in the presence of water, or which produce corrosive vapour or mist in the presence of natural moisture of the air (UNECE, 2001)". As a consequence of these properties there have been packaging groups defined, each packaging group has packaging requirements. Substances of ADR class 8 are classified in three packing groups according to the degree of danger they present for carriage. Group I are the highly corrosive substances, group II the corrosive substances and group III the slightly corrosive substances. The allocation of substances to these three groups are based on experiences taking into account the additional factors such as inhalation risk and reactivity with water (including the formation of dangerous decomposition products) (UNECE, 2001). The ammonium bisulfate of the pharmaceutical industry are considered to be corrosive substances and therefore assigned to packaging group II.

Ammonium bisulfate	
Supplier	Katwijk Chemie
Molecular formula	$(NH_4)HSO_4$
Waste/virgin	Waste
Known/unknown	Known
EURAL code	06.02.03*
UN number	2506
ADR class	8, II
EC number	232-265-5
CAS number	7803-63-6

Table 3-7: Ammonium bisulfate (waste)

3.2.4 Sulfuric acid from semiconductor industry

This waste stream is the sulfuric acid derived from the processes of the NXP company. This company also provides an ammonium sulfate stream to SUEZ. The sulfuric acid from this company, that operates in the semiconductor industry, is a 80% concentrated sulfuric acid waste stream. Because this stream is also transported to SUEZ on a regular basis there is internal know-how on the transport and storage of this waste stream.

With regard to the EURAL code (06.01.01*) of this waste stream it is considered to be part of the inorganic chemical processes. The subcategory related to this stream is the waste from the MFSU (manufacture, formulation, supply and use) of acids and it is placed within the sulfuric acid and sulfurous acid column.

Sulfuric acid	
Supplier	NXP
Molecular formula	H2O4S
Waste/virgin	Waste
Known/unknown	Known
EURAL code	06.01.01*
UN number	1830/1832
ADR class	8, II
EC number	231-639-5
CAS number	7664-93-9

Table 3-8: Sulfuric acid (waste)

The ADR classification for this substance is class 8 (described within the ammonium bisulfate). This class includes those substances that have corrosive properties. The package group that is related to the sulfuric acid from NXP is group II.

3.2.5 Sulfuric acid

Besides the sulfuric acid waste stream from NXP there is also a so called 'virgin' sulfuric acid stream that can be purchased by SUEZ, when this material is demanded. The product is a 96% concentrated sulfuric acid and has been bought by SUEZ at an earlier stage.

Sulfuric acid	
Supplier	Vivochem
Molecular formula	H2O4S
Waste/virgin	Virgin
Known/unknown	Known
EURAL code	06.01.01*
UN number	1830
ADR class	8, II
EC number	231-639-5
CAS number	7664-93-9

Table 3-9: Sulfuric acid (virgin)

According to the EURAL code (06.01.01*) of this waste stream the substance is considered to be part of the inorganic chemical processes. The subcategory related to this stream is the waste from the MFSU (manufacture, formulation, supply and use) of acids and it is placed within the sulfuric acid and sulfurous acid column.

The ADR classification for this substance is class 8 (described within the ammonium bisulfate). This class includes those substances that have corrosive properties. The package group that the sulfuric acid from NXP is assigned to is group II.

3.2.6 Urea

Another substance that is a potential input stream for the production of inorganic fertilizers is urea. This is a substance that can add nitrogen to the fertilizer when this is required. Because it is a virgin stream it will have to be bought by SUEZ and it is not considered to be a waste stream. The EURAL code for this substance is 16.05.08*, which means that according to the European waste list it is considered to be a hazardous substance. Urea is classified as 'waste not otherwise specified in the list' and under this chapter it is assigned to the sub-category of gases in pressure containers and discarded chemicals. In this sub-category it is listed under the discarded organic chemicals consisting of or containing dangerous substances. Although the urea is classified within the EURAL list as hazardous it is not considered to be dangerous for the transportation, there is no ADR class assigned to this substance and it does not have an UN number.

Urea	
Supplier	Vivochem/NXT
Molecular formula	CO(NH2)2
Waste/virgin	Virgin
Known/unknown	Known
EURAL code	16.05.08*
UN number	N.A.
ADR class	N.A.
EC number	200-315-5
CAS number	57-13-6

Table 3-10: Urea

3.2.7 Ammonia

The production of fertilizers will also require the addition of ammonia, this is required to neutralize the pH value of the fertilizer. Ammonia is a virgin stream and will have to be bought by SUEZ in order to use it in the production process of the fertilizers. Because the substance has been purchased before there is enough internal knowledge on the storage and transport for this product.

When considering the EURAL code of this product it turned out to be 06.02.03*. This code relates to the chapter of wastes from inorganic chemical processes and the related sub-category is the wastes from

MFSU (manufacture, formulation, supply and use) of bases and is listed under the ammonium hydroxide column.

According to the ADR classification the ammonia is classified as corrosive. According to the package requirements of the product it should be classified as group III, which implies that the product is seen as a slightly corrosive substance.

Ammonia	
Supplier	Vivochem
Molecular formula	H5NO
Waste/virgin	Virgin
Known/unknown	Known
EURAL code	06.02.03*
UN number	2672
ADR class	8, III
EC number	215-647-6
CAS number	1336-21-6

Table 3-11: Ammonia

3.2.8 Water

Another ingoing material stream that can be necessary for the production of fertilizers is water, this can be used to dilute waste streams. But because water is considered to be a well known and non-hazardous substance there are no EURAL codes or ADR classes assigned to this product.

Water	
Supplier	
Molecular formula	H2O
Waste/virgin	Virgin
Known/unknown	Known
EURAL code	N.A.
UN number	N.A.
ADR class	N.A.
EC number	231-791-2
CAS number	7732-18-5

Table 3-12: Water

3.3 Transportation and storage

The majority of the abovementioned material streams have been transported and stored at SUEZ before. Customers, materials and the related rules and regulations are known. Therefore there will be no attention paid to these materials because the relevant information is assumed to be known and rewriting this is considered to be of little additional value. The only material stream for which no or little information is available is the ammonium sulfate from the agricultural industry, the farmers. This material stream has been described in the previous section. This section builds on this by adding the requirements on the transportation and the storage of the ammonium sulfate from farmers. There are specific transportation and storage requirements set for this material stream and these are described below. Firstly the packaging and the labelling requirements are mentioned, these are relevant for the transportation of the substance

3.3.1 Packaging requirements

- The transport of the washing fluids requires a poster stamp or casing. The stamp or casing should be irreparably damaged if opened. This means for the ReFertilizer project that when the washing fluids from farmers are used it should be provided with a poster stamp (or casing) that cannot be opened during transport.

3.3.2 Labelling requirements

- An attached document or label should contain the following data:
    - Name or tradename of the manufacturer
    - Name or tradename of the fertilizer
    - Substantial operation that is carried out by the fertilizer
    - The levels nitrogen (N)
    - The levels phosphate (P_2O_5/P) (not applicable for the ReFertilizer project)
    - The present fertilizing ingredients potassium, neutralizing value, secondary nutrients or micronutrients with the exception of nitrogen and phosphate if these are present within the fertilizer in large quantities
    - The fertilizing ingredients will be expressed as follows:
        - Potassium K_2O and if desired also K
        - Calcium CaO and if desired also Ca
        - Magnesium MgO and if desired also Mg
        - Sodium Na_2O and if desired also Na
        - Sulfur SO_2 and if desired also S
        - The quantities (in kilogram or in tons)
    - The composition
    - A manual for other inorganic fertilizer that mainly supply micronutrients that suits the soil and crop conditions under which the fertilizer is used, not applicable for the ReFertilizer project because the washing fluids mainly supply nitrogen and sulfur, which are macronutrients

3.3.3 Storage requirements

After all the requirements for the transport and purchasing have been satisfied, there are other regulations that apply with regard to the storage. As mentioned in the mixing part, the washing fluids can release the toxic gas hydrogen sulfide if mixed with animal manure. Therefore, as already described within the general requirements, the washing fluids of air scrubbers should never be mixed with animal manure. For this reason washing fluids should be stored in tanks or in closed caves. The washing fluids of the chemical air scrubber contain ammonium sulfate, dust and possibly a residual sulfuric acid. Therefore the washing fluids have corrosive effects and a low pH value. To guarantee the external security there are performance requirements applied to the storage of washing fluids (InfoMil, Technische informatiedocumenten over stalsystemen, 2013). Washing fluids are classified as potentially soil-threatening substances. The requirements for the washing fluids are the same as the requirements for liquid manure (in case of storage in a facility for the storage of liquid manure) or the requirements for storage of soil-threatening substances in an aboveground tank. The storage facility should be able to withstand the influence of the washing fluids (possibly containing some small levels of sulfuric acid). The specific storage requirements related to the washing fluids are (InfoMil, Technische informatiedocumenten over stalsystemen, 2013):

- Washing fluids from a chemical air scrubber should be stored in a dedicated impermeable storage;
- Walls and floors should be resistant to the influence of washing fluids, within the organization there should be evidence that the storage is treated with acid-resistant material or that the storage is acid-resistant;
- The washing fluid storage should have sufficient capacity and should not be provided with an overflow;
- It is not allowed to discharge the washing fluids into the sewerage;
- When filling or emptying the storage, pollution of the soil or surface water is not allowed
- When disposing the washing fluids, the environment must not be contaminated;

Transport of the washing fluids should take place in closed tanks.

3.4 Production process

The important legal issues for all the incoming (waste) streams are outlined in the previous part and once the input materials for the production process are legally transported and stored at SUEZ it is important to map all the legal issues concerning the production process. Within this part the legal issues that are important for the production process will be discussed. To start with the production of fertilizers it is important to comply with all laws and obtain all required permits.

3.4.1 Environmental permit

To start the production of fertilizers at the location of SUEZ in Almelo it is important to have all relevant permits. One of these important permits is the environmental permit (in Dutch: omgevingsvergunning) which is issued by the province of Overijssel. The current environmental permit has been provided to SUEZ on August 26, 2006. However, due to changes and the introduction of new (European) legislations, it is required for SUEZ to file an overhaul permit that allows them to stay in business. The major difference with respect to the 2006 permit are the changes in regulations regarding hazardous waste and the desire of SUEZ to expand their current base of activities. The application of the permit refers to the collection, storage and processing of (non)hazardous waste, the transformation of waste streams in order to create new streams that can be sold to customers.

Formulation of liquids and solids

The most important part for the ReFertilizer project in the environmental permit is the part where the new additional activities are introduced. This new part in the permit will be described in this section. The description is based on the current submitted permit that is expected to be assigned mid-2016.

The permit describes the FLS (Formulation of Liquids and Solids) that SUEZ would like to add to their current activities. This chapter within the permit describes the production of chemicals by the mixing of substances by a certain specification, the dissolving of solids in liquids or by the execution of simple chemical processes.

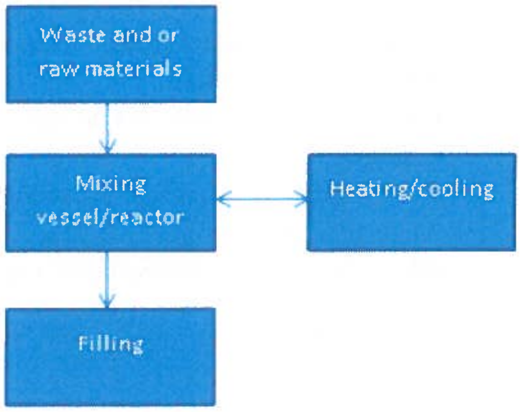

Figure 3-6: Formulation of liquids and solids

Before the FLS installation will be used for the production of chemicals by simple production processes there will be tests performed in the laboratory. This is part of the acceptance procedure[7], which will be applicable for this project. For the production there will be mixing vessels and reactors installed, that will optionally be equipped with heating or cooling elements. The final product will after production be stored in packing (cans, drums, IBCs) or in tanks.

The storage of chemicals (in bulk) will take place in the tank park TP-1 (for inorganic liquids) or in one of the tanks in G-4.1 and G-2.2, as can be found within figure 3-7.

[7] Acceptance procedure is an extensive procedure that describes the incoming, process and output control.

Besides the part in the permit that describes the formulation of liquids and solids there is another important aspect in the permit. This aspect is the placing of a new urea silo on the location of SUEZ in Almelo. This silo will provide input materials for the end product of the ReFertilizer project. Urea is an important nitrogen supplier when the level of nitrogen in the other used waste streams is too low. Another expansion activity is the expansion of the storage options for the purpose of the FLS activities. The expansion has been included in the permit and takes into account the additional placement of two extra tanks in the tank park.

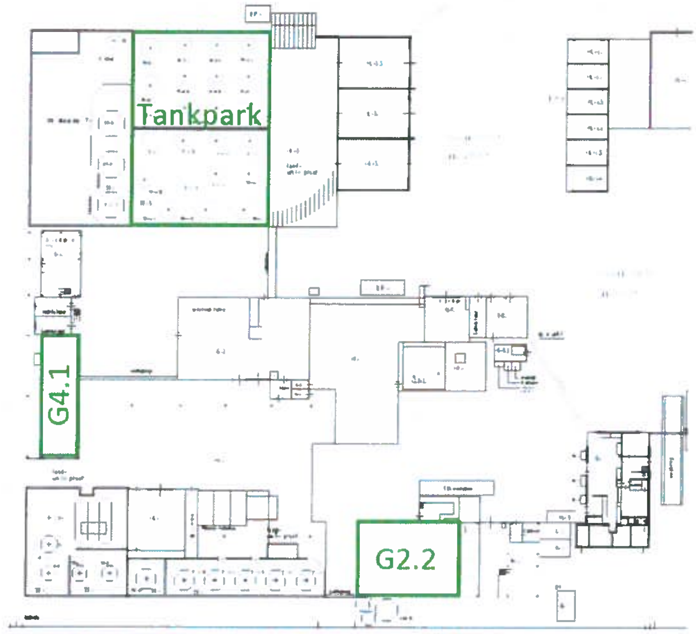

Figure 3-7: Storage possibilities of bulk materials

EURAL codes

Another important aspect of the submitted permit is the list with EURAL codes. This list contains all the (hazardous) substances that are transported to and possibly treated at the location in Almelo. The submitted file contains all relevant EURAL codes and describes whether it is collected by SUEZ (pumping to a tank, bulking, store, sort, disassemble or overflow), on which installation it can be treated or if it can be used in the (new) formulation process to create new product. The relevant installations on the treatment location in Almelo are the distillation, solid dry installation (SDI), paint installation (RWF), IWR, ONO or the OIF installation. When the list is approved by the province, SUEZ is allowed to collect the substance, formulate substances or use them in the installations.

All waste streams that are transported to the location in Almelo should be listed in this EURAL code list. A large range of EURAL codes is filed by SUEZ but not all substances are currently treated in an installation within SUEZ, this large range of codes is listed because the customers want SUEZ to quickly respond to the needs of waste streams. Customers expect SUEZ to collect all sorts of different waste streams, including those waste streams that have not been collected by SUEZ before.

The EURAL codes that are related to this ReFertilizer project are all listed in the submitted EURAL list. The selection of substances that apply to this ReFertilizer project can be found in appendix 4. New in this permit and important for the ReFertilizer project is the column "formulate". This column is important because it shows which waste streams SUEZ would like to use for the forming of liquids and solids (FLS). The waste streams considered to be relevant for the ReFertilizer project are not treated in one of the installations but are used for the forming of liquids and solids.

The idea within SUEZ is to set up a register with all new substance that are formed based on the FLS principle. This register will be launched because it is yet unknown what possible solids or liquids will be produced in the future and what substances will be used to do so. Once a liquid or solid has been formulated the permission will be requested and required once and then the formulated combination will be added to the register. Based on this principle a 'grow-list-register' will be built up. All streams that will be processed in the FLS and included in the register will also be described in another part of the permit under the 'general description activities Treatment'. The related EURAL codes that are currently included relate to the vaguely defined process that SUEZ has in mind that is about the aqueous stream (not contaminated with pesticides) that will be enriched with excipients to sell the mixture as new product.

Best available techniques reference

Another aspect of the environmental permit are the best available techniques reference documents, abbreviated as BREF-documents. These documents are also described as Best Available Techniques (BAT) documents. These documents describe the currently available and optional production activities. The province would like to have information on what activities are performed within SUEZ, based on the IED (Industrial Emissions Directive).The Integrative Pollution Prevention and Control (IPPC) guidelines are part of this directive and are defined to integrally prevent and combat pollution. The guidelines are part of the European environmental laws and consist of a set of rules to control industrial installations. The IPPC consist of:

- An integrated approach
- Application of the BAT (Best Available Techniques)
- Flexibility
- Public participation

For all the companies that are part of the IPPC guidelines there are, on European level, reference documents created. Within these documents the best available techniques (BAT) for all kinds of processes and business units are described. In order to determine whether a company should comply to the regulations there should be an analysis on whether one or more activities from the directive industrial emissions take place within the establishment. Because SUEZ performs activities that are described in the directive, they should comply to the IPPC guidelines and are required to have a permit. The province will base the release of a permit on the BAT for the installations that are part of the IPPC guideline.

When SUEZ would like to start with the ReFertilizer project it is important to apply the BAT for fertilizers. The Best Available Technology for the production of fertilizers is listed and can be researched to generate information on how the fertilizers should be produced (European Commission, 2007). This reference document can be used when the production technique for the inorganic fertilizers will be defined. However, discussions on this topic within SUEZ revealed that the guidelines for the Best Available Technique are not strictly applied by the province. When SUEZ can show that the applied way of producing is a conventional way of producing and there are no techniques that are significantly better, there will be no problems concerning the BAT.

3.4.2 BRZO

SUEZ in Almelo is a company that falls within the scope of the Dutch BRZO (Besluit Risico's Zware Ongevallen). This is the Dutch interpretation of European regulation for the risks of major incidents and applies to all companies where large amounts of hazardous waste are stored above a certain threshold value. The BRZO combines the labor safety, external safety and disaster control. The goal of the BRZO regulation is to prevent and control major incidents with hazardous waste. The BRZO regulation classifies two types of companies, the PBZO-company (Preventie Beleid Zwaar Ongeval) and the VR-company (VeiligheidsRapport). Companies that are above the highest threshold are classified as VR-companies where companies that have a lower threshold are classified as a PBZO company. SUEZ is currently classified in the latter category. Therefore SUEZ has to take all measures to prevent major accidents and to limit the effects on humans and environment, design a PBZO and to execute and define the PBZO it should implement a safety management system (VBS), do a quantitative risk analysis and design a notification which summarizes what amounts and categories of waste are located at the company (SZW, 2015). However, due to legal changes in categorization (start of BRZO III in July 2015) of waste streams and the expected expansions of SUEZ, the threshold value of the PBZO will be exceeded. Therefore the new permit will be submitted based on the fact that SUEZ will operate as a VR-company. As VR-company SUEZ is obliged to set up a safety report as addition to the actions required for the PBZO regulation (BRZO+, 2015). The so-called sparklers safety report is currently in development and will be submitted together with the application of the environmental permit.

Within SUEZ a lot of attention has been paid to these subjects, on the one hand because it is very important for the people and the environment and on the other hand because it is mandatory and required to operate in the hazardous businesses. SUEZ developed a safety management system, this system aims to prevent major incidents as well as quality, environmental care and the control of labor risks. Besides this system SUEZ did research, by various risk analysis and evaluations, on the risk of all the activities that take place on the SUEZ location in Almelo. All different possibilities for situations that could happen have been listed and the assessed risks for all these activities are linked to the situations to create insights on what could happen, what are the risks of appearing, what are the related chances that it happens and what are the adverse effects of it. Next to this analysis SUEZ performed a Quantitative Risk Analysis that listed the risks of accidents for the environment and the risk of an accident for other parts of the location.

Because SUEZ has to comply with the BRZO regulation and should apply the VR legislation it is important to identify what the risks are for the implementation of the ReFertilizer project. When the ReFertilizer project is implemented, there will be new sorts of materials at the location in Almelo and there will be new activities that will be performed at the location. For these materials, the activities and the production facilities all the possible accidents and risks should be listed to identify what could happen, what are the chances that these accidents occur and what are the adverse effects of these activities if something will go wrong. Based on this data it is possible to prevent certain accidents from occurring or minimizing the risks of other accidents.

3.5 Outgoing material stream(s)

This section will describe what legal issues apply to the final fertilizer product. The product produced out of a combination of the different described ingoing waste or virgin streams will be applied in the agricultural sector. However, it is not allowed to apply fertilizers throughout the whole year. The Dutch government designed rules that define when it is allowed to apply fertilizer to agricultural grounds. However, fertilizers can be applied for different purposes and not all purposes have the same allowed application period. The periods that are allowed to use fertilizers on agricultural grounds are listed per sort of application in table 3-13 below. Besides the restricted periods for the application of fertilizers there are specific regulations that apply for the use of inorganic fertilizers on agricultural grounds and these are listed below as well. Next to these requirements are the maximum amounts of heavy metals that are allowed for the application of fertilizers, these requirements and regulations are listed in table 3-14. Besides the regulations that apply to the application of fertilizers, there are several risks for the soil attached to the application and these risks are listed below.

Before it is allowed to use the inorganic fertilizer there are certain requirements that have to be met. When someone wants to apply the other inorganic fertilizer to farmland than compliance to the usage standards system (gebruiksnormenstelsel) is required. The amount of other inorganic fertilizers that may be applied to farmland is infinite as long as it fits within the usage standards. These usage standards are considered to be out of scope for this project. Amounts of fertilizers that are used by the customer are the responsibility of the end user that applies the product. Other inorganic fertilizers do not count for the standard of the livestock manure but do count for the nitrogen and phosphate standards. The amount of nitrogen or phosphate applied do count for 100%.

There are certain rules for the application of other inorganic fertilizers (LNV, 2013). When the fertilizers are applied to farmland the nitrogenous fertilizers can be applied within the time ranges within the table 3-13 below:

Application	Starting date	End date
Arable and grassland	February 1	September 1
Arable land with only fruit	September 16	October 15
Arable land evenly planted with hyacinths	January 16	January 31
Arable land evenly planted with outdoor vegetables	January 1	December 31

Table 3-13: Application dates fertilizers

The starting and end dates are visually displayed in the figure 3-8.

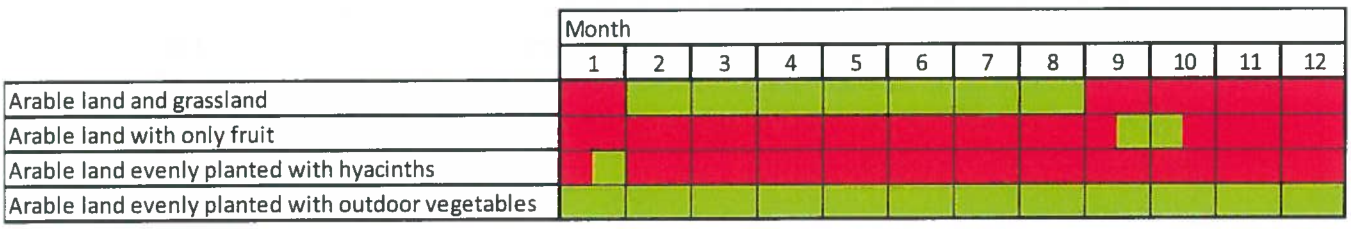

Figure 3-8: Application dates fertilizers

It is not allowed to apply nitrogenous other inorganic fertilizers, or mixtures of these fertilizers, when:

- the soil is completely or partially frozen, or completely or partially covered in snow
- the upper layer of the soil is saturated with water
- from September 1 to January 31 if the soil is irrigated or infiltrated at the same time
- the slope of the ground is seven per cent or more when the land is affected by gully erosion
- the land is not cultivated and the slope of the ground is seven per cent or more
- the arable land has a slope of 18 per cent or more

For the storage of other inorganic fertilizers on farms the rules of the environmental permit apply. For the application of fertilizers there are requirements with regard to the maximum amount of heavy metals in the fertilizer. These requirements can be found in the table 3-14 below, it presents the maximum value in mg/kg of the heavy metal of the value giving ingredient (RVO, 2015). For the NS fertilizer the value giving ingredient will be the nitrogen (N column).

Heavy metal	Maximum value in milligrams per kilogram of the respective value-giving ingredient (mm/kg)				
	PO4	N	K	Neutralizing value	Organic substance
Cd	31.3	**25**	16.7	6.3	0.8
Cr	1875	**1500**	1000	375	50
Cu	1875	**1500**	1000	375	50
Hg	18.8	**15**	10	3.8	0.5
Ni	750	**600**	400	150	20
Pb	2500	**2000**	1333	500	67
Zn	7500	**6000**	4000	1500	200
As	375	**300**	75	75	10

Table 3-14: Maximum values heavy metals

Besides the maximum value of heavy metals in the fertilizer there are maximum amounts of organic micro-pollutants (RVO, 2015). This list has been added to appendix 3. The values relevant for this ReFertilizer project have been listed under the nitrogen column because nitrogen will be the most relevant macronutrient. The other inorganic fertilizer that mainly supply primary macronutrients should also at least contain 5% nitrogen of the dry matter. To make sure that all these maximum and minimum values are not exceeded, the material streams should be tested by an accredited company to guarantee that the products are legally allowed to transport and sold.

As mentioned in the introduction there have been discussions with SUEZ and customers that showed interest in the outgoing material stream. The customer(s) that showed interest in the inorganic fertilizer demand a certain level of sulfur and nitrogen, these levels have been introduced in section 2.1.2. For the sulfur component the industry demands a 7 per cent of the related sulfur trioxide. Converting this number to the level of sulfur results in the market demand of sulfur of 2.8 per cent. The demanded level of nitrogen in the liquid inorganic fertilizer is 21 per cent. The pH value is demanded by the agricultural sector should be between 4.5 and 6.

3.6 Conclusion

This chapter summarizes the previously described relevant legal aspects for the ReFertilizer project within SUEZ Almelo. The chapter is divided into different subchapters, where each subchapter addresses another topic.

The introduction described all relevant information classes of the materials that are considered to be relevant for the ReFertilizer project. At first the EURAL codes, UN numbers and ADR classes, CE and CAS numbers are introduced to create an insight on what general material information can be used as background information for this project. Then the different types of fertilizers, that are defined within the Dutch legislation, are described after which the relevant fertilizer types for this project are highlighted. After this general background information, two important legal aspect are introduced within the introduction chapter.

At first the end-of-waste directive is introduced, this directive describes a regulation that creates the opportunity for companies to declare their waste streams into new products. If a company can prove that certain criteria are met the waste material can be seen as new product. For SUEZ this directive is of major importance because SUEZ would like to transform certain waste materials, together with virgin product streams, into a new product stream. Somewhere in this process the end-of-waste directive should be applied. Two options are considered to be possible for this directive. SUEZ can apply the end-of-waste directive to all single input waste material streams or it can apply the directive to the final product after formulation. An analysis of these options revealed the advantages of the application of the end-of-waste directive to the final product after formulation. Therefore this report recommends to apply the end-of-waste directive after formulation, as is described in the end-of-waste section 3.1.5.

Another important legal aspect described within the introduction is the REACH regulation. This regulation is about the registration, evaluation, authorization and restriction of chemical substances. For the ReFertilizer project there are different substances that are considered to be relevant with regard to the REACH regulation. The ingoing material substances consist of several waste material streams, these waste material streams are exempted from the REACH regulation. The ingoing material streams that are considered to be non-waste will have to apply to the REACH regulations. SUEZ will be recommended to make sure that the suppliers do comply to the REACH regulation and send, if necessary, a MSDS with the chemical substances. With respect to the outgoing material SUEZ will produce a new product, the inorganic fertilizer. Formulating the new product is a process that combines different ingoing materials and within this formulation process there is no chemical reaction that occurs. Because there is no chemical reaction within the formulating process the end product is considered to be a mixture according to the REACH regulation. For mixtures REACH obligates companies to register or make sure that all substances that have been mixed are registered within REACH.

The ingoing material stream subchapter describes all material streams that are considered to be useful and relevant for this ReFertilizer project. Because the majority of the ingoing material streams have been transported and stored at SUEZ before there is little attention paid to these material streams because internal experiences and knowledge is present. These material streams are described and all relevant codes and numbers are described. The material stream that has not been transported and stored at SUEZ before, and is relatively new within the business of SUEZ is the ammonium sulfates from the farms. For this stream all relevant rules and laws have been listed. The section on ammonium sulfate from farms describes the general, mixing, agronomic, environmental, packaging, labelling, sampling and storage requirements.

The fourth section describes the legal aspects that are considered to be relevant for the production process. Outlined here is the environmental permit that is expected to be assigned in 2016. Important in this permit is the description of the process of "formulating of liquids and solids", relevant EURAL codes and Best Available Techniques (BAT). The process of formulating liquids and solids describes the expansion of the activities that SUEZ would like to start. The ReFertilizer project is based on this new formulation process. Besides this, the environmental permit listed all relevant EURAL codes for SUEZ . The permit includes the new EURAL codes that SUEZ would like to produce in the formulation process. SUEZ did also include a column for the formulation of products and marked all EURAL codes that have been considered to be relevant for the formulation of new products. All relevant EURAL codes for the ReFertilizer project, as described in the ingoing material streams, have been included in the submitted environmental permit. The environmental permit also requires the description of all relevant Best Available Techniques (BAT), these have been included in the permit but internal experiences clarified that the BAT references are considered to be of little relevance to the involved authorities. A document for the BAT of fertilizers is available and therefore little attention has been paid to the BAT reference in this report. Next to this the related regulation on BRZO (Besluit Risico Zwaar Ongeval) has been described, the section describes the requirements from the Dutch government that are related to the possibilities and risks of major accidents. When the ReFertilizer project will be implemented there will be new sorts of materials at the location in Almelo and there will be new activities performed at the location. For these new materials, activities and production facilities the possible accidents that could occur and the related risks should be listed to identify what could happen, what are the chances that these accidents occur and what will be the adverse effects of the accidents if they occur.

The last subchapter is about the outgoing material stream, the formulated inorganic fertilizer. This subchapter describes the application dates of different application possibilities for the fertilizer. The most common fertilizers may be applied from February until August. The section also describes the Dutch application rules on the application of fertilizer onto Dutch arable lands. Besides these dates and rules the section outlines the required values of the inorganic fertilizer.

4. Qualitative

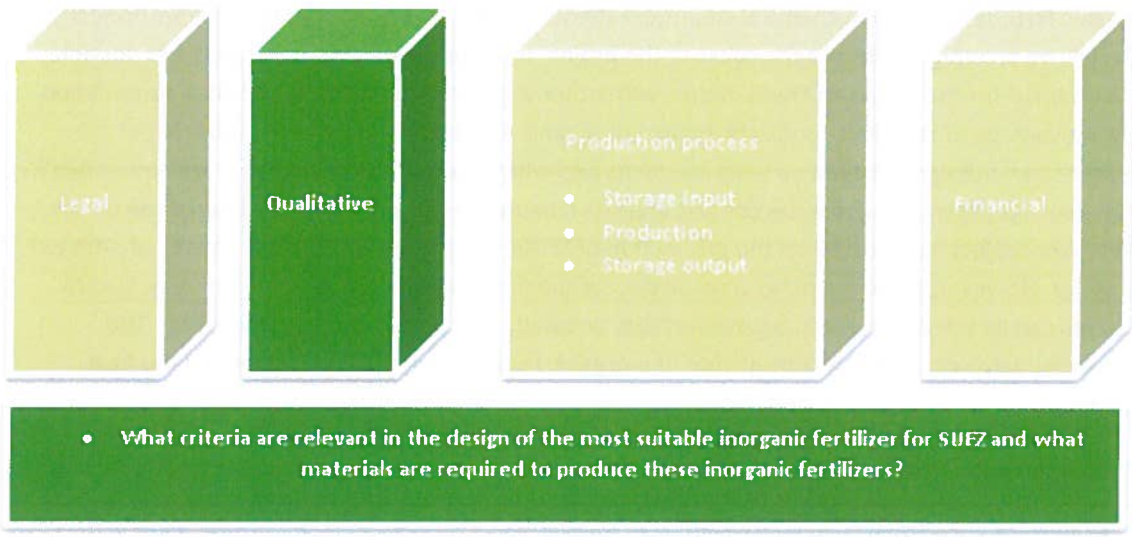

Figure 4-1: Second block ReFertilizer project

The previous chapter outlined all legal aspects that influence this ReFertilizer project. It described all relevant codes and classes related to the involved material streams, described the regulations related to the transportation and storage of the materials and addressed the legal aspects with respect to the production process and the produced final product. This chapter uses part of this information to define what legal aspects influence the qualitative section. This chapter also describes the qualitative aspects of the ReFertilizer project. At first the fertilizer industry and market are investigated and outlined to gain background knowledge on what the current developments and demands in the fertilizer market are. The subsequent section summarizes all major fertilizer types that are common in the global fertilizer industry. Fertilizers are composed out of different nutrient components, these components can be used in different compositions and there are different ways to produce all fertilizers types. Besides the commonly known global nutrient components there are (waste) material streams within SUEZ that contain nutrient components. Given these global demands and the supplies available within SUEZ, a selection can be made on what fertilizer types are possible to formulate. The options that are considered to be relevant for this ReFertilizer project are analyzed based on the information that has been outlined in the legal part to guarantee that the options meet the requirements to formulate. Besides the legal aspects of the fertilizer product there are additional sections on what is demanded within the relevant markets and a cost estimation has been formulated on all relevant options. All abovementioned steps are listed in figure 4-1. Based on these selection steps an advice can be drafted on what the possibilities to produce are and what currently the most suitable option is for SUEZ .

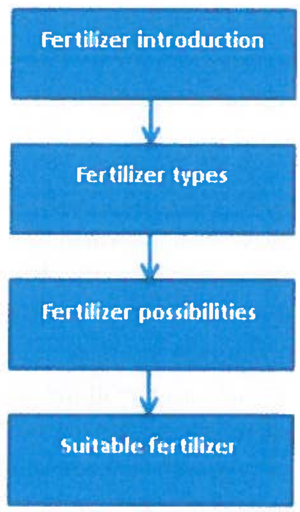

Figure 4-2: Suitable fertilizer selection

Important for the remainder of this chapter is that, as described in the context analysis, distinctions can be made between organic and inorganic fertilizers, organic fertilizers are plant or animal derived and inorganic fertilizers require a chemical treatment (Benton Jones, 2012). For the ReFertilizer project the focus will be on inorganic fertilizers, because the project involves waste stream materials as possible input material for the fertilizer. These inputs, with other virgin streams, require chemical formulation steps. Advantage of inorganic fertilizers instead of organic fertilizers is that the composition of the fertilizer can be designed based on what elements and what levels of these elements are demanded by the market. As described within the context analysis (chapter 2) the work that has been done on the ReFertilizer project has focused on the production of NS-fertilizers, these fertilizers consist of nitrogen and sulfur. However, there are other possibilities for the formulation of inorganic fertilizers. Several nutrients can be present in the inorganic fertilizer as briefly mentioned in the introduction. The possibilities with respect to the production of inorganic fertilizers are further outlined in the next sections.

4.1 Fertilizer demands

4.1.1 Fertilizer market

The fertilizer industry identifies four categories of fertilizers. These four major categories are nitrogen fertilizers, phosphate fertilizers, potash fertilizers and complex fertilizers. Global fertilizer demands have shown increases over the past decades, see appendix 1, and current demands show a 2.0 % increase over the year 2014/2015 and are expected to grow with 1.0 % over the next year, to 186 million ton (IFA, 2015). The medium-term forecasts for 2019/2020 are expected to increase with an annual change of 1.7 % up to the amount of 200 million ton, as represented in table 4-1.

Medium-term Forecasts for World Fertilizer Demand (Mt nutrients)

	N	P_2O_5	K_2O	Total
Av. 2012/13 to 2014/15 (e)	110.1	41.1	30.3	181.4
2019/20 (f)	119.2	45.7	35.3	200.2
Av. Annual Change	+1.3%	+1.8%	+2.6%	+1.7%

Source: P. Heffer, IFA, June 2015

Table 4-1: Medium-term fertilizer forecast

Although the global fertilizer market and demands increase, the European market lags behind. The growth of yields in developing countries (in wheat, rice and maize) have all declined since 1980, where the current growth in the agricultural productivity in western Europe is almost static. Besides the decrease in demands, the agricultural land base is shrinking due to the increase in nutrient exhaustions, soil erosions and urbanization (Fertilizers Europe, 2015). Although the fertilizer market in Europe seems to stagnate it remains to be an industry that is developing and employs many people. The average annual turnover in the industry is 13.2 billion where 1.12 billion of investments are made on an annual basis. The industry currently employs 95,000 people and within Europe there are over 120 production sites related to the production of fertilizers (Fertilizers Europe, 2015). Focusing on the Dutch fertilizer market reveals that the Dutch fertilizer industry is one of the largest fertilizer producers of Europe, only Germany produces larger quantities of fertilizers. Total production amounts for 7.5 million tons, of which 6 million tons are nitrogenous fertilizers. The Dutch market uses 11 percent of these fertilizers and the rest is being exported.

The four major fertilizer producers in the Netherlands are Yara, OCI Nitrogen, Rosier and ICL Fertilizers. The total Dutch fertilizer market employs around 1,700 people and the indirect employment amounts to 5,000 jobs. The four largest producers have invested over a billion euros in the last five years, partly to increase their productivity but also to reduce the impact of the production of fertilizers on the environment (Meststoffen Nederland, 2015). Despite all these investmests Fertilizers Europe, an organisation that represents the major fertilizer manufacturers in Europe, expect the Dutch market to decline considerably in the period 2014-2024. The decrease is expected for all three primary macronutrients (Fertilizers Europe, 2015). The Food and Agriculture Organization (FAO) of the United Nations on the other hand expects for West Europe a decline in the nitrogen market but small increases for the phosphate and potash market (FAO, 2015).

The increase in the world population to 9 billion people in 2050 leads to an increase in food production of 70%. On the other hand, there is a decrease in the available farmland and major concerns about the environment (FAO, 2009). This has led to a different view on fertilizing where the productivity should increase and farmlands should be fertilized in a sustainable and optimal way. Important here is the optimal and efficient application of fertilizers and nutrients (Meststoffen Nederland, 2015). The ReFertilizer project does perfectly fit into this new view on fertilizing, where more attention is paid to the sustainable (re)use of fertilizers and nutrients. The project considers nutrient-rich waste materials to be raw materials for new fertilizer products. This results in a better and more sustainable way of producing fertilizers.

For the ReFertilizer project it is important to gain knowledge on the local fertilizer market. Based on the fact that 80 percent of the Dutch fertilizer market consists of nitrogenous fertilizers, this is the major and most important market segment. Based on this market information and the fact that the related waste materials all contain nitrogen, this is expected to be the most important segment. This, and the other relevant aspects with regard to the formulating of the most suitable fertilizer are outlined in the next sections.

4.2 Fertilizer opportunities

The focus within the work that has been done within SUEZ is on the fertilizer that is circumscribed as the NS fertilizer or ammonium sulfate fertilizer. The main elements of this type of fertilizer are the nutrients nitrogen and sulfur. Besides this type of fertilizer, there are other options to formulate fertilizers. These other options are outlined in this chapter. At first all different components to produce a fertilizer are introduced and the function are represented in the component section. The fertilizer components can be mixed to create a fertilizer combination. Combinations of fertilizers can be made on different levels, the number of nutrients can vary (single- or multi-nutrient), the type of combination can vary (mixed or complex), the physical condition of a combination can vary (solid, liquid or gas) and the nutrient release can vary (quick-acting, slow-acting, controlled-release and stabilized) (IFA, 2015). All combination levels are described and the most useful and promising fertilizer combinations are described in detail. Within all possible combinations of fertilizers there will be a few that will be relevant for production within SUEZ. These combinations are highlighted and the different possibilities with regard to their composition is described. The fertilizer combinations can consist of different compositions where each combination is composed of different levels of components.

4.2.1 Fertilizer components

The context analysis already introduced the application of fertilizers. The fertilizer application in the ReFertilizer project is an application that is based on a new, innovative idea. However, the application of fertilizers within the agricultural sector is conventional. The valuable components of the fertilizers can be arranged in different categories. As briefly introduced in the context analysis, distinctions are made between macronutrients and micronutrients. The macronutrients are classified as 'macro' because they are demanded in larger quantities. These two classes and their related nutrients are outlined below.

4.2.1.1 Macronutrient

Within the macronutrients, distinctions are made between primary and secondary nutrients. The most important macronutrients are classified as the primary macronutrients. These nutrients are nitrogen, phosphorus and potassium. The secondary macronutrients are calcium, magnesium, sodium and sulfur. The main functions of the macronutrients are listed in table 4-2 . All six nutrients are important constituents in the soil that promote plant growth and development. The macronutrients that are currently considered to be of major importance for this ReFertilizer project are nitrogen and sulfur, as mentioned in the previous section, and therefore these elements are described.

Nitrogen (N)

Nitrogen is the most important nutrient for a plant, mainly for firmness and yields. It is an important component of many structural, genetic and metabolic compounds in plant cells. The demand of nitrogen fertilizers is large and globally increasing (see 4.1 Fertilizer demands). The nitrogen fertilizer urea is currently the most popular nitrogen fertilizer, with about 56 percent of the world market. The increases in growth over the years has stimulated the growth in production (IFA, 2013).

Nitrogen is directly absorbed by the plant which results in a rapid growth of the plant. Nitrogen easily leaks to the soil and it is expensive to upgrade the soil stockpiles. An important element in successfully managing the cultivation of crops is the efficient managing of the nitrogen element in the soil. Nitrogen is mainly available in amino acids, proteins and sugars.

Efficiently utilizing the nitrogen in a plant is essential for the supply of other elements, especially the phosphorus, potassium, calcium and magnesium. If the availability of one or more of these elements is not enough, the application of nitrogen will not have the desired result. Results are that the crops are sensitive for diseases, bloom late and produce low-quality fruits. If the total nutrient balance is good it will result in nice crops with good, undisturbed growth.

Nitrogen can be provided by the application of nitrate (NO_3^-) and ammonium (NO_4^+). Nitrate can directly be absorbed by the plant and should therefore be applied when fast results are demanded. Nitrogen can be administrated through the leaves or through the soil, where administration through the soil is more effective (YARA, 2012).

Phosphorus (P)

Phosphorus is a vital element which plays a role in the energy management of the plant and therefore essential in the decent development of the plant. Phosphorus mainly promotes the root growth (YARA, 2012).

Potassium (K)

Potassium affects the operation of a number of enzymes. These enzymes can accelerate certain processes in the plant, potassium is important for the transport of other substances. Potassium enhances the firmness of the plant and increases the osmotic value of the cell fluids. Potassium influences the uptake of substances which enhance the cell wall (YARA, 2012).

Sulfur (S)

Sulfur is essential for the production of proteins in the plants and is an essential part of many amino acids and proteins. Sulfur-rich proteins have a fixed nitrogen-to-sulfur ratio where nitrogen is needed the most. Sulfur is essential for the production of proteins in the plants and is an essential part of many amino acids and proteins (YARA, 2012).

The symptoms of sulfur deficiencies are a reduction in growth and deferred ripening. Younger leaves will firstly turn light green where older leaves turn yellow. Toxicity can be a problem when applying sulfur. However, an excess amount of sulfur rarely occurs. But an excess amount of sulfur application can result in an accelerated aging and leaf fall. The gas hydrogen sulfide can be formed and is toxic if present in high concentrations. Plants are normally able to break down these toxic substances via oxidation or excretions through the leaves (YARA, 2012).

Calcium (Ca)

Calcium is generally considered to be the most important secondary element. Calcium strengthens the cell walls and is important for the cell division processes. Improving the cell wall leads to better quality, shelf life and a better yield. At the same time calcium improves the structure of the soil (YARA, 2012).

Magnesium (MG)

Magnesium functions as a building material for chlorophyll. Chlorophyll is an essential element for photosynthesis. Levels of magnesium that are too high result in a decrease in yield and quality of the product (YARA, 2012).

Macronutrient	Function
Nitrogen	Structural component of enzymes, proteins, DNA, etc.
Phosphorus	Structural component of DNA; involved in conversion of energy
Potassium	Essential for many chemical reactions in plants
Sulfur	Structural component of some proteins
Calcium	Influences permeability of cell membranes
Magnesium	Central component of chlorophyll

Table 4-2: Functions of macronutrients

4.2.1.2 Micronutrient

There are many micronutrients, such as zinc, copper, iron, boron, cobalt, nickel and molybdenum. As mentioned in the introduction the micronutrients are demanded in smaller quantities than the macronutrients. The presence of micronutrients in the soil is not stable and is affected by the pH value and the possible combination with organic compounds. Micronutrients play an important role in the activation of several enzyme systems (Verheye, 2007). The micronutrients are considered to be of little relevance for the ReFertilizer project and will therefore not be outlined in this report.

4.2.2 Fertilizer combinations

As mentioned above the fertilizers can be combined in various ways. Combinations can be based on the number of nutrients, physical conditions and nutrient release. The number of nutrients can vary between single/straight nutrient fertilizers, where only one nutrients is supplied, or multi-nutrient fertilizers where two, three or more nutrients are supplied. Next to these options for combinations there are the physical conditions of the fertilizers. As mentioned above, the fertilizers that are considered to be relevant for the ReFertilizer project are inorganic fertilizers. The inorganic fertilizer can be supplied in different conditions. The conditions are liquid, solid or gaseous. Because the gaseous condition is considered to be useless for the application within the agricultural sector the two relevant fertilizer conditions within the ReFertilizer project are solid and liquid. Between those two conditions, the liquid form is considered to be the most relevant condition. On the one hand because the materials that are considered to be options for the ingoing material streams are in a liquid state and on the other hand because the liquid state of a fertilizer has many advantages. A major advantage of applying liquid fertilizer instead of solid fertilizers is the ability to apply a precise dosage of fertilizers. Losses at field borders will be minimized and overlap on parcels can be reduced by applying the newest technologies. Another advantage of applying liquid fertilizers is the possibility to combine urea-, ammonium-, and nitrate nitrogen. This provides the user the ability to choose what the composition of the fertilizer should look like. Other advantages of the use of liquid fertilizers are that a larger working width and fewer tracks can be achieved by the commissioning of a spraying machine (Triferto, 2015). Besides these variations the fertilizers can be distinguished on their way of releasing the nutrients, by quick-acting, slow-acting, controlled release or stabilized. The combinations that are considered to be relevant for the ReFertilizer project are outlined in the next sections. The quick-acting fertilizers are those fertilizers that are water-soluble and immediately available to the crops. Besides the quick-acting fertilizer types new fertilizer types have been developed over the last decades. The slow-acting or controlled release fertilizers are those fertilizers that contain nutrients in a form that delays their availability for plant uptake, or which extends their availability to the crop significantly longer than the quick-release fertilizer. Stabilized fertilizers are those fertilizers that include a stabilizing component which extends the time that the nutrient components of the fertilizer remain in the soil (Trenkel, 2010).

4.2.3 Fertilizer compositions

As outlined above the most important nutrients are the macronutrients which consist of nitrogen, phosphorus, potassium, sulfur, magnesium and calcium. Nitrogen and sulfur are the elements that are solely present in the fertilizer, where the phosphorus, potassium and magnesium are measured as part of a larger molecule. The phosphorus is present in the form of phosphate ($P2O5$), potassium in potassium oxide ($K2O$) and magnesium in magnesium oxide (MgO).

The international fertilizer industry association (IFA) listed the compositions of the most important fertilizers. The association, that represents the global fertilizer industry, listed the numbers that represent the average range of nutrients in the currently available commercial fertilizers. The available data is used and listed in the tables 4-3, 4-4, 4-5 and 4-6. They are listed to create insights on the most common fertilizer combinations and their compositions (IFA, 2015).

Nitrogen fertilizers (Nutrient as % of fertilizer)	**N**	**P2O5**	**K2O**	**S**	**MgO**
Ammonia	82	0	0	0	0
Ammonium sulfate	**21**	**0**	**0**	**23**	**0**
Ammonium nitrate	33-34,5	0	0	0	0
Calcium ammonium nitrate	20.4-27	0	0	0	0
Urea	45-46	0	0	0	0

Table 4-3: Most common nitrogen fertilizers and the related concentration of macronutrients

Phosphate fertilizers (Nutrient as % of fertilizer)	**N**	**P2O5**	**K2O**	**S**	**MgO**
Single superphosphate	0	16-20	0	12	0
Triple superphosphate	0	46	0	0	0
Diammonium phosphate	18	46	0	0	0
Monoammonium phosphate	11	52	0	0	0
Ground rock phosphate	0	20-40	0	0	0

Table 4-4: Most common phosphate fertilizers and the related concentration of macronutrients

Potash fertilizers (Nutrient as % of fertilizer)	**N**	**P2O5**	**K2O**	**S**	**MgO**
Muriate of potash (potassium chloride)	0	0	60	0	0
Sulfate of potash	0	0	50	18	0
Sulfate of potash magnesia	0	0	22-30	17-22	10-11
Magnesium fertilizers					
Kieserite	0	0	0	20-22	25-27
Epsom salt	0	0	0	12-13	15-16

Table 4-5: Most common potash fertilizers and the related concentration of macronutrients

Complex fertilizers (Nutrient as % of fertilizer)	**N**	**P2O5**	**K2O**	**S**	**MgO**
NPK fertilizer	5-25	5-25	5-25	*	*
NP fertilizer	15-25	15-25	0	*	0
NK fertilizer	13-25	0	15-46	*	0
PK fertilizer	0	7-30	10-30	*	*

Table 4-6: Most common complex fertilizers and the related concentration of macronutrients

*The boxes filled with an asterisk possibly include sulfur and/or magnesium and/or micronutrients.

With regard to the ReFertilizer project there are fertilizer types that are considered to be irrelevant because the ReFertilizer project is based on the implementation of waste material. These waste materials consists of a certain combination of useful elements and a composition of these elements in the waste material. The elements that are present and their composition determine to a large extent the possibilities for the production of a fertilizer.

The waste material streams that are currently considered to be relevant for the ReFertilizer project have been mentioned before and are listed below in table 4-7. When other waste material streams become available for the production of inorganic fertilizers they will be added to the current list of waste materials. The first column lists all waste materials that have been tested within the SUEZ laboratory and are considered to be relevant for the ReFertilizer project, the other columns provide information on the levels of macronutrients present in the waste material.

Waste materials (Nutrient as % of fertilizer)	**N**	**P2O5**	**K2O**	**S**	**MgO**
Ammonium sulfate from farms	**2**	0	0	**3.5**	0
Ammonium sulfate from computer industry	**6.73**	0	0	**7.59**	0
Ammonium bisulfate from semicondustor industry	**4.56**	0	0	**17.04**	0
Sulfuric acid from computer industry	**0**	0	0	**26.80**	0

Table 4-7: Available waste materials and their related concentrations of macronutrients

As waste is considered to be useless for the majority of the companies, there is little attention paid to the concentrations of these waste materials. Because less attention is paid to these substances there is expected to be more variation in the concentrations of the substances. The concentration values of the waste materials in the table above are based on averages of the tests performed by the SUEZ laboratory or are based on internal and external discussions and information. The determination of these concentrations will be described in the next sections of this chapter.

The implementation of these waste streams strongly reduces the number of opportunities for fertilizers. Based on the fertilizers above the only fertilizer that can be composed, without the addition of other nutrients is ammonium sulfate (nitrogen fertilizer). However, there are opportunities to produce complex fertilizers. The base nutrients available provide the possibility to produce the NPK, NP and NK fertilizer. These possibilities require one or both of the additions of phosphorus or potassium. Because SUEZ does already treat a phosphorus stream, the NP fertilizer could be used within the ReFertilizer project. However, to limit the scope of this project the only fertilizer that is considered to be relevant for this ReFertilizer will be a fertilizer containing nitrogen and sulfur. Depending on the future developments with regard to this project and the developments in the waste and fertilizer market the other fertilizer options (NPK, NP and NK) may be relevant again.

4.3 Inorganic fertilizer

As described in the previous sections (4.1 and 4.2) there are different possibilities and different demands concerning the inorganic fertilizers. Based on these options and related possibilities the suitable inorganic fertilizer(s) are outlined in this section. The suitability is based on the current demands and the current available material streams. The material streams that are considered to be relevant have been tested and the related test results are summarized in this section. The tests provide information on the composition of the waste substances and the required additions to formulate an inorganic fertilizer. This information is used to define if the waste substances meet the legal limits of heavy metals, organic values, and potentially nutrient levels. Besides this, information is listed on what materials are required and in what composition the materials should be mixed in order to produce an inorganic fertilizer. Based on this information, recommendations to SUEZ will be made on what the best option for the formulation of an inorganic fertilizer is.

4.3.1 Limiting values within waste materials

Besides the fertilizer demands related to the customers, there are particular demands with respect to the fertilizer that are imposed by the governments. The fertilizer that is to be placed on the market should comply to several composition requirements. These composition requirements comprise the three following subjects:

1. The maximum level of heavy metals
2. The maximum level of organic micro pollutants
3. The mimimum level of nutrients

These subjects will all have to be analyzed before the product can be approved and classified as inorganic fertilizer. The subjects have been outlined in the legal chapter and will be applied within this chapter to define if the minimum or maximum levels will be exceeded. The first two composition requirements apply to all the materials that are considered to be relevant for this ReFertilizer project. The third requirement is related to the incoming ammonium sulfate from the farmers and related to the inorganic fertilizer output material. The third requirement is only applicable to these two because these streams are considered to be fertilizer materials, and materials that are classified as inorganic fertilizer materials should satisfy this requirement. The next sections within this chapter indicates, by an analysis of every relevant substance, whether or not the material complies to the requirement standards.

Other than the regulations that are set by the government there are additional aspects that should be highlighted in order to make sure that the end-product can safely be transported and sold to customers. SUEZ should exclude the possibilities for undesirable bacteria and viruses. To guarantee that these bacteria and viruses are not present in the substance, SUEZ should sample the end-products and test these samples. However, SUEZ is not able to perform these tests within the organisation. Therefore SUEZ should contact companies that are able to perform tests on samples provided by SUEZ. These tests should exclude the risks of bacteria and viruses being present in the liquid inorganic fertilizer.

4.3.1.1 Level of nutrients of incoming materials

The idea behind the ReFertilizer project is to formulate an inorganic fertilizer out of waste materials, possibly added with virgin materials. Problem with the waste materials is that these are the output materials of processes and these outputs are generally not considered to be useful for the company. Therefore the company generally pays less attention to this waste material. The waste material streams that are considered to be useful for this ReFertilizer project can be streams that will be relatively stable in their composition but there will be others that strongly vary in their composition.

A large problem for the production process can be the application of the ammonium sulfate from the farmers. The ammonium sulfate is the output of an air-scrubber that is used to wash the air of farm stables, as visualized in figure 4-4. However, the washing fluids consist of varying levels of nitrogen and sulfur. Contact with both suppliers of air scrubbers and customers that purchase the ammonium sulfate confirmed the varying levels of nitrogen and sulfur. According to the supplier of the air scrubbers the variation in concentrations depends on a number of different aspects. The concentration can vary per sort of animal. Farms can be based on pig, poultry or cattle. The dimensioning plan of the stables can have impact on the composition of the washing fluids because there are different possibilities to use and apply the air scrubbers within the farms. Also the feed composition can influence the compositions of the air scrubbers output. All these factors influence the concentrations of the ammonium sulfate. These variations in compositions can be a problem for the implementation of the ammonium sulfate from farms in the ReFertilizer project. Different compositions require different levels of additions to reach the same concentration of fertilizer output product. The first test batches that have been sampled show nitrogen levels that are around 1.02 (% m/m) and sulfur levels around 2.42 (% m/m). However, information from the internet, suppliers and users of air scrubbers revealed that the nitrogen and sulfur levels can be significantly larger. Nitrogen levels could be around 4 (% m/m) and sulfur around 5 (% m/m). In order to create the right image of the concentrations of the ammonium sulfate from farms, the values that are used for calculations are set between the low values of the initial tests and the higher values that can be achieved based on the available information and experiences of others. The nitrogen level is set to be 2 (% m/m) and sulfur to be 3.5 (% m/m). These values are considered to be realistic and achievable when large amounts of ammonium sulfate will be considered to be input for the ReFertilizer project. However, in order to gain more insights on the levels of the nitrogen and sulfur of the washing fluids from the farms it is important to do additional tests in order to know what levels of nitrogen and sulfur can generally be expected from the market.

Figure 4-4: Air scrubber used within the agricultural sector

The values of the ammonium sulfate from the semiconductor industry turned out to be varying as well. The variations in values did not differ as much as the variations in the ammonium sulfate from the farms. Nevertheless, the samples that have been taken from the three test batches delivered to SUEZ are averaged out to define concentrations that are realistic and achievable. These concentrations will be used in calculations in the next sections on the suitable fertilizer, to define what additional materials are required and within the remaining chapters of this ReFertilizer project.

4.3.1.2 Maximum level of heavy metals

The maximum value of heavy metals in all related substances should not exceed the values in the table as outlined in table 4-8. The substances have recently been tested in the laboratory of SUEZ , based on the X-Ray Fluorescence (XRF) method. This method is widely used to measure the elemental composition of materials. The XRF method defined for 47 elements the amount that is present in the material in milligram per kilogram. Among these 47 elements that have been tested by the XRF method are the heavy metal values that have been listed in table 4-8. The table below indicates the maximum allowed value of milligrams per kilogram of the eight relevant heavy metals in the respective value-giving ingredient. The ingredient that is considered to be the value-giving ingredient within this ReFertilizer project is the nitrogen macronutrient, highlighted in green. All heavy metal values in the fertilizer should be below the maximum values in order for the fertilizer to be approved for sale and transport.

Maximum value in milligrams per kilogram of the respective value-giving ingredient (mg/kg)								
	Cd	Cr	Cu	Hg	Ni	Pb	Zn	As
PO4	31.3	1875	1875	18.8	750	2500	7500	375
N	**25**	**1500**	**1500**	**15**	**600**	**2000**	**6000**	**300**
K	16.7	1000	1000	10	400	1333	4000	200
Neutralizing value	6.3	375	375	3.8	150	500	1500	75
Organic substance	0.8	50	50	0.5	20	67	200	10

Table 4-8: Maximum value of heavy metals in value-giving ingredients

The table above can be interpreted that for one kilogram of fertilizer based upon the nutrient, we may have a maximum value of heavy metal as summarized in the table. For example, when applying a fertilizer with the value-giving ingredient nitrogen (N), we may for each kilogram of N-based fertilizer have a maximum of 25 milligram of cadmium (Cd).

The tests that have been performed based on the XRF method have been analyzed and are summarized in table 4-9. The table 4-9 will have to be compared with the table above (table 4-8) in order to define if the maximum values are exceeded. The tables can be divided into two parts. The first part of the table lists the results on all the tests that have been performed to define the milligrams heavy metal per kilogram of the mono material stream. The last part refers to the tests that have been performed with the mixtures of material streams and provides information on the value in milligrams per kilogram of the heavy metal in kilogram present in the mixture. The table below indicates that, e.g., for the semiconductor ammonium sulfate that each kilogram of this material contains two milligram of the heavy metal cadmium (Cd). Comparing this outcome with the maximum allowed value in milligrams per kilogram shows that the tested values are smaller than the maximum allowed value. Which includes that the maximum value of cadmium in the ammonium sulfate from the semiconductor industry has not ben exceeded and does not infringe the regulations.

Value in milligrams per kilogram of the mono material stream (mg/kg)								
Semiconductor ammonium sulfate	2	2.4	1.7	1	5.6	0.5	0.5	0.5
Pharmaceutical ammonium bisulfate	2	2.3	0.2	0.3	6.7	0.2	1.7	0.5
Value in milligrams per kilogram of the mixture of material streams (mg/kg)								
Farms ammonium sulfate with sulfuric acid	2	3.2	0.2	1	5.8	0.1	1.2	0.5
Farms ammonium sulfate with semi conductor ammonium sulfate	2	3	0.9	1	5.1	0.1	0.9	0.1
Farms ammonium sulfate with pharmaceutical ammonium sulfate	2	3	0.6	1	5.1	0.2	1	0.5

Table 4-9: Maximum values of heavy metals in waste materials

Comparing the results of the XRF test outcomes with the maximum values of heavy metals shows that all single waste material streams and all tested mixtures have values of heavy metals that are amply below all maximum values of heavy metals. The maximum values of heavy metals, set by the Dutch authorities, are not exceeded. Analyzing the results shows that the value that is closest to the maximum value is cadmium. The cadmium values in all tested material streams are not more than 8 percent of the maximum values.

All material streams that are considered to be relevant for the current scope of the ReFertilizer project are tested by the XRF method. Either by material stream or by a mixture of material streams. The only waste stream that has not been tested by the XRF method, and for which not yet can be defined if it exceeds the maximum values of heavy metals, is the sulfuric acid originating from the semiconductor industry. Additional tests within the laboratory of SUEZ on the composition of this waste material should provide insights on the levels of heavy metal in the waste material. However, the tests that have been performed indicate that can be assumed that all material streams have levels of heavy metals that are legally allowed. To approve these results the final mixed product should be tested by an accredited laboratory.

4.3.1.3 Maximum level of organic micro pollutants

The materials that will be used for the production of an inorganic fertilizer should comply to the regulations that are related to the organic micro pollutants. These pollutants occur in small quantities but are undesirable because of their hazardous properties. The maximum values that are allowed in the fertilizers are outlined in appendix 3. The maximum values are outlined for each primary macronutrient fertilizing ingredient. Because the ReFertilizer project focuses on the nitrogen and sulfur nutrients the most important column of the organic micro pollutants table is the nitrogen column. The laboratory of SUEZ is not capable of performing tests to define the organic micro pollutants levels of a substance. To guarantee that the organic micro pollutant levels do not exceed the maximum values additional tests should be performed by a laboratory that is capable of performing these tests. SUEZ has contacted another company that is capable of performing these tests. Eurofins Analytico has previously performed tests for SUEZ and is capable of performing tests on organic micro pollutants. Before selling or transporting the products of the ReFertilizer project SUEZ should test the different combinations to verify whether or not the product exceeds the maximum levels of organic micro pollutants.

4.3.1.4 Minimal level of nutrients

Substance	Nitrogen (% m/m)
Ammonium sulfate from farms	1.02
Mixture 1: ammonium sulfate from farms with ammonium sulfate from semiconductor industry	20.99
Mixture 2: ammonium sulfate from farms with ammonium bisulfate from pharmaceutical industry	21.03
Mixture 3: ammonium sulfate from farms with sulfuric acid	20.96
Mixture 4: ammonium sulfate from semiconductor with water	21.01

Table 4-10: Level of nitrogen in substances

As already mentioned in the legal chapter there are requirements for other inorganic fertilizers on the minimal level of macronutrients. The other inorganic fertilizers that mainly supply primary macronutrients should at least contain 5% nitrogen, or 5% phosphate, or 5% potassium of the dry matter. Because this relates to the minimum levels of fertilizers it only applies to the ingoing other inorganic fertilizer originating from the farms or the output material that will be sold to customers. For these streams it is important to define whether or not the minimal levels of micronutrients are met. The minimal levels are applicable on the ammonium sulfate from farms and the mixtures of inorganic fertilizer combinations. Because the nitrogen nutrient is the main value-giving ingredient the macronutrient nitrogen is given in table 4-10 and indicates that all mixtures are allowed to trade and transport, but the ammonium sulfate does not meet the requirement of the minimal level of macronutrients. This implies that the ammonium sulfate that has been tested should be upgraded before it can be traded and transported as other inorganic fertilizer. This minimal level of macronutrients will be no problem for the ReFertilizer project because the potential customers of the inorganic fertilizer demand nitrogen levels of around 21%. Therefore all mixtures will have concentrations of around 21% and will exceed the minimal requirements.

Analyzing the three limiting value categories showed that for the minimal level of nutrients and the maximum heavy metal values the values of the mixtures turned out to be within the allowable margins. But because SUEZ does not have an accredited laboratory, samples should be tested by accredited laboratories to confirm the nutrient and heavy metal values. Because the laboratory of SUEZ is also not capable of performing a test on the organic micro pollutants, there should be additional tests performed by specialized companies to define whether the substances do have level(s) of organic micro pollutants that do not exceed the maximum values.

4.3.2 Fertilizer mixtures

The incoming waste material streams that are considered to be useful for the production of inorganic fertilizers and the related suppliers of the waste stream are listed in table 4-10. Subsequently, the material stream is analyzed based on the composition of the material. With this composition, calculations can be made on what additional materials are required to formulate an inorganic fertilizer.

No.	Substance	Supplier
1	Ammonium sulfate	Farms
2	Ammonium sulfate	Semi-conductor industry
3	Ammonium bisulfate	Pharmaceutical industry
4	Sulfuric acid	Semi-conductor industry

Table 4-11: Waste substances and the associated suppliers

Using waste material streams to produce an inorganic fertilizer with the required compositions is, for the majority of combinations, not possible without the addition of additional virgin materials. Therefore there are a few materials required to upgrade the waste material(s). The materials that can be used to upgrade the product to the required quality level are listed in table 4-12 below.

No.	Substance
6	Sulfuric acid
7	Urea
8	Water
9	Ammonium

Table 4-12: Virgin substances

The incoming waste material streams can be used in mixtures to formulate an inorganic fertilizer. However, some combinations of waste substances will not yield the required specifications as demanded by the customers that purchase the final product. The formulated inorganic fertilizer will therefore have to be upgraded with other non-waste materials. The combinations that are possible based on the waste material streams of SUEZ are outlined below in table 4-13. The information is based on the tests that have been performed within the laboratory of SUEZ. The combinations are upgraded with an amount of virgin sulfuric acid, urea, water or ammonium. With the sulfuric acid it is possible to increase the sulfur level, the urea can increase the level of nitrogen, water can be used to dilute the mixture (and decrease the level of sulfur or nitrogen) and the amount of ammonia can be used to decrease the pH value and eliminate the acidic properties of the mixture. The possible combinations for the production of an inorganic fertilizer are listed in the table below. The laboratory has mixed the first four combinations (A, B, C, D), but the combinations (E,F) have not yet been tested. Combination E has been theoretically calculated. Based on the tested combinations it is possible to calculate what amounts of additional materials are required to add. Combination F has not been tested and calculated, because tests that have been performed with this substance showed that there is relatively much ammonia required to neutralize the substance this substance will be left out of the rest of this Fertilizer project.

Combination	No.	No.	No.	No.
A	1	2	7	9
B	1	3	7	9
C	1	6	7	9
D	2	8	7	9
Combination	No.	No.	No.	No.
E	1	4	7	9
F	3	8	7	9

Table 4-13: Possible combinations to produce a fertilizer (based on tables 4-11 and 4-12)

The tables below describe the tested combinations. The first part consists of the input materials for the mixture where the last part represents the output values of the mixture.

Ammonium sulfate from farms and from the semi-conductor industry			
Substances			
Substance	**Sulfur (%m/m)**	**Nitrogen (%m/m)**	**Weight (kg)**
Ammonium sulfate from farms	3.5	2.0	100
Ammonium sulfate from semi-conductor industry	7.43	6.47	45.5
Urea	0	46.5	99.9
Ammonia	0	20.56	1.58
Mixture			
Substance	**Sulfur (%m/m)**	**Nitrogen (%m/m)**	**Weight (kg)**
Inorganic fertilizer	2.79	21.00	246.98

Table 4-14: Combination A and the associated concentrations

This mixture combines the ammonium sulfate that is discharged from farms with the ammonium sulfate discharged from the semi-conductor industry. Because the nitrogen level of this combination is insufficient there is an amount of urea added to the substance. During the addition of urea the temperature of the mixture declined from 22°c (the temperature of the laboratory) to a temperature of 3°c, this indicates that the dissolving of urea in water is an endotherm process. After 40 minutes the temperature has increased to 11°c.

The pH value of the mixture after combining the three substances is 3.2. To neutralize the substance an amount of ammonia is added to the substance which results in the pH value to increase up to 4.6. After the addition of ammonia the temperature increased with two degrees.

Ammonium sulfate from farms with virgin sulfuric acid			
Substances			
Substance	**Sulfur (%m/m)**	**Nitrogen (%m/m)**	**Weight (kg)**
Ammonium sulfate from farms	3.50	2.00	100
Sulfuric acid	31.38	0	4.50
Urea	0	46.65	77.60
Ammonia	0	20.56	9.35
Mixture			
Substance	**Sulfur (%m/m)**	**Nitrogen (%m/m)**	**Weight (kg)**
Inorganic fertilizer	2.57	20.96	191.45

Table 4-15: Combination C and the associated concentrations

This mixture combines the waste stream of ammonium sulfate from farms with the virgin material sulfuric acid. Because the nitrogen level of the combination is too low the substance urea is added. When urea is added the temperature declines from 22°c (the temperature of the laboratory) to 11.5°c, this indicates that the dissolving of urea in the other liquid substances is an endotherm process.

The pH value of the mixture after combining the three substances is 1.69. The addition of ammonia increases the pH value to 4.5.

Ammonium sulfate from farms with ammonium bisulfate from pharmaceutical industry			
Substances			
Substance	**Sulfur (%m/m)**	**Nitrogen (%m/m)**	**Weight (kg)**
Ammonium sulfate from farms	3.50	2.00	100
Ammonium bisulfate from pharmaceutical industry	17.04	4.56	13.50
Urea	0	46.65	83.10
Ammonia	0	20.56	9.35
Mixture			
Substance	**Sulfur (%m/m)**	**Nitrogen (%m/m)**	**Weight (kg)**
Inorganic fertilizer	2.82	21.03	205.95

Table 4-16: Combination B and the associated concentrations

The mixture combines the waste streams of ammonium sulfate from farms with the ammonium bisulfate from the pharmaceutical industry. Because the nitrogen level of the combination of these substances is insufficient, urea will be added to the combination. Adding urea results in a decline in temperature of 22°c (the temperature of the laboratory) to 3°c, this indicates that the dissolving of urea in the other liquid substances is an endotherm process. The pH value of the mixture after combining the three substances is 1.67. Adding ammonia increases the pH value to 7 and neutralizes the mixture.

Ammonium sulfate from semiconductor industry with water			
Substances			
Substance	**Sulfur (%m/m)**	**Nitrogen (%m/m)**	**Weight (kg)**
Ammonium sulfate from semiconductor industry	7.43	6.47	203.40
Water	0	0	100
Urea	0	46.65	197.30
Ammonia	0	20.56	1
Mixture			
Substance	**Sulfur (%m/m)**	**Nitrogen (%m/m)**	**Weight (kg)**
Inorganic fertilizer	3.01	21.01	501.70

Table 4-17: Combination D and the associated concentrations

The mixture originally consisted of the ammonium sulfate from the semiconductor industry. Because the ammonium sulfate consists of a sulfur level that is considered to be too high for the target values of the output inorganic fertilizer, water will be added to the waste substance. This water will dilute the ammonium sulfate. Where the sulfur level is too concentrated, the nitrogen level is too low for the specifications. To increase the level of nitrogen an amount of urea has to be added to the mixture. Adding the urea results in the decline of the temperature from 22°c to 4°c, this indicates that the dissolving of urea in the mixture is an endothermic process. The pH value of the mixture after combining the ammonium sulfate, water and urea is 3.66. The addition of ammonia increased the pH value to 5.5.

Ammonium sulfate from farms with sulfuric acid from semiconductor industry			
Substances			
Substance	**Sulfur (%m/m)**	**Nitrogen (%m/m)**	**Weight (kg)**
Ammonium sulfate from farms	3.50	2.00	100
Sulfuric acid	26.80	0	5.35
Urea	0	46.65	78.45
Ammonia	0	20.56	8.08
Mixture			
Substance	**Sulfur (%m/m)**	**Nitrogen (%m/m)**	**Weight (kg)**
Inorganic fertilizer	2.57	20.98	191.88

Table 4-18: Combination E and the associated concentrations

The data on the different options that have been outlined above, are summarized in table 4-19 below. The table, introduced in chapter 1, includes the amounts in kilogram that are required to produce the inorganic fertilizer.

Combination no.	Substance	Sulfur (% m/m)	Nitrogen (% m/m)	Weight (kg)
1	Ammonium sulfate from farms	3.50	2.00	100
	Ammonium sulfate from semiconductor	7.43	6.47	45.50
	Urea	0	46.65	99.90
	Ammonia	0	20.56	1.58
	Fertilizer	**2.79**	**21.0**	**246.98**
2	Ammonium sulfate from farms	3.50	2.00	100
	Ammonium bisulfate from pharmaceutical	17.04	4.56	13.50
	Urea	0	46.65	83.10
	Ammonia	0	20.56	9.35
	Fertilizer	**2.82**	**21.03**	**205.95**
3	Ammonium sulfate from farms	3.50	2.00	100
	Sulfuric acid (96%)	81.88	0	4.50
	Urea	0,00	48.66	77.60
	Ammonia	0	20.66	9.35
	Fertilizer	**2.57**	**20.96**	**191.45**
4	Ammonium sulfate from farms	3.50	2.00	100
	Sulfuric acid from semiconductor (83%)	26.80	0	5.35
	Urea	0	46.65	78.45
	Ammonia	0	20.56	8.08
	Fertilizer	**3.01**	**21.01**	**191.88**
5	Water	0	0	100
	Ammonium sulfate from semiconductor	7.43	6.47	203.40
	Urea	0	46.65	197.30
	Ammonia	0	20.56	1.00
	Fertilizer	**3.01**	**21.01**	**501.70**

Table 4-19: Summary of combinations

4.3.3 Suitable fertilizer

This section uses the information on the mixtures from the previous section with the related costs for the material streams. Based on this cost estimation and other relevant criteria recommendations are made on what fertilizer SUEZ should focus. When using the laboratory test outcomes on the formulation of inorganic fertilizers, it is possible to make a cost estimation on the considered fertilizer combinations. The table below summarizes this information. The cost calculations take into account the fact that the waste streams are considered to be free. Customers that want to dispose waste do usually pay an amount of money to get rid of the waste substance. However, to simplify the calculations the waste streams are not considered to cost or yield anything. The costs for the virgin streams are based on the current available market information. All costs are based on the costs for the substance per ton fertilizer output. The amounts required per combination type are used to calculate the costs per fertilizer type. The calculations, in case of the addition of ammonium sulfate from farms, are based on the input of 100 kilogram of washing fluids. Calculation on the costs per combination will be described in more detail in section 6.1.

Combination no.	Substance	Weight (kg)	Weight per ton fertilizer (kg)	Costs per ton (€)	Costs per ton fertilizer (€)
1	Washing fluids	100	404.89	€ -	€ -
	Ammonium sulfate	45.50	184.23	€ -	€ -
	Urea	99.90	404.49	€ 340.00	€ 137.43
	Ammonia	1.58	6.40	€ 330.00	€ 2.11
	Fertilizer	246.98	1000		€ 139.64
2	Washing fluids	100	485.55	€ -	€ -
	Ammonium bisulfate	13.50	65.55	€ -	€ -
	Urea	83.10	403.50	€ 340.00	€ 137.19
	Ammonia	9.35	45.40	€ 330.00	€ 17.98
	Fertilizer	205.95	1000		€ 152.17
3	Washing fluids	100	522.33	€ -	€ -
	Sulfuric acid (96%)	4.50	23.50	€ 145.00	€ 3.41
	Urea	77.60	405.33	€ 340.00	€ 137.81
	Ammonia	9.35	48.84	€ 330.00	€ 16.12
	Fertilizer	191.45	1000		€ 157.34
4	Washing fluids	100	521.16	€ -	€ -
	Sulfuric acid (83%)	5.35	27.88	€ -	€ -
	Urea	78.45	408.85	€ 340.00	€ 139.01
	Ammonia	8.08	42.11	€ 330.00	€ 13.90
	Fertilizer	191.88	1000		€ 152.90
5	Water	100	199.32	€ 2.50	€ 0.50
	Ammonium sulfate	203.40	405.42	€ -	€ -
	Urea	197.30	393.26	€ 340.00	€ 133.71
	Ammonia	1.00	1.99	€ 330.00	€ 0.66
	Fertilizer	501.70	1000		€ 134.87

Table 4-20: Costs per ton fertilizer for all relevant combinations

Table 4-20 shows that the starting points of 100 kilogram of washing fluids yields at the end a fertilizer with around 2.5/3 (%m/m) of sulfur and around 21 (%m/m) of nitrogen. However, the total amount of fertilizer product differs a lot. Therefore the costs are based on the output of a ton (1000 kg) of fertilizer product. Analyzing the table shows that combination number 2 and 4 are less expensive than the other two combinations. These combinations are the combination of ammonium sulfate form farms with the ammonium sulfate from the semiconductor industry (combination no. 2) and the ammonium sulfate from the semiconductor industry diluted with water (combination no. 4). These combination are less expensive because they require less ammonia compared to the other options. When analyzing the urea, which is considered to be relatively expensive, it can be concluded that all five options require relatively the same levels of urea. The cheapest combinations requires €6 less of urea per ton fertilizer than the most 'expensive' fertilizer combination. Based on the best two options there are no major differences in the costs, also because the waste materials can have small variations in their compositions.

Based on the second and the fourth option it will be the best choice to use the second option because this option includes the ammonium sulfate from farms and the ammonium sulfate from the semiconductor industry. Both ammonium sulfate streams are considered to be waste streams and fit therefore perfectly in the idea behind the ReFertilizer project. This idea is based on the circular economy idea which aims to reuse materials and the reduce waste. Because both waste substances are not really acidic there is little ammonia required to neutralize the mixtures and the required amounts of urea do not differ for all four options. Another advantage of using option 2 is the fact that the ammonium sulfate originating from the farms are available in large quantities. There are many farms in the Netherlands that produce these substances. For all other ammonium (bi)sulfate substances there are less available. Therefore the option that is considered the best suitable option for SUEZ to further develop will be option 2. This option combines both the ammonium sulfate from the farms and the ammonium sulfate from the semiconductor industry. To upgrade the material to a marketable fertilizer there is an amount of urea added to increase the nitrogen level.

Combination no.	Mixed substances				Costs per ton (€)
5	Water	Ammonium sulfate from semiconductor industry	Urea	Ammonia	€ 134.87
1	Ammonium sulfate from farms	Ammonium sulfate from semiconductor industry	Urea	Ammonia	€ 139.64
2	Ammonium sulfate from farms	Ammonium bisulfate from pharmaceutical industry	Urea	Ammonia	€ 152.17
4	Ammonium sulfate from farms	Sulfuric acid from semiconductor industry (83%)	Urea	Ammonia	€ 152.90
3	Ammonium sulfate from farms	Sulfuric acid (96%)	Urea	Ammonia	€ 157.34

Table 4-21: Cost ranking

Footnote by these recommendations is that there is one combination that has not been tested. Based on the relevant material streams there are two other combinations possible. The other combination that has not been tested is the mixture of ammonium bisulfate from the pharmaceutical industry diluted with water. This will be mixed with urea and ammonium to increase the nitrogen level and decrease the pH value. This combination is not considered to be better than the combination 2 and 4 because the ammonium bisulfate from the pharmaceutical industry is considered to be of little additional value because there is relatively much ammonia needed to react with the bisulfate and neutralize the substance.

Ammonium sulfate from farms is considered to be the major waste material. Especially when the production of an inorganic fertilizer increases. The ammonium sulfate from farms is suitable because it contains levels of nitrogen and sulfur and it is available in large quantities. In addition, SUEZ will not have to rely on one customer. Relying on one customer is the risk of using the ammonium sulfate from the semiconductor industry and the ammonium bisulfate from the pharmaceutical industry because for these waste streams SUEZ has just one customer. As already mentioned there are strong variations in the compositions of the ammonium sulfate from farms. The sulfur and nitrogen levels strongly vary, where the nitrogen levels vary between 1 and 4 %. In order to estimate what the effects of these different values have on the costs per ton fertilizer of the mixture, calculations have been made based on different values of nitrogen and sulfur in the ammonium sulfate from farms. The outcomes of the costs for different values of nitrogen can be found in figure 4-5.

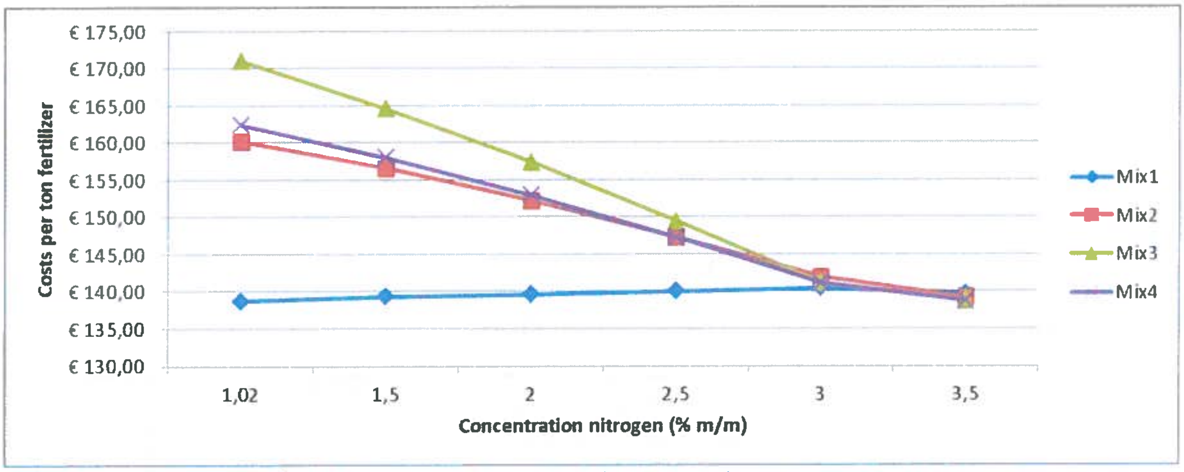

Figure 4-5: Costs per ton fertilizer related to the concentration of nitrogen within the mixture

As substantiated above the value that is chosen to be achievable and realistic is a nitrogen concentration of 2 (% m/m). For the mixture that involves the ammonium sulfate from farms there are clear differences in costs per ton fertilizer. Mixture 1 is the option with the lowest costs, this option requires the least additional virgin materials. For the nitrogen concentrations of 3 (% m/m) and higher the mixtures are all equal. The mixtures are equal because these mixtures do not need a second waste material stream or virgin material stream that supplies sulfur. The only additions to the ammonium sulfate with these relatively high nitrogen concentrations are urea and ammonia. However, these high composition values are not considered to be achievable for large amounts of ammonium sulfate from farms. Therefore, as mentioned in the previous sections, the nitrogen level of the ammonium sulfate from farms is considered to be 2 % m/m. Proportionally to this the sulfur level will be 3,5 % m/m.

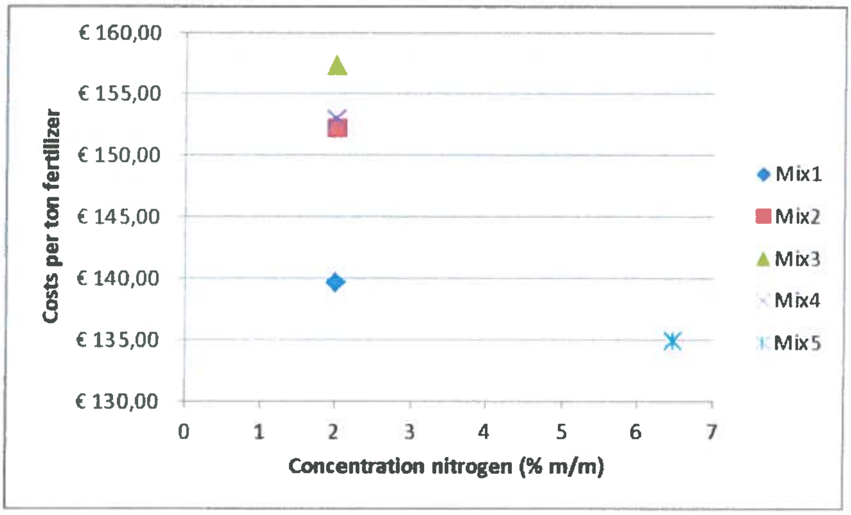

Figure 4-6: Costs per ton fertilizer based on expected concentration levels of nitrogen

The tested mixtures with ammonium sulfate from farms and the tested mixture with ammonium sulfate from the semiconductor industry diluted with water have been analyzed. This analysis is graphically represented in the image above. The results show that the mixtures of ammonium sulfate originating from the farms are more expensive than the mixture that involves the ammonium sulfate from the semiconductor industry. The mixture also has higher levels of nitrogen and sulfur, this elucidates the higher costs for the other mixtures involving ammonium sulfate from farms because there is more virgin material required to upgrade the waste material to the required levels of the inorganic fertilizer. However, as mentioned before, when implementing the ReFertilizer project the idea is to produce large quantities and this will not be possible when merely using the ammonium sulfate from the semiconductor industry.

Although the cost analysis based on the laboratory tests reveals a certain ranking based on the lowest costs, there are other factors that influence the selection of materials for the production of inorganic fertilizers within SUEZ . One of these factors is the fact that the ReFertilizer project is based on the circular economy idea which promotes the re-use of valuable waste materials, therefore the ammonium sulfate from farms will be involved in the production process. Another important aspect is the availability of the waste materials. The availability of the waste materials depends on the amounts of waste materials that will be offered to SUEZ . Because these factors do not directly influence the qualitative aspects of the ReFertilizer project, these aspects will be addressed in the next chapter on the production process.

4.4 Conclusion

This chapter outlines the qualitative aspect of the ReFertilizer project. The first section of this chapter outlines the current fertilizer market and the developments within this market. This outlook shows that the worldwide fertilizer demands are increasing, where the European market seems to stagnate. Some parts, especially the western part of Europe show decreases. The Dutch market, as part of this western European market declines as well. Although the Dutch market experiences a period with declining demands and stringent environmental requirements, it remains to be a large market that directly and indirectly employs many people. When comparing the four different fertilizer market segments, nitrogen/phosphor/potash and complex, the nitrogen market segment turns out to be the largest market segment with the highest worldwide growth rates.

The section thereafter outlines all different fertilizer opportunities. A fertilizer consists of different micro- and macronutrients. The macronutrients are the most important, where distinctions are made between the primary macronutrients and the secondary macronutrients. The primary macronutrients are nitrogen, phosphorus and potassium and the secondary macronutrients are sulfur, calcium and magnesium. The material streams that turned out to be useful for this ReFertilizer project are outlined in this chapter as well. Comparing the potentially useful material streams that arrive within SUEZ with the different fertilizer possibilities reveals that the majority of the fertilizer combinations cannot be formulated within this ReFertilizer project. The fertilizer that can be formulated, based on the currently available waste and virgin materials within SUEZ , is ammonium sulfate. Because the waste material stream of phosphoric acid is considered to be an option for the future, there can be other fertilizers produced but these are left out of consideration for this ReFertilizer project. The focus within the remainder of this ReFertilizer project is on the ammonium sulfate fertilizer.

For the inorganic fertilizer to be useful there are regulations that demand that the fertilizer does not exceed the maximum levels of heavy metals and the maximum level of organic micro pollutants. The fertilizer should also contain a minimal level of value-giving macronutrient. SUEZ tested several inorganic fertilizer combinations to determine the level of heavy metals and the level of value-giving macronutrient in the inorganic fertilizer. For all tested combinations the tests showed positive results, which indicates that the fertilizers do not exceed the maximum levels of heavy metal and do exceed the minimum level of macronutrients. Although SUEZ can perform these tests in their laboratory, they are not accredited to do these tests and external companies should do additional tests to confirm the conclusions of the SUEZ laboratory. SUEZ is not able to define the levels of organic micro pollutants which implies that these levels should also be tested by an external accredited company. Additional tests should make sure that there are no viruses or bacteria within the inorganic fertilizer product. This implies that, to guarantee that SUEZ can market the right quality of product , it should rely on tests of other accredited companies.

Based on this fertilizer type there were test performed within the laboratory of SUEZ with different possible inorganic fertilizer combinations. These test outcomes showed in what proportions the different material streams should be mixed to create an inorganic fertilizer. Combining these test results with the currently available market information on the costs of the material streams results in an overview of cost estimates of the different combinations. This overview is concisely described below.

Comparing these outcomes results in two combinations that are significantly lower than the other combinations. When comparing the cheaper combinations there is one which is considered to be better than the other, because the combination with ammonium sulfate from both the farms and the semiconductor industry consists of two waste material streams. And the available supplies of the ammonium sulfate from farms are higher. The table below ranks the different mixture outcomes.

Combination no.	Ranking mixed substances				Costs per ton (€)
1	Ammonium sulfate from farms	Ammonium sulfate from semiconductor industry	Urea	Ammonia	€ 139.64
5	Water	Ammonium sulfate from semiconductor industry	Urea	Ammonia	€ 134.87
2	Ammonium sulfate from farms	Ammonium bisulfate from pharmaceutical industry	Urea	Ammonia	€ 152.17
4	Ammonium sulfate from farms	Sulfuric acid from semiconductor industry	Urea	Ammonia	€ 152.90
3	Ammonium sulfate from farms	Sulfuric acid (virgin)	Urea	Ammonia	€ 157.34

Table 4-22: Cost ranking mixtures

All mixtures received a number, the number of the ranked mixtures can be found in the table above. The table below shows the differences between these mixtures, based on their costs and the nitrogen concentration of the primary waste material.

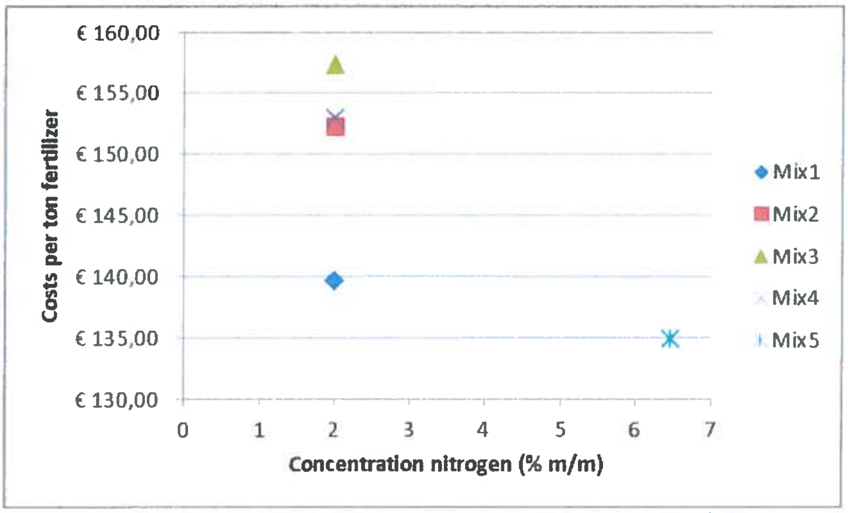

Figure 4-7: Costs per ton fertilizer based on expected concentration levels of nitrogen

5. Production process

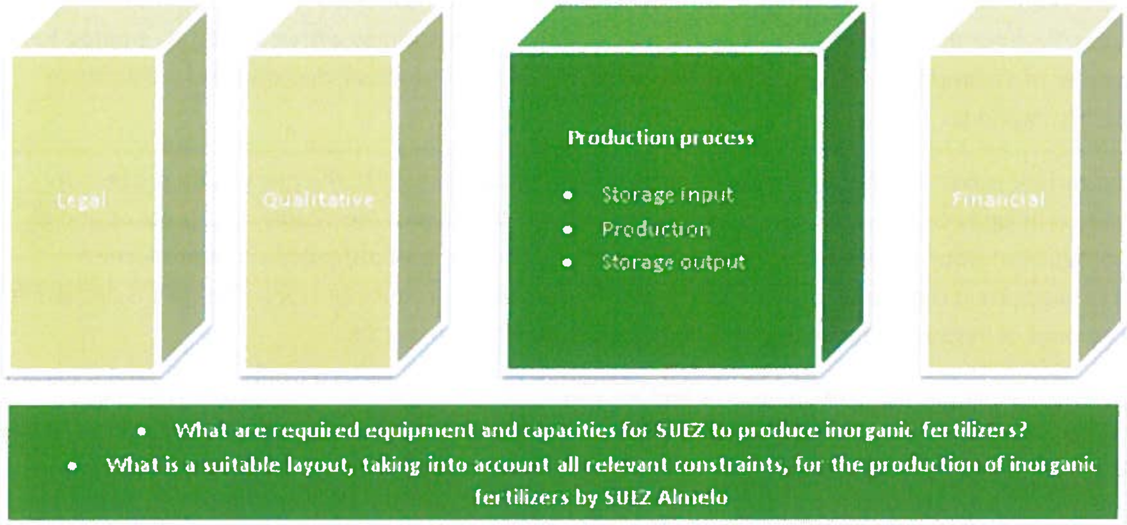

Figure 5-1: Third block ReFertilizer project

This section describes the production process to formulate an inorganic fertilizer. It describes the relevant production steps and the required production facilities. The relevant production steps are described to create insight on the different required production materials. Besides the production steps, this chapter summarizes the expected yearly handled waste material streams. This information creates additional knowledge on what amount of fertilizers can be produced and what production equipment is required. A basic flow diagram, representing the schematic overview of the production process of the inorganic liquid fertilizer can be found in figure 5-2.

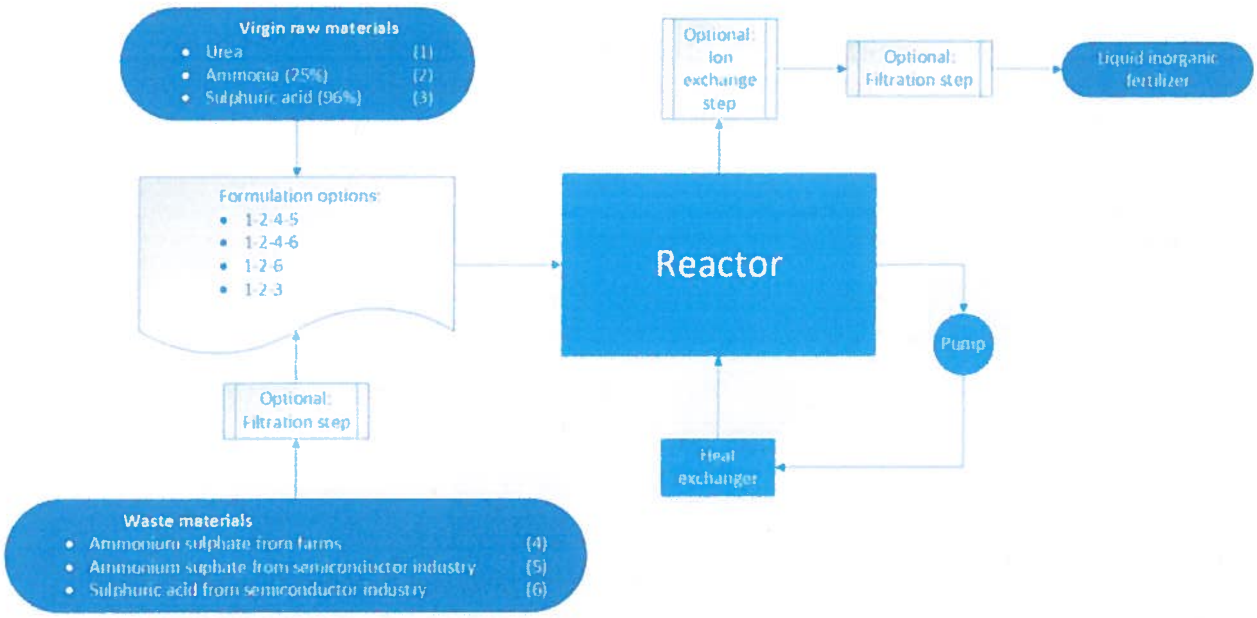

Figure 5-2: Flow diagram of production process

The production process is designed starting from the storage of the ingoing materials. This storage is considered to be the starting point of the production process. To gain insights on the production process and the required production materials, a number of assumptions have been made in order to design the process. Because there is currently no production and the process is new within SUEZ it is required to do a number of assumptions. When assumptions are required, this thesis will describe and substantiate these assumptions.

An important aspect for the production process is the addition of heat to the production process. As visualized in figure 5-2, there is a heat exchanger required to improve the dissolving process of one of the production steps. This production step, the addition of urea, is a bottleneck in the production process because it requires a lot of time compared to the other production steps. This step is decisive in the amount of batches that can be produced at the SUEZ location per day.

The remainder of this production process and the remainder of this ReFertilizer project is based on the formulation that has been considered to be the best option to produce an inorganic fertilizer. Described within the previous chapter on the qualitative aspects. This chapter outlined the different possibilities that have been tested in the SUEZ laboratory. Based on these tests a cost analysis has been performed. As already mentioned in the previous chapter there are other factors, besides the qualitative and cost aspects, that influence the composition of the produced inorganic fertilizer. The circular economy idea and the availability of waste materials do also influence the choices for the compositions of the inorganic fertilizer.

When taking into account all these factors, a flow scheme can be drafted on what the best composition of the inorganic fertilizer is. This scheme takes into account the costs, availability and reusability of the formulation. The scheme is visualized in the figure 5-3. The combination that belongs to box 1 will be formulated first, the combination that is related to box 2 thereafter, etcetera. Advantage of this method is that the most important and valuable material streams are used first and that, when these material streams are not available in sufficient levels for the estimated production quantities, the second combination can be used. In this way it is possible to meet the determined production quantities by firstly using the most important formulation options.

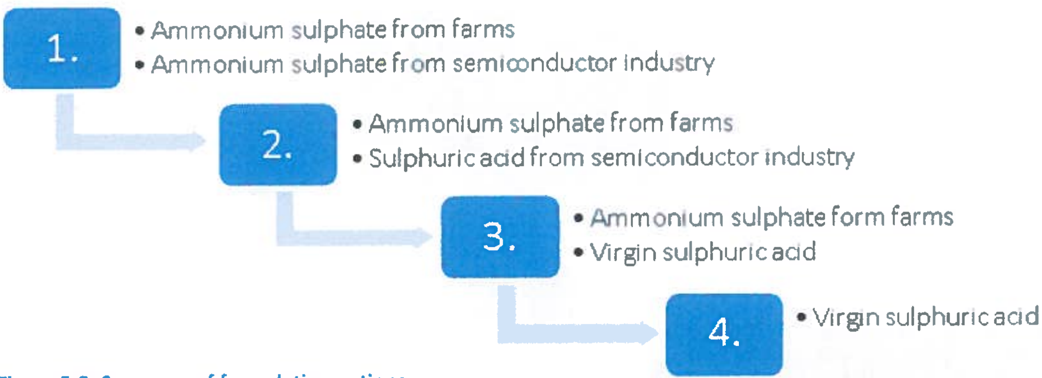

Figure 5-3: Sequence of formulation options

The scheme above outlines the best options that can be used for the production of inorganic fertilizers. The previous chapter ranked the different possible options mainly on the costs of producing the option.

However, the image above ranked the different possibilities in a different way. It takes into account the costs of the different options but does also take into account the availability of the materials. Production should start with option 1, this is the combination of ammonium sulfate from farms with the ammonium sulfate from the semiconductor industry. This option is relatively cheap (second cheapest option) and is based on two waste materials streams and the circular economy idea. This option is considered to be, after internal discussions, better than the cheapest option because there are two waste materials involved instead of one. Besides this, the ammonium sulfate from farms is considered to be available in large quantities. Where the ammonium sulfate from the semiconductor industry is only supplied in limited amounts. Therefore the availability of the ammonium sulfate from the semiconductor industry limits the production of inorganic fertilizers by SUEZ. To be able to produce a larger amount of inorganic fertilizer the second combination in figure 5-2 will be produced when the amount of ammonium sulfate from the semiconductor industry has been fully used. This second combination combines the ammonium sulfate from farms with the sulfuric acid from the semiconductor industry. This option also combines two waste material streams, is based on the circular economy idea but is relatively expensive compared to the other options. Nevertheless, the materials that are used in this combination are available in large amounts and can be used to increase the production quantities. The option that combines ammonium sulfate from farms with sulfuric acid from the semiconductor industry is chosen to be the second best option to produce because it consists of two waste material streams and because it is available in large quantities. In case the second option does not measure up to the desired amount of inorganic fertilizer the third option can be produced. Within this option the ammonium sulfate from farms is combined with virgin sulfuric acid. This sulfuric acid will have to be bought from the producers of sulfuric acid and is not considered to be a waste material. Because this option is produced out of only one waste material and it is the most expensive option that is considered to be useful, it is placed on the third position. The fourth option is an option that is produced out of the virgin sulfuric acid combined with the usual additions urea and ammonia. This combination will only be produced in exceptional cases because it does not contain any waste material. Therefore does not conform to the circular economy idea and it will be an expensive option. It will only be produced when the sum of the produced amounts of the first three options are not enough to meet the demanded quantities.

As already mentioned there are two compositions that have been used in the previous chapter, but have been excluded from the flow scheme above. The first composition is the combination where ammonium sulfate from the semiconductor industry is diluted with water. This composition is left out of consideration because it only involves one waste material stream. Where this waste material stream does fit less good in the circular economy idea, the ammonium sulfate from farms perfectly fits within this idea. It perfectly fits in the circular economy idea because the waste material originates from the farms and will be applied within the farming industry as well. Therefore waste material can better be combined with the ammonium sulfate from farms (box 1 in figure 5-2).The other excluded combination in comparison with the previous chapter is the ammonium bisulfate from the pharmaceutical industry. This material has been tested within the SUEZ laboratory to define in what composition it should be mixed to derive an inorganic fertilizer, but the material is available in very small, negligible quantities and is therefore considered to be useless for the remainder of this report.

The production of the inorganic fertilizers that have been listed in figure 5-2 can be divided into different production steps. Where each single step requires different materials and equipment to perform the production step. The relevant steps for the production of an inorganic fertilizer are outlined in this chapter. The production process within this chapter is divided in the storage of the input materials, the production process itself, the related production equipment and then the storage of the final product. Each part is described in different sections of this chapter.

Before estimates can be made on what equipment and materials are required it is important to define or assume what amounts of inorganic fertilizers are expected to be produced and sold. Internal discussions and discussions with potential customers and intermediaries revealed that sales are estimated to be around 10,000 ton of inorganic fertilizer per year when the production and the ReFertilizer project is fully developed. However, when starting the project it will not be possible to immediately achieve these amounts of end products and therefore the production is estimated and assumed to increase stepwise. Estimations have been made on what can be produced during the start-up years of the ReFertilizer project. These estimations are on the one hand based on the currently available waste materials and internal discussions, and on the other hand these estimations are based on the expected amounts of final products that can be sold. Table 5-1 below shows the stepwise increases that can be achieved during the years. Substantiations on and calculations with these production quantities will thereafter be described.

Production year	Quantity (ton)
1	2,000
2	4,000
3	6,000
4	8,000
5	10,000

Table 5-1: Production quantities related to production years

The 2,000 ton of inorganic fertilizer in the first year can, based on the available input materials, easily be produced. Also the other quantities for the production years thereafter can be achieved by the current available waste material streams (figure 5-3). However, SUEZ has no experience with the production of inorganic fertilizers in large quantities. Only small test batches have recently been produced to gain insights on the chemical reactions and compositions of the material. To start with the production of inorganic fertilizers in the amounts of table 5-1 above, more knowledge will be required. Therefore the next sections will calculate and substantiate what is required to set up the production of inorganic fertilizers within SUEZ in large quantities.

The next section describes the different input materials required for the production of inorganic fertilizers, taking into account the different characteristics of the input materials. Based on the data of the input materials it is possible to define the required storage facilities for the input materials. Section 5.2 describes all relevant production steps that are necessary to produce an inorganic fertilizer. Based on these steps it is possible to define the required production equipment and the possible production facilities. Subsequently the storage of the output materials is defined and the last section (section 5.5) will, based on the other sections of this chapter, define an optimal production plant layout.

5.1 Storage of input materials

Producing inorganic fertilizers as SUEZ envisions it, requires several (preferably waste) input materials. The input materials will have to be stored before they can be used in production. For the input materials distinctions are made between two categories of materials. The first category are the 'virgin materials', these are produced by suppliers and are not considered to be waste. The other category are the waste materials. Materials out of this waste category are preferred by SUEZ because they are based on the circular economy and will not have to be bought by SUEZ . For each different material stream, waste or non-waste, different storage facilities are required. Storage of all relevant input materials are described in the next section (section 5.1.3). Firstly, all relevant material streams will be introduced where differentiations are made between the virgin material streams and the waste material streams. Thereafter, calculations have been made to underpin the selected and required storage units.

5.1.1 Virgin material streams

5.1.1.1 Urea

The currently available waste materials consist of nitrogen levels that do not meet the demanded nitrogen levels of the market. Therefore urea is used as additive to increase the nitrogen level of the inorganic fertilizer. Because all combinations lack the required nitrogen level, all combinations will have to be supplemented with urea.

As already mentioned in the legal chapter of this thesis, the environmental permit has recently been updated and submitted. This new permit includes the placement of a urea silo to the SUEZ location. Because urea is the most expensive virgin material (€340 per ton), it should preferably be added in the smallest possible amounts in order to lower the production costs. According to the tests and calculations that have been performed on all combinations, around 40% of the mixtures will have to consist of urea in order to meet the required nitrogen concentrations that are set by the customers. Calculations on these nitrogen levels can be found in appendix 7. This implies that, on a yearly base around 4,000 ton of urea is needed to satisfy the required 10,000 ton fertilizer product. Where during the fist startup year, a level of 800 ton of urea will be required.

Important for the addition of urea is that urea is the only substance that is involved in the production process that is in a solid state. It will have to be dissolved in the other liquid substances. As described in the previous qualitative chapter, the dissolving of urea in ammonium sulfate is an endothermic reaction. It requires additional heat to dissolve faster. This does not have direct consequences for the storage of the urea itself but the endothermic properties of the reaction will have to be taken into account in the remainder of this chapter. Important for the storage of the urea is the bulk density, the weight in kilograms per cubic meter. Within the laboratory of SUEZ measurements revealed a bulk density of 811 kilogram per cubic. However, material safety data sheets (MSDS) of producers of urea describe bulk densities between 725 and 760 cubic meters. Therefore these values are averaged at 765 kilogram per cubic meter to use a reliable number of bulk density within the further calculations. Because the product is delivered in a solid state this bulk density is important, however when using the product in the production process, the density of the product dissolved in the other liquid materials is required as well. The density of urea is 1330 kilogram per cubic meter. Because the material is a virgin material stream there are no restrictions on the amounts of materials that can be bought by SUEZ for the ReFertilizer project.

5.1.1.2 Ammonia

Besides the urea that will have to be added to the mixture, there is the ammonia solution that will have to complement the formulated mixture. Ammonia is the dissolving of ammoniac into water and is also expensive (€330 per ton) but is required in relatively low amounts compared to urea. The ammonia solution is used to decrease the pH value of the mixture and therefore decrease the acidic properties of the substance. The percentages of ammonia required in the inorganic fertilizer compositions vary between 5 and 9%. Based on the estimated 10,000 ton of inorganic fertilizer to be produced in the future, the required amount of ammonia will vary between 500 and 900 ton on a yearly base. The ammonia does also contain nitrogen but is mainly used for neutralizing the inorganic fertilizer. The ammonia that has been used within the test batches for the different inorganic fertilizers compositions has been tested to define the density of the ammonia. The density of the ammonia batches that have been used are averaged at 909 kilograms per cubic meter. This material stream is a virgin material stream and there will be no restrictions on the amount of available material that can be used for the production of inorganic fertilizers.

5.1.1.3 Sulfuric acid

Next to the ammonia and urea, there can be virgin sulfuric acid material used within the production process of the ReFertilizer project. This virgin material will only be used if the first two combinations (ammonium sulfate from farms with ammonium sulfate from semiconductor industry and ammonium sulfate from farms with sulfuric acid from semiconductor industry) are not available. The virgin sulfuric acid will have to be bought by SUEZ (€120 per ton). The material is 96% concentrated. The density of this material will be around 1,802 kilograms per cubic meter. Based on the current available waste materials and estimated production quantities, there will be no sulfuric acid required for the production. However, when the availability of these materials is too low for the estimated production quantities, the virgin sulfuric acid will be used in production. Nevertheless because under the current circumstances this material is not required, it will not be taken into account in the remainder of this report. As with the other virgin materials there are no restrictions on the availability of the sulfuric acid.

5.1.2 Waste material streams

5.1.2.1 Ammonium sulfate from farms

The ammonium sulfate from farms will be one of the most important streams in the ReFertilizer project. Major advantages of this material stream are that it can be supplied in large quantities and that it is an important material stream for the circular economy idea. It can be used by SUEZ in large quantities because there are many farms that would like to discharge the ammonium sulfate from their air scrubbers. This material is important for the circular economy idea because it is a perfect circular process. The waste material is derived from farmers and will, after the production process, be sold to farmers again to increase their arable and grass yields.

When producing the inorganic fertilizers (consisting of ammonium sulfate from farms with ammonium sulfate from the semiconductor industry), the percentage of ammonium sulfate from farms in the substance will be around 40%. When adding sulfuric acid (either from the semiconductor industry or virgin material) the percentage of ammonium sulfate from farms in the substance will be around 50%. The density of the ammonium sulfate from farms has been calculated within the laboratory of SUEZ and average values of these tests turned out to be 1,062 kilogram per cubic meter. Because there are many farms that supply this material, the waste material ammonium sulfate from farms is considered to be available infinitely.

5.1.2.2 Ammonium sulfate from semiconductor industry

The ammonium sulfate from the semiconductor industry is another important material stream for the ReFertilizer project. It is a waste stream that fits within the circular economy idea, where nutrients are not depleted but reused. Besides the possibility to reuse the nutrients, it is a waste material stream that has high concentrations of the nutrients nitrogen and sulfur and is therefore very useful for the ReFertilizer project. Disadvantage of this waste material stream is that the ability to use the material stream in the project by SUEZ is limited. The material stream is currently supplied by just one customer in a relatively small amount.

The density of the ammonium sulfate from the semiconductor industry has been calculated within the SUEZ laboratory and turned out to be around 1,207 kilograms per cubic meter. Under the current circumstances there are around 104 cubic meters of ammonium sulfate from the semiconductor industry delivered to SUEZ per year. Based on the density this will be around 125 ton of ammonium sulfate per year, these numbers will be used in the calculations to define what amounts of additional materials will be required to produce the inorganic fertilizers.

5.1.2.3 Sulfuric acid from semiconductor industry

The sulfuric acid from the semiconductor industry is another important waste material stream. It is less concentrated (82%) than the virgin sulfuric acid (96%), but can be useful within the production process of the inorganic fertilizers. Within the ReFertilizer project the nutrients that are present in the sulfuric acid will be reused and therefore this substance is based on the circular economy idea. Another advantage of this material stream is that it is available for SUEZ in large quantities, although there is currently only one customer that supplies the material.

The density of the sulfuric acid has been calculated after several tests within the laboratory. A cubic meter is expected to weight around 1,693 kilograms. The current expectation is that around 600 ton per year of sulfuric acid can be used from the semiconductor industry. This information will be used in the next section for the calculations on the required input materials.

5.1.3. Quantities of input materials

As mentioned in the beginning of this chapter the quantities of inorganic fertilizer that are estimated to be produced at the start of the ReFertilizer project are 2,000 ton in kilograms. This starting amount is considered to increase over the years up to an amount of 10,000 tons of inorganic fertilizer when the production facility is fully operational. Based on this estimation and the calculations that are based on the tests that have been performed within the laboratory, calculations can be made on what quantities of input materials are required for the production by the SUEZ location in Almelo.

Total material amounts required	Ton (1000 kg)	Density (kg/m³)	Volume (m³)
Ammonium sulphate from farms	963.43	1062.45	906.80
Ammonium sulphate from semiconductor industry	125.00	1207.33	103.53
Sulphuric acid from semiconductor industry	36.85	1693.21	21.76
Sulphuric acid (96%)	0.00	1802.10	0.00
Urea	814.74	1330.00	612.59
Ammonia	59.99	908.67	66.02
Fertilizer	2000.00		1710.70

Table 5-2: Yearly required amounts and volumes

These amounts are summarized in table 5-2. These are the amounts of input materials required to produce 2,000 ton of liquid fertilizer. Based on the density of the ammonium fertilizer, this sums up to 1710.70 cubic meter of liquid fertilizer. These amounts will be used in the remainder of this chapter for the calculations on the required equipment and storage of output materials. Based on these yearly amounts of input materials it is possible to make estimations on what equipment is required for the storage of the input materials. Because it is important to know the volume of the materials, the cubic meters that have been calculated will be used to define the required storage capacity. The volumes that are listed in the table above are based on the yearly demands, but for the calculations that are related to the storage of the input materials it will be more convenient to use the monthly demands, because materials will be transported to SUEZ several times a year. Using these monthly demands provides more knowledge on the number of deliveries and the required capacities of the storage equipment. The monthly demands, based on the 2,000 ton fertilizer production, are listed in table 5-3.

	Yearly	Monthly
Total material amounts required	Volume (m ³)	Volume (m³)
Ammonium sulphate from farms	906.80	75.57
Ammonium sulphate from semiconductor industry	103.53	8.63
Sulphuric acid from semiconductor industry	21.76	1.81
Sulphuric acid (96%)	0.00	0.00
Urea	612.00	88.71
Ammonia	66.02	5.50
Fertilizer	1710.11	142.51

Table 5-3: Yearly required amounts and volumes

Figure 5-2: 200 liter barrel

The table indicates that the ammonium sulfate from farms and the urea are the input materials that are required in large quantities. For the other material streams (ammonium sulfate from the semiconductor industry, sulfuric acid from the semiconductor industry and virgin ammonia) it is not necessary to invest in large storage equipment. The ammonium sulfate and the sulfuric acid from the semiconductor industry can be stored in the IBCs. The storage container in which the materials are generally delivered. The virgin ammonia can be stored in 200 liter barrels in which it is generally delivered. The IBCs that are required on a monthly basis are around nine for the ammonium sulfate from the semiconductor industry and two for the sulfuric acid from the semiconductor industry. The ammonia is delivered in barrels (0.2 m³) which will require 28 barrels of ammonia on a monthly basis. Although the IBCs and barrels can satisfy the storage demand in the beginning of the ReFertilizer project, it can be useful to use other facilities for the storage in order to decrease costs and increase efficiency. When production quantities increase silo's and tanks can be used for the storage of these materials.

When storing the other two input materials that are required in larger quantities it will not be possible to store them in IBCs because they are required in such large quantities that it will be necessary to store them in larger equipment. For the storage of urea the idea within SUEZ is to use a silo. The permit that is expected to be approved mid-2016 includes the placement of a urea silo. The lime silo will have a volume of 120 m³. This storage capacity will be large enough for the production of 2,000 ton of liquid inorganic fertilizer. Under the current circumstances the production of 2,000 ton of inorganic fertilizer requires 88.71 m³ of urea per month. Also for larger production amounts the storage capacity is expected to be sufficient. Under the current circumstances the volume of urea that is required for the production of 10,000 ton of fertilizer is calculated to be 444.89 m³ per month. Based on these numbers the urea silo will have to be supplemented four times a month.

Figure 5-3: One cubic meter IBC

Considering the storage of the ammonium sulfate there will also be new storage facilities required. The volume of ammonium sulfate from farms that is required, on a monthly basis, for the production of 2,000 ton of inorganic fertilizer is calculated to be 75.57 m³ (see table 5-3). Where for the production of 10,000 ton of inorganic fertilizer there are 403.33 m³ of ammonium sulfate required. Because the required quantities of the ammonium sulfate from farms is comparable to the required amounts of urea it will be wisely to install a large silo for the storage of ammonium sulfate from farms as well. A silo of 100-120 m³ meets the required monthly demands in the starting years and the requirements when the production will be increased to 10,000 ton of end product.

Figure 5-4: Possible storage options

When analyzing the possibilities for the storage of the input materials in silo's or tanks there are several options . Figure 5-4 shows the possibilities for storage of the incoming materials. All yellow and blue circles represent the possible storage tanks for the incoming materials. Yellow circles represent possible new storage locations where the blue circle(s) represent existing storage locations that can be used. It depends on the location of the production facility, described in the next section, what the best location is to store the incoming materials. Under the current circumstances there are five different incoming materials that will be required to produce the inorganic fertilizer. With these five input materials it is possible to produce the two most promising compositions as described in the previous section. When using these five materials in large quantities it will be necessary to use at least five tanks, one tank for each input material. It depends on the volume of the input material whether one storage tank per input material will be sufficient or more storage tanks are required.

5.2 Production steps

When the input materials have been stored, as mentioned in the previous section, it is important to map all relevant production steps in the production process of the liquid inorganic fertilizer. The steps will have to be performed in a predefined sequence to formulate the inorganic fertilizer. The production that will have to be carried out consists of a few steps that depend on the mixture that is being produced. As outlined in the previous parts of this thesis, there can be different compositions in the production of the inorganic fertilizer. However, the formulation of these compositions do have certain similarities whereby the production process can be simplified in a few steps. The relevant steps for the production process are summarized in table 5-4 below.

Production step	Description
1	Add primary substance to reactor vessel
2	Add secondary substance to reactor vessel
3	Add urea to the reactor vessel
4	Measure the pH value of the mixture in the reactor vessel
5	Add ammonia to the reactor vessel
6	Sample the mixture in the reactor vessel
7	Transport the mixture from the reactor to the final product storage

Table 5-4: Production steps for producing inorganic fertilizers

Table 5-4 above summarizes the production steps that are relevant for the production of the inorganic fertilizer, these steps will be described below.

1) The first production step will be to add the primary substance to the reactor vessel. The primary substance is the substance that is considered to be the most relevant substance of the mixture. As outlined in the introduction, the primary substance is mostly the ammonium sulfate from farms. The primary substance will be transported from the input storage of the primary substance to the reactor vessel of the production location. The amount of primary substance that will be added depends on the mixture, production quantities, production capacities and availability of the primary material.
2) The second step in the production process is to add the secondary substance to the reactor vessel. The secondary substance that will be added to the reactor vessel will be the substance that is considered to be less important that the primary substance, but is required to complement the mixture. The secondary substance will be transported from the input storage to the reactor vessel of the production location. The amount of secondary material that is added

to the reactor vessel depends on the amount of primary substance that has been added to the reactor vessel in step 1 and the availability of the secondary substance. In exceptional cases it can be possible that there will be no secondary substance that will have to be added to the reactor vessel, see figure 5-3. In this case only virgin sulfuric acid will be added.

3) Third step of producing inorganic fertilizers will be to add the solid urea to the liquid substance(s) that have or has been added to the reactor vessel. Because the urea is in a solid state it will not be possible to pump the substance into the vessels, as has been possible within the first two steps. A dosing slide or a dosing screw is required to add the solid urea to the reactor vessel. The amount of urea that will have to be added depends on the amount of the first two substances that have been added to the reactor vessel and their compositions. This step in the production process will be a time-consuming step because it requires relatively much time to dissolve urea in the liquid substances, as mentioned in the introduction of this chapter. The dissolving of urea is an endothermic reaction. Previous experiments within SUEZ showed that the non-heated addition of urea in the test batch took 24 hours to dissolve, where the heated addition of urea in the test batch took 8 hours to dissolve.
4) The fourth step will be to measure the mixture that is present in the reactor vessel. This measurement reveals the current pH value. With the current pH value it is possible to calculate what amount of ammonia is required to neutralize the mixture to a pH value of 5.
5) Based on the measurement and calculations in the previous step (step 4) the right amount of ammonia should be added to neutralize the inorganic fertilizer mixture. When this amount of ammonia has been added, the mixture should be measured again and should reveal a pH value that will be around five.
6) After adding the right amount of ammonia in the previous step it is required the sample the mixture to measure all the relevant information of the mixture. This information consists of the levels of nitrogen and sulfur, the total amount of the substance and the pH value of the substance.
7) When the substance has been sampled (step 6) it can be transported to the storage of the final product storage. The whole mixture should be transported to the storage of final products.

The abovementioned production steps can be used to produce the inorganic fertilizer. Based on these steps it is possible to determine what additional equipment is required. The storage materials of the input materials have been mentioned in the previous sections. Mentioned above in the production steps is that a reactor vessel is required to add the mixtures. But for the production of inorganic fertilizers there is other equipment required to produce. Before the waste material is added to the reactor there will be a filtration step. There will be a filtration process between the storage tanks of the waste input material and the reactor. This additional filtering step is added to filter the waste material and to be sure that there will be no products ending up in the reactor that should not end up in the reactor. Because the materials are considered to be waste there can be sand, dust or other materials in the substance that should be eliminated. The reactor itself should be a reactor that can be heated in order to increase the dissolving process of urea in the inorganic fertilizer. The reactor should also contain a pump or a mechanical mixer that rotates the content inside of the reactor. When the inorganic fertilizer is mixed it is possible to add an ion exchanger to the production process in order to take out the ions that are not desired within the substance. An important aspect of the reactor will be the size of the reactor. Self-evidently the larger the reactor, the larger the amount of final product that can be produced per batch. It depends on the requirements of the batch sizes what reactor should be bought.

The required production equipment described above is general equipment, the actual detailed equipment that is required depends on the production facility that will be determined as best option for SUEZ . The production equipment will be described in the next section on the production facilities.

5.3 Production facilities

For the production of the ReFertilizer project there are different options with regard to the production facility. Because SUEZ Almelo does currently have a permit and will have an updated permit to store and process waste materials, the production facility should be an existing or new facility that is located in Almelo.

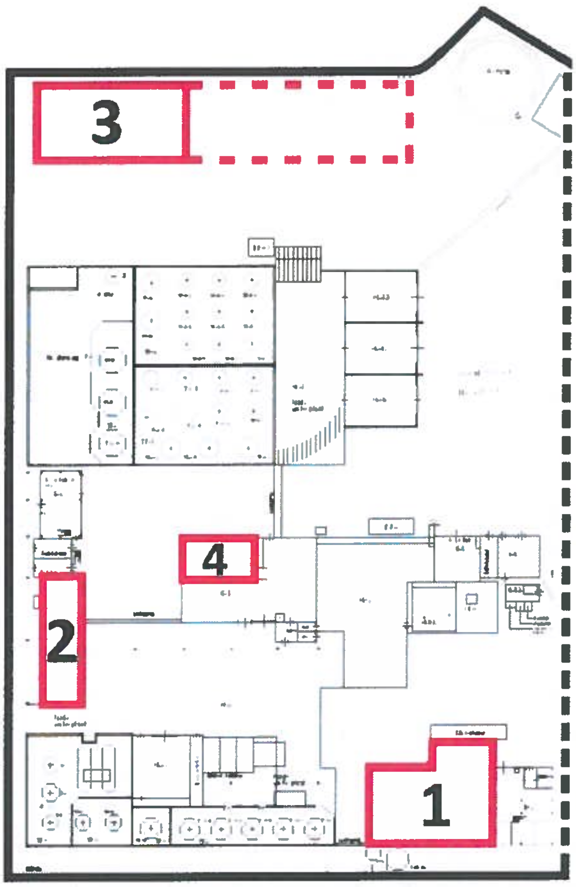

Figure 5-5: Possible locations for storage and production

Discussions with the processing department revealed that there are currently three different options for the production of inorganic fertilizers at the location of SUEZ in Almelo. These three options are numbered one, two and three in figure 5-5. Besides the production facility there is a storage location considered to be suitable for the storage of final products. The storage location is numbered four in the image above, but storage of final products will be outlined in the next section (section 5.4). This section will describe the relevant production facilities. At first it will be possible to start the production of the ReFertilizer within the ONO-installation of the SUEZ plant. The ONO-installation is numbered one (1) in figure 5-5. However, when production quantities will increase over time there will not be enough capacity within the ONO-installation to meet the required production quantities. When this point of production is met it is necessary to use other production facilities. Because there is no current available alternative for the production of fertilizers it will be necessary to identify the other possibilities for the production process. There are two options possible that, after further development, can be used for the production of the inorganic fertilizer. The first option is to start the production in an outdated installation, the spent catalyst installation. This installation has previously been used for other processes but can be updated to be used in the production for inorganic fertilizers. This installation is numbered two (2) in figure 5-5. The other possibility will be to set up a completely new production facility within SUEZ , this will have to be within the location of SUEZ. There is a location, numbered three (3) in figure 5-5, that might be suitable for a new production line because this location is a facility that is currently out of use. Based on the above there are three different possibilities for the production of inorganic fertilizers, each option with the associated dis- and advantages will be described within the next sections.

5.3.1 ONO Installation

The ONO installation has been introduced in section 2.1.3. This section will provide a more detailed description of this installation. The ONO installation is an installation that is used for the treatment of chemically polluted wastewater. The installation is suitable for the removing of inorganic compounds that are dissolved in the wastewater. ONO (Ontgiften Neutralizeren Ontwateren) is the Dutch abbreviation of detoxification, neutralizing and the dehydration of liquid substances, as already mentioned in chapter 1. It can also be a suitable installation for the production of the inorganic fertilizers. However, the ONO installation is currently used for other activities and can only be used for the production of inorganic fertilizers when the other activities are completed. This means that the amount of inorganic fertilizer that can be produced in the ONO installation is limited. Disadvantage of using this option is that the possibility depends on the amount of inorganic fertilizer that is estimated to be produced. The processing capacity of the current ONO installation is 15,000 ton of material. The installation is largely occupied in the current situation, although there are variations in the occupancy because the amount of material that is treated by SUEZ differs from week to week. The ONO installation has two large reactor vessels of 20 m^3 each. These vessels can be used for the formulation of inorganic fertilizers. However, before the installation can be used for production of inorganic fertilizers it should be completely cleaned to make sure that the inorganic fertilizer will not be contaminated. This is a time consuming activity that should be performed each time the ONO installation is switched from their usual activities to the production of inorganic fertilizers. The small capacity that remains available for the production of inorganic fertilizers and the time consuming cleaning activities cause the ONO installation to be not the ideal installation for the production of inorganic fertilizers.

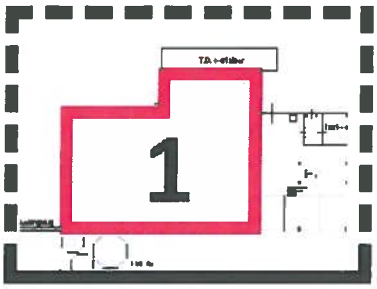

Figure 5-6: Location ONO installation

5.3.2 Spent catalyst installation

The spent catalyst installation is an installation that has not been used for many years. The installation has been used for the treatment of antimony pentachloride in the past. The advantage of this option will be that the production can be performed in an existing installation. Therefore, this installation will require adaptions and additions in order to upgrade the outdated production facility. Disadvantages are that production quantities also depend on the capacity of the current installation and upgrading the outdated installation will require additional investments. The reactor vessel that is currently installed in the spent catalyst installation has a capacity of six cubic meter.

We made calculations based on the six cubic meters of capacity. These calculations can be found in the table 5-5 below. The capacity of the reactor vessel is assumed to be six cubic meters and therefore this is also considered to be the maximum batch size. Calculating with this batch size reveals that based on a yearly production of 2,000 ton of inorganic fertilizer there is one daily production batch required. However, when the yearly production will increase with 2,000 ton it is necessary to produce two batches a day. Another increase of 2,000 ton per year will also lead to an increase in the required batches to three batches per day. When the yearly production will increase to the level of 8,000 or 10,000 ton of inorganic fertilizer the required daily batches that should be produced will increase to four.

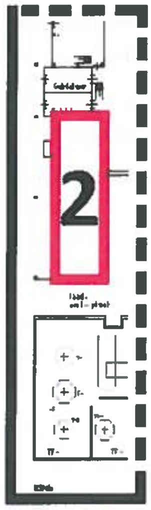

Figure 5-7: Location spent catalyst installation

Problems with these required daily batches are the estimated batch completion times. Previous batches (7,500 kg and 7,421 kg) revealed that the non-heated batch took 28 hours to complete where the heated batch took 16 hours to complete. Therefore additional tests will have to be performed with larger batch sizes in order to define whether or not the batches should be heated. When the current capacity of the old spent catalyst can be used and the installation can be heated it will be possible to produce 2,000 tons of inorganic fertilizer on a yearly basis. However, it will not be possible to increase the amount of inorganic fertilizer produced in the spent catalyst installation to more than one batch per day. This will not be possible because the non heated batch took 24 hours to complete where the heated batch took 16 hours to complete. Because two batches of 16 hours exceed the 24 hours of a day it is not possible to produce two batches a day with this installation. Another disadvantage of the installation is that it has not been used for several years and because it has been used to threat the antimony pentachloride it has been aged and affected. Besides this the current reactor vessel that is present in the installation (6 m^3) is considered to be too small to produce large amounts of inorganic fertilizer.

	Batch		Ratio (m^3/ton kg)
	Capacity (m^3)	Capacity (ton kg)	0,86
Reactor vessel	6	7,01	

	Yearly		Daily		Required daily batches
	Demanded (m^3)	Demanded (ton kg)	Demanded (m^3)	Demanded (ton kg)	
Production	1710,70	2000	4,69	5,48	1
	3421,40	4000	9,37	10,96	2
	5132,10	6000	14,06	16,44	3
	6842,80	8000	18,75	21,92	4
	8553,50	10000	23,43	27,40	4

Table 5-5: Required daily batches with capacity 6 m^3

Besides upgrading the current outdated installation it is possible to break down this installation and rebuild a new installation on the location of the spent catalyst installation. Advantages of this option are that the location is close to the storage locations and the tank park. Besides this, there is already one tank installed in this location and the submitted permit allows SUEZ to install additional tanks on this location. The spent catalyst has dimensions of 6.5 to 20 meter, which equals a 130 square meter of available space for the production layout.

Concluding, the spent catalyst installation as option for the production of inorganic fertilizers is relevant. However, there will be investments required to start production within this installation and other disadvantage of this installation will be the capacity. The current capacity of the reactor vessel is six cubic meter, which will be too low when production quantities of the inorganic fertilizers will be increased. Another option is to rebuild the facility on the current location. This options regarding the spent catalyst installation will be taken into account in the next sections.

5.3.3 New production plant

This option is based on the building of a new production plant. Where the advantage of this option will be that it is possible to build a new production line based on the expected demands of SUEZ . Only restriction here is the available space within the production plant of SUEZ , without the necessity to take into account the maximum production amounts and the available production equipment. Disadvantage of this option is that it requires higher investments costs because the production line will have to be build from scratch.

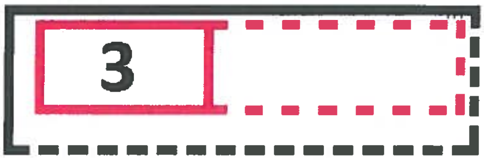

Figure 5-8: Location new production plant

Calculations have been made with different volumes of reactor vessels in order to define what number of batches are required with different volumes of reactor vessels. The calculations have been made with the volumes of 6, 12, 18 and 24 cubic meters of capacity. These calculations are made for the different demanded amounts of inorganic fertilizer, varying between 2,000 ton and 10,000 ton. The outcomes of these calculations can be found in the tables 5-6 and 5-7. The outcomes show that doubling the initial capacity of six cubic meters results in a decrease in the daily required batches for 4,000 ton of final product to one batch. Where the other amounts of final product require two daily batches. When increasing the batch capacity to 18 m^3 it is possible to produce up to 6,000 ton of inorganic fertilizer with one daily batch. The other amounts of inorganic fertilizer do still require two batches per day, only when increasing the capacity of the reactor vessel to 24 m^3 results in a required daily batch of one for all considered amounts of inorganic fertilizer. Based on the information on the required production time of a single batch, it will be most likely to maximally produce one batch per day. When SUEZ aims to produce an amount of 10,000 tons of inorganic fertilizer in the future, the required batch capacity should therefore be at least 24 cubic meters.

As mentioned before the major advantage of using a new production plant is that it is possible to adapt the production plant to the requirements of the ReFertilizer project. Based on the current available information on the demands and compositions of the inorganic fertilizers it is possible to define what daily amounts of fertilizer is required. The new production plant can be located at the location where currently an installation is situated that is out of use and is scheduled to be demolished. On this new area without installation it will be possible to design a new production line for the production of inorganic fertilizers. The optional space that can be used for the inorganic fertilizer installation is 12 by 17.5 meter, which equals a surface of 210 m^2. The next section on the production plant layout will take into account this surface to design a plant layout for this option.

	Yearly		Daily	Batch	Daily batches	Batch	Daily batches
	Demanded (m³)	Demanded (ton kg)	Demanded (m³)	Capacity (m³)		Capacity (m³)	
Production	1710,70	2000	4,69	6	1	12	1
	3421,40	4000	9,37		2		1
	5132,10	6000	14,06		3		2
	6842,80	8000	18,75		4		2
	8553,50	10000	23,43		4		2

Table 5-7: Required daily batches with capacities 6 m³ and 12 m³

	Yearly		Daily	Batch	Daily batches	Batch	Daily batches
	Demanded (m³)	Demanded (ton kg)	Demanded (m³)	Capacity (m³)		Capacity (m³)	
Production	1710,70	2000	4,69	18	1	24	1
	3421,40	4000	9,37		1		1
	5132,10	6000	14,06		1		1
	6842,80	8000	18,75		2		1
	8553,50	10000	23,43		2		1

Table 5-6: Required daily batches with capacities 18 m³ and 24 m³

5.4 Storage of output materials

The storage of the output materials takes into account several important aspects. One of these aspects is that the inorganic fertilizers will be produced throughout the whole year, where the demand of the liquid fertilizer for the most common applications (arable and grass land) will only be in the months February up to September (see legal chapter 3). This chapter will therefore outline the different possibilities for the storage of inorganic fertilizers. Besides the time frames in which the products will have to be stored it is important to define what amounts of materials will have to be stored. The relevant stock levels, related to the possible production quantities, will be mentioned in the next section. Thereafter the different possibilities for the storage of inorganic fertilizers (internal and external), as mentioned in section 2.1.4, will be described and substantiated in more detail.

Month	Temperature
January	3.1
February	3.3
March	6.2
April	9.2
May	13.1
June	15.6
July	17.9
August	17.5
September	14.5
October	10.7
November	6.7
December	3.7

Table 5-8: Monthly average temperatures

5.4.1 Stock levels

It has been considered to decrease the production volumes during the period from September to January. This can be useful because the product cannot be sold in this period and because the temperatures are generally lower during these periods. Table 5-8 shows the average temperatures of the months based on historical data. This shows that the months November, December, January, February and March have relatively low temperatures. As mentioned before this may be problematic because the urea that is added to the waste materials can crystalize under lower temperatures. To avoid this it is possible to store the final inorganic fertilizer product in a heated and isolated tank. However, the amount of inorganic fertilizer that can be stored at the location of SUEZ in Almelo is limited. Advantages of lowering the production are that the stock levels of the final product will be lower and that the produced final products can be stored at the SUEZ location in Almelo during the period that the materials cannot be sold. This implies that the production in the months September until January should be lowered significantly. To store the final product it is required to install a tank at the location of SUEZ. When installing a large tank of 150 m³ it is possible to continue the production process with 30 m³ per month. This results in the production of 150 m³ during the winter period independent of the yearly produced quantities.

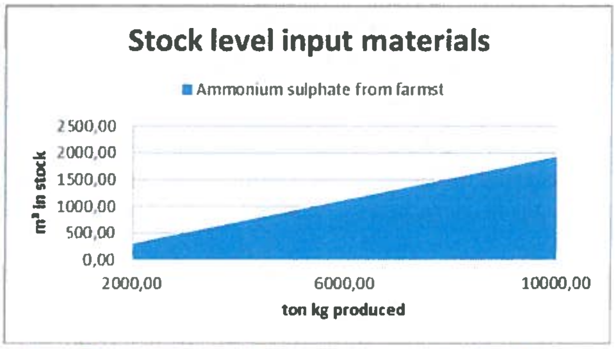

Figure 5-9: Stock level ammonium sulphate from farms

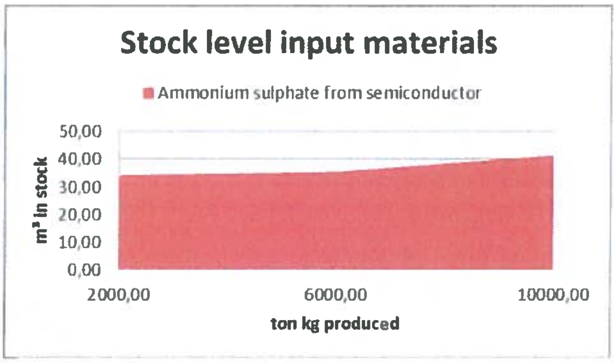

Figure 5-10: Stock levels ammonium sulphate from semiconductor industry

However, decreasing the amounts produced during the winter period results in the problem that the stock levels of the input materials will increase. The assumption that has been made within this project is that the amounts of waste materials used within the ReFertilizer project, become available at constant rate on a monthly or weekly basis. This results in the fact that the final product will be reduced during the winter periods, but the amount of incoming materials remains the same after which the input materials in stock increase significantly. This is illustrated in the figures 5-9, 5-10 and 5-11. Especially the ammonium sulfate from farms will increase significantly. The quantity of ammonium sulfate from farms when producing 2,000 ton of fertilizer on a yearly basis and a lowered production of 30 m³ during the winter period, results in a stock level of this ammonium sulfate at the end of the winter period of 298 m³. Which increases when producing larger amounts of fertilizers. Up to 1,115 m² when producing 6,000 ton of final product and 1,928 m³ when producing 10,000 ton of fertilizer product. Because these amounts of input materials are too high to be stored at the SUEZ location in Almelo it is considered to be impossible to lower the production for a certain period. When the ReFertilizer project will be executed the amounts of inorganic fertilizers that will be produced will be equally divided throughout the year. The storage options that are considered to be an option, for the constant production, will be outlined in sections 5.4.2.1 and 5.4.2.2.

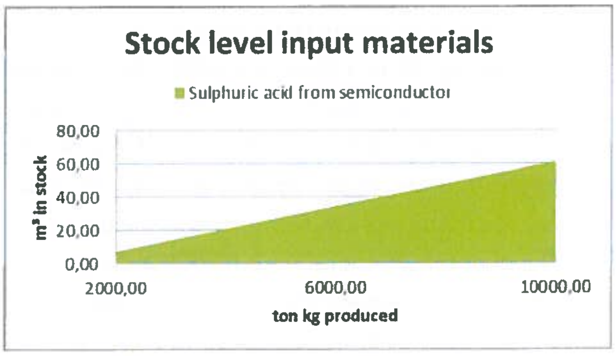

Figure 5-11: Stock level sulphuric acid from semiconductor industry

The inorganic fertilizers will be produced during the whole year, which implies that the stock levels will increase linearly starting in September. The stock level is considered to be zero at the start of September because this will be the end of the period that application is allowed. The assumption is made that all produced inorganic fertilizer amounts will be sold during these periods. The stock levels can be found in the graph of figure 5-12. The stock levels are shown for the five different production quantities that can be achieved during the implementation years of the ReFertilizer project. When 2,000 tons of inorganic fertilizers are produced in the beginning of the project, the highest stock level that is achieved during the year is 712.79 cubic meter of

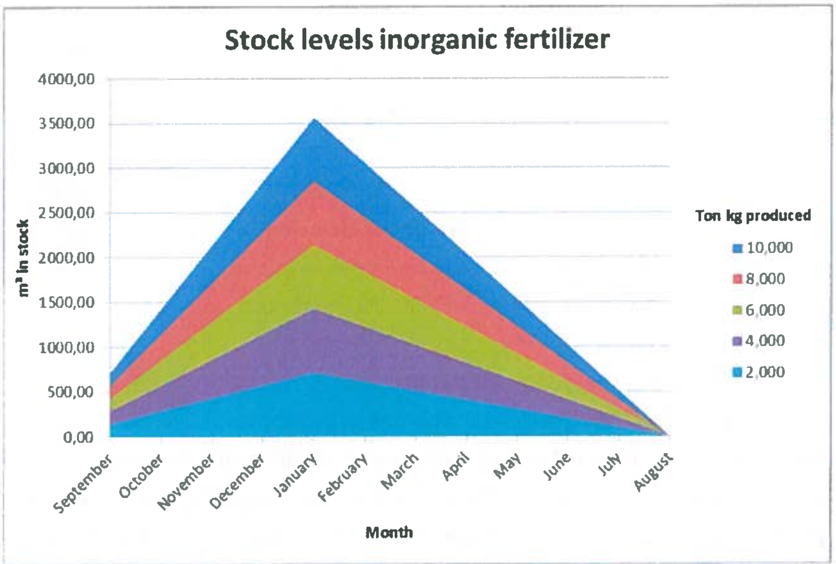

Figure 5-12: Stock levels inorganic fertilizer for different production quantities

inorganic fertilizer. This highest stock level is reached at the end of January. This is considered to be the highest stock level because at the beginning of February it is possible to sell the inorganic fertilizer again. From that point the stock level will decline. Obviously, when larger amounts of inorganic fertilizers are produced during the year the stock levels will also increase. When 4,000 tons of inorganic fertilizers are produced the highest stock level is assumed to be 1,426 m^3, when 6,000 tons are produced the highest stock level is 2,139 m^3, when 8,000 tons are produced the highest stock level will be 2,852 m^3. And when the amount of 10,000 tons of inorganic fertilizer are produced the expected highest amount of stock level will be 3,564 m^3.

For the storage of the produced inorganic fertilizer there are two different possibilities, external and internal storage. The first possibility for the storage is to store the final product for a short period of time within the location of SUEZ and thereafter transport the product to a customer or partner of SUEZ to store the product in a heated location. The other option for the storage will be to store the final product within the location of SUEZ in Almelo. This will reduce the storage costs but it is questionable if there will be enough space available for the storage of the final product within SUEZ. If the available space does not meet the requirements it is possible to build another storage location, but this will require additional investments. Another option can be to use large fertilizer bags. These bags can be placed on external wastelands and filled with large amounts of fertilizers. However, the addition of urea in the inorganic fertilizer can result in the fact that the urea crystallizes during colder periods of the year. When the temperature increases again the urea dissolves, but the temperatures during the months February/March/April can be too low. Therefore another option can be to externally store the final product in a warehouse that has experience with storing high quantities of products.

5.4.2 Storage options

5.4.2.1 Internal storage

The first option is to store the produced inorganic fertilizer within the SUEZ location of Almelo. There is currently no storage available where such large amounts of fertilizers can be stored but there are possibilities for the storage of fertilizers within Almelo. There is currently a small warehouse room where the temperature can be controlled but this storage location will not be large enough when the amounts of inorganic fertilizers will increase over the years. The current dimensions of the storage location are 7 by 12 meter. This implies a surface of 84 square meters. This can, in an optimal situation and a stack height of three IBCs, result in the storage of 210 cubic meters of inorganic fertilizer ((84/0.96)*3). This optimal situation will be when all the surface space can be used for the storage of inorganic fertilizers. However, practical limitations will make it harder, if not impossible, to optimally use the surface.

Another option for the storage of inorganic fertilizers at the location of SUEZ in Almelo is to build a new warehouse. However, this will require a large surface area of the SUEZ location. Table 5-9 shows the different required surfaces for the stock that is related to different production levels. When using the stock height of three IBCs there is a required surface of 238 m^2. When using a square storage location this will imply that a square dimension of at least 15.4 meters is required for the storage of the inorganic fertilizers.

	Stack height (IBC)			
	2		3	
Highest stock (m^3)	Required surface (m^2)	Square dimension (m)	Required surface (m^2)	Square dimension (m)
712.79	356.40	18.88	237.60	15.41
1425.58	712.79	26.70	475.19	21.80
2138.38	1069.19	32.70	712.79	26.70
2851.17	1425.58	37.76	950.39	30.83
3563.96	1781.98	42.21	1187.99	34.47

Table 5-9: Required surfaces for all relevant stock levels

Concluding, it is considered to be difficult to use internal storage as storage location for the inorganic fertilizers. The available storage location in Almelo is relatively small and will not be capable of storing the highest stock level when producing 2,000 ton or more. When building a new storage facilities there are problems as well, there is a lack of building space at the location in Almelo and the investments that will have to be made for this option are relatively large as well.

5.4.2.2 External storage

The second option would mean that the product will be transported, after it has been produced, to a temporary storage location at the plant of SUEZ Almelo. This temporary facility will be a storage tank for liquid substances. This tank will have to be double walled, isolated and heated. Once this temporary storage location is full, the content of the tank will have to be transported to a warehouse. Possible warehouse where the fertilizers can be transported to is the ViVoChem company. VivoChem delivers many virgin materials to SUEZ and is also located in Almelo. Or it can be transported to JPB, another company that has a warehouse for chemical products. These storage warehouses have experiences with the storage of the materials of the ReFertilizer project and can store the materials in a warehouse on a regulated constant temperature. Because the temperature within these warehouse will not decline, the urea that dissolved in the inorganic fertilizer will not crystallize again.

Production (ton)	Highest stock (m^3)
2000	712.79
4000	1425.58
6000	2138.38
8000	2851.17
10000	3563.96

Table 5-10: Production quantities and related stock levels

However, based on internal discussions and information from the warehousing companies this storage option is not considered to be relevant. The storage of the large amounts of inorganic fertilizers will be too expensive, whereby the ReFertilizer project will never be viable and profitable. The large amounts, displayed in table 5-10, will have to be stored in the warehouses. These amounts are so high that the capacity of the mentioned warehouses are nearly sufficient enough. Besides this, there will be large investments required to purchase an exorbitant amount of IBCs. On top of these costs are the additional costs for storing the IBCs in the warehouse. Altogether, the sum of all these investments are considered to be too high.

The other external storage option is the storage of the produced inorganic fertilizers in bag tanks. These large bags are made of polyester fabric, equipped with a plastic coating. These bags have a storage capacity up to 7,000 cubic meters. The bag tank can be equipped with mixing equipment, with this equipment it is possible to mix the liquids inside the bag. This equipment can be useful for the ReFertilizer project, it is possible to keep the urea dissolved in the other materials. Contact with suppliers and tests will have to make sure that the urea that has been dissolved in the other liquid materials will not crystallize in the substance. As can be seen in table 5-10 the highest required stock level, based on a 10,000 ton production, is 3,564 cubic meters. As mentioned above this quantities can be easily stored in one bag tank. Figure 5-13 shows a bag tank, with at the top-left an intersection of an empty bag tank and at the top right an intersection of a filled bag tank. The tank can, dependent on the highest groundwater, be placed under the surface. Bag tanks can be placed in several different sizes and in squares or rectangles. The bag tank can simply be emptied because of the slope and can be placed on several different surfaces. Contact with an experienced supplier of these bags revealed that storage is possible for different capacities starting with 200 cubic meters. With 20 other capacities ranging up to 7,000 cubic meters. The required bag tanks and their related costs can be found in table 5-11.

Figure 5-13: Bag tank

Production (ton)	Highest stock level(m³)	Mimumum capacity bagtank (m³)	Costs bagtank	Costs mixer bagtank
2000	712.79	800	€ 29,725.00	€ 4,845.00
4000	1425.58	1500	€ 45,890.00	€ 5,065.00
6000	2138.38	2200	€ 60,745.00	€ 9,205.00
8000	2851.17	3000	€ 69,740.00	€ 9,205.00
10000	3563.96	4000	€ 77,285.00	€ 9,205.00

Table 5-11: Costs bag tanks and mixers

When analyzing both external options, the best options will be to use the bag tanks. These bag tanks are large enough for all production amounts that SUEZ can produce and this option is relatively cheap compared to the storage of the inorganic fertilizer within a warehousing company. Also when comparing both the internal and external storage options, the storage option in the bag tanks is the most promising storage facility. It is capable of storing large amounts of final products at relatively low costs. Only problem with the bag tanks can be the low temperatures during the winter periods.

5.4.3 Conclusion

The options that are considered to be possible for the storage of the output product of the ReFertilizer project have been described in the sections 5.4.1 and 5.4.2. The conclusion of these sections is that the storage of the output materials within the location of SUEZ Almelo is too expensive, mainly because of the high stock levels during the period that the product cannot be sold (see section 5.4.1). Storage of the output product at an external warehousing company is also not considered to be an option. The capacities of the warehousing companies can be too low and the costs of this option will be too high. Remains the external storage of the output products in a bag tank. This is considered to be the most useful option because it can handle large quantities of inorganic fertilizer products and it is relatively cheap compared to the other storage options.

5.5 Production plant layout

In order to start with the production of inorganic fertilizers it is required to design a production plant layout to gain knowledge on what the optimal design would be for SUEZ. Different options are considered to be relevant for the production location of inorganic fertilizers as mentioned above. Two of these options are (partly) new. The existing ONO installation is considered to be an option for the production process of fertilizers, but this is an existing location that does not require the draft of a new layout. When considering the other two options, there is a new layout required. The spent catalyst installation is an existing installation but requires additional facilities and a new design. Self-evidently, there is a new production plant layout required when the decision is made to build a completely new production line. For the design of the production line the theory on Systematic Layout Planning will be used. This theory, designed by Muther (1973), creates conceptual block layouts. The method adds complicating data categories until a block layout has been designed. It is one of the methods that is frequently used in the design of equipment layouts (Muther, 1961). The block layout is created after the process of figure 5-14 has been conducted. The Systematic Layout Planning (SLP) designed by Muther can be divided into the following four phases:

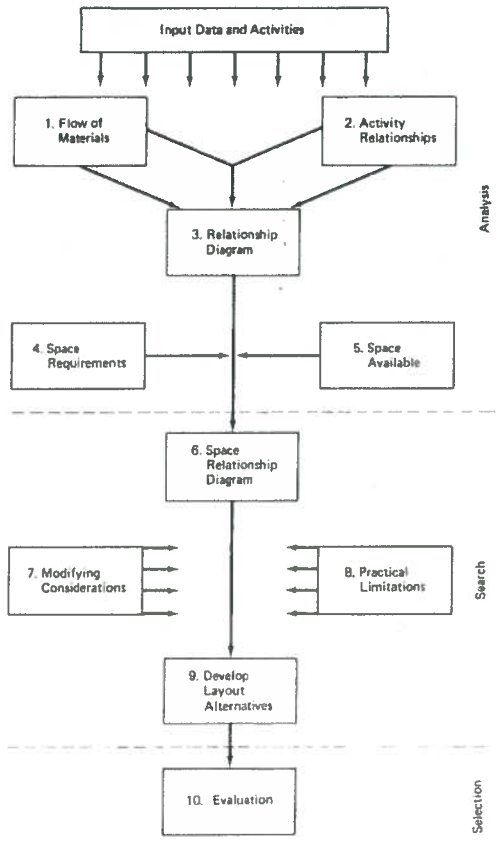

Figure 5-14: Analysis, search and selection for design of a general overall layout and a detailed layout

1. Location - Which area is to be used for equipment planning?
2. General overall layout - Construction of departmental arrangement/block layout
3. Detailed layout - Placement of resources within departments/blocks
4. Installation - Planning and execution of physical placement

The first step, location, has already been introduced in the section (5.3) above. The locations that are considered to be relevant are mentioned. The equipment planner mainly deals with the second (2.) and third (3.) step. For these steps Muther developed a procedure that can be applied, consisting of three phases: analysis, search and selection (figure 5-14). The three major phases can also be described as:

1) Data collection and analysis — Analysis
2) Searching among the possible layout solutions — Search
3) Evaluating alternatives and selecting the best layout — Selection

5.5.0 Input data: PQRST and activities

The first step, the data collection and the PQRST analysis consists of gathering the following required data:

- Which product does the equipment handle? (Product)
- How much of these products does the equipment handle? (Quantity)
- What series of steps does each product go through? (Routing)
- Which extra activities do the processes require? (Supporting services)
- When and how long do the processes have to be executed? (Time)

Based on this analysis, the flow of materials and the activity relationships, it is possible to design a relationship diagram. This is generally a node and arc structure to depict interdepartmental flows.

Product – the product that is handled within the equipment is the liquid inorganic fertilizer. There are different possible options to produce the inorganic fertilizer, but the outcomes will always be based on a specified level of nitrogen and sulfur. The relevant product options have been outlined in the previous chapter (chapter 4) and in the beginning of this chapter (section 5. Production process).

Quantity – the quantity of the product that will be produced varies between 2,000 ton and 10,000 ton of inorganic fertilizer, see table 5-10. The approach will be to start the production with 2,000 ton of final product and, when the project has started successfully, increase the production amounts to around 10,000 ton of final fertilizer product. However, the systematic layout planning in this chapter will be based on 2,000 ton of production.

Routing – the routing of the product is relatively simple. Input products are transported to the associated storage location. When production is ready to start the required amounts of input materials are transported to the reactor vessel. After all required amounts of input products have been mixed in the reactor vessel, the final product is transported to the storage of final products.

Supporting services – the supporting services for the ReFertilizer project are the measuring and sampling activities. These services are required in order to determine the right levels of products and the concentration levels of the final products.

Time – the complete production of a batch takes 28 hours when there is no additional heat added to the process, where the production of a batch takes 16 hours when the process is heated. The dissolving of the urea is the most time consuming activity, respectively 24 and 8 hours. The production steps that are based on the adding of substances are summarized in table 5-12.

Production step	Production time batch 1 (hour)	Production time batch 2 (hour)
Heated/non-heated	*Non-heated*	*Heated*
Adding two (waste) materials	3	5
Adding urea	24	8
Adding ammonia	1	3

Table 5-12: Production time of heated and non-heated batches

The related and critical activities can be found in table 5-13, where differentiations are made between storage, transport and measurement.

Step	Activity
1	Store ammonium sulfate (1)
2	Store ammonium sulfate (2)
3	Store sulfuric acid (1)
4	Store sulfuric acid (2)
5	Store urea
6	Store ammonia
7	Transport primary substance to reactor vessel
8	Transport secondary substance to reactor vessel
9	Transport urea to reactor vessel
10	Measure pH value of mixture in reactor vessel
11	Add ammonia to reactor vessel
12	Sample the mixture in the reactor vessel
13	Transport the mixture to the final product storage

Table 5-13: All relevant production steps

5.5.1 Flow of materials

Step 2 is the flow of materials. All material flows are aggregated in a from-to chart representing the flow intensities of different departments or tool sets. Table 5-14 shows all relevant symbols and descriptions.

Symbol	Description
	Operation
	Transportation (Flow process chart only)
	Inspection
	Delay (Flow process chart only)
	Storage

Table 5-14: Description of symbols used in flow chart

Table 5-15 outlines the general material flow of the production process. The production process is based on several input materials. Although these materials are different in composition, they follow the same flow through the production process. The input materials are stored within SUEZ Almelo where the materials that require an inspection step will be tested. It is important to test the incoming waste materials, because these materials can be contaminated and can vary in composition per delivery. The virgin materials that are bought from producers are not considered to be contaminated and ready to be used in the production process. After the optional inspection step, the materials are transported to the reactor vessel. After all input materials have been transported to the vessel and the input materials have been mixed, the mixture is sampled. When the final product is sampled it is transported to the final product storage.

Flow	Description
	Storage of input materials
	Inspection of waste materials
	Transportation of input materials to reactor vessel
	Mixing in reactor vessel
	Inspection of produced materials
	Transportation of final product to final storage
	Store final products

Table 5-15: Flow chart of production process

5.5.2 Activity relationships

The activity relationships (step 3.), will perform the qualitative analysis towards the closeness relationship decision among different departments. Production of the inorganic fertilizers will require a number of production equipment's. These equipment's will be placed according to a certain layout. The first facilities that are important are the storage facilities of incoming materials. Because there are several incoming materials there are several storage facilities required. There are currently six incoming materials involved which results in the fact that there should be six different storage facilities involved, numbered SF1 (storage equipment 1) up to SF 6 (storage equipment 6). The reactor vessel that is required for the mixing of the incoming materials is abbreviated with RV (Reactor Vessel) and the storage equipment of the final product is abbreviated as SFF (Storage Equipment Final product). Resulting in the following facilities for the production line:

Abbreviation	Material	Supplier	Storage
SF1	Ammonium sulfate	Farms	Tank
SF2	Ammonium sulfate	Semiconductor	IBC
SF3	Sulfuric acid	Semiconductor	IBC
SF4	Sulfuric acid	VivoChem	IBC
SF5	Urea	VivoChem	Tank
SF6	Ammonia	VivoChem	Barrel
RV	Mixture	-	Reactor vessel
SFF	Inorganic fertilizer	-	Tank

Table 5-16: Equipment required for production

The different types of equipment have been used in the relationship diagram below. The relationships between the equipment's has been analyzed. The relationship between a number of facilities differ. However, the majority of the relationships are considered to be unimportant and classified in the relationship diagram with the letter U. These relationships are left out of consideration in the (space) relationship diagram. The only relationships that are considered to be important for the space relationship diagram are the not desired, normally important, especially important and absolutely necessary. However, there are within this production process no relationships that are considered to be 'not desired'. The relevant closeness relationships are summarized in table 5-17.

Importance	Description
A	Absolutely necessary
E	Especially important
N	Normally important
U	Unimportant
X	Not desired

Table 5-17: Closeness relationships

The relationships that are considered to be other than unimportant and not desired will be shortly explained below per production equipment.

SF1 – Ammonium sulfate from farms

For storage equipment one the only normally important other equipment is the reactor vessel. This relationship is considered to be normally important because the products from storage equipment one will have to be transported to the reactor vessel. Because the materials are stored in a tank it can be transported through a fixed pipeline, it is not necessary to store the storage equipment one close to the reactor vessel.

SF2 – Ammonium sulfate from semiconductor industry

Within storage equipment two the ammonium sulfate from the semiconductor industry are stored. Because this material stream is only available in a limited amount it is especially important to place the storage of these materials close to the reactor vessel, there will be no fixed pipeline attached to this storage equipment and the product will have to be pumped into the reactor vessel. Therefore it is more practical to locate the material close to the reactor vessel. Because the storage facilities three, four and six are also required in small amounts, and should also be located close to the reactor vessel, they are normally important compared to this storage equipment. It is useful to store these small amounts of materials close to each other, by doing this it is possible to simply add these materials to the reactor vessel.

SF3 – Sulfuric acid from semiconductor industry

The third storage equipment is similar to the second storage equipment in terms of relationships. The materials stored in this equipment are demanded in relatively small quantities and are therefore required to be situated close to the reactor vessel and close to the other storage facilities that store small amounts of materials (SF2, SF4 and SF6).

SF4 – Sulfuric acid from manufacturer

This storage equipment is similar to SF2, SF3 and SF6 when considering the relationships. It should be close to the reactor vessel and close the storage facilities two, three and six.

SF5 – Urea

Urea is the material that is stored in this fifth storage equipment. This material is the only solid material that is used as input material for the production of liquid inorganic fertilizers. Because this material is solid and required in relatively large quantities, a lime silo will be installed at the SUEZ location in Almelo. A dosing slide or screw is used to transport the urea into the reactor vessel, therefore it is absolutely necessary to locate the lime silo close to the reactor vessel. Because problems occur when a large distance has to be covered by this dosing slide or dosing screw, it is important to locate the silo close to the reactor vessel.

SF6 – Ammonia

The sixth storage equipment has the same relationships as SF2, SF3 and SF4. For the production process the ammonia is required in relatively small amounts and is therefore stored in barrels. To pump these barrels into the reactor vessel it is more practical to locate them close to the reactor vessel.

RV – Reactor vessel

The reactor vessel has been mentioned in all the storage facilities above. It is the most important equipment of the production process, all activities take place around this equipment. The reactor vessel has a normally important relationship with the storage equipment of final products because it should be taken into account when designing a layout. However, because the final product will be produced in large quantities it will be useful to install a fixed pipeline from the reactor vessel to the storage equipment of final products.

SFF – Storage facility final product

Because the storage facility of the final product has been mentioned in all other equipment's that are related to this storage facility it will be needless to further describe this equipment.

	SF1	SF2	SF3	SF4	SF5	SF6	RV	SFF
SF1	-	U	U	U	U	U	N	U
SF2	-	-	N	N	U	N	E	U
SF3	-	-	-	N	U	N	E	U
SF4	-	-	-	-	U	N	E	U
SF5	-	-	-	-	-	U	A	U
SF6	-	-	-	-	-	-	E	U
RV	-	-	-	-	-	-	-	N
SFF	-	-	-	-	-	-	-	-

Table 5-18: Activity relationships

5.5.3 Relationship diagram

Based on the previous sections about activity relationships it is possible to draft a relationship diagram. In order to keep things simple the unimportant links will not be depicted. The relationship that is considered to be normally important has one single link, the especially important relationship has two links and the absolutely necessary relationship is visualized by three links. Figure 5-15 represents the relationship diagram that can be drafted based on the activity relationships. As visible, the reactor vessel is considered to be of major importance and is centered in the middle of the diagram.

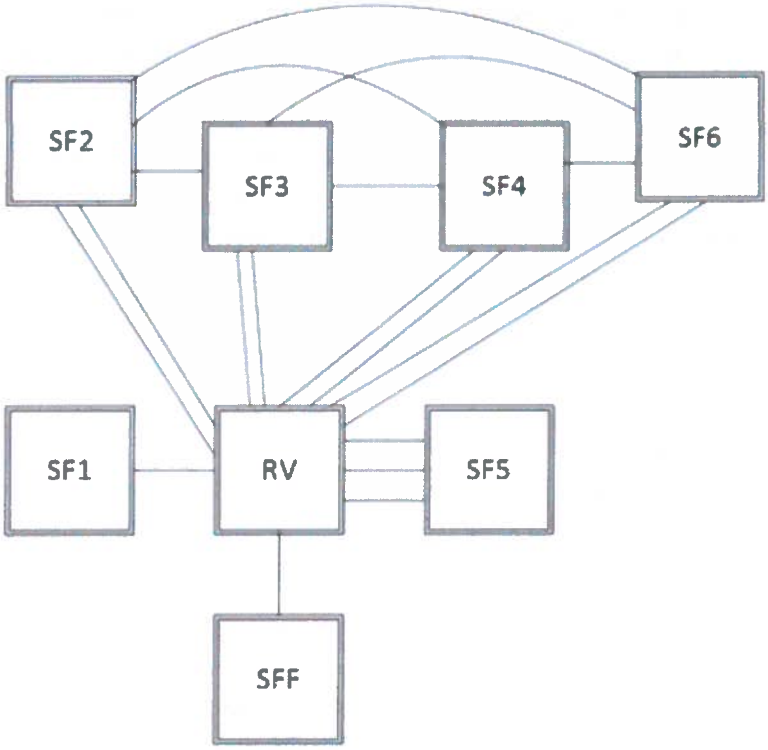

Figure 5-15: Relationship diagram

5.5.4 Space requirements

This section delineates the required space per incoming material. The information that is mentioned below is based on a production of 2,000 ton fertilizer on a yearly basis. The required volumes can be found in table 5-19. The demanded volumes are provided for the monthly and weekly volumes for the 2,000 tons per year, and the weekly demands when 10,000 tons are produced on a yearly basis. Calculations are based on the monthly volumes for all materials because the assumption is made that the materials are replenished on a monthly basis. An exception is made for the ammonium sulfate from the semiconductor industry which is delivered on a weekly basis.

			2,000 yearly	10,000 yearly
	Yearly	Monthly	Weekly	Weekly
Total material amounts required	**Volume (m^3)**	**Volume (m^3)**	**Volume (m^3)**	**Volume (m^3)**
Ammonium sulphate from farms	906.80	75.57	17.44	92.90
Ammonium sulphate from semiconductor industry	103.53	8.63	1.99	1.99
Sulphuric acid from semiconductor industry	21.76	1.81	0.42	2.95
Sulphuric acid (96%)	0.00	0.00	0.00	0.00
Urea	612.00	88.71	11.77	59.07
Ammonia	66.02	5.50	1.27	8.40
Fertilizer	1710.11	142.51	32.89	165.32

Table 5-19: Required yearly, monthly and weekly volumes

Based on the required weekly amounts of input material required, it is possible to define what space is required for the storage facilities. The input materials that are required in larger quantities will be stored in tanks that are placed within the location of SUEZ . In order to define the surface required for a tank it is important to define what the diameter of the most common tanks are. Based on internal SUEZ information and external research the most common diameters for tanks vary between 2.5 and 3.5 meter. To plan sufficient surfaces in the plant layout there is a surface of 16 square meters reserved for the placement of a silo. This implies that when the diameter of a tank will be 3.5 meter there is a buffer zone, because the silo's or other storage equipment cannot be placed against each other. This 16 square meter will be enough to place the tank and it will not be too close to other equipment. Therefore for both silo's 16 square meters are reserved.

As mentioned in the previous parts, the other input materials do not need a tank in the beginning years of the ReFertilizer project. These materials will be transported and stored at SUEZ either in an IBC or a barrel. The required surface for the storage of the ammonium sulfate from the semiconductor industry is limited to the maximum delivery per week. Current available amounts are based on a weekly two cubic meter delivery. Since an IBC has dimensions of 1 meter by 1.2 meter, the surface of an IBC is 1.2 square meter and there is 2.4 square meter required of surface for the ammonium sulfate from the semiconductor industry. Because the IBC is developed in such a way that it is possible to store in height it is possible to store more than one IBC at the surface. On a surface of one IBC it is possible to store two or three IBCs which results in the fact that 2.4 square meters are enough for the current situation and even provides a buffer zone because the IBCs can be stored in height.

The storage of the ammonia is done within barrels. A barrel has generally a capacity of 200 liters, which results in the fact that five barrels are equal to one cubic meter. The barrels are generally stored on pallets, where four barrels fit on one pallet. As mentioned before there are 28 barrels required on a monthly basis. When assuming that four barrels fit on a pallet there are seven pallets required for the monthly storage of the ammonia. A pallet has dimensions of 0.8 meter by 1.2 meter, resulting in a surface of 0.96 square meter. The same as with the IBCs, used for the storage of ammonium sulfate and sulfuric acid, it is possible to pile up these pallets in stacks of two or three. When assuming that stacks of two are prevailing, there is the possibility to store four pallets at this surface. This complete surface sums up to 3.84 m^2.

The storage of the sulfuric acid will be based on the assumption that on a monthly basis around 1.81 cubic meters of material will be required. To simplify calculations we will use two cubic meters because this equals two IBCs. Therefore the same space requirements as for the ammonium sulfate from the semiconductor industry will be used.

The reactor vessel that will be used for the production is expected to have the same dimensions as the storage tanks of the input materials. The surface that will be used for the reactor vessel will therefore be 16 square meters as well. As mentioned in the previous sections the reactor vessel should be around 24 cubic meters in order to meet the required production quantities over the years. With a 24 cubic meter reactor vessel it will be possible to produce 10,000 tons of inorganic fertilizer on the long term by performing one batch per day (see table 5-6 and 5-7). However, in order to increase the functionality of the reactor vessel, the surface will be increased to 36 m². This increase yields extra space in order to produce the product. The reactor vessel requires additional space to operate and test.

Besides the storage facilities for the input materials and the reactor vessel there is a (temporarily) storage location required for the storage of the produced inorganic fertilizer. When the large amount of final fertilizer products are produced there are also large storage locations required. When 10,000 tons of inorganic fertilizer are produced on a yearly basis the produced weekly amount of product will be 165.32 cubic meter. Storage of these large amounts can be temporarily at the location of SUEZ in one or two storage tanks. When one tank will be used the required capacity will be 180-200 cubic meter, when two tanks are used the capacity of the tanks will be around 90-100 cubic meters. These amounts are relatively large and will require additional investment for most likely temporary storage of the produced inorganic fertilizer. However, production of these large amounts has not been taken into account in this report.

Equipment	Width required (m)	Length required (m)	Space required (m^2)
SF1	4	4	16
SF2	2	1.2	2.4
SF3	2	1.2	2.4
SF4	0	0	0
SF5	4	4	16
SF6	2.4	1.6	3.84
RV	6	6	36
SFF	4	4	16
Total	-	-	84

Table 5-20: Space requirements per equipment

The required space per equipment is used in section 5.5.6 to define the space relationship diagram. This figure shows the relationships of the figure 5-15 in 5.5.3 combined with the outcomes of this section, summarized in table 5-20.

5.5.5 Space availability

To draw a suitable production layout it is important to define the right amount of space that is available. Within the description of the possible options for producing inorganic fertilizers this information has already been described. As mentioned in the part on production facilities there are three different options considered to be relevant in this ReFertilizer project. The ONO installation, the Spent Catalyst installation and the building of a new production line. When considering space availability we will analyze the possibilities for the production of inorganic fertilizers in large quantities. When these quantities (2,000 – 10,000 ton of final product) will be

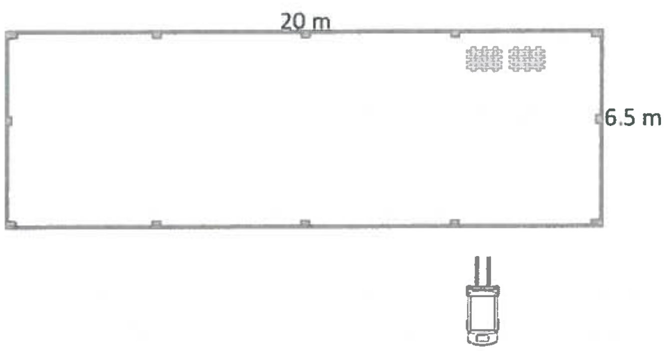

Figure 5-16: Spent Catalyst installation

produced, it will be hard to produce these products in or next to the ONO installation. The ONO installation has an occupancy that is too high and the space next to the ONO installation is considered to be too small for the large equipment requirements. Remains the Spent Catalyst installation, this installation is build within a roofed location that is open and accessible from the front. The dimensions are 6,5 meter by 20 meter, resulting in a 130 square meter surface (see figure 5-16).

The other option is to start with a new production facility on a location that is currently not used by SUEZ for an installation. As mentioned in the part on the production facilities, this can be achieved on a location where currently a building is situated that is outdated and not used anymore. This surface has dimensions of 12 by 17.5, resulting in a surface of 210 square meter. However, the surface required to build a production facility for the ReFertilizer project will not comprise that amount of square meters. Therefore a design will be made with the minimal amount of space required in an optimal layout.

5.5.6 Space relationship diagram

Figure 5-17 displays the space relationship diagram. This diagram is a combination of the space requirements that are described and summarized in section 5.5.4 and the relationship diagram in 5.5.3. The figure takes into account the right required surfaces of the facilities and it takes into account the relationships between the facilities and the importance of these relationships. Based on this space relationship diagram it is possible to develop alternatives for the production layout, taking into account the modifying considerations and practical limitations in 5.5.7. Compared to the relationship diagram that has been formulated in section 5.5.3, this space relationship diagram does not take into account the SF4. This storage part has initially been developed for the storage of the virgin sulfuric acid from the manufacturer. However, under the current situation, where a large amount of 'waste' sulfuric acid is available, it will not be necessary to buy 'virgin' sulfuric acid. Therefore this storage part is left out of the space relationship diagram.

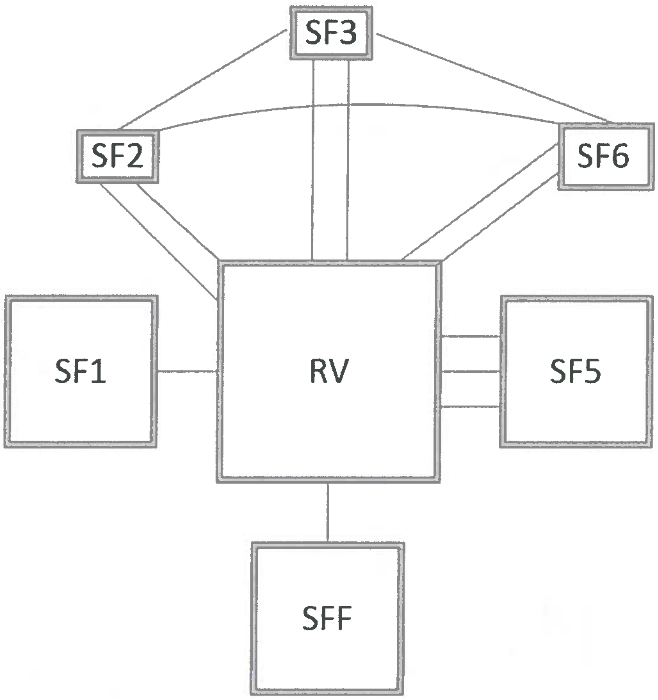

Figure 5-17: Space relationship diagram

5.5.7 Modifying considerations and practical limitations

When designing a plant layout for the production of inorganic fertilizers it is important to take into account the modifying considerations and practical limitations. When considering the first option, the spent catalyst installation, it is important to take into account that the location is only accessible for forklift trucks from the front side. This is important when transporting materials to or from the production location. Especially the barrels and IBCs because these will have to be brought in by a forklift truck. Also the reactor vessel will have to be accessible from the front side because the IBCs and the barrels will have to be pumped in there. Besides that, it is important to load and unload the storage tanks for the input and final output materials. Figure 5-18 is the traffic circulation plan that is designed within previous research projects for SUEZ. Note that our project only focuses on the left part of the figure. The figure is based on the plant layout such as displayed in figure 4-5 and 5-5. The arrows in the image represent the traffic movements for the large trucks and tankers. These trucks and tankers can load and unload their materials at the load/unload places that are marked within the figure. As can be seen on the traffic circulation plan, the load and unload for the outdated spent-catalyst installation is at the side of the location. This means that the materials that are transported to SUEZ by the trucks or tankers (such as those in figure 5-19), should be loaded and unloaded at this location. The materials that will be loaded at this location will be the final inorganic fertilizer product, where the products that will be unloaded at this load/unload point will be the ammonium sulfate from the farms and the urea that is bought by SUEZ.

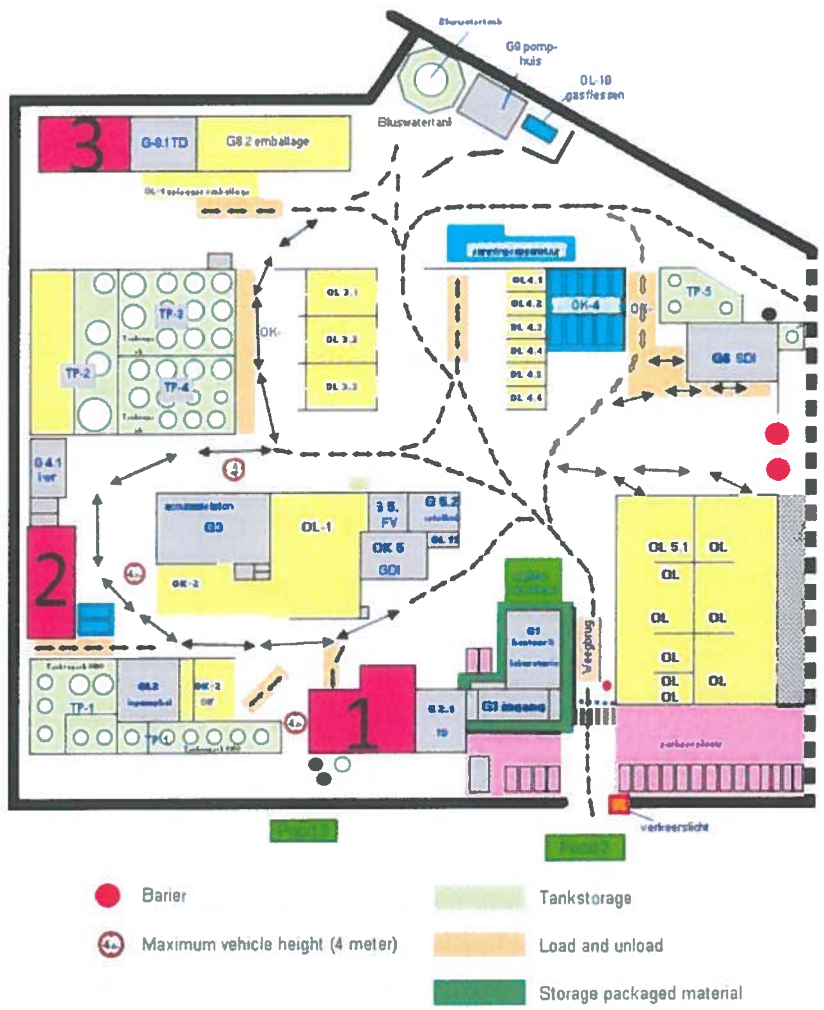

Figure 5-18: Traffic circulation plan of SUEZ Almelo. Internal document (2010)

Figure 5-19: Truck and tank used for loading and unloading

Considering the option where a new production layout can be build from scratch there will be no major practical limitations or modifying considerations that will have to be taken into account. Because the available space is relatively large (210 m²) and there are no further obstacles it is possible to design a layout. This layout will take into account the space requirements and availability but this design will be relatively easy. The layout can be designed in an optimal way without the need to reckon with any limitations. As can be seen in the figure of the traffic circulation plan (figure 5-18) there are currently no load/unload points assigned to this location. When considering load/unload points for this location the only side that will be not accessible will be the backside which is adjacent to the boundary of the SUEZ site.

5.5.8 Developing alternatives

Alternative layouts can be designed in various ways. They can be developed by executing an algorithm or they can be drafted based on trial and error. Because the space relationship diagram in this ReFertilizer project is not considered to require an algorithm, it can be drafted by trial and error. Based on the space requirements, the activity relationships, the space availability and the modifying considerations & practical limitations it is possible to develop alternative layouts.

When considering the spent catalyst installation (numbered 2 in figure 5-18) the amount of alternatives that can be designed is limited. Because of the fact that the width of the location is only 6.5 meters, it is not possible to place the tanks or reactor vessels next to each other in width. The reactor vessel requires a width of 6 meters and the tanks require a width of 4 meters. Therefore the reactor vessels and the tanks will have to be placed in line over the length (20 meter) of the location. This should be possible because the sum of the lengths of the tanks and the reactor vessel is 18 meter. Besides the limited width of this location, the location is only accessible for a forklift truck from the front side. Therefore the IBCs and barrels will have to be stored at the front side of the location, or at least not behind the tanks and reactor vessel. The loading and unloading of the tanks and silo can be performed from the side of the spent catalyst installation (see figure 5-18), there is a load/unload point where the substances can be pumped into the tanks or silo. These limitations strongly reduce the amount of alternatives. The alternatives that can be developed, based on the above, are outlined in figures 5-22, 5-23 and 5 -24.

Alternative layout 1 takes into account the fact that the current reactor vessel will be used. In this case the reactor vessel will be situated to the far right. Disadvantage is that the current reactor vessel has a capacity of only 6 cubic meters. The SF5, the storage equipment for the urea will be placed next to the reactor vessel because it has a absolutely necessary relationship. In this case it is not possible to locate SF2, SF3 and SF6 (all especially important) close to the RV

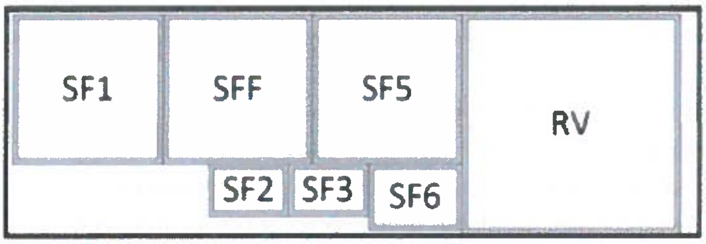

Figure 5-20: Alternative layout 1 - Spent catalyst installation

because there is no space left for all three. The first alternative layout (figure 5-2) is considered to be a suitable option when the current reactor vessel (RV) will be used. All other alternatives are worse or six of one half a dozen of the other.

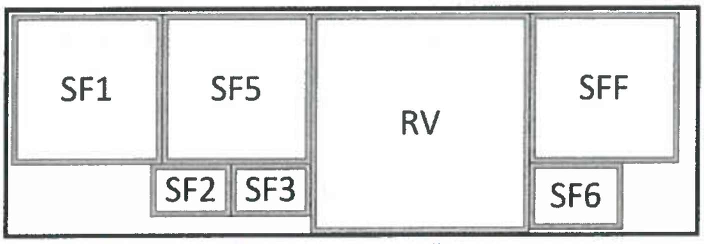

Figure 5-21: Alternative 2: Spent catalyst installation

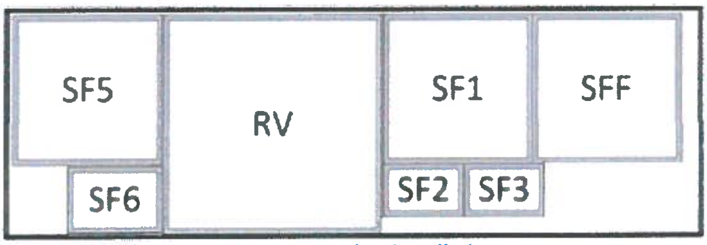

Figure 5-22: Alternative 3 - Spent catalyst installation

However, when production will be increased over the years and a larger reactor vessel will be required, it is useful to install a larger reactor vessel. Because the reactor vessel can be placed at a location other than the current location, it is possible to draft other layouts. These layouts are the second and third alternative layouts (figure 5-21 and 5-22). Within both the alternative layouts the SF5 is located close to the RV (absolutely important). Besides this the SF2, SF3 and SF6 (which have an especially important relationship with RV) are located close to the RV. Also the SF2, SF3 and SF6 are accessible from the front side of the location. However, the load/unload location for trucks and tanks is located at the left side of the layout. Because the material in SF5 (urea) is in a solid state, it is considered to be harder to unload this substance. Therefore it is more convenient to locate the SF5 equipment close to the load/unload point at the left side. This implies that out of the three alternatives, the best alternative is considered to be alternative 3 (figure 5-22).

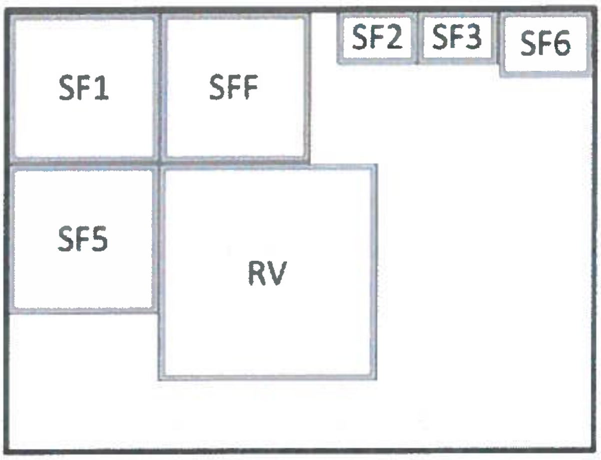

Figure 5-23: Alternative 1- new installation

Analyzing the possibilities for the other option on the plant of SUEZ Almelo (numbered 3 in figure 5-20), there are different alternatives that can be drafted. Working with this facility under the assumed dimensions of 12 by 17.5 meter, there are more possibilities when developing alternatives. The surface possible to build an installation is larger within this option compared to the spent catalyst installation. Besides this, there is the advantage that the width of this option is larger (12 meter instead of 6.5 meter). Therefore there is a possibility to place tanks or a tank and the reactor vessel next to each other in width. However, it is not possible to place the tanks and silo in line over the length. This is possible within the spent catalyst installation. Because there is currently no tank or reactor vessel installed it is possible to draft any layout, given the dimensions of the facility and the equipment's. Limitation is that the location is only accessible from the front side and it is only possible to load/unload there and enter the location with a forklift truck from here. Therefore it is more useful to place the storage equipment for the urea (solid substance) at the front side. It is easier to load the solid substance compared to the other tanks that will be loaded with liquid materials (ammonium sulfate and fertilizer product).

When analyzing the first alternative in figure 5-23, it can be concluded that SF5 is close to the RV. This is the most important relationship, however the second most important relationships are not situated close to the RV. Other important aspects, the accessibility from the front for loading/unloading of trucks and forklift trucks, are taken into account. Reviewing the other two alternatives that have been drafted reveals that the other (especially) important activity relationships are taken into account. Because there is enough space available it is possible to connect all important equipment's and locate them in a proper way. Therefore the second and third alternative are considered to be better than the first alternative. Comparing the second and the third alternative shows that both alternatives take into account the importance relationships and both take into account the accessibility for the tanks and (forklift) trucks. Based on the theory of Muther, both options are considered to comply to the activity relationships and the modifying considerations and practical limitations. Therefore both alternatives can be considered to be suitable for the production of inorganic fertilizers. However, alternative 2 is selected within this ReFertilizer project because it might be more practical. There is more space available around the reactor vessel and the storage equipment. There it is easier to walk around or drive around with the forklift trucks. Within figure 5-25 there is less space available to enter the space of the reactor vessel.

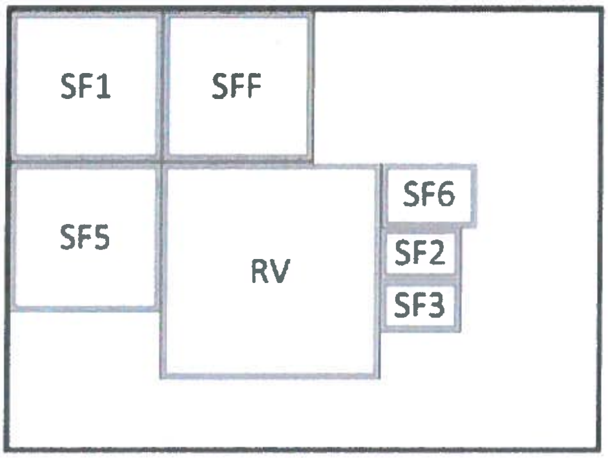

Figure 5-24: Alternative 2 - new installation

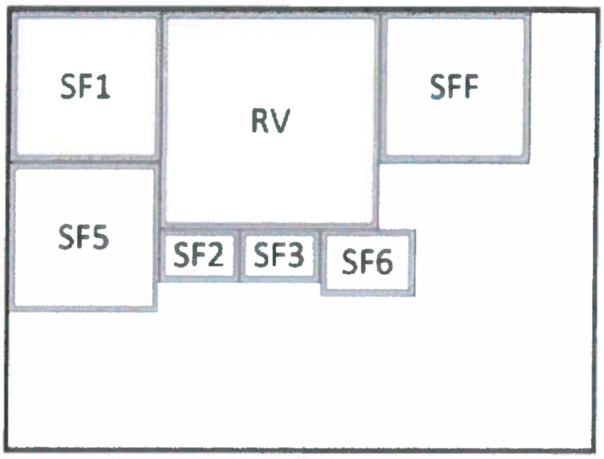

Figure 5-25: Alternative 3 - new installation

5.5 Conclusion

This chapter describes the production process of the ReFertilizer project and the required equipment's and storage facilities. The first part of this chapter visualizes the production process in a flow scheme, hereafter the relevant production options are described. The options are ranked based on the costs and availability of the material. The ranking of the materials can be found in table 5-21. The options are based on one or two material streams and all options are complemented with ammonia and urea.

Option	Material 1	Material 2
1	Ammonium sulfate from farms	Ammonium sulfate from semiconductor industry
2	Ammonium sulfate from farms	Sulfuric acid from semiconductor industry
3	Ammonium sulfate from farms	Virgin sulfuric acid
4	Virgin sulfuric acid	N.A.

Table 5-21: Ranking of production options

The next section within this chapter (5.1) describes the storage of input materials. The required storage facilities for the input materials are based on the data from table 5-22. Assumed is that the input materials (except the ammonium sulfate from the semiconductor industry) are supplemented every month. Based on this data it is advised to use a storage tank for the ammonium sulfate farms, a lime silo for the urea, IBCs for the ammonium sulfate from the semiconductor industry and sulfuric acid from the semiconductor industry and to use barrels for the storage of ammonia.

	Yearly	Monthly
Total material amounts required	**Volume (m^3)**	**Volume (m^3)**
Ammonium sulphate from farms	906.80	75.57
Ammonium sulphate from semiconductor industry	103.53	8.63
Sulphuric acid from semiconductor industry	21.76	1.81
Sulphuric acid (96%)	0.00	0.00
Urea	612.00	88.71
Ammonia	66.02	5.50
Fertilizer	1710.11	142.51

Table 5-22: Required yearly and monthly production volumes

The production of the inorganic fertilizers in the quantities of table 5-22, based on the ranking of table 5-21, can be produced in a certain way based on a number of production steps. The production options in table 5-21 can be produced by performing the steps in table 5-23. These production steps will have to be performed in the predefined sequence in order to produce an inorganic fertilizer. For producing these inorganic fertilizers there have been three different facilities that could be used. However, due to the large amounts of output product the ONO installation is considered to be useless because of the

Production step	Description
1	Add primary substance to reactor vessel
2	Add secondary substance to reactor vessel
3	Add urea to the reactor vessel
4	Measure the pH value of the mixture in the reactor vessel
5	Add ammonia to the reactor vessel
6	Sample the mixture in the reactor vessel
7	Transport the mixture from the reactor to the final product storage

Table 5-23: Production steps for producing inorganic fertilizers

occupancy and space available. The remaining facilities are the spent catalyst and a new production facility. These facilities are, under the current circumstances, considered to be available for the production of inorganic fertilizers. The production equipment should exist of storage equipment for both the incoming and the produced material. But also a reactor vessel in which the incoming materials can be added. This reactor vessel should be double walled and isolated, such that the inside temperature cannot decline. Besides this it should contain a pump that rotates the substances and it should contain a heat exchanger. When the production quantities produced on a yearly base are 2,000 ton the capacity of the reactor vessel should be 6 m^3, where for the production of 8,000 ton or 10,000 ton the vessel should have a capacity of 24 m^3. Producing 4,000 and 6,000 ton of inorganic fertilizer can be achieved by a batch capacity of 12 m^3.

For the storage of the produced inorganic fertilizer there are several possibilities. The final product can be stored internally (within SUEZ Almelo) or externally. Because the products can only be sold during the period between February 1 and September 1 the storage facility requires a lot of capacity. These capacities rise up to more than 3,500 cubic meters of stock for a production level of 10,000 ton of inorganic fertilizer and 712 cubic meter for the production of 2,000 ton of inorganic fertilizer. These amounts are considered to be so high that storing within SUEZ Almelo is not considered to be an option. The other option is external storage. External storage consists of two options, the storage within a warehousing company and the storage within a bag tank. Because the storage within a warehouse is considered to be too costly, the storage of inorganic fertilizers within bag tanks are considered to be the best option. These bag tanks have capacities of more than 7,000 cubic meter.

Production (ton)	Highest stock (m^3)
2000	712.79
4000	1425.58
6000	2138.38
8000	2851.17
10000	3563.96

Table 5-24: Production quantities and related stock levels

The last part that has been disclosed in this chapter is the production plant layout. The theory of Muther is applied to design several possible layouts, taking into account the space availability and relationships between equipment. The best layout for the spent catalyst installation can be found in figure 5-26 where the best layout for a completely new production line can be found in figure 5-27. These layouts are suitable layouts and take into account the relevant space requirements, space availability, space relationships and the modifying considerations & practical limitations.

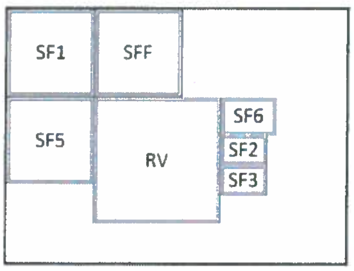

Figure 5-27: Best alternative option 2

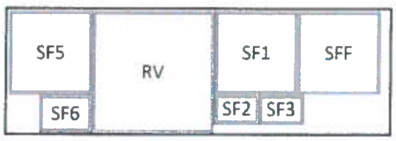

Figure 5-26: Best alternative option 1

6. Financial

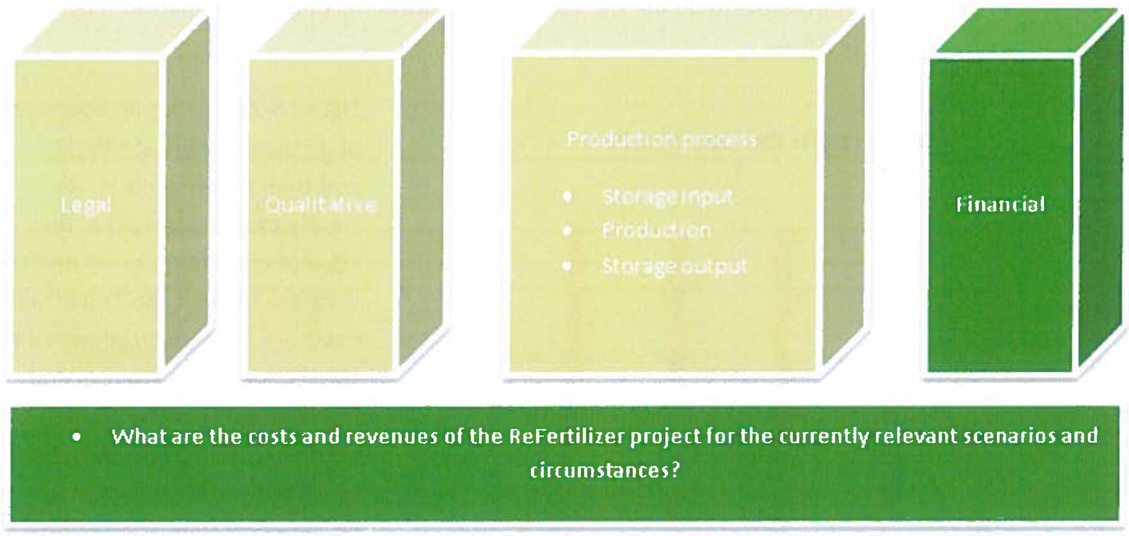

Figure 6-1: Fourth block ReFertilizer project

This chapter will outline the most important financial aspects of the ReFertilizer project. Within SUEZ there has been some effort in gathering information on the financial aspects of the project. This internally available information, together with market information, will be used to address a number of financial aspects. The costs for the production of the fertilizers will be outlined, the investment costs for the production facilities will be outlined and the market aspects of the fertilizer product will be described. Based on this information and assumptions it is possible to do a few financial analyzes. The first section that will be addressed are the costs for the fertilizers to be produced. This part has already been described in section 4.3.3 to define what the most suitable fertilizer combination would be for SUEZ. This information will be used within this chapter to create a better view on the total costs of the ReFertilizer project. After the costs of the fertilizers, the next section will describe the investments costs that are relevant for producing inorganic fertilizers at the SUEZ location in Almelo. The other section in this chapter will define the market for inorganic fertilizers. Based on this market information it is possible to do assumptions on what the revenues can be for SUEZ. Last section will be the summary and conclusion of all other sections, defining the most important financial opportunities and possibilities.

6.1 Production material costs

This section describes the material costs that are relevant for the production of liquid inorganic fertilizers. The costs for the produced fertilizers are based on the virgin materials that are used within the materials. As already mentioned in section 4.3.3, the only costs that

Product	Costs per ton (€)	
Washing fluids	€	-
Ammonium sulphate	€	-
Sulphuric acid	€	145.00
Urea	€	340.00
Ammonia	€	330.00
Water	€	2.50

Table 6-1: Purchasing costs virgin materials

are taken into account in the ReFertilizer project are the costs for the virgin sulfuric acid, urea, ammonia and water. The costs for these materials per ton are visualized in table 6-1. Based on these costs and the tests from the laboratory it is possible to define the costs per produced fertilizer combination. The waste materials are considered to be free.

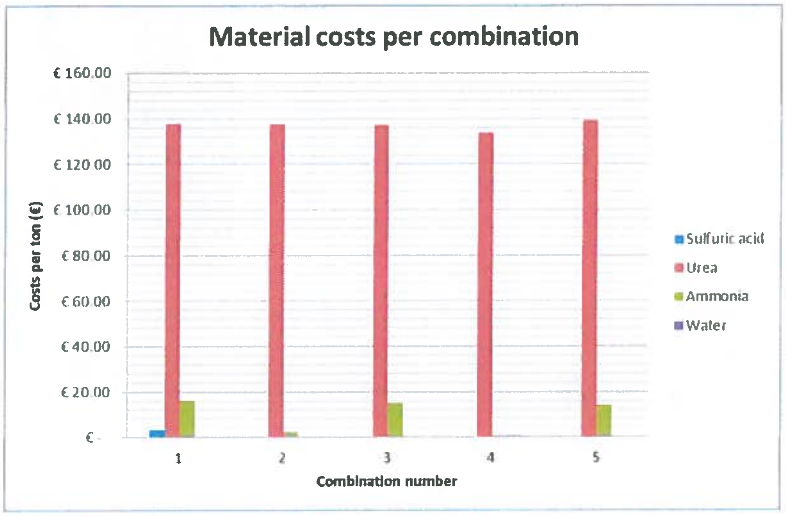

Figure 6-2: Material costs per fertilizer combination

Figure 6-2 provides an overview of all the relevant combinations and their material costs. As clearly can be concluded, the ratio of costs that are related to urea are the highest. The other costs are negligible compared to the costs on urea. The second highest costs are the costs related to ammonia. The costs for sulfuric acid and water are very low percentages of the total material costs.

Within the introduction of chapter 5, the sequence is outlined that should be followed in the production process for fertilizers. For different reasons (costs, availability, etc.) the first option that should be produced is the ammonium sulfate from farms combined with the ammonium sulfate from the semiconductor industry. When the ammonium sulfate from the semiconductor industry is completely used in production, the second option (ammonium sulfate from farms combined with sulfuric acid from the semiconductor industry) should be produced. This combination, together with the first combination, are available in such large quantities that 2,000 ton of inorganic fertilizer can be produced. With the current available information 678 ton of the first combination and 1322 ton of the second combination should be produced. Using the material costs per ton for both combinations it is possible to calculate the total production costs. This turns out to be €296,809.72 (see table 6-2). This results in the weighted average material costs per ton fertilizer of €148.40.

Combination	Costs per ton (€)	Amount of fertilizer (ton)	Total costs (€)
1	€ 139.64	678	€ 94,675.92
2	€ 152.90	1322	€ 202,133.80
			€ 296,809.72

Table 6-2: Total production material costs when producing 2,000 ton of inorganic fertilizer

6.2 Investment costs installation

Starting with the production of inorganic fertilizers requires additional investments by SUEZ Almelo. Either by updating the older spent catalyst installation or by building a new installation. These options have been described in the previous chapter (chapter 5). Calculations are required on the costs for an installation to produce inorganic fertilizers. Two possibilities have been considered to be relevant in the previous chapters. Previous internal information on the updating of the outdated installation revealed that the estimated costs for updating are €45,000, consisting of a number of cost categories. These costs are the costs that are required to update and modify the outdated spent catalyst installation and other additional pipes, vessels, silo and tanks that should be installed. The costs for these investments can be found in table 6-3 (option 1). Disadvantage of using this installation is the limited capacity of this reactor vessel. When replacing this reactor vessel by a larger reactor vessel the costs are (roughly) considered to be equal to building a new production line.

The costs of building a new production line are considered to be higher because the additional costs of buying and installing a new reactor vessel are involved. This option does also involve the costs for lime pipes, vessels, silo's and tanks. The costs for the building of a new installation can also be found in table 6-3, under option 2.

The costs in table 6-3 provide an overview of the estimated investments that are required for both possible options. Calculations are based on the current market values and experiences with previous investments.

Investment			
	Option 1 (Spent catalyst installation)		**Option 2 (New installation)**
Lime silo urea	€ 15,0000.00	Lime silo urea	€ 15,0000.00
Storage tank and pumps	€ 20,0000.00	Storage tanks and pumps	€ 20,0000.00
Adaptions	€ 10,0000.00	Pipes and valves	€ 10,0000.00
		Reactor	€ 30,0000.00
Sum of investments	**€ 45,0000.00**	**Reactor**	**€ 75,0000.00**

Table 6-3: Investments for both installation options

6.3 Revenues

The revenues are a major aspect of the financial part. Self-evidently this is important to make sure that the ReFertilizer project is profitable. However, there is little information on the revenues because there are not many companies available or willing to provide information on this sensitive information. Besides this, the ReFertilizer project is a product-form that has not been introduced to the market in large quantities before. It is important to gather more information on this subject in order to make the ReFertilizer project a success. On the one side this market information will be used to define the selling price of the product and thereby the revenues of the project. On the other side the information that is derived from the financial analysis that has been done will be used. The analysis defines a number of costs that are related to the ReFertilizer project and based on these costs and the financial ratio's it is possible to define what EBIT or EBITDA ratio's compared to the revenues can be achieved and what is desired by the higher authorities of SUEZ.

Market values from different suppliers reveal costs of inorganic liquid fertilizers of €28-€30 per 100 kilograms. This means prices between €280 and €300 per ton of fertilizer. In order to be competitive and because the product will be new in the market the prices per ton fertilizer will be set around €275 per ton. When starting the project with a quantity of 2,000 tons during the first year this will result in a revenue of €550,000. Table 6-4 shows the revenues during the starting years of the ReFertilizer project, the financial analysis takes into account a slower growth rate than used in the previous chapters to take into account any disappointing sales. The yearly production is set to increase yearly with an amount of 200 ton fertilizer product. The starting price for the fertilizer product starts the first year with €275, where an yearly increase of 2% is considered to be achievable. These revenues are used in the remainder of this chapter on the valuation of the ReFertilizer project.

Revenues		Year				
		1	2	3	4	5
	Ton					
	1	2,000	2,200	2,400	2,600	2,800
Price per ton	€ 275.00	€ 275.00	€ 280.50	€ 286.11	€ 291.83	€ 297.67
Sum of revenues		€ 550,000.00	€ 617,100.00	€ 686,664.00	€ 758,763.72	€ 833,472.76

Revenues						
		6	7	8	9	10
	Ton					
	1	3,000	3,200	3,400	3,600	3,800
Price per ton	€ 275.00	€ 303.62	€ 309.69	€ 315.89	€ 322.21	€ 328.65
Sum of revenues		€ 910,866.66	€ 991,022.93	€ 1,074,021.10	€ 1,159,942.79	€ 1,248,871.73

Table 6-4: Yearly revenues based on 2,000 ton of production

6.4 Valuation

To define whether the project can be viable when starting the production of inorganic fertilizers it is important to do a valuation of the ReFertilizer project. The previous sections (material costs, investment costs and revenues) will be used in this valuation part. These previous sections will be supplemented with a number of additional cost assumptions. Besides the material costs and required investments, it takes into account the costs for labor, electricity, maintenance, location and transportation. These costs influence the profitability of the project and are added to appendix 10. In order to do a valuation of the project it is important to valuate the project over a number of years, for this project the timespan that is considered to be relevant is 10 years. Because the costs and revenues will change in the course of time, it is important to index these numbers. For all relevant costs and revenues a number of indexations are used. These indexation numbers are also added to appendix 10.

With these numbers an analysis has been performed to define the profits or losses of the project during the years. At first all revenues are listed, as defined in section 6.3. From these revenues the costs of goods sold (COGS) are deducted. This calculation reveals the gross margin of the project, to define the EBITDA the SGA costs have been deducted. The SGA costs consists of the selling, general and administrative expenses. Besides this it is possible to define a percentage of overhead costs for the head quarters or regional department of SUEZ, these costs will also be deducted from the gross margin. When these costs are deducted the EBITDA has been calculated. The only thing that should be deducted from the EBITDA to calculate the EBIT are the depreciation and the amortization. A tax rate has been used to define what remains after deducting the taxes from the EBIT. This net operating profit is used in the remainder of the valuation. All details on these assumptions can be found in appendix 10.

The outcomes of the analysis for the profit and loss for both options (spent catalyst installation and new installation) can be found in table 6-6.

P&L										
Year	1	2	3	4	5	6	7	8	9	10
Option 1										
EBIT	€ 7,895.89	€ 2,107.88	€ 10,919.38-	€ 13,144.78	€ 22,308.35-	€ 22,749.88	€ 28,349.46	€ 14,521.72	€ 41,299.45	€ 48,716.92
EBIT%	1.58%	0.50%	1.90%	2.47%	2.99%	3.49%	3.96%	4.40%	4.83%	5.24%
NOPAT	€ 7,895.89-	€ 2,107.88	€ 10,919.38-	€ 13,144.78	€ 22,308.35-	€ 22,749.88	€ 28,349.46	€ 14,521.72	€ 41,299.45	€ 48,716.92
Option 2										
EBIT	€ 10,895.89-	€ 189.49-	€ 8,169.38-	€ 10,894.78	€ 9,558.35-	€ 20,499.88	€ 26,099.46	€ 17,271.72	€ 39,049.45	€ 46,466.92
EBIT% / ROS	2.18%	0.03%	1.43%	2.05%	2.61%	3.14%	3.64%	4.12%	4.57%	5.00%
NOPAT	€ 10,895.89-	€ 189.49-	€ 8,169.38-	€ 10,894.78	€ 9,558.35-	€ 20,499.88	€ 26,099.46	€ 17,271.72	€ 39,049.45	€ 46,466.92

Table 6-6: EBIT and NOPAT values for both options

To define if the project is profitable over this 10 year time span it is important to do a final valuation. To do this, calculations have been made on the costs of debt and equity. With these costs the WACC has been calculated, the weighted average costs of capital. Using this WACC and the NOPAT it is possible to define the net present value (NPV). This NPV defines the profit or loss that this ReFertilizer project will yield over the project time span. The assumptions that have been made to calculate the WACC can be found in table 6-6. Using this WACC percentage and the EBIT or NOPAT values it is possible to define the NPV of the project. The NPV values for the project can be found in table 6-7. This shows that both options will be profitable, however the first option will be more profitable than the second option. The first option outlines the updating of the outdated spent catalyst installation, which will require less investments at the start of the project. However, the first option requires more additional investments during the project lifespan. But the additional investments within the duration of the project do not result in lower profit values.

WACC	5.85%
Risk Free Rate	4%
Unlevered Beta	0.5
Market risk premium	5%
Costs of equity	8.29%
Interest rate	4.75%
Tax rate	28%
Cost of debt	3.40%
Debt/equity ratio	1
Equity	50%
Debt	50%

Table 6-5: WACC values to calculate NPV

	Option 1	Option 2
NPV	€ 30,678.38	€ 1,926.31

Table 6-7: Net present values of both production options

An important note that has to be taken into account is the fact that the calculations are based on a number of assumptions made by the author. Time restrictions limit the substantiation of this chapter. When SUEZ decides to continue with the ReFertilizer project it is important to do further research on these assumptions. Continuing the ReFertilizer project will have to include price inquiries and tenders.

6.5 Conclusion

Chapter 6 addressed the financial aspects of the ReFertilizer project. Besides the aspects that have been discussed in the previous chapters (legal, qualitative, production and storage) the financial aspect of the ReFertilizer project is important for the viability of the project. Negative financial outcomes of the financial analysis would mean that the project will not be profitable and therefore not considered to be of additional value for SUEZ. The chapter divided the financial aspect into different subparts, the production materials, investment costs, revenues and valuation.

Combination	Costs per ton (€)	Amount of fertilizer (ton)	Total costs (€)
1	€ 139.64	678	€ 94,675.92
2	€ 152.90	1322	€ 202,133.80
			€ 296,809.72

Table 6-8: Total production material costs

Important for the production of fertilizers are the production material costs. Because it is currently not considered to be possible to produce the inorganic fertilizers with only waste materials (see chapter 4), there are additional materials required. These additional materials will have to be bought by SUEZ. The prices for the materials per ton that will have to be bought can be found in figure 6-1. When producing the amount of 2,000 ton of fertilizer based on the combinations outlined in chapter 5 (see figure 5-3), the costs for the production materials are €296,809.12 (see table 6-6).

When the production of inorganic fertilizers will be performed in large quantities, there are additional investments required in the building or updating of a production facility. Related investment costs can be found in table 6.3. These costs differ per production option. Updating of the spent catalyst installation is assumed to require a lower amount of initial investment compared to the building of a completely new installation. However, the updating of the outdated installation will require additional investments later on. These additional investments have been taken into account in the financial part and are to be found in the valuation.

The revenues are based on previously prevailing rates for the inorganic fertilizers. Within the current market, with low commodity prices, the prices for fertilizers are under pressure. Market information revealed that the prices have decreased during the last year(s). However, this report uses average expected prices for the future.

Based on the costs and revenues mentioned in the section 6.1, 6.2 and 6.3 a valuation has been drafted in section 6.4. This valuation shows that, taking into account a number of assumptions, that the ReFertilizer project can be profitable. Table 6-9 below indicates that under the current circumstances the first option is more profitable than the second option.

	Option 1	Option 2
NPV	€ 30,678.38	€ 1,926.31

Table 6-9: Net present value of both production options

7. Conclusions and recommendations

This chapter presents the conclusions of our research followed by recommendations for SUEZ Almelo. The first section lists all conclusions on the different subjects that have been addressed in this report. The second section includes several recommendations for SUEZ Almelo to successfully continue with the ReFertilizer project.

7.1 Conclusions

7.1.1 Legal

The first chapter on all relevant legal aspects of the ReFertilizer project outlined several important aspects. At first all relevant information classes of the materials that are considered to be relevant are listed (EURAL codes, UN numbers, ADR classes, CE and CAS numbers). Thereafter additional information on the fertilizer types that are defined within the Dutch legislation are summarized.

Besides this general information there are two major aspects that are described in the legal part. The first part is the section on the end-of-waste directive. This directive creates the opportunity for companies to declare their waste material into a new product. For SUEZ this is an important directive because the ReFertilizer project is based on the transformation of waste materials into new product streams. There are two options to apply this directive. SUEZ can apply the end-of-waste directive to each incoming waste stream or it can apply the end-of-waste directive to the produced inorganic fertilizer. Based on the criteria that are drafted for the end-of-waste directive it is easier to achieve the end-of-waste directive when applying the directive to the inorganic fertilizer after production.

The next major legal subject is the REACH regulation, the regulation about the Registration, Evaluation, Authorization of CHemicals. REACH is applicable to all materials, but there are a few exceptions. One of these exceptions are the waste materials, because for waste materials there are other regulations that apply. The ingoing material streams used within this project that are not considered to be waste should comply to the REACH regulation. Because SUEZ produces a new material, this material should also comply to the REACH regulation. However, because the inorganic fertilizer is considered to be a mixture, SUEZ can meet the REACH regulation by making sure that all incoming materials used within the mixture, are registered. If it can be shown that all incoming materials are registered, SUEZ meets the requirements of the REACH legislation. If there are substances that are not yet registered within REACH, SUEZ should register these products.

Because SUEZ did not receive or treat the ammonium sulfate from farms before, this chapter outlined all legal aspects related to this 'new' stream. General, mixing, agronomic, environmental, packaging, labelling, sampling and storage requirements are listed.

The legal part also describes all relevant legal issues that are related to the production process. Important there is the environmental permit that is expected to be assigned mid-2016. This permit describes the process of 'formulating liquids and solids' and includes all relevant EURAL codes and Best Available Techniques (BAT) for the ReFertilizer project. Besides that, the Dutch Besluit Risico Zwaar

Ongeval (BRZO) is described and SUEZ has to identify and list possible risks and chances of accidents occurring.

The last part summarizes the legal issues for the outgoing material. Most important here are the minimum and maximum values that are required. Values on heavy metals, micro-organic pollutants, nutrient levels, bacteria and viruses are important. These values will have to be investigated by an accredited laboratory. The application date is another important aspect (February until September) for the most common fertilizers.

7.1.2 Qualitative

This chapter describes the most common fertilizer types and the fertilizer market. The fertilizer industry is expanding, where the Dutch market seems to stagnate. The chapter describes all possible fertilizer types. Based on the available waste material streams, the most obvious fertilizer type to produce by SUEZ is the ammonium sulfate fertilizer. In order to comply to the legal maximum and minimum values, mentioned in chapter 1, SUEZ performed a number of tests within the laboratory to define the maximum level of heavy metals and the level of nutrients in all relevant substances. All tests showed positive results, where no maximum values of heavy metals are exceeded and all minimum levels of macronutrients are exceeded.

Based on test batches that have been produced by the SUEZ laboratory, it is possible to define what combinations can be made. The outcomes of these tests have been summarized in table 7-1. The outcomes show that the ammonium sulfate from the semiconductor industry diluted with water is the cheapest option where the ammonium sulfate from farms combined with virgin sulfuric acid turns out to be the most expensive option. The next section will determine what options are considered to be useful for the production process, taking into account the cost aspect and other aspects of the materials.

Ranking mixed substances				Costs per ton (€)
Water	AS from semiconductor industry	Urea	Ammonia	€ 134.87
AS from farms	AS from semiconductor industry	Urea	Ammonia	€ 139.64
AS from farms	ABS from pharmaceutical industry	Urea	Ammonia	€ 152.17
AS from farms	SA from semiconductor industry	Urea	Ammonia	€ 152.90
AS from farms	SA (virgin)	Urea	Ammonia	€ 157.34

Table 7-1: Cost ranking test batches

7.1.3 Production

After analyzing all relevant aspects (costs, availability, origin) of the combinations mentioned in table 7-1. the best combination to produce by SUEZ Almelo is ammonium sulfate from farms with ammonium sulfate from the semiconductor industry. Because the ammonium sulfate from the semiconductor industry is a very valuable material stream this should be used in production until there is nothing of this material stream left or until the required production amount is reached. The second option is to use the ammonium sulfate from farms with the sulfuric acid from the semiconductor industry. An achievable amount of inorganic fertilizer that can be produced is 2,000 ton. Based on this amount and the available input materials there is enough material available to produce 2,000 ton out of the first two

	Yearly	Monthly
Total material amounts required	**Volume (m^3)**	**Volume (m^3)**
Ammonium sulphate from farms	906.80	75.57
Ammonium sulphate from semiconductor industry	103.53	8.63
Sulphuric acid from semiconductor industry	21.76	1.81
Sulphuric acid (96%)	0.00	0.00
Urea	612.00	88.71
Ammonia	66.02	5.50
Fertilizer	1710.11	142.51

Table 7-2: Required monthly and yearly volumes

combinations. The required input amounts (m^3) on a yearly and a monthly base can be found in table 7-2. The large demanded amounts of ammonium sulfate from farms and urea, require SUEZ to invest in large storage facilities. The ammonium sulfate from farms can be stored in a tank where the urea can be stored in a lime silo. The other materials can be stored in IBC's, where the ammonia can be stored in barrels.

Production of the fertilizers can be performed by doing a number of production steps. These steps will have to be performed in a predefined sequence and are described in table 5-23. When considering the production of inorganic fertilizers in large quantities, there are two production facility options. The production can take place in the, currently out of use, spent catalyst installation. Or a new installation can be build. A production facility should include storage equipment for all input and output materials and a reactor vessel. This reactor vessel should be double walled, isolated and contain a pump and heat exchanger. For the production of 2,000 ton of inorganic fertilizer the reactor vessel in the current spent catalyst installation is suitable, when production amounts are increased the size of the reactor vessel should also increase.

Storing of the produced inorganic fertilizer is considered to be a problem for this ReFertilizer project. The period that the products can be sold is limited, February 1 up to September 1, but the production will be equal during the year. Therefore stock levels will increase and because of the crystallization of urea, the substance cannot be stored at locations that have too low temperatures. Storage at an external warehouse or at a (new to build) warehouse at the SUEZ Almelo location is considered to be too costly. Storage within bag tanks is considered to be an option, because this option is relatively cheap and is capable of storing high capacities. However, this possibility will have to be better explored because it is unknown what happens when the temperature decrease during the winter periods.

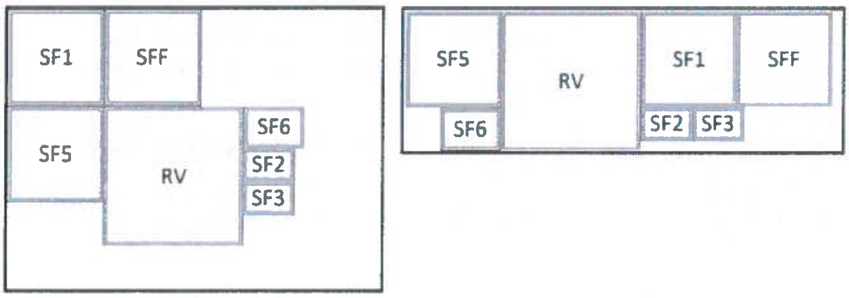

Figure 7-1: Proposed layouts for production facility

In order to build a (new) production plant for the inorganic fertilizers, two options have been designed to build a production plant. One option for the spent catalyst installation and another option for the new to build installation.

The proposed layouts take into account the space availability, relationships and space requirements. The layouts can be seen in figure 7.1, where the description of the abbreviations can be found in chapter 5.5.

7.1.4 Financial

Last part of this chapter addresses the financial aspects. All costs have been evaluated and listed, revenues have been estimated and based on the costs and revenues a valuation of the project has been made. Based on the tests that have been performed by the laboratory of SUEZ it is possible to define what additional substances are required, and what the total costs of these additional substances will be. The material costs vary between the €140 and €150. Based on the expected production quantity of 2,000 ton that have been mentioned in the qualitative and production part, the material costs are around €296,809. With these material costs, other relevant costs (labour, electricity, maintenance, installation, etc.) and revenues a valuation has been developed. This valuation is based on a ten year project plan, where different assumptions are made for the costs, revenues and the developments of these costs and revenues over the ten year. The valuation resulted in the NPV of option 1 (spent catalyst installation) and option 2 (new installation). The NPV shows that, with the current production quantities, it will be better to upgrade the spent catalyst installation. Disadvantage of this financial analysis is that it is based on a high number of assumptions and that the raw material costs have fluctuated during the last few quartiles. In order to increase the knowledge level on the financial aspects of the ReFertilizer project it is important to further research this subject.

	Option 1	Option 2
NPV	€ 30,678.38	€ 1,926.31

Table 7-3: NPV of both production options

7.2 Recommendations

This report investigated a number of aspects that are related to the ReFertilizer project, conclusions of this research can be found in the previous section 7.1. However, due to the time span of this master thesis not all aspects have been elaborated in the detailed levels as it should have been. There are a number of recommendations that should be taken into account. Therefore a number of recommendations will be provided to SUEZ to continue with this project and to determine the best continuation for this project.

Phase	Action	Date	Actor
1	Achieve end-of-waste status	Q3 – 2016	HSE manager
2	Find company to investigate product	Q2 – 2016	Head of laboratory
3	Define amount to produce	Q2 – 2016	Director treatment and manager hazardous waste
4	Define where to produce	Q2 – 2016	Director treatment
5	Extensive financial analysis	Q3 – 2016	Manager hazardous waste
6	Look for new high-quality waste flows	2016	Waste manager
7	Make Go / No-Go decision	Q4 – 2016	*All actors*

Table 7-4: Folluw-up actions ReFertilizer project

Recommendations with respect to the legal part are to achieve the end-of-waste status for the product after formulation. This is based on the fact that the criteria can be easier met when it is applied on this product. The Health Safety and Environment (HSE) manager has experience with these directives and can start the procedure to achieve the end-of-waste status.

Before achieving the end-of-waste status it will be useful to find a company that can test the input materials and the final product on heavy metals, level of nutrients, bacteria, viruses and organic micro pollutants. When these tests show positive outcomes it will be possible to use them in the ReFertilizer project. Proving that the materials meet the requirements that are set can be used in achieving the end-of-waste status, because one of the criteria is that "The use of the substance or object will not lead to overall adverse environmental or human health impacts". Because the laboratory is the department that operates in this business and will have connections in this discipline it will be logical for them to take up this action point.

Important for the ReFertilizer project will be the amount of inorganic fertilizer produced. The amount of 2,000 ton of inorganic fertilizer is plausible, based on the current available information. However, it will be useful to internally define what amounts, on the one hand can be produced (supply) and on the other hand can be sold (demanded). The director treatment will know the amount of materials that are available to SUEZ Almelo and what amount SUEZ is capable of producing, the manager hazardous waste will be able to define what amount of material can be sold to the market.

As outlined in this report, there are two options in which the production of inorganic fertilizers can be carried out. An older spent catalyst installation or a new to build installation. Both options have dis- and advantages (see chapter 5), therefore the director treatment will have to define what the best option will be for SUEZ Almelo to start production of inorganic fertilizers.

Chapter 6 consists of the financial analysis. The financial analysis in this report shows positive results for the ReFertilizer project. However, the financial analysis is based on the available information within SUEZ and a number of assumptions. In order to get a better picture of the whole project, it is important to pay extra attention to the financial analysis. Based on the current financial analysis it is important to validate the assumptions that are made and, if necessary, adapt the current financial analysis and draft an updated valuation of the ReFertilizer project.

Another important recommendation will be to look for more valuable waste streams. On the one hand the waste streams (such as the ammonium sulfate from NXP) that have sufficient sulfur levels and relatively high nitrogen levels. With on the other hand, looking for a urea substitute. Because urea is currently the most expensive component of the inorganic fertilizer product that can be produced by SUEZ Almelo. When an urea substitute can be found, the costs of materials will decline significantly and the viability and profitability of the project will increase substantially.

When all recommended actions above are completed it is possible to do a final assessment on the ReFertilizer project. When one of the recommended actions turns out to result in negative outcomes with respect to the ReFertilizer project, and there will be no prospect on improvement, the decision to not start with production can be made. When all outcomes of the actions are positive, the actors can decide to start with the production of inorganic fertilizers.

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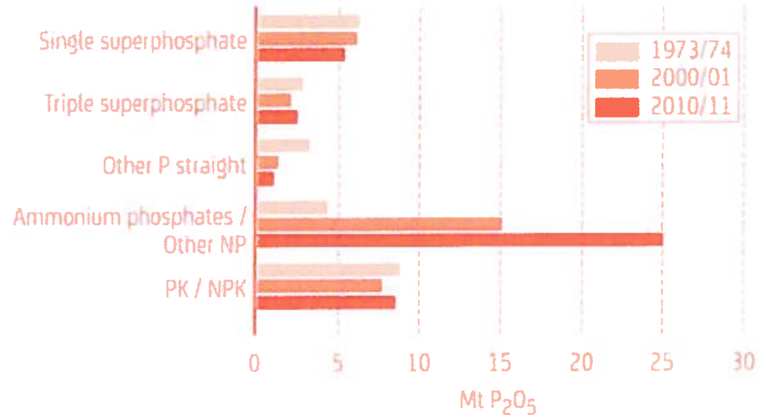
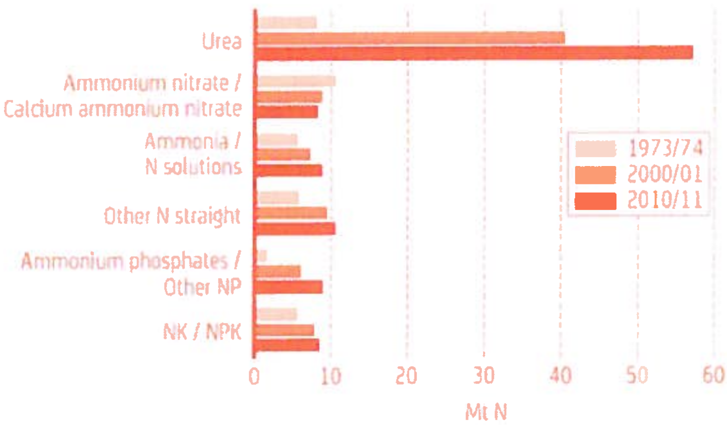
Appendices

Appendix 1

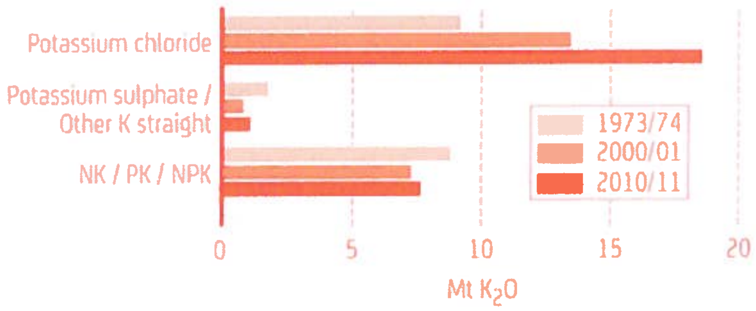
World phosphate fertilizer consumption



World nitrogen fertilizer consumption



World potash fertilizer consumption



Appendix 2

Purchasing costs

Product	Costs per ton (€)
Washing fluids	€ -
Ammonium sulphate	€ -
Sulphuric acid	€ 145,00
Urea	€ 340,00
Ammonia	€ 330,00
Water	€ 2,50

Production costs per ton fertiliser

Cost sort	Costs (€)
Direct and indirect installation costs	70
Energy costs	4,3
Personnel costs	29,2
Depreciation	43
Holding fee	12,5
Total	**€ 159,00**

Combination no.	Substance	Sulphur (% m/m)	Nitrogen (% m/m)	Weight (kg)	Weight per ton fertiliser (kg)	Costs per ton (€)	Costs per ton fertiliser (€)
1	Washing fluids	3,5	2	100	522,33	€ -	€ -
	Sulphuric acid (96%)	81,88	0	4,5	23,50	€ 145,00	€ 3,41
	Urea	0	48,66	77,6	405,33	€ 340,00	€ 137,81
	Ammonia (25%)	0	20,66	9,35	48,84	€ 330,00	€ 16,12
	Fertilizer	2,57	20,96	191,45	1000		**€ 157,34**
2	Washing fluids	3,5	2	100	404,89	€ -	€ -
	Ammonium sulphate	7,43	6,47	45,5	184,23	€ -	€ -
	Urea	0	46,65	99,9	404,49	€ 340,00	€ 137,53
	Ammonia	0	20,56	1,58	6,40	€ 330,00	€ 2,11
	Fertilizer	2,8	21	246,98	1000		**€ 139,64**
3	Washing fluids	3,5	2	100	485,55	€ -	€ -
	Ammonium bisulphate	17,04	4,56	13,5	65,55	€ -	€ -
	Urea	0	46,65	83,1	403,50	€ 340,00	€ 137,19
	Ammonia	0	20,56	9,35	45,40	€ 330,00	€ 14,98
	Fertilizer	2,82	21,03	205,95	1000		**€ 152,17**
4	Water	0	0	100	199,32	€ 2,50	€ 0,50
	Ammonium sulphate	7,43	6,47	203,4	405,42	€ -	€ -
	Urea	0	46,65	197,3	393,26	€ 340,00	€ 133,71
	Ammonia	0	20,56	1	1,99	€ 330,00	€ 0,66
	Fertilizer	3,01	21,01	501,7	1000		**€ 134,87**
5	Washing fluids	3,5	2	100	521,16	€ -	€ -
	Sulphuric acid (83%)	26,8	0	5,35	27,88	€ -	€ -
	Urea	0	48,66	78,45	408,85	€ 340,00	€ 139,01
	Ammonia (25%)	0	20,66	8,08	42,11	€ 330,00	€ 13,90
	Fertilizer	2,57	20,96	191,88	1000		**€ 152,90**

Appendix 3

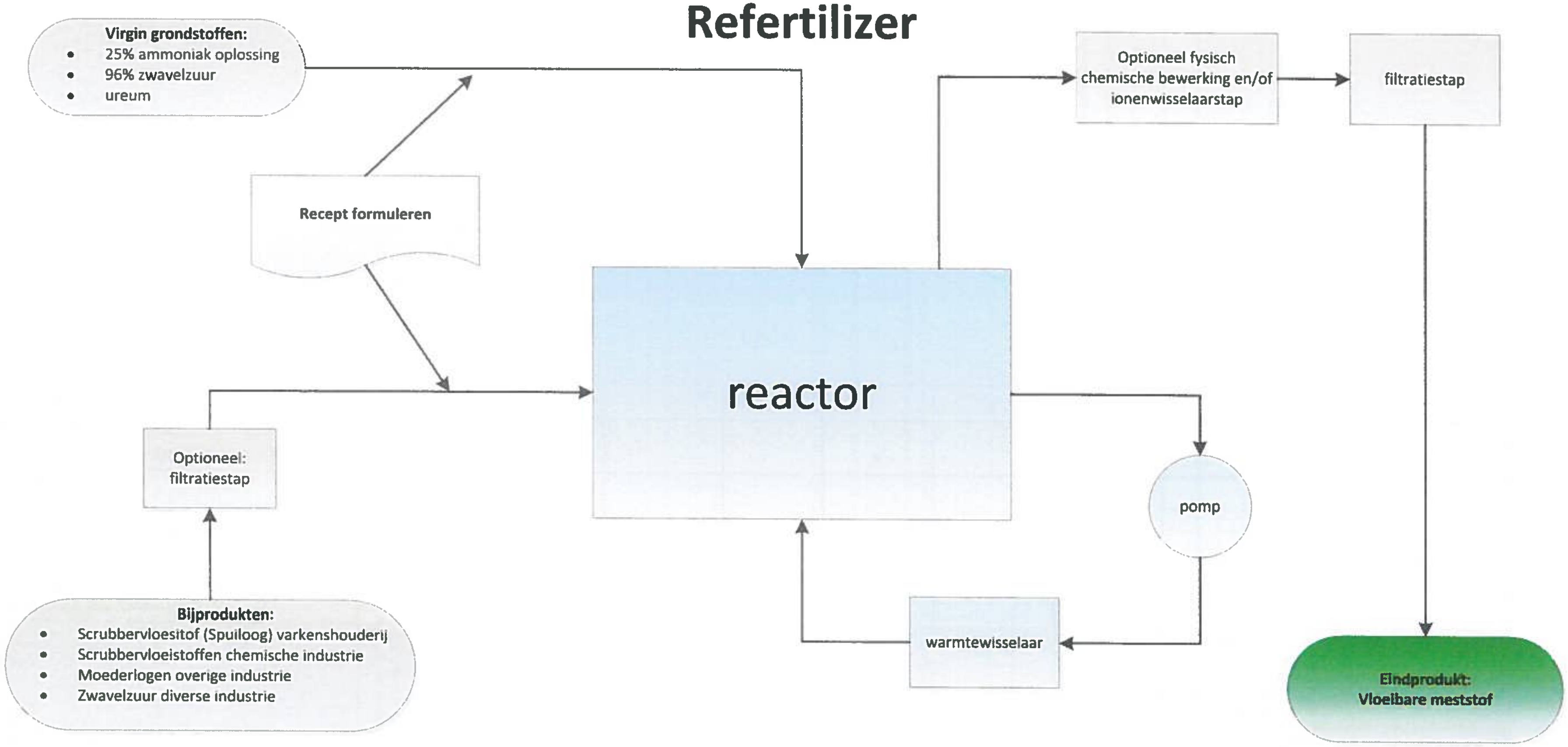
Organic micro-pollutants	Maximum value in mg per kg of the relevant fertilizing ingredient				
	Phosphate	Nitrogen	Potassium	Neutralizing value	Organic value
Σ PCDD/PCDF	0.019	0.015	0.010	0.0038	0.00051
α-HCH	310	248	165	62	8.3
β-HCH	12	9.6	6.4	2.4	0.32
γ-HCH (lindaan)	1.2	0.96	0.64	0.24	0.032
HCB	31	31.2	20.8	7.8	1.0
Aldrin	7	5.6	3.7	1.4	0.2
Dieldrin	7	5.6	3.7	1.4	0.2
Σ aldrin/dieldrin	7	5.6	3.7	1.4	0.2
Endrin	7	5.6	3.7	1.4	0.2
Isodrin	7	5.6	3.7	1.4	0.2
S endrin/isodrin	7	5.6	3.7	1.4	0.2
S DDT + DDD + DDE	23	18.4	12.3	4.6	0.6
PCB-28	18.5	14.8	9.9	3.7	0.48
PCB-52	18.5	14.8	9.9	3.7	0.48
PCB-101	75	60	40	15	2
PCB-118	75	60	40	15	2
PCB-138	75	60	40	15	2
PCB-153	75	60	40	15	2
PCB-180	75	60	40	15	2
Σ 6-PCB (excl. PCB-118)	375	300	200	75	10
Naftaleen	600	480	320	120	16
Fenanthreen	750	600	400	150	20
Antraceen	600	480	320	120	16
Fluoranteen	185	148	98	37	4.9
Benzo(a)antraceen	230	184	123	46	6.1
Chryseen	230	184	123	46	6.1
Benzo(k)fluoranteen	270	216	144	54	7.2
Benzo(a)pyreen	290	232	155	58	7.7
Benzo(g.h.i)peryleen	210	168	112	42	5.6
Indeno(1.2.3-c.d)pyreen	235	188	125	47	6.3
Σ 10-PAK	11500	9200	6133	2300	307
Minerale olie	935000	748000	498668	187000	24933

Appendix 4

eural	omschrijving	inname (verpomp naar tank, overkranen, opbulken, op-/overslaan, sorteren, demonteren, overstorten,)	Destillatie GDI, FV, blenden tank	destillatie = blenden toegevoegd onder destillatie	SDI Solid Dry = solvent droog installatie	formuleren	RWV (verfinstallatie)	TL lampen	IWR	ONO +regeneratie ionenwisselaars-kolommen	OIF (immobilisatie en steekvast maken)
06 01 01*	zwavelzuur en zwaveligzuur	x				x				x	
06 02 03*	ammoniumhydroxide	x				x				x	
16 05 08*	afgedankte organische chemicaliën die uit gevaarlijke stoffen bestaan of deze bevatten.	x	x	x	x	x					
16 10 02	niet onder 16 10 01 vallend waterig vloeibaar afval	x				x				x	
19 02 99	niet elders genoemd afval	x	x		x		x	x		x	x

Appendix 5

Flowschema Proces Refertilizer



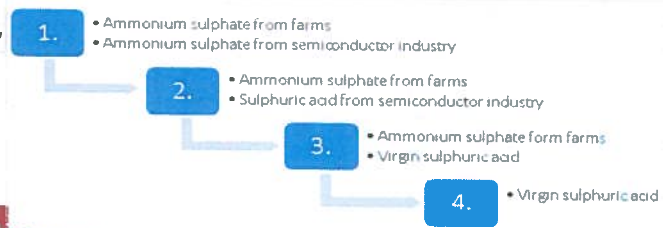
Appendix 6

Substance	Weight (kg)	Weight per ton fertiliser (kg)	Ratio to fertilizer (%)	Weight per 2kTon fertilizer (1000 kg)	Maximum production (10	Required production (1000 kg)
1. • Ammonium sulphate from farms • Ammonium sulphate from semiconductor industry						
Ammonnium sulphate from farms	100,00	404,89	40,5%	809,78	274,73	274,73
Ammonium sulphate from semiconductor industry	45,50	184,23	18,4%	368,45	125,00	125,00
Urea	99,90	404,49	40,4%	808,97	274,45	274,45
Ammonia	1,58	6,40	0,6%	12,79	4,34	4,34
Fertilizer	246,98	1000	100%	2000	678,52	678,52
2. • Ammonium sulphate from farms • Sulphuric acid from semiconductor industry						
Ammonium sulphate from farms	100,00	521,16	52,1%	1042,32	11214,95	688,70
Sulphuric acid (85%)	5,35	27,88	2,8%	55,76	600	36,85
Urea	78,45	408,85	40,9%	817,70	8798,13	540,29
Ammonia (25%)	8,08	42,11	4,2%	84,22	906,17	55,65
Fertilizer	191,88	1000	100,0%	2000	21519,25	1321,48
3. • Ammonium sulphate form farms • Virgin sulphuric acid						
Ammonium sulphate from farms	100,00	522,33	52,2%	1044,66	-	0,00
Sulphuric acid (96%)	4,50	23,50	2,4%	47,01	-	0,00
Urea	77,60	405,33	40,5%	810,66	-	0,00
Ammonia (25%)	9,35	48,84	4,9%	97,68	-	0,00
Fertilizer	191,45	1000	100,0%	2000	-	0,00

Total material amounts	Ton (1000 kg)	Density (kg/m³)	Volume (m³)
Ammonium sulphate from farms	963,43	1062,45	906,80
Ammonium sulphate from semiconductor industry	125,00	1207,33	103,53
Sulphuric acid from semiconductor industry	36,85	1693,21	21,76
Sulphuric acid (96%)	0,00	1802,10	0,00
Urea	814,74	765,33	1064,55
Ammonia	59,99	908,67	66,02
Fertilizer	2000,00	1200,00	1666,67

Availability waste materials

Material	Supplier	Amount (ton)
Ammonium sulphate	Farmers	Infinite
Ammonium sulphate	Semiconductor industry	125
Sulphuric	Semiconductor industry	600
Ammonium bisulphate	Pharmaceutical industry	Negligible



Total production	2000,00

Appendix 7

Substance (kg)

	Sulphur (% m/m)	Nitrogen (% m/m)	Ammonium sulphate Farms	Ammonium sulphate NXP	Urea VivoChem	Ammonia -	Total	Ratio ureum/fertilizer
Original	2,42	1,02	100	84,5	125,72	1,58	311,8	0,4032
	3	1,5	100	63,5	112	1,58	277,08	0,4042
	3,5	2	100	45,5	99,9	1,58	246,98	0,4045
	4	2,5	100	27,5	87,75	1,58	216,83	0,4047
	4,5	3	100	9,3	75,45	1,58	186,33	0,4049
	5	3,5	100	0	68,25	1,58	169,83	0,4019

	Sulphur (% m/m)	Nitrogen (% m/m)	Ammonium sulphate Farms	Ammonium bisulphate Katwijk	Urea VivoChem	Ammonia -	Total	Ratio ureum/fertilizer
Original	2,42	1,02	100	25,06	94,55	17,73	237,34	0,3984
	3	1,5	100	19	88,7	13,58	221,28	0,4008
	3,5	2	100	13,5	83,1	9,35	205,95	0,4035
	4	2,5	100	8,1	77,7	5,12	190,92	0,4070
	4,5	3	100	2,7	72,2	0,89	175,79	0,4107
	5	3,5	100	0	68,5	0,89	169,39	0,4044

	Sulphur (% m/m)	Nitrogen (% m/m)	Ammonium sulphate Farms	Sulphuric acid (96%) Elementis	Urea VivoChem	Ammonia -	Total	Ratio ureum/fertilizer
Original	2,42	1,02	100	9,77	85,9	17,81	213,48	0,4024
	3	1,5	100	7,04	81,75	13,58	202,37	0,4040
	3,5	2	100	4,5	77,6	9,35	191,45	0,4053
	4	2,5	100	2,05	73,6	5,12	180,77	0,4071
	4,5	3	100	0	70,05	0,89	170,94	0,4098
	5	3,5	100	0	68,1	0,89	168,99	0,4030

	Sulphur (% m/m)	Nitrogen (% m/m)	Ammonium sulphate Farms	Sulphuric acid (83%) NXP	Urea VivoChem	Ammonia -	Total	Ratio ureum/fertilizer
Original	2,42	1,02	100	11,5	87,3	15,4	214,2	0,4076
	3	1,5	100	8,25	82,8	11,74	202,79	0,4083
	3,5	2	100	5,35	78,45	8,08	191,88	0,4088
	4	2,5	100	2,38	74	4,43	180,81	0,4093
	4,5	3	100	0	70,05	0,89	170,94	0,4098
	5	3,5	100	0	68,1	0,89	168,99	0,4030

Appendix 8

Ratio (m³/ton kg)
0,86

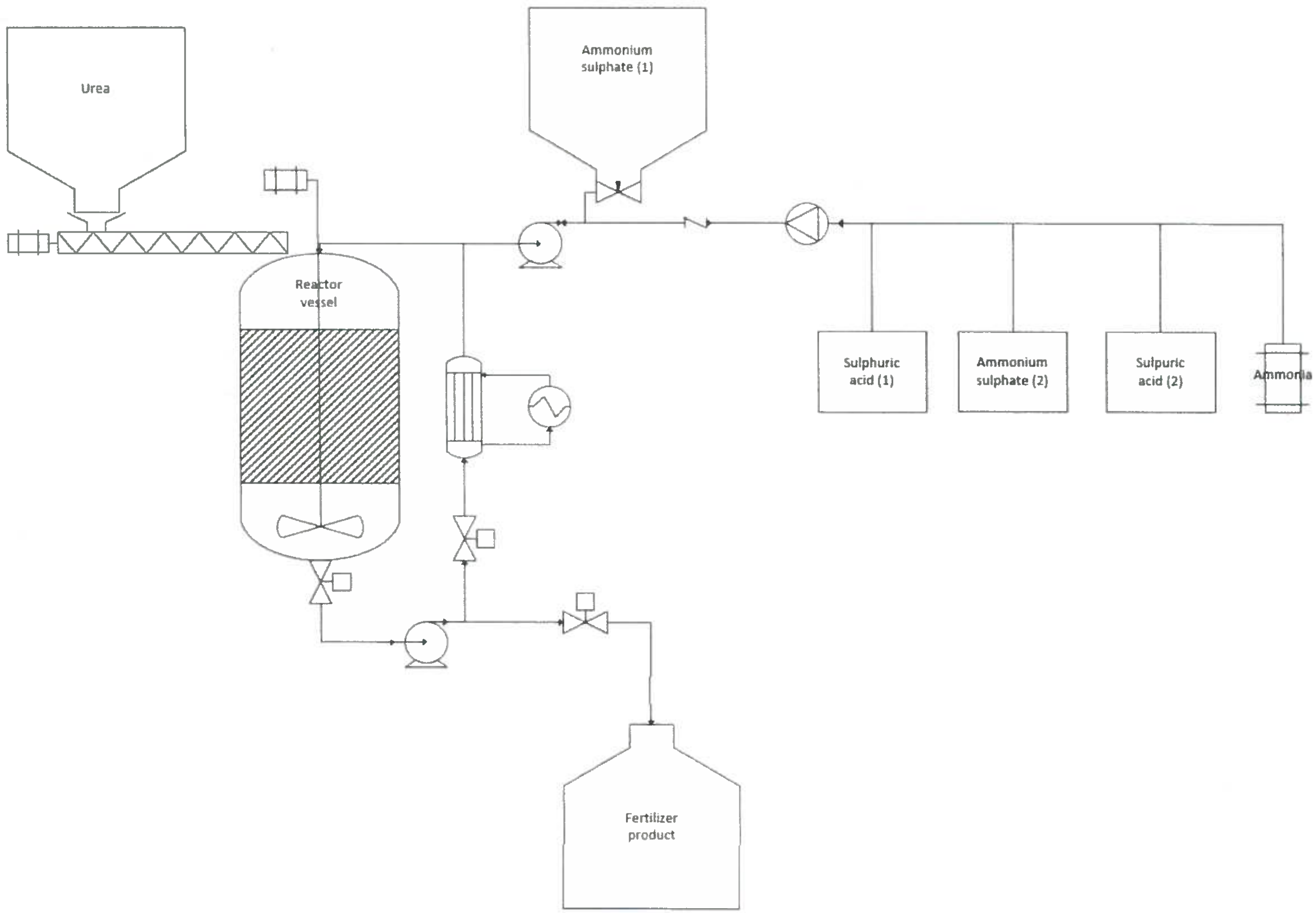
Production	Yearly Demanded (m³)	Yearly Demanded (ton kg)	Daily Demanded (m³)	Daily Demanded (ton kg)	Reactor vessel	Batch Capacity (m³)	Batch Capacity (ton kg)	Required daily batches
	1710,70	2000	4,69	5,48		6	7,01	1
	3421,40	4000	9,37	10,96				2
	5132,10	6000	14,06	16,44				3
	6842,80	8000	18,75	21,92				4
	8553,50	10000	23,43	27,40				4

Production	Yearly Demanded (m³)	Yearly Demanded (ton kg)	Daily Demanded (m³)	Daily Demanded (ton kg)	Reactor vessel	Batch Capacity (m³)	Batch Capacity (ton kg)	Required daily batches
	1710,70	2000	4,69	5,48		12	14,03	1
	3421,40	4000	9,37	10,96				1
	5132,10	6000	14,06	16,44				2
	6842,80	8000	18,75	21,92				2
	8553,50	10000	23,43	27,40				2

Production	Yearly Demanded (m³)	Yearly Demanded (ton kg)	Daily Demanded (m³)	Daily Demanded (ton kg)	Reactor vessel	Batch Capacity (m³)	Batch Capacity (ton kg)	Required daily batches
	1710,70	2000	4,69	5,48		18	21,04	1
	3421,40	4000	9,37	10,96				1
	5132,10	6000	14,06	16,44				1
	6842,80	8000	18,75	21,92				2
	8553,50	10000	23,43	27,40				2

Production	Yearly Demanded (m³)	Yearly Demanded (ton kg)	Daily Demanded (m³)	Daily Demanded (ton kg)	Reactor vessel	Batch Capacity (m³)	Batch Capacity (ton kg)	Required daily batches
	1710,70	2000	4,69	5,48		24	28,06	1
	3421,40	4000	9,37	10,96				1
	5132,10	6000	14,06	16,44				1
	6842,80	8000	18,75	21,92				1
	8553,50	10000	23,43	27,40				1

Appendix 9



Urea
Ammonium sulphate (1)
Reactor vessel
Sulphuric acid (1)
Ammonium sulphate (2)
Sulpuric acid (2)
Ammonia
Fertilizer product

Appendix 10

Cost assumptions	
Material cost (€/ton)	€ 148.40
Revenue (€/ton)	€ 250.00
Lime silo & transportation system	€ 15,000.00
Storage tank s	€ 15,000.00
Pumps	€ 5,000.00
Adaptions	€ 10,000.00

Valuation assumption	
Overhead HG/Region	5%
Tax	25%

Cost indexation assumptions	
Labour costs	2%
Electricity	1.5%
Location/maintenance	2%
Raw materials	3%
Transport	2%
Revenue	3%

Other cost assumptions	
Labour costs (€/year)	€ 45,000.00
Electricity costs (€/ton)	€ 12.50
Maintenance costs (€/ton)	€ 5.00
Delivery costs (€/ton)	€ 12.00
Location costs (€/ton)	€ 20.00

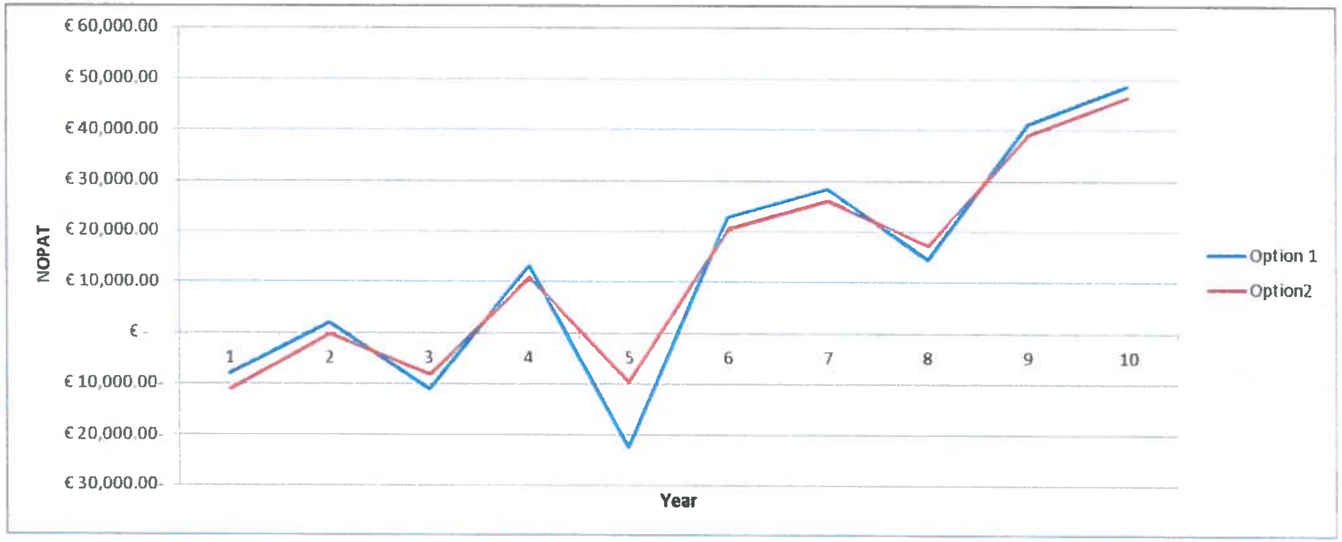
Production quantities										
Production increase (ton)	200									
Year	1	2	3	4	5	6	7	8	9	10
Quantity	2000	2200	2400	2600	2800	3000	3200	3400	3600	3800

COGS	Year									
	1	2	3	4	5	6	7	8	9	10
Material costs	€ 296,800.00	€ 336,274.40	€ 377,850.14	€ 421,617.79	€ 467,671.42	€ 516,108.82	€ 567,031.55	€ 620,545.16	€ 676,759.25	€ 735,787.69
Other costs	€ 140,095.89	€ 157,050.09	€ 174,601.67	€ 192,767.43	€ 211,564.61	€ 231,010.89	€ 251,124.40	€ 271,923.71	€ 293,427.89	€ 315,656.49
Sum of total costs	€ 436,895.89	€ 493,324.49	€ 552,451.81	€ 614,385.22	€ 679,236.04	€ 747,119.71	€ 818,155.95	€ 892,468.87	€ 970,187.14	€ 1,051,444.18

Investment	Option 1 (spent catalyst installation)		Option 2 (new installation)
Lime silo urea	€ 15,000.00	Lime silo urea	€ 15,000.00
Storage tank and pumps	€ 20,000.00	Storage tanks and pumps	€ 20,000.00
Adaptions	€ 10,000.00	Pipes and valves	€ 10,000.00
		Reactor vessel	€ 30,000.00
Sum of investments	€ 45,000.00		€ 75,000.00

Revenues		Year									
	Ton	1	2	3	4	5	6	7	8	9	10
	1	2,000	2,200	2,400	2,600	2,800	3,000	3,200	3,400	3,600	3,800
Price per ton	€ 250.00	€ 250.00	€ 257.50	€ 265.23	€ 273.18	€ 281.38	€ 289.82	€ 298.51	€ 307.47	€ 316.69	€ 326.19
Sum of revenues		€ 500,000.00	€ 566,500.00	€ 636,540.00	€ 710,272.55	€ 787,856.17	€ 869,455.56	€ 955,241.84	€ 1,045,392.79	€ 1,140,093.07	€ 1,239,534.52

P&L										
Year	1	2	3	4	5	6	7	8	9	10
Option 1										
EBIT	€ 7,895.89-	€ 2,107.88	€ 10,919.38-	€ 13,144.78	€ 22,308.35-	€ 22,749.88	€ 28,349.46	€ 14,521.72	€ 41,299.45	€ 48,716.92
EBIT%	1.58%	0.50%	1.90%	2.47%	2.99%	3.49%	3.96%	4.40%	4.83%	5.24%
NOPAT	€ 7,895.89-	€ 2,107.88	€ 10,919.38-	€ 13,144.78	€ 22,308.35-	€ 22,749.88	€ 28,349.46	€ 14,521.72	€ 41,299.45	€ 48,716.92
Option 2										
EBIT	€ 10,895.89-	€ 189.49-	€ 8,169.38-	€ 10,894.78	€ 9,558.35-	€ 20,499.88	€ 26,099.46	€ 17,271.72	€ 39,049.45	€ 46,466.92
EBIT% / ROS	2.18%	0.03%	1.43%	2.05%	2.61%	3.14%	3.64%	4.12%	4.57%	5.00%
NOPAT	€ 10,895.89-	€ 189.49-	€ 8,169.38-	€ 10,894.78	€ 9,558.35-	€ 20,499.88	€ 26,099.46	€ 17,271.72	€ 39,049.45	€ 46,466.92



	Option 1	Option 2
NPV	€ 30,678.38	€ 1,926.31