Sustainable logistics with biogas

„From the sludge for the sludge"

Final report

18th January 2016

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Nomenclature

WWTP	Waste Water Treatment Plant
SNB	Slibverwerking Noord–Brabant
CNG	Compressed Natural Gas
CBG	Compressed BioGas
LNG	Liquefied Natural Gas
LBG	Liquefied BioGas
LPG	Liquefied Petroleum Gas
NG	Natural Gas
NGV	Natural Gas Vehicle
kW	Kilowatt
kWh	Kilowatt hour
dB	Decibel
HP	Horsepower
MJ	Megajoule
GJ	Gigajoule
TJ	Terajoule

Abstract

The following report summarises the five–month–long investigation concerning the sludge logistics between seven sewage treatment plants, owned by the governmental company Waterschap Aa en Maas, which has its main office in 's–Hertogenbosch, the Netherlands. As a result of wastewater treatment, significant amount of sludge is produced. From this side product, biogas is created in three WWTPs of Waterschap Aa en Maas. The technology processes, performed at the plants, are followed by the sludge transportation to the finale destination, namely SNB premises in Moerdijk, the Netherlands [1].

The digester at the plant of 's–Hertogenbosch will be renovated until 2018. Taking the opportunity of the reconstruction, a new logistics solution could be innovated in a more cost–effective and sustainable way. Therefore, the main focus of the project is to study the current logistical situation and to answer the following question:

What is the optimal way to use the biogas, produced by 's–Hertogenbosch WWTP, as the main truck fuel to transport the sludge?

Thorough investigation proves, qualitatively and quantitatively, the most advisable solution and reveals the most favorable alternative of sludge transportation.

1 Introduction

Waterschap Aa en Maas operates seven wastewater treatment plants in the eastern part of Noord–Brabant. All the domestic and industrial wastewater from these plants is treated and flushed into surface water.

The main WWTP and the head office are located in ‘s–Hertogenbosch.

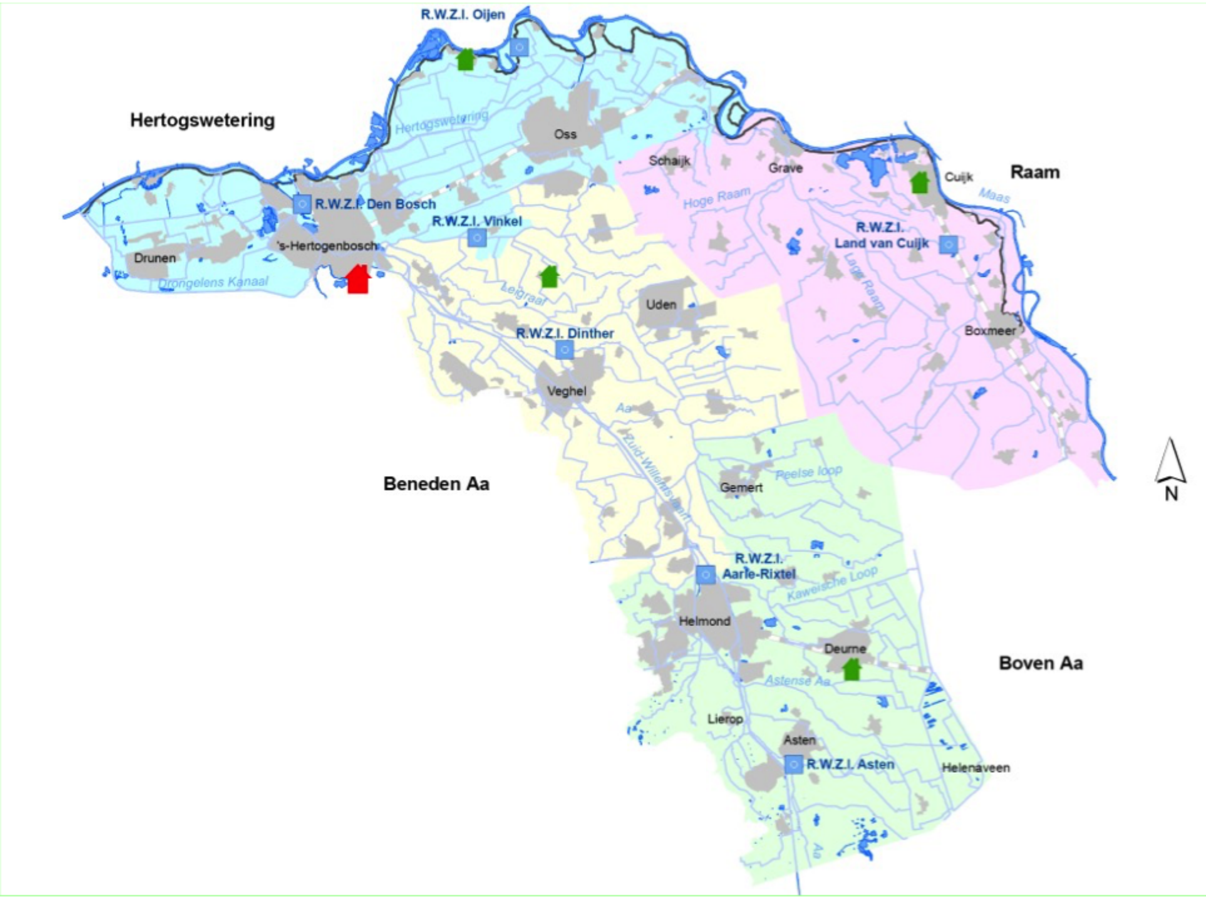

Figure 1: *Waterschap Aa en Maas.*

The side product of wastewater treatment processes (the sludge) is being digested, which results in biogas. That is why the fermentation performed in Waterschap Aa en Maas are of significance and influence the sustainable development in the Netherlands.

Nowadays, the plant in ‘s–Hertogenbosch is being renovated until 2018 [2]. The installations and the technology are no longer in use due to their age and bad condition. Therefore, they are no longer capable of carrying out the processes. The result of this restoration will be a fully operational, completely renovated plant, with the new, innovative technologies implemented which allow the operations to be carried out more efficiently way. After the refit, significant amounts of the sludge from the other plants (Dinther and Aarle Rixtel) will be transported to ’s–Hertogenbosch and then digested, resulting in the increase of biogas production [3].

2 Goal of the project

The main purpose of this project is to find the most cost–effective and most sustainable way to run the sludge logistics of Waterschap Aa en Maas. Therefore, it also describes the CBG produced in the wastewater plants as a reasonable fuel alternative for diesel. This involves not only the transportation to the incinerator in Moerdijk which is performed by SNB, but also the internal transportation between the WWTPs. The practical issues that may occur by the usage of CBG trucks will be revealed. The investigation is aimed to answer the main question:

What is the optimal way to use the biogas, produced by 's–Hertogenbosch WWTP, as the main truck fuel to transport the sludge?

The secondary focus of the investigation is a view at abstract alternatives routes and transport modes, which may be reasonable solutions for the future.

3 Research and execution methods

At the beginning, it was necessary to get into the structure of Waterschap Aa en Maas. The project is based on the firm investigation of possible alternatives, analysing them numerically and drawing conclusions. Searching and reading several documents about how is the process carried out in these WWTPs, getting in touch with their internal structure while meeting employees of Waterschap Aa en Maas.

In October, it was planned to make a schedule of interviews with the WWTP operator managers and stakeholders. Moreover, to organize the whole project execution in a convenient way, MS Project Calendar was prepared [Appendix 1].

The operator managers working at the plants of 's–Hertogenbosch, Aarle Rixtel and Dinther described the nature of wastewater treatment plants and the sludge specifications. The following undertaking was to interview truck manufacturers, which could be vehicle delivers for the transportation company. The last step was a conversation with the main stakeholders of Waterschap Aa en Maas, namely, SNB and Heeren Transport. SNB, as a final destination of the sludge logistics chain, has wide knowledge concerning the topic of transportation (data and statistics). Heeren Transport, though, is the transportation company that performs current sludge logistics. It was a crucial issue to gather the information concerning the way of organising the routes and working time of the drivers. Ultimately, all the information was recovered and analysed in order to form final valid conclusions with strong arguments.

All the facts mentioned above are explained in the chapters of this report. Firstly, in the chapter of "The Pathway from sludge to CBG trucks", all the steps of sludge processing will be summerized. Following that, it was necessary to acquire a thorough knowledge of compressed natural gas. SWOT analysis will show the significant strengths, weaknesses, opportunities and threats of CNG. Then, the current logistical situation will be examined, in order to get into the structure of the sludge logistics of Waterschap Aa en Maas. The main focus of this report will be explained in the two logistical scenarios. Both of them are described in detail and focus primarily on one day of the sludge transportation.

The responsibilities of Waterschap Aa en Maas, as a governmental company, are rising more and more in this globalised world: sustainable transportation is becoming an unignorable issue. Consequently, the following report focuses on the sustainability aspects of the sludge logistics. In this way, the environmental effects of diesel and CBG will be presented. In addition, there will be several idealistic alternatives revealed, which could be attractive options for the future. Finally, several conclusions and recommendations will be presented in order to give a proper response to the main question.

4 The pathway from sludge to CBG trucks

Sewage sludge is a by–product of wastewater treatment processes by removing the solids from the effluent. The two main types are the primary and the secondary sludge. Primary sludge is the outcome of suspended solids and organics in the primary treatment process through gravity sedimentation. The secondary treatment process, though, is executed in the aeration tank via biological process, where microorganisms are used to consume the organic matter in the wastewater. After flowing into the secondary clarifier, the biomass settles out and is being removed as secondary sludge.

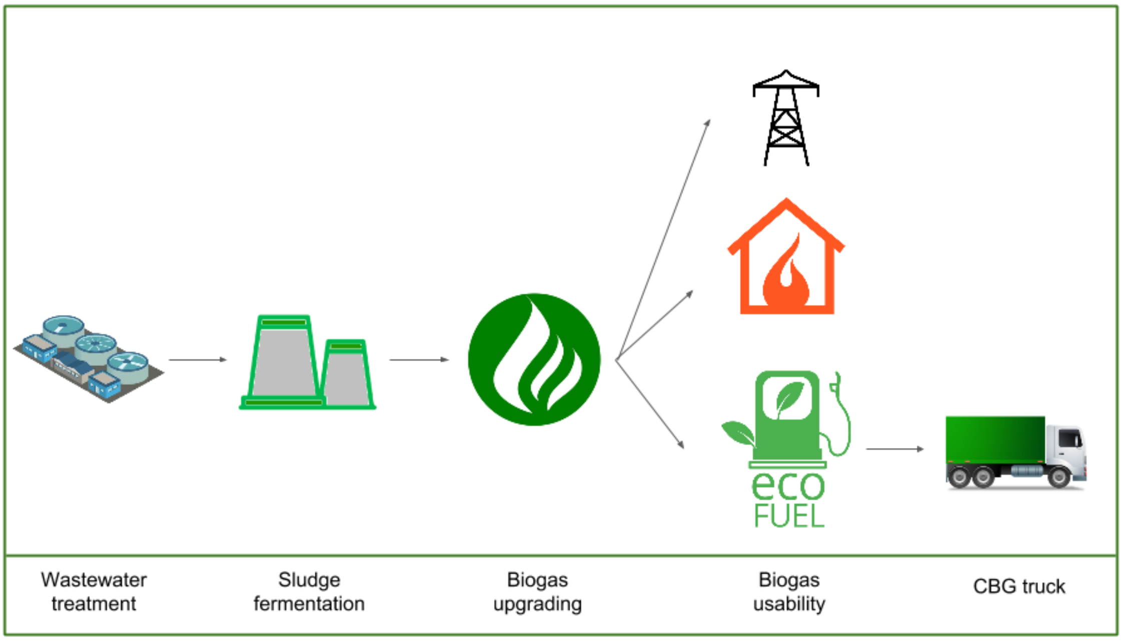

Figure 2: *The pathway of sludge.*

Anaerobic digestion is the most widely utilized method for reducing the amount of sludge that needs to be disposed and gain green energy for achieving self–supplement. In this process, around 40% to 60% of the organic matter will be broken down into methane and carbon dioxide in the absence of oxygen. Primary sludge contains higher biogas production potential, since the energy content has not yet been consumed during the aerobic treatment. In this context, the secondary sludge has lower biogas potential because the microorganisms have consumed most of their energy content leaving behind mainly inactive biomass. After the digestion, there are two products which plants have to be focused on. These are the biogas and the aerobically treated sludge. The digested sludge has to be dewatered. As a result, decreased amount of the sludge is obtained and then transported to the final destination. This procedure is accomplished at Waterschap Aa en Maas by centrifuge dewatering systems. The result of this high speed process is a "sludge cake" with a dry matter between 20% and 25%.

Following table shows the property of the sludge and the equipment of the WWTPs of Waterschap Aa en Maas.

Table 1: *Sludge type and processing equipment at the WWTPs of Waterschap Aa en Maas [4].*

WWTP	Primary sludge	Secondary sludge	Digester	Dewatering system
Den Bosch	×	×	×	×
Land van Cuijk		×	×	×
Oijen	×	×		×
Dinther		×		×
Vinkel		×		
Aarle Rixtel		×		×
Asten		×	×	

Another product of anaerobic decomposition of sewage sludge is biogas, which can be converted into renewable energy through combined heat and power cogeneration. Furthermore, it can be used as a green, eco–friendly fuel for vehicles. First of all, biogas has to be upgraded to natural gas quality in order to be used as such a fuel.

Following to the swedish national standards, it is stated that the methane content must be higher than 97% [5]. It also sets limits for dew point, sulphur content and some other minor constituents. According to investigations of Waterschap Aa en Maas, the most optimal upgrading technology is purifying the biogas by membrane separation [6]. This technology is based on gas dissolution and diffusion into polymer materials – membranes. Membrane separation has a lower energy consumption, good selectivity, simply engineered modules and consequently lower costs.

After conditioning, in practice the biogas will have the same quality as natural gas. Both biogas and natural gas appear in two different states as a fuel. One is the compressed gas stored at a pressure of 20–25 MPa. The other one is the liquefied gas, which is converted into cryogenic liquid typically between -120°C and -170°C. For producing lower amount of fuel, it is more suitable to compress the biogas. Furthermore, the technology of liquefying any type of gas is relatively new and so has a higher risk of investment. Therefore, Waterschap Aa en Maas has decided to produce CBG at WWTP 's-Hertogenbosch.

In order to make the CBG available for the trucks, which are operating at Waterschap Aa en Maas, a filling station is needed. The appropriate infrastructure for Waterschap Aa en Maas will be the fast–fill refueling station. This will be further explained in the chapter named "Commercial filling stations".

After all these steps, the CBG is finally able to be used as the main fuel for the vehicles implementing the transportation of sludge.

5 Compressed Natural Gas

Compressed natural gas, in fact methane, is stored at high pressure and can be used in place of gasoline, diesel fuel and propane or LPG. It is obtained by natural gas compression, which is a fossil fuel formed when layers of decomposing plant and animal matter were exposed to intense heat and pressure over thousands of years. Then, it was found in deep underground rock formations or associated with other hydrocarbon reservoirs in coal beds [Appendix 2].
Furthermore, CNG may be found above oil deposits. The non–fossil form of it may be collected from landfills or produced in digesters using sludge, manure or other organic materials. This is known as biogas, a CO_2 neutral energy source.

5.1 CNG Characteristics

Natural gas is a hydrocarbon consisting mainly methane, although it usually contains a variable percentage of nitrogen, ethane, CO_2, H_2O, butane, propane, mercaptans and traces of heavier hydrocarbons as well. Methane is one carbon atom joined to four hydrogen atoms (CH_4) and can constitute up to 97% of natural gas. This percentage is different in tthe Netherlands, where the natural gas has a less heating value and less energy content so consequently, less range for CNG trucks.
This gas can be used directly for production of heat and/or electricity. Alternatively, it can be further processed to natural gas quality for being used as vehicle fuel or for injection into the gas grid.

Additionally, it is safer than other fuels in the event of a spill, since natural gas is lighter than air and disperses quickly when released. Overall, CNG combustion produces fewer undesirable gases and solid particles than other fuels since natural gas is one of the cleanest fossil fuel energy sources, emitting less pollutant gas per unit of energy produced [7] [8].

5.2 CNG SWOT analysis

SWOT is an acronym that stands for Strengths, Weaknesses, Opportunities and Threats. It is important and highly recommended at every new plan, to consider all of these topics before proceeding. The plan's strengths and weaknesses are factors within the company's control. Opportunities and threats, though, are external factors within the community that could affect the project's success.

This SWOT analysis shows the comparison of CNG to conventional fuels. It is made on purpose for the fuel of CNG and not for the non–fossil version CBG, as the analysis is more relevant for the transportation company itself. Although the main goal is to use the CBG from Waterschap Aa en Maas, the art of the fuel consumption of the transportation company cannot be conditioned.

Table 2: *SWOT analysis of CNG.*

	Helpful (to achieve the objective)	Harmful (to achieve the objective)
Internal origin (product/company attributes)	**Strengths** • cheaper than other fuels • predictable price and low taxes • environmentally friendly • low CO_2 and NO_2 emissions • less noise is made • it can be easily replaced with biogas • renewable energy source • can be used in current internal–combustion engines without any change [9] • natural gas is the only alternative for large–volume transport (passenger and freight transport) • known technology	**Weaknesses** • lobbies on the fuel market • little knowledge and awareness of the consumers • narrow variety of CNG vehicles • higher price of CNG vehicles than diesel or gasoline vehicles • CNG trucks have a range shorter than diesel vehicle • high cost of CNG filling station investment • availability of filling stations • strict, outdated law legislation
External origin (environment/market attributes)	**Opportunities** • lower cost of heavy duty vehicles maintenance than diesel • constantly rising oil and gasoline prices • increasing ecological awareness among entrepreneurs and society • the objectives of European Energy and Climate Policy are in favor of methane–based products (biogas) • environmental controls (i.e. smog alarm) is becoming more strict – CNG is the solution • investment opportunities (support from government and EU) and fundings • energy dependence on other countries (Middle East) is decreased	**Threats** • natural gas price can increase on the world market • changing taxation policies (excise duty) • changeover to LPG requires less money • changeover to LPG is based on well–known technological solutions

5.3 Compressed Biogas - CBG

Biogas typically refers to a mixture of different gases produced during the breakdown of organic matter in the absence of oxygen and it is a renewable energy source. Moreover, it usually exerts relatively small carbon footprint. It can be produced of raw materials such as agricultural waste, manure, municipal waste, plant material, sewage, green waste or food waste [10].

In addition, biogas can be produced by anaerobic digestion with anaerobic bacteria, which digest material inside a closed system, or fermentation of biodegradable materials.

Biogas is primarily methane and carbon dioxide and may have small amounts of hydrogen sulfide, moisture and siloxanes. The methane gas can be combusted or oxidized. This energy release allows biogas to be used as a fuel [11].

Table 3: *Typical composition of biogas produced by normally functioning digesters.*

Compound	Chemical	Range
Methane	CH_4	50–75 %
Carbon dioxide	CO_2	25–50 %
Nitrogen	N_2	0–10 %
Hydrogen	H_2	0.01–5.00 %
Oxygen	O_2	0.1–2.0 %
Water vapour	H_2O	0–10 %
Hydrogen sulphide	H_2S	10–30×1000 ppm
Ammonia	NH_3	0.01–2.50 mg/m^3

CBG is the renewable type of compressed natural gas. Driving on this fuel is nearly completely CO_2 neutral. Moreover, the production and usage of it is good for both, the economy and the agricultural sector. Because of its organic origin, CBG is a sustainable energy source and sustainable successor to natural gas as a result.

Moreover, having the same composition as natural gas means that it is possible for all natural gas vehicles to run on biogas with no modifications being required. At present, the current network of filling stations can also make the conversion into CBG [12].

Table 4: *Advantages and disadvantages of using biogas as a fuel [13] [14].*

Advantages	Disadvantages
Renewable energy source	Not attractive to large–scale market
Non–polluting	Should be locally implemented
Technology is cheaper and simpler than other bio–fuels	Young, not advanced technology
No adaptation of regular CNG vehicles required	Technological efficiency is difficult to enhance
Reduces greenhouse effect	Purification is required
Efficient energy conversion	
Low cost investment	

5.4 CBG Upgrading at Waterschap Aa en Maas

The upgrading technology which Waterschap Aa en Maas is going to implement, is the same method as the one applied by the garbage company of 's–Hertogenbosch (Afvalstoffendienst). The following technology explanation is based on a Swedish report [6].

The fermented biogas needs to be purified and upgraded (impurities and CO_2 must be removed) to enable a considerable quality and energy content and its efficient usage as a transport fuel to be used.

The energy content of biogas depends on the concentration of methane. As it is shown in Appendix 7, the energy content of biogas is around 9.7 kWh/Nm^3 (22 MJ/Nm^3). Contemporarily, the biomethane needs to have a methane concentration on the level of 97% and 98%, therefore, the upgrading process needs to have a methane recovery above 97% in most of CNG applications in Europe.

To be able to combine high methane recovery with high methane concentration, selective membranes and suitable design are required. A membrane is a dense filter that can separate the components in a gas or a liquid down to the molecular level. The estimated lifetime for these membranes is between five and ten years.

The membranes used for biogas upgrading retain the majority of the methane while most of the carbon dioxide permeate through the membrane. This results in biomethane which can be injected into the gas grid or used as vehicle fuel.

During the separation of carbon dioxide, the water vapor, hydrogen and parts of the oxygen are also removed from the biomethane.

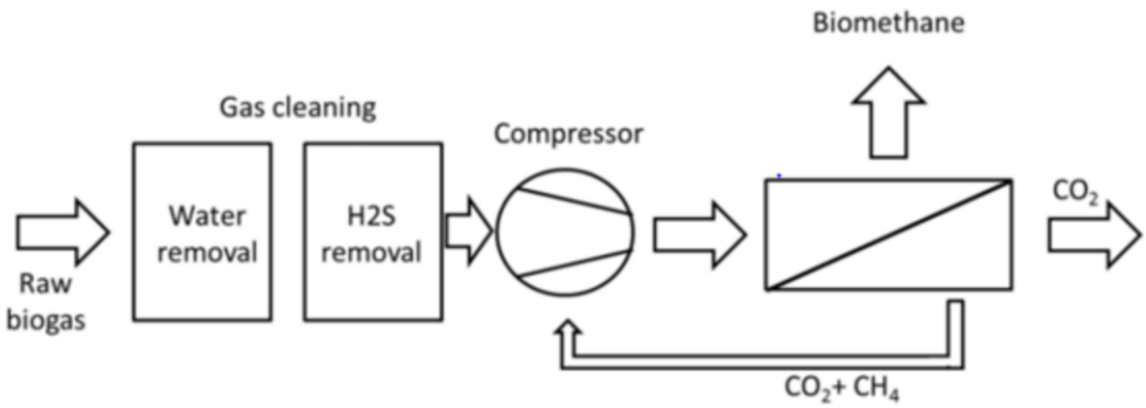

Figure 3: *A design of a typical biogas upgrading unit with the usage of membranes.*

The raw biogas is usually cleaned before compression to remove water, hydrogen sulfide including ammonia and volatile organic carbons when they are expected in significant concentrations before the biogas is upgraded. After gas cleaning, it is compressed to 6–20 bar. Usually this membrane process is done by vacuum in order to decrease the partial pressure in the permeate and facilitate higher methane concentrations (97%) and less carbon concentrations (3%) in the produced biomethane. Therefore, splitting the process in two stages would minimise the need of vacuum, since the removal of the main part of the carbon dioxide takes place in the first stage.

5.5 CNG heavy–duty vehicle

The environmental impact of trucking has received a great deal of attention nowadays. Heavy–duty vehicles are a threat and danger to the environment for two major quantifiable reasons: the air pollution and noise. With lower operating and life–cycle costs, less noisy engines, and reduced air pollution, gas fueled trucks are becoming more and more meaningful competitors for diesel trucks.

Searching for the information concerning different companies in the Netherlands working with natural gas powered trucks, resulted in interviewing Scania and Iveco representatives. Both companies are advanced in design, development and implementation of CNG trucks.

Additionally, these engines are also able to use renewable biogas without any additional adjustments made to the vehicle [15]. Consequently, if the transportation company winning the tender of SNB operates with CNG trucks, the proper technology for using CBG from Waterschap Aa en Maas will be avaliable.

It is known that the maximum weight for a diesel truck driving on the highway is 50 tons, according to Dutch legislation [16].

Table 5: *Maximum weights of lorries in the Netherlands expressed in [ton] unit.*

Weight per non–drive axle	Weight per drive axle
10	11.5

However, the maximum allowed weight of EURO VI gas trucks is 44 tons as yet. In order to get the permission of 50 tons for a truck running on biogas, the minimal level of 340 HP is required. Until now, none of the vehicle manufacturers have obtained this concession, though, it is expected, that in the following year of 2016 it will be achieved.

Table 6: *Formula for the relation between the weight of the truck and horsepower.*

kW	HP(1kW$\times$1.36)	ton
5	6.8	1
250	340	50

The conformation of a CNG truck (depending on various items) can be different than of a diesel truck. A critical issue is the placement of the gas fuel tanks. Assuming that those are placed behind the driving cabin of the truck, the space for the trailer will be shortened. The semi–trailers currently used have a length of 925 cm. There is a possibility to relocate the fifth wheel coupling more to the back of the tractor unit, in order to expand the space and use it for the kip–trailer [Appendix 3].

Table 7: *Specification of the trailers currently used.*

Type	kipper
Capacity [kg]	34 600
Weight [kg]	7 400
Length [m]	925

Table 8: *Combination of truck body and trailer.*

Total length combination	405 cm + 925 cm = 1330 cm
Total weight combination	7800 kg + 7400 kg = 15200 kg

On the other hand, the number and the size of the tanks influence the range of the truck. The average range of a CNG truck is between 300 km and 350 km, which is approximately four times than of the diesel engine. This is one of the main challenges that the transport company has to face, if it decides to operate with gas heavy–duty vehicles. The range affects mainly the refilling time in one day (15 minutes per every single refill). Moreover, the time for driving to the fuel station has to be taken into account. Considering the number of refueling stops, the driving hours can be extended (up to two hours per day).

Gas engines, however, have less power and torque than the diesel version. Basing on the information given from Scania and Iveco, the average horsepower of CNG trucks are now around 330–340 hp, while diesel trucks have around 420 hp. This affects the time of speed–up, though, it expands the lifetime of the engine at the same time. These technical attributes are still under development, causing a slight uncertainty when it comes to the predictions for future situation.

It has to be mentioned that natural gas engines improve on noise level. They are having a peak–light certificate, which means that they operate below 72 dB. So it is possible to drive in the cities for 24 hours a day.

Table 9: *Noise level of heavy–duty vehicles run on different fuels expressed in dB.*

Diesel	CNG	LNG
80	72	72

Investing in vehicles with peak–light certificate leads to another advantages. As these trucks are eco–friendly, the Dutch government offers a tax credit of 10.000 € for every single new truck which is bought. In the context of the price difference of 30.000 € compared to a diesel truck, the governmental support has a high importance.

5.6 Bi–fuel heavy–duty vehicle

In addition, combined diesel–CNG trucks could be another alternative to be considered since many vehicles can operate on both diesel and NG being called bi–fuel NGV. Indeed, an NGV that operates only on NG is called a dedicated NGV.

Hence, with a bi–fuel conversion, a switch installed on the dashboard allows the driver to easily rearrange from natural gas/biogas to gasoline or diesel at any time (even while driving, gearing, parking or transmission). In general, bi–fuel vehicles automatically switch to the reserve tank of conventional fuel when the NG tank is empty.

Furthermore, refilling a bi–fuel vehicle is easier than refilling a dedicated NGV. A bi–fuel vehicle can always run on the more available fuel (gasoline or diesel) until it is convenient to refuel at an NG station.

The bi–fuel conversion allows the vehicle to start on gasoline or diesel and then switch to NG once the engine reaches a certain temperature. A bi–fuel NGV has the additional advantage of having a back–up fuel tank in case the NG tank runs empty.

Since the investment costs of these bi-fuel trucks are lower than of the CNG–dedicated ones, this could be also the alternative to consider. To convert the vehicle from the gasoline to bi–fuel, the fuel storage cylinders should be installed on the vehicle, usually underneath the vehicle or in the trunk.

The conversion for using biogas is the same as for using natural gas, although, due to the lower energy density, consumers may want to install additional fuel cylinders to extend their driving range [9].

5.7 Commercial filling stations

The Netherlands has a developed network of CNG filling stations. In total, there are approximately 60 public stations in total and 15 in the province of Noord–Brabant. All these filling stations are available for trucks, which means that there is enough space for the trucks driving into and out from the station.

The two types of compressed gas infrastructure are: the fast–fill and the time–fill. The vehicles at the time–fill stations are refueled during the night, as the filling time needs (depending on the size of the tank) around 8–12 hours. In contrast, the fast–fill stations are suitable for vehicles arriving randomly and need to be filled up quickly, as the refilling time takes only around 15 minutes.

The stations listed in Table 10 are all fast–fill stations.

Furthermore, there is another aspect which has to be taken into consideration – the filling nozzle. The type NGV1 is suitable for passenger cars, type NGV2 is suitable for buses and trucks [17]. Unfortunately, not all of the filling stations in Noord–Brabant are equipped with NGV2 nozzles. On the other hand, truck manufacturers are now prepared to build both types of nozzles into their trucks. Nevertheless, there are some adapters available at the filling stations which can be used to refill a truck with an NGV1 nozzle.

Table 10: *CNG fuel stations and their availability for heavy–duty vehicles in Noord–Brabant [18].*

Location	Adress	Company	Trucks avaliability
Rosmalen	Molenstraat 9, 5242 HA	BP Station	NGV1
Oss	Singel 1940/1945 320, 5348 PV	Tango	NGV1
Heesch	Nistelrodeseweg 3, 5384 BA	Orange Gas	NGV1
Cuijk	Beersebaan 1, 5431 SR	Schell	under construction
Uden	Handelslaan, 35405 AE	Hopmans	NGV1
Oosterhout	Innovatiepark 3, 4906 AA	Shell	NGV1
Breda	Zwijnsbergenstraat 7, 4834 JN	Trumpi	NGV1
Etten–Leur	Nijverheidsweg 102, 4878 AZ	Tamoil	NGV1
Roosendaal	Aanwas 33, 4704 SC	DCB–Energy	NGV1
Zevenbergen	Zuidelijke Randweg 3, 4761 RN	Total	NGV1
Tilburg	Goirke Kanaaldijk 28, 5046 AT	ABC	NGV1+NGV2
Tilburg	Schepersvenweg 7, 5056 DX	Rolande	NGV1
Eindhoven	Rooyakkerstraat 12, 5652 BB	Orange Gas	NGV1
Eindhoven	Habraken 2601–2605, 5507 TR	Shippers Stop	NGV1
Eindhoven	Het Schakelplein 26, 5651 GR	Fuwell	NGV2
Bergen op Zoom	Van Konijnenburgweg 40, 4612 PL	Tamoil	NGV1

6 Current logistical situation

There are seven wastewater treatment plants belonging to Waterschap Aa en Maas: 's–Hertogenbosch, Dinther, Vinkel, Aarle Rixtel, Asten, Oijen and Land van Cuijk, where the wastewater from neighbouring parcels is being collected to and then purified.

The logistics can be devided in two: the transportation to the incineration facility of Slibverwerking Noord–Brabant and the internal transportation between the plants. The dewatered sludge is transported to Moerdijk (SNB) from 's–Hertogenbosch, Oijen, Land van Cuijk, Aarle Rixtel and Dinther. The internal transport takes place from the plant in Asten to Aarle Rixtel and from the plant in Vinkel to Dinther.

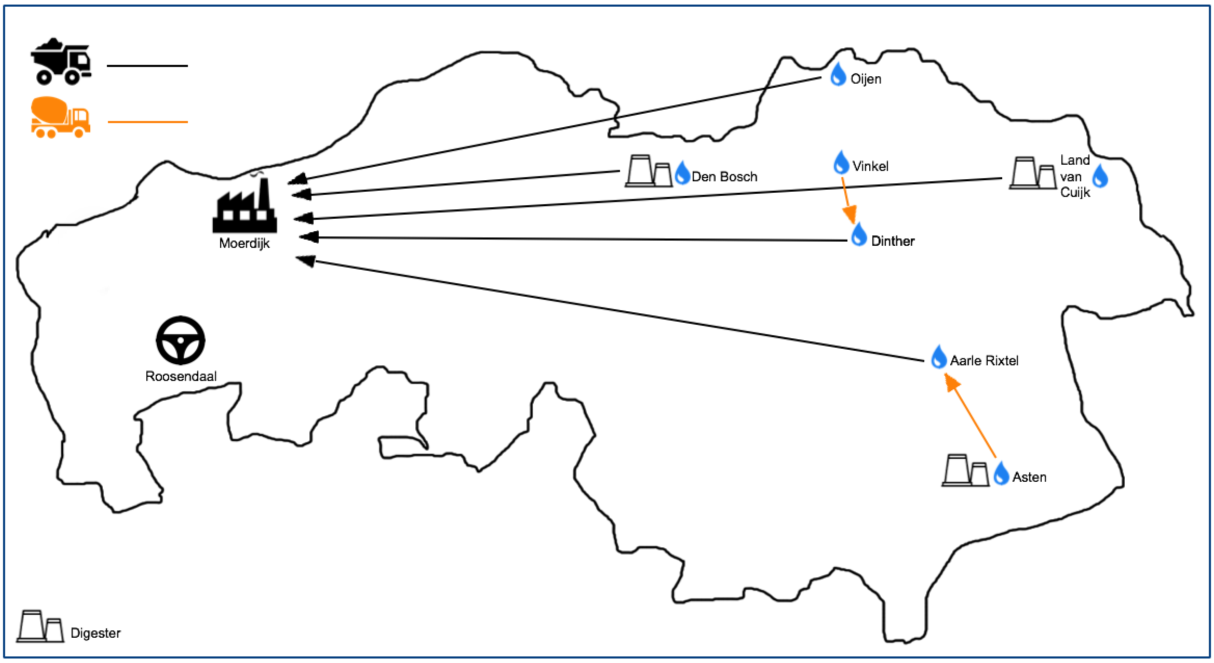

Figure 4: *The visual representation of current logistical situation at Waterschap Aa en Maas.*

Nowadays, the logistics is performed mainly by Heeren Transport, which works with 18 trucks destined for SNB (including 5 working for Waterschap Aa en Maas). They all have EURO VI engines run by diesel. The fuel tanks are being refilled in the facility at the headquarter of Heeren Transport in Roosendaal. For the internal transportation there is a direct contract between Waterschap Aa en Maas and Vakutrans.

Table 11: *Amount of sludge and concentration of dry matter in each WWTP.*

WWTP	Amount [tons]	Dry matter [%]
Oijen	16 037	27
Land van Cuijk	9 205	23,4
Den Bosch	13 361	25,5
Asten	23 198	3,5
Aarle Rixtel (incl. Asten)	24 739	21,6
Vinkel	27 097	2,8
Dinther (incl. Vinkel)	26 769	22

WWTP Oijen

The dewatering process takes place, then the sludge is directly transported in kip–trailer to Moerdijk.

WWTP Land van Cuijk

The sludge is digested and dewatered, then directly transported in kip-trailer to Moerdijk.

WWTP 's–Hertogenbosch

The sludge is digested and dewatered, then directly transported in containers (two on one truck) to Moerdijk. In the near future, the uploading method will be changed and kip–trailers will be used.

WWTP Asten

The sludge is digested and then transported in liquid form in a tank trailer to Aarle Rixtel. That transport is performed by the company Vakutrans.

WWTP Aarle Rixtel

The sludge is mixed together with the one from Asten. It is then dewatered and directly transported in kip–trailer to Moerdijk.

WWTP Vinkel

The sludge is only settled and then transported in liquid form in a tank trailer to Dinther. The drives are made by the same company as between Asten and Aarle Rixtel – Vakutrans.

WWTP Dinther

The sludge is mixed with the Vinkel one, then dewatered and directly transported to Moerdijk in kip–trailer.

7 Logistical scenarios

In 2018, the main WWTP ‘s–Hertogenbosch is going to be renovated. Therefore, it will be possible to ferment the sludge not only produced in ’s–Hertogenbosch, but also from other WWTPs. The produced biogas can be used as an energy source supplying the WWTP with electricity and heat, making it energetically independent. Furthermore, there will be a possibility to convert the produced biogas into upgraded compressed biogas. The plans forecast the construction of a filling station, giving the opportunity to supply the vehicles with this sustainable source of CBG.

In this chapter, two scenarios are going to be described. The first one is going to pertain the alternative routes proposed by Waterschap Aa en Maas. The second one describes the idea of students basing on out–of–the–box attitude and fresh insight into company structure and logistical processes. The routes are slightly different, though, the comparison will show the favorable one, which is more cost–effective and fully uses the potential and capability of the wastewater plants.

Both scenarios are based on the assumption that the transport company will get the opportunity to invest in CBG trucks in order to be used as vehicles to handle SNB logistics.

7.1 Background of logistics

In order to create a precise logistical plan, there are plenty of factors which have to be taken into account. Not only the amount of the delivered freight and the distances between the destinations, but also the European and national regulations of labour are influencing the planning phase.
Furthermore, it has to be mentioned that plans are never the same as the reality. There are a lot of variables, which cannot be predicted and which are influencing the flow of the transportation work.

The driving time for the trucks is estimated basing on the distances between the wastewater treatment plants of Waterschap Aa en Maas and SNB [Appendix 4] and the average velocity of 65 km/h. Obviously, this is also combined with the number of loads which have to be transported every day. To calculate the average number of loads at each WWTP per day, the annual amount of sludge produced is required.

The working hours do not only consist of the driving hours. The duration of the sludge uploading, unloading and the fuel refilling time must be included. Regularly, it takes around 30 minutes to upload the sludge at the WWTPs and also to unload it at the property of SNB. The tank refueling time depends on amount of fuel which has to be filled. It varies between 10 minutes and 20 minutes, therefore in further calculations the average of 15 minutes is assumed [Appendix 5]. The fuel consumption of a CNG heavy-duty vehicle is around 28 kg/100 km, which leads to the range of 300–350 kilometers. In this way, the numbers of refilling stops can be calculated.

With the combination of the driving hours, the breaks and the time for other operations, the total working hours can be determined. Following the European Union rules on driving hours, it is allowed to drive 9 hours a day, which can be extended to 10 hours twice a week [Appendix 6].

It has to be mentioned that for the final logistic plan the routes from and/or to the headquarter of Heeren Transport in Roosendaal is included. Only in this way it is possible to calculate the exact working hours for a truckdriver in one day.

Following scenarios are based on these documents and summaries.

7.2 Internal transportation

In the current logistical situation there are only two internal routes. First one is between Asten and Aarle Rixtel, second one is between Vinkel and Dinther. Since the main goal is the usage of the CBG fuel produced at Waterschap Aa en Maas (solely and the only filling station will be in 's–Hertogenbosch), it is recommendable to separate the route between Vinkel and Dinther. Instead of carrying the sludge to Dinther, the sludge would be transported directly to the WWTP 's-Hertogenbosch, where the refueling of the trucks could be operated. This means an increase in the distance of 5 km each way.

Moreover, this would be a good alternative since the presence of phosphates is an issue at WWTP Dinther. Therefore, these phosphates have to be removed from the wastewater and sludge. Dewatering of sludge releases phosphates and as a result no dewatered the sludge from WWTP Vinkel at WWTP Dinther would decrease the phosphate load at Dinther.

After 2018 not only the sludge from 's–Hertogenbosch will be digested at the main WWTP, but also from other plants, there will be several route changes in the logistics. The affected routes are from WWTP Dinther and WWTP Aarle Rixtel, where the sewage sludge will be carried to the WWTP 's–Hertogenbosch instead of be transported to SNB in Moerdijk.

These new lines will be a part of the internal transport of Waterschap Aa en Maas, which means that the operating company could be different from the company which has a contract with SNB. Taking into account that there is a lack of transportation companies owning heavy–duty vehicles running on CBG, it is reasonable to cooperate with the same company as SNB is working with at the moment.

Furthermore, the routes combining would become more simple for the operating company. This means, inter alia, that after carrying sludge to WWTP 's–Hertogenbosch, the same truck could upload already digested and dewatered sludge and continue the route to Moerdijk. In this case, it could be possible to save driven kilometers and time, which means a significant decrease in costs. Overall, it would lead to more efficient logistics.

7.3 Fuel stations owned by Waterschap Aa en Maas

All of the sludge carried to WWTP 's–Hertogenbosch will be processed to obtain biogas as it was mentioned in previous chapters. Furthermore, a part of this biogas will be turned into CBG to use it as the main fuel for the sludge transportation between all the WWTPs of Waterschap Aa en Maas and the incineration facility of SNB in Moerdijk.

It is planned to build a compressed biogas station in WWTP 's–Hertogenbosch to allow the trucks to fill their tanks and execute their routes. Even though, depending on which scenario will be developed, different locations of CBG stations are considered in order to carry out the sludge transport in the most optimal way.

Scenario I

- Gas station in WWTP 's–Hertogenbosch

Scenario II

- Gas station in WWTP 's–Hertogenbosch
- Gas station in WWTP Aarle–Rixtel

Land van Cuijk produces relatively small amount of biogas per year (around 400,000 m^3). In such a context, it is unreasonable and unprofitable to equip this plant with an own filling station.

Since 's–Hertogenbosch is on the way from Land van Cuijk to Moerdijk, there will be an opportunity to refill the vehicles with CBG there. This situation also occurs at the WWTP Oijen,

as the route can be done through the plant of 's–Hertogenbosch.
The main station referring to the logistics will be in 's–Hertogenbosch. Additionally, there will not be any internal transportation between Aarle Rixtel and 's–Hertogenbosch if Scenario II is implemented.
The main suggestion is to use CBG fueled trucks instead of diesel fueled ones. It goes without saying that such a change has a significant impact not only on the environment, but also on the cost–effectiveness of the company and its reputation (PR) on the way to sustainability.

7.4 Scenario I

First of all, the scenario proposed by Waterschap Aa en Maas assumes the closure of the digester in WWTP Asten. Such a decision was made basing on the intern investigation [19]. In this case, only two digesters will remain – one in Land van Cuijk and one in 's–Hertogenbosch.

Furthermore, it is also planned to construct a filling station in WWTP 's–Hertogenbosch, where trucks could be filled up with CBG. Apart from the fact that it is going to be the main WWTP after the renovation, it also has a good location in relation with the other WWTPs. Indeed, it is located nearby to all of the routes from Moerdijk to the different WWTPs.

Thereby, WWTP 's–Hertogenbosch will be the main plant and also the main filling station for all routes carried out as it is visible in the Figure 5.

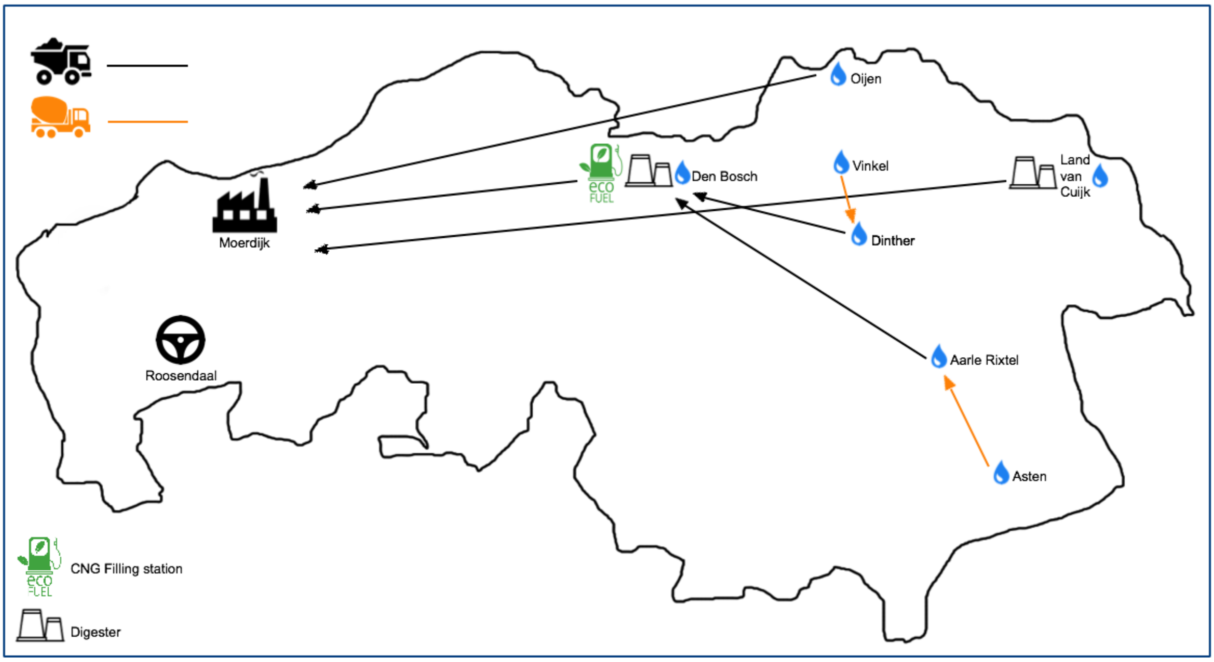

Figure 5: *The visual representation of Scenario I.*

WWTP 's–Hertogenbosch

This first scenario assumes that all of the sludge from Dinther (including Vinkel) and Aarle Rixtel (including Asten) will be carried to 's–Hertogenbosch in order to produce biogas.

Furthermore, a new thermophilic digester will be operating in WWTP 's–Hertogenbosch and as a result, the residence time of the fermentation will be decreased. The conditions for this sludge digestion are 9% of dry matter content and a residence time of 18 days [Appendix 7].

As Appendix 8 shows, there will be a total dewatered sludge production of 42.000 tonnes in a year. This leads to five loads per day. In Appendix 5 it becomes clear that to accomplish this routes with one truck one driver would have to spend 18 hours. According to the European driving regulations, it is not allowed to execute such amount of hours during one shift. Therefore, it is required to combine these routes with routes of other WWTPs [Appendix 9]. It is recommended to transpose two loads per day to other WWTPs, namely Land van Cuijk and Aarle Rixtel.

WWTP Oijen

The plant in Oijen is configured to work in the same way as currently. The only modification which would be applied is the refilling place for the vehicles. Since the only CBG filling station is in 's-Hertogenbosch, it is necessary for all of the trucks to drive through that wastewater plant.

WWTP Land van Cuijk

As the only station for refueling CBG will be at WWTP 's–Hertogenbosch, one additional stop per day is required. Moreover, as the five loads per day from 's–Hertogenbosch to Moerdijk are not possible to carry out, it is recommended to transpose one load to the truck of Land van Cuijk. This means that after that load of Cuijk, the driver returns to WWTP 's–Hertogenbosch and carries one load of dewatered sewage sludge to Moerdijk.

WWTP Vinkel

It is planned to carry the sludge from Vinkel to Dinther in a liquid form, where they will be mixed.

As it was already mentioned, it is recommendable to carry the sludge straight to 's–Hertogenbosch. Therefore, in Appendix 5 and Appendix 9 the routes are calculated based on this assumption.

WWTP Dinther

The sludge from Dinther will be transported to 's–Hertogenbosch in the same way as it is accomplished now.

WWTP Asten

Since the digester in Asten will be closed [19], its liquid sludge will be transported to Aarle Rixtel in order to be mixed and dewatered there.

WWTP Aarle Rixtel

In Aarle Rixtel the sludge is mixed with the one from Asten and then transported to WWTP 's–Hertogenbosch to digest it and produce biogas. As there are still four loads remaining from 's–Hertogenbosch to Moerdijk, it is advised to transpose one load the same way as at Land van Cuijk.

7.5 Scenario II

The second scenario is proposed by students who were basing their assumptions and ideas on firm factual and numerical investigation. The main goal of this scenario is to harness the full potential of fermentation process and produce as much biogas as it is possible. The digestion will result in a depletion of the total amount of sludge which will consequently result in a reduction of the routes performed by the trucks. Consequently, it will lead to less transportation costs and less pollutant emission.

It must be emphasised that the overproduction of biogas can be easily sold. As a result of such an undertaking, the company can increase the income and feasibly contribute to sustainable development in the Netherlands.

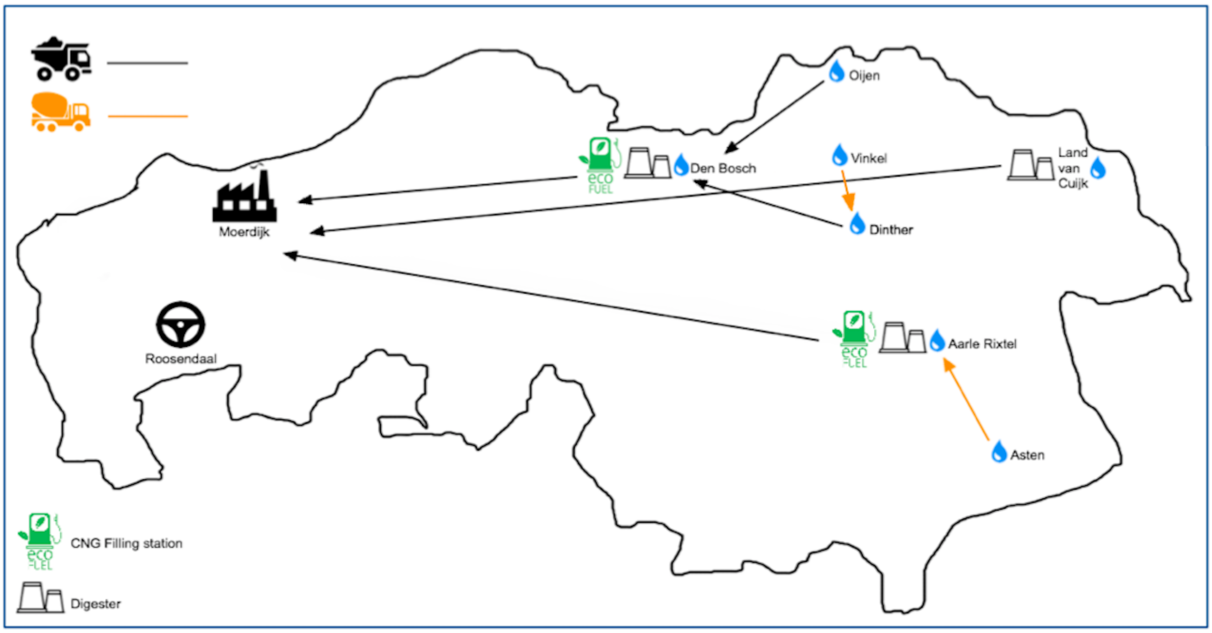

Figure 6: *The visual representation of Scenario II.*

7.5.1 Digester review

The first concept was to keep the digester in WWTP Asten working. As an internal report [19] shows, the digester has to be renovated. After the reconstruction, the plant would have two digesters (capacity 2300 m^3 each, 4600 m^3 in total).

In order to gain the highest amount of biogas possible, the recommended fermentation method is the thermophilic one, as it will be done in WWTP 's–Hertogenbosch. In this case the new digester would have more capacity than before. So the sludge from WWTP Aarle Rixtel could be digested also there, instead of being transported to WWTP 's–Hertogenbosch. This would make WWTP Asten 100% a self–sufficient plant [Appendix 10]. What is more, it would be possible to produce and sell CBG taking advantage of biogas overproduction.

Though, there are several obstacles which should be taken into account before making such a decision. One of them is the installation of a new dewatering system in Asten, which would increase the investment greatly. Also, the dewatering system in Aarle Rixtel would get more idle capacity.

Drawing the inference from the cost analysis [Appendix 11], allowed to prove that a new digester in the WWTP Aarle Rixtel is more profitable. In this case, there is no need for a new installation of dewatering system. The sludge from Asten would be carried with the same dry matter content and the same way as now.

This digester would be designed for both WWTPs sludge processing (in total 3600 m^3), with a biogas production of 1.7 million Nm^3 per year [Appendix 12], which can be converted into electricity (namely 4 million kWh). With this amount of electricity, the WWTP can achieve a self–sufficiency of 50% [Appendix 13]. In this situation, capacity will be released from the digester in 's–Hertogenbosch. There is only one WWTP where the sludge is not used for further fermentation, in order to obtain biogas – WWTP Oijen.

Accordingly, the sludge would be carried from Vinkel, Dinther and Oijen to 's–Hertogenbosch. The total amount is only slightly different from Scenario I [Appendix 14].

Under the assumption that digester's total capacity is going to be used, 6,7 million m^3 of biogas will be produced [Appendix 15]. The purchase price of the electricity (0.09 €/kWh) is always higher than the sell price (0.05 €/kWh). Therefore, it is reasonable to accomplish a self–sufficiency of 100%. The surplus can be sold as biogas or as CBG to domestic companies in the area of 's–Hertogenbosch [Appendix 16].

WWTP 's–Hertogenbosch

Similarly to the first scenario, 's–Hertogenbosch has a central role with the new thermophilic digester among other WWTPs. The sludge from Oijen, Dinther and Vinkel will be carried to 's–Hertogenbosch to produce biogas. As it is shown in Appendix 8, there is around 2000 tons difference (per year) in the amount of dewatered sludge compared to Scenario I. This means unchanged amount of five loads per day. Therefore it is recommended to transpose two loads to other WWTPs.

WWTP Oijen

The plant in Oijen will work in the same way as presently. With only one discrepancy - the sludge will be carried to 's–Hertogenbosch instead of Moerdijk. Afterwords, the sludge will be digested at WWTP 's–Hertogenbosch. The same way as in Scenario I, it is required to transpose one drive from 's–Hertogenbosch. This means that after the last round, the truck driver pursues his work and takes one load of the sludge from 's–Hertogenbosch to Moerdijk.

WWTP Land van Cuijk

The logistics is planned to be similar to the first scenario. After the digestion, the sludge will be transported straight to Moerdijk. One load from WWTP 's–Hertogenbosch is transposed to the truck of WWTP Land van Cuijk.

WWTP Vinkel

The liquid sludge from Vinkel will be transported to Dinther like in Scenario I. The assumption of carrying the sludge to 's–Hertogenbosch is also made.

WWTP Dinther

In Dinther the sludge will be mixed with the one from Vinkel and then carried to the main digester in 's–Hertogenbosch.

WWTP Asten

The plant in Asten will work in the same way as in the first scenario.

WWTP Aarle Rixtel

In Aarle Rixtel the sludge is mixed with the liquid one from Asten. Then biogas will be produced in the renovated thermophilic digester. After that, the dewatered sludge will be transported straight to Moerdijk.

7.6 Comparison of the scenarios

There are several aspects which have to be considered while comparing two scenarios. Not only the number and placement of the digesters, but also the combining of the routes makes significant changes in the logistics plan.

7.6.1 Biogas production

First, as has already been described in Scenario I, there will be two digesters functioning ('s-Hertogenbosch, Land van Cuijk). In Scenario II, though, there will be three digesters in total under power ('s-Hertogenbosch, Land van Cuijk, Aarle Rixtel). With the additional digester in Aarle Rixtel, there will be notable difference in the total biogas production of Waterschap Aa en Maas. Consequently, this will rise the self–sufficiency at WWTP Aarle Rixtel.

In both scenarios, 's–Hertogenbosch and Land van Cuijk will achieve same self–sufficiency of 100% in 's-Hertogenbosch and 17% in Land van Cuijk [Appendix 17]. Additionally, it is of significance that in Scenario II there will be around 300,000 m^3/year more biogas produced in 's–Hertogenbosch [Appendix 16]. That is because the sludge from Oijen has a higher quality, since it contains more primary sludge [Appendix 15]. This results in a profit increase of around 48,600 €/year. As it is shown in Appendix 18, the sell of biogas is more profitable than selling it as electricity. These calculations were made under the assumption that the electricity consumption will be the same as in the year 2015 [4].

Moreover, with the new thermophilic digester in Aarle Rixtel, a self–sufficiency of 50% will be reached. This means savings of electricity costs around 250,000 € per year [Appendix 19]. Adding together the profit and the savings, of both the electricity and the incineration, there will be around 520,000 €/year available for investments. Following the cost calculations of the thermophilic digester at WWTP Aarle Rixtel [Appendix 11], the pay off period will be only 10 years.

7.6.2 Transportation routes

As was mentioned before, both the digesters and the combined routes affect the costs of transportation. As can be observed in Appendix 8, if Scenario II is developed, more sludge will be digested in Waterschap Aa en Maas. Consequently, less dewatered sludge will remain, which means a decrease of the transportation loads. The reduction of 7,500 tons/year in dewatered watered sludge production will lead to savings of the incineration costs of around 92,000 € each year.

Having looked at Appendix 5, it is notable that the combination of the routes is necessary, as the drivers will not be able to complete their shifts between 's–Hertogenbosch and Moerdijk. Referring only to the combined routes in both scenarios [Appendix 20], it can be observed that the difference is not that significant, but there are still less driving hours accomplished and less CBG consumed.

8 Sustainability

By 2020, the European Union aims to reduce its greenhouse gas emissions by at least 20%, to increase the share of renewable energy to at least 20% of consumption and to achieve energy savings of at least 20% [20]. All EU countries must additionally achieve a 10% share of renewable energy in their transport sector. Through the attainment of these targets, the European Union can help to combat climate change and air pollution, decrease its dependence on fossil fuels, and keep the energy affordable for consumers and businesses.

The action plan of the Netherlands includes all of these goals. Their main strategy is to make the supply of energy cleaner and more efficient through the encouragement of energy savings, the production of more renewable energy, and the capture and storage of CO_2 [19].

Accordingly, Waterschap Aa en Maas contributes to these objectives with an agreement, that 40% of the energy used in the company will be self–produced by sustainable resources [20]. Consequently, at three WWTPs the wastewater is turned into renewable energy through several installations. The product of anaerobic fermentation of sludge is an energy–rich biogas. This green energy source can be used in different ways. First of all, with combined heat and power cogeneration, it can be converted into heating and electricity for the buildings and treatment processes. Moreover, with transforming into compressed or liquefied biogas it can be used as a local clean fuel.

In this way, sustainability can be appreciated and used as a main topic taken into account in the entire investigation.

8.1 Environmental effects of diesel

The gases which are exhausted by diesel engines are dangerous air pollutants and greenhouse gases. The smog is an effect of incomplete burning of diesel. There are CO_2 (carbon dioxide), CO (carbon monoxide), NO_x (nitrogen oxides), SO_x(sulfur oxides) and PM (particulate matter) as main ingredients. In other words, the composition includes harmful chemical elements such as sulfates, ammonium, nitrates, elemental carbon, condensed organic compounds, carcinogenic compounds, heavy metals (arsenic, selenium, cadmium, zinc). These particles have various sizes. Some of them are small enough to penetrate into our body through the skin, eyes and lungs. The scary fact is that these particles comprise 80–95% of total diesel air pollution.

As a result, they have a real contribution to respiratory and cardiovascular illnesses and even premature death. According to the scientific researches [21] [22], thousands of people die every year as a result of the air pollution. It was proven [22] that truck and bus garage workers exposed to high levels of diesel exhaust over many years, demonstrate a 20–50% increase in the risk of lung cancer and mortality as a result.

Additionally, the emissions of nitrogen oxides contribute to the formation of ozone in ground level, which irritates the respiratory system, causing coughing, asthma symptoms, and reduced lung capacity.

8.2 Environmental effects of CBG

Using wastewater to produce a fuel for heavy-duty vehicles contributes to a sustainable development and a climate neutral transportation. CNG produced from biogas was found to have the lowest greenhouse gas emissions of any fuel analyzed. It emits significantly fewer pollutants than petrol, for example: CO_2 (carbon dioxide), CO (carbon monoxide), NO_x (nitrogen oxides), SO_x (sulfur oxides) and PM (particulate matter). Moreover, it does not contain any lead, thereby eliminating fouling of spark plus.

The consistence of biogas depends on various factors, i.e. the production process, the raw material used for anaerobic digestion, etc.

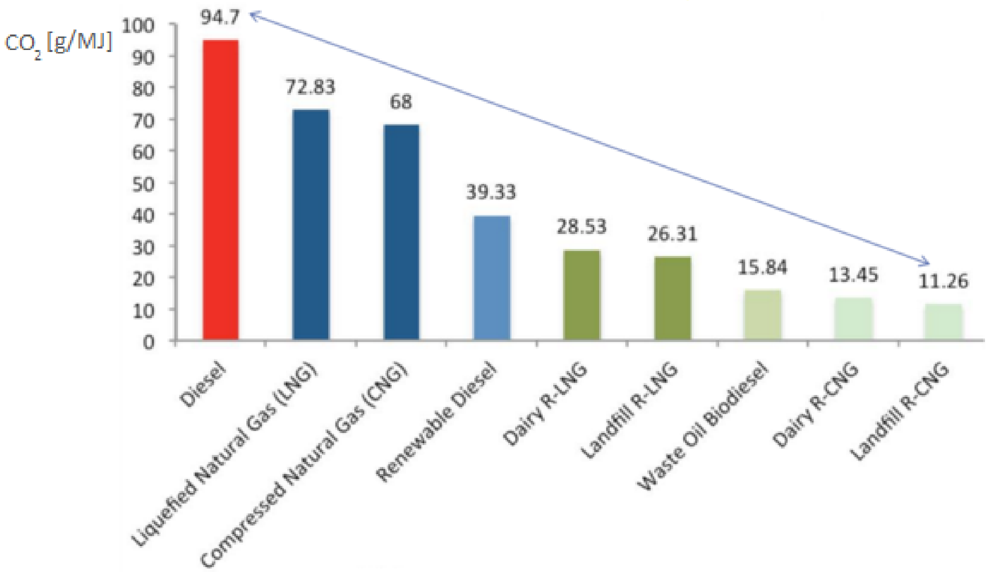

Figure 7: *Direct greenhouse CO_2 gas emissions of diesel and alternative fuels [g/MJ] [23].*

Apart from having the lowest carbon footprint, CBG has also other advantages. Due to the local production and availability it supplies the domestic market. In addition, it is cost–competitive to fossil–based fuels and its price do not fluctuate and it is more predictable. Therefore, using CBG can be a major benefit for freight companies.

8.3 Logistics

Unfortunately, using diesel as a main fuel is not environmentally friendly. Undoubtedly, such a fossil fuel should not be used if SNB and Waterschap Aa en Maas want to be considered as companies actively involved in sustainability and unconventional approach. It goes without saying, that diesel usage has a strong advantage – the availability.

In the Appendix 8, it is visible that the total driven kilometers for sludge transportation are in average around 200,000 km. Switching to CBG fuel could save, depending on the scenario, the following amount of CO_2 emissions.

Table 12: *CO_2 emission of diesel at Waterschap Aa en Maas [24].*

		Scenario I	Scenario II
Heat value	MJ/kg	42.7	42.7
CO_2 Emission factor	kg/GJ	74.3	74.3
CO_2 Emission	kg/l	2.67	2.67
Total CO_2 Emission	kg	159,823	151,003
Total CO_2 Emission	ton	160	151

The total CO_2-footprint of Waterschap Aa en Maas is approximately 15,000 ton CO_2 per year [25]. The savings of 160 tons of CO_2 may not look very attractive while compared to the total emissions of the company, but in case of achieving a healthy and green environment, every step counts.

Alternative approach for analysing the sustainability of logistics is the energy aspect. The energy usage of the sewage sludge transportation with the diesel fuel is 2,87 MJ/ton-km. The Table 13 shows the saving of fossil energy if the fuel is replaced with CBG. This is around 5% compared to the total energy usage of Waterschap Aa en Maas, which was approximately 350 TJ in 2014 [26]. In this way, the importance of sustainable transportation is more representative.

Table 13: *The savings of the energy useage of transportation*

Scenario I	18897384 MJ	18,9 TJ
Scenario II	17854600 MJ	17,9 TJ

Not only the change of the fossil fuel into renewable one affects the sustainability of the transport. Additional optional factor could be combination of the routes in a more efficient way. As it is shown in Appendix 20, the difference between the two logistical plans is 115 km per day, around 30,000 km in a year. Accordingly, it becomes clear that this measure will also lead to a better solution.

Table 14: *Savings of the CO2 emissions with the combining of the routes [24].*

Heat value	MJ/kg	42.5
CO_2 Emission factor	kg/GJ	74.3
CO_2 Emission	kg/l	2.67
Total CO_2 Emission	kg	23,950
Total CO_2 Emission	ton	24

It has to be mentioned, that the result of combining the routes with other wastewater treatment companies is complex and needs further investigation. Nevertheless, there is one significant difference between these two scenarios. The connections of the routes save one driver for the transport company [Appendix 20]. This results in less labour costs.

8.4 Green energy through biogas

Appendix 18 shows that Waterschap Aa en Maas is producing (depending on the scenario) yearly between 6-7 millions of Nm^3 of biogas. The first goal is to provide the maximum amount of electricity as possible. Therefore, in both scenarios a self-sufficiency of 100% at the WWTP 's–Hertogenbosch and 17% at the WWTP Land van Cuijk will be achieved. Furthermore, placing a digester in WWTP Aarle Rixtel could result in 50% of self–sufficiency.

Beyond the raising sustainability, the self–support of the plants creates a significant cost savings for Waterschap Aa en Maas. Moreover, it is a reasonable decision to serve the renewable fuel to the cooperating transport company. As it can be seen in Appendix 20, the amount of biogas which would be enough for supporting the transportation of sludge with CBG is approximately 240,000 m^3 annually. Additionally, the remaining biogas can be used for promoting domestic market.

9 Risk analysis

Considering to change the fuel from diesel to CBG, it is highly recommended to identify the project risks during the planning phase. This risk analysis shows the hazards and the complications which can appear by using CNG trucks for the sludge transportation at Waterschap Aa en Maas. First of all, it is useful to separate the potential threats, according to the importance of parties involved. These risks are considered in two different viewpoints: probability of the event and its influence on different stakeholders. Combining these views all the threats become valuable between low, medium and high risks.

Table 15: *Risk analysis matrix.*

		Concequences				
		catastrophic	major	moderate	minor	insignificant
Likelyhood	almolst certain	25	20	15	10	5
	likely	20	16	12	8	4
	moderate	15	12	9	6	3
	unlikely	10	8	6	4	2
	rare	5	4	3	2	1

Table 16: *Summary of sludge transport risks with CBG trucks for Aa en Maas*

Type	Risk	Likelyhood	Concequences	Proposed actions	Risk ranking
AA en Maas					
	Failure in the building process of the own filling station at the wastewater plant	Moderate	Major	Investigation of technical and legal requirements; firm project planning	Medium
	Error or break down of the filling station at the wastewater plant	Unlikely	Major	Regular control of technical devices; professionals involved; using temporarily commercial CNG filling stations	Medium
	Not sufficient gas pressure at the filling station, due to the high number of trucks refilling fuel	Moderate	Major	Smart planning of the sludge transportation, optimal number of trucks waiting; using temporarily commercial CNG filling stations	Medium
	Temporary demurrage of biogas production	Rare	Catastrophic	Regular control of technical devices and processes; using temporarily commercial CNG filling stations	Medium
	Interim cessation of CBG production	Rare	Major	Regular control of technical devices. Safety reserve is highly recommended; using temporarily commercial CNG filling stations	Low
	Not sufficient quality of CBG	Unlikely	Major	Regular controls of quality; using temporarily commercial CNG filling stations.	Medium
	The wastewater plant is closed when the truck arrives for upload sludge	Unlikely	Major	Proper communication between Aa en Maas and transport company/driver	Medium
	Dependence of Aa en Maas on the transport company using CNG trucks	Likely	Insignificant	Finding other customers for CBG	Low

Table 17: *Summary of sludge transport risks with CBG trucks for Transport Company*

Type	Risk	Likelyhood	Concequences	Proposed actions	Risk ranking
Transport company					
	Lack of experience with CNG trucks causes delays	Likely	Major	More precise scheduling (lower range of the CNG trucks); proper communication between Aa en Maas and the transport company.	High
	Transport company strongly depends on Aa en Maas	Likely	Major	Keeping updated with the CNG production market, finding alternative suppliers and clients	High
	Loosing current clients	Moderate	Catastrophic	It is neccessary to use diesel trucks for long distance routes; convince the customers about the importance, advantages and sustainability of CNG	Medium
	Not suffcient maintenance of the trucks	Moderate	Minor	CNG trucks require more attenction than diesel trucks; it is advisable to be in touch with a specialized truck repair.	Medium
	Complication with the CNG truck components supply	Rare	Major	It is recommended to have a safety reserve of the components frequently used.	Low

Table 18: *Summary of sludge transport risks with CBG trucks for drivers and trucks.*

Type	Risk	Likelyhood	Concequences	Proposed actions	Risk ranking
Drivers					
	Drivers work overtime	Likely	Major	Precise time scheduling; optimal shifts planning.	High
	Running out of CNG on the way.	Moderate	Major	Range of the truck must be constantly known; if the tank is close to be empty, driver should refill it immediately.	Medium
	Low fuel level, away from the plant of Aa en Maas.	Likely	Minor	Driver has to be informed about the CNG, truck-friendly filling stations.	Medium
	Human errors due to poor man-machine collaboration.	Unlikely	Moderate	Drivers has to be trained how to use the CNG trucks drivers acceptance of trucks.	Medium
CNG trucks					
	Truck error, break down.	Likely	Moderate	Avaliable CNG specialist truck repair; proper communication between driver and the truck repair point.	Medium
	Fire	Rare	Catastrophic	Observe the special safety regulations.	Medium

As we can observe in this analysis that most of the risks are in medium classification. All of the high risks are related to the planning management of the transportation company. These risks could be avoided by improving the communication with Waterschap Aa en Maas.

Due to several risks having relation with the filling station owned by Waterschap Aa en Maas, it is advisable to have a wider knowledge about the commercial filling stations. This is detailed in the chapter „Compressed natural gas“ in the Table 9.

10 Idealistic alternatives

Considering the sustainability as a prior issue, wide range of transportation possibilities appeared. In this chapter, three of them will be described: construction of a pipeline, production of LBG for the trucks fuel and shipping with barges through the canals of Noord–Brabant. After a brief investigation, it becomes clear that these options cannot compete in the financial aspect with the initial idea of replacing the fuel of diesel with CBG.

10.1 Pipeline between Vinkel and Dinther

Basing on the assumption that the sludge transported from Vinkel to Dinther is in a liquid form (the concentration of dry matter is only 2.8% [4]), the focus was aimed at pipelines. They were considered as a competitive alternative for heavy-duty vehicles due to its undoubtedly higher sustainability connected with significant reduction of pollutants emission.

The distance between these two WWTPs is seven kilometers in straight line. Unfortunately, the pipeline would have to be placed on tens of private parcels, what would entail issues connected with proper permissions and legislations. The pipeline could be therefore alternatively placed parallelly to the channels owned by Waterschap Aa en Maas. As a result, the complications connected with the plots of lands could be avoided. Obviously, the length of potential pipe will naturally increase. According to map investigation [Appendix 21], it was estimated that the length would be 11 kilometers.

Such a length would cause the significant increase of the investment. In order to construct such an underground canal, several expenses must be considered. They are presented in Appendix 22. The calculations show that the cost would be around 4mln €. Comparing that number to the annual cost of truck transport (around 50.000 €) it can be easily deduced that such an investment is not cost–effective in the case of Waterschap Aa en Maas. Though, it may be a good alternative, when transport costs will rise in future or for the moment when not money, but sustainability factor will be the most important one influencing the final decision.

10.2 LNG/LBG Trucks

Liquefied natural gas is also an alternative for the diesel. This fuel has the same components as CNG, depending on the source of it (natural or biogas). Such a source can be converted into liquid form which results in an ease of storage and transport.

The liquefaction process involves removal of certain components, such as dust, acid gases, helium, water, and heavy hydrocarbons, which could cause difficulty downstream. The natural gas is then condensed into a liquid at pressure, which is close to atmospheric one, by cooling it to approximately –162°C [27] [28].

Table 19: *Condensation temperatures of compounds present in biogas [28].*

Compound	Condenstation temperature [°C]
CO_2	-78,5
CH_4	-161
N_2	-196

The LBG, in Waterschap Aa en Maas, could be produced in several ways:

- Cryogenic upgrading technology that is based on differences in the condensation of the temperature for different compounds. By chilling biogas the impurities and CO_2 can be separated from CH_4. Also liquid CO_2, LCO_2, comes as a by–product, which could be used in external applications;
- Conventional technologies connected with a small–scale liquefaction plant;
- Injection of biogas into the gas grid and then liquefaction of a part–flow at a pressure letdown station.

With one of the two main ways, it takes between 0.8–1.8 kWh/Nm^3 clean biogas to produce LBG. If the energy is expressed in primary energy, this energy consumption corresponds to 12–23% of the energy content in the product. The net energy consumption is affected by the disposal of waste heat and use of LCO_2 in external processes while CH_4 losses have a small influence.
The production of LBG is more energy intensive than the production of CBG but in some situations the product is more valuable since the biogas becomes available for more customers.

However, the conversion process of biogas, produced in the WWTPs of Waterschap Aa en Maas, into LBG has a high risk, due to its considerable investment costs, relatively new technologies applied and lack of backup LNG filling stations in case of failures. Therefore, such a solution is considered as a future possible alternative to carry the sludge of Waterschap Aa en Maas.

The main argument to switch to LBG trucks would be based on the fact that CBG trucks have a low range possibilities and continuous refilling requirement. A truck running on LNG has approximately three times more range - around 1000 km, which is more close to the range of diesel trucks. This means, that it is enough to refill the tank only once during a day or even every second day. As a result, it saves time and decreases the working hours of the drivers. Moreover, the truck routes are crossing the city of 's-Hertogenbosch, so to stop for refilling them could be easily arranged.

10.3 River transportation

It goes without saying that the Netherlands is the land of water. The canals and rivers are crossing the country in all of the direction possible – it is hardly possible to find an "empty" space in your sight. Looking on the map, it has been discovered, that there is a canal between most of the plants, where the sludge could be shipped by vessels. After a short investigation it turned out, that there are only two routes where the barge shipping is not a possibility at all: from Vinkel to Dinther and from Asten to Aarle Rixtel. The transportation at all of the other routes (Oijen, Den Bosch, Land van Cuijk, Dinther, Aarle Rixtel to Moerdijk) could be changed into shipping. However, in some locations, it would be necessary to have transportation by truck between the WWTP and the facility in the river, due to its distance.
In order to plan this type of transport, following aspects have to be considered:

- place for sludge containers (possibility, costs);
- amount of the sludge (vessel capacity);
- buffering time of the sludge in ports;
- proper installations and devices provided (in plants, ports, SNB facilities).

The firm investigation performed in 2005 by SNB revealed that the highway transportation is around 50% cheaper than the vessel transportation. The main issue to face is that only a low amount of sludge has to be transported compared to the capacity of the vessels. The smallest barge which can be used, has a capacity of 350 tons.

Even at the most busy route (from 's-Hertogenbosch to Moerdijk), there are only 120 tons of sludge processed in one day. As a result, it is a must to buffer the sludge for at least 2 days. Considering less busy route (from Land van Cuijk to Moerdijk) having only 35 tons per day to transport, clearly implies the buffering time of ten days.

Nevertheless, it would be possible to collect the sludge from the plants following the river Maas and the river Aa, in order to use more capacity of the vessels. This method combined with shared shipping could save fuel, and decrease the emission of greenhouse gases. Taking the sustainability into account, it can be a significant competitor of diesel and CNG trucks in the future.

This survey clearly proves that transportation by barge needs complex planning, which requires a further investigation.

11 Conclusions and recommendations

This report has primarily introduced the options for using CBG as the main fuel for the sewage sludge transportation of Waterschap Aa en Maas. Furthermore, two different scenarios were considered in order to obtain as much quantity of biogas as possible. There is more than one optimal answer to the main question, which is the following: *What is the optimal way to use the biogas, produced by 's–Hertogenbosch WWTP, as the main truck fuel to transport the sludge?* Therefore, several conclusions and proposals will be presented in this chapter.

After analysing the functional structure of Waterschap Aa en Maas, it was discovered that there could be several alternatives proposed to improve the production of biogas. The first scenario is based on the future plan of the company. The second one was developed to perform the purpose of using all of the sludge present in the wastewater treatment plants. Researches of the students show that the most optimal location for an additional digester is at the WWTP Aarle Rixtel.

First of all, the high quality sludge from Oijen could be involved into the total sludge digestion process at WWTP 's–Hertogenbosch. This improves, in a significant way, the biogas production compared to Scenario I. With the over 6 millions Nm^3 of produced biogas, a higher level of self-sufficiency is approachable. Apart from the savings of 470.000 € at WWTP 's–Hertogenbosch, also around 250.000 € at WWTP Aarle Rixtel is saved on the electricity costs [Appendix 19]. This led to the conclusion that the second scenario is the most suitable one. Furthermore, the overproduction of biogas at WWTP 's–Hertogenbosch profits more as itself or transformed into CBG instead of being sold as green electricity for domestic companies [Appendix 18].

Hereby, it should be mentioned that it has not only advantages in connection with the cost perspective, but also in increasing the level of sustainability. The amount of biogas which could be used to replace the diesel fuel for the sludge transportation is only around 240.000 Nm^3. This is related to the total amount of 6 millions Nm^3 produced biogas at Waterschap Aa en Maas, only an irrelevant part. Consequently, the goal of reaching a sustainable logistics in the future is more than attainable.

On the other hand, the transportation of the sewage sludge to the incineration facility is not under the responsibility of Waterschap Aa en Maas. It is regulated by a governmental tender from Slibverwerking Noord-Brabant. Besides Waterschap Aa en Maas, two other waterboards operate in the province of Noord-Brabant, namely Waterschap Brabantse Delta and Waterschap De Dommel. SNB carries out the sludge transportation for all these waterboards. Therefore, all of the implemented routes are separated into different packages. This means that every package could be applied by different transportation company.

As it is already mentioned, after the renovation in WWTP 's–Hertogenbosch in 2018, there will be new internal transportation routes for the dewatered sludge. In order to combine these routes in an efficient way with the already existing ones, it is recommended to gather them in one package of the tender. Furthermore, in the package of the routes done for Waterschap Aa en Maas, no other wastewater treatment companies should be included.

After all, it was proved that the companies are usually applying for all of the packages. Accordingly, the assumption that one transport company will win the whole tender could be considered.

In this way, if Waterschap Aa en Maas wants to implement CBG trucks for the whole logistics, the cooperation with other waterboards is required. Usually, the freight companies are combining their routes during one day. Hence, only one CBG filling station will not suffice in the future. Since the other waterboards possess sludge fermenter, it could be possible to provide CBG in the same way as at Waterschap Aa en Maas [Appendix 23]. This could mean more potential CBG filling stations in the conveying zone of SNB .

On the other hand, according to the high investment of the heavy-duty natural gas vehicles, transport companies are aiming to take the complete advantage. In order to persuade them, a chapter about the availability of CBG at the WWTPs should be included in the tender.

Answering the question of this report, the optimal way to use the biogas produced by Waterschap Aa en Maas depends on the number of winners of the tender. At first, if one transportation company will perform the routes of all of the packages, the cooperation between the wastewater treatment companies is a precondition. Since these companies have different interests, it would be useful to create a platform, where every stakeholder could be involved in order to achieve an appropriate solution. Secondly, if a transport company accomplishes only the routes of Waterschap Aa en Maas, then it becomes possible to switch any fuel into CBG, with the condition of having the adequate heavy duty vehicles.

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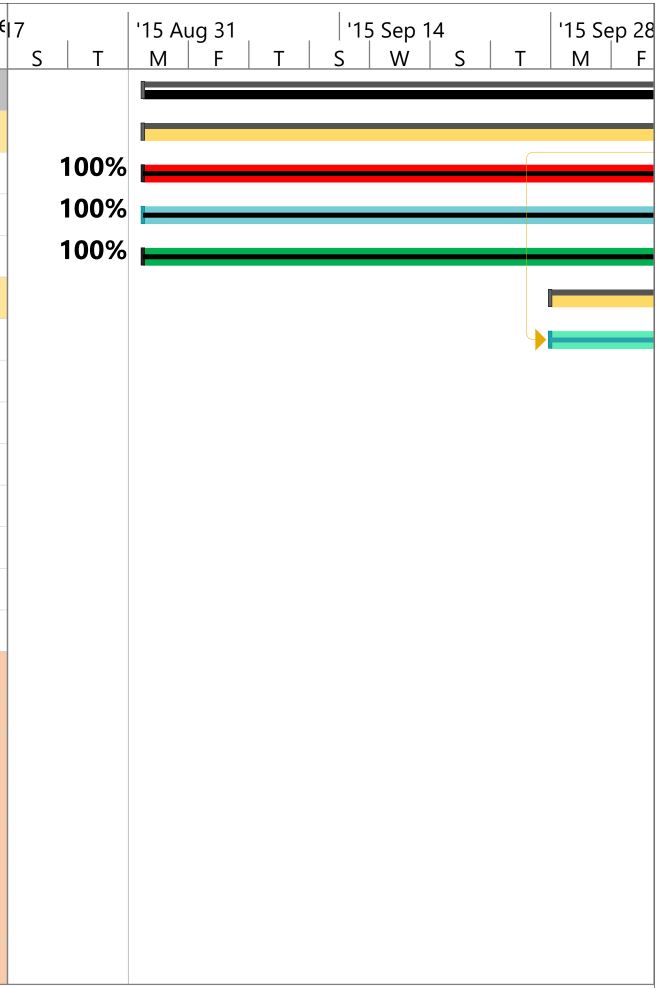
List of Appendices

Appendix 1 - MS Project plan

ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors
1			**Project**	**121 days**	**Tue Sep 01**	**Tue Jan 26**	
2	✓		**Initiation**	**40 days**	**Tue Sep 01**	**Mon Oct 19**	
3	✓		Project agreement	33 days	Tue Sep 01	Fri Oct 09	
4	✓		Contract	33 days	Tue Sep 01	Fri Oct 09	
5	✓		Definition of scope	33 days	Tue Sep 01	Fri Oct 09	
6	✓		**Planning**	**64 days**	**Mon Sep 28**	**Tue Dec 15**	
7	✓		Project plan	9 days	Mon Sep 28	Wed Oct 21	2
8	✓		**Searching**	**22 days**	**Tue Oct 06**	**Mon Nov 02**	
9	✓		Biogas trucks	17 days	Tue Oct 06	Mon Oct 26	
10	✓		Pipes	22 days	Tue Oct 06	Mon Nov 02	
11	✓		Ships	22 days	Tue Oct 06	Mon Nov 02	
12	✓		Exel data	12 days	Tue Oct 06	Tue Oct 20	
13	✓		Digester Asten	20 days	Tue Oct 06	Thu Oct 29	
14	✓		**Interviews**	**56,86 days**	**Mon Oct 05**	**Fri Dec 11**	**7**
15	✓		Asten and Aarle Rixtel	1 day	Wed Oct 07	Wed Oct 07	13
16	✓		den Bosch	1 day	Tue Oct 13	Tue Oct 13	9;12
17	✓		Vinkel and Dinther	1 day	Tue Oct 20	Tue Oct 20	10
18	✓		SNB	1 day	Wed Oct 21	Wed Oct 21	9
19	✓		Bart Verberkt	1 day	Wed Oct 28	Thu Oct 29	13
20	✓		IVECO	1 day	Tue Oct 27	Tue Oct 27	9
21	✓		Scania	1 day	Thu Oct 29	Thu Oct 29	9
22	✓		Heeren Transport 1	1 day	Fri Nov 06	Fri Nov 06	9;18



Project: MS Project
Date: Wed Jan 06

Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
Milestone	Duration-only	Deadline
Summary	Manual Summary Rollup	Progress
Project Summary	Manual Summary	Manual Progress
Inactive Task	Start-only	
Inactive Milestone	Finish-only	

ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors
23			Oijen- Mrs van de Craats	1 day	Mon Nov 23	Mon Nov 23	
24			Pipe-Frank Bertholet	1 day	Wed Nov 11	Wed Nov 11	10
25			Heeren Transport 2	1 day	Thu Dec 10	Thu Dec 10	22
26			**Analysis**	**45,43 days**	**Mon Oct 05**	**Fri Nov 27**	
27			Asten and Aarle Rixtel	6 days	Mon Oct 12	Mon Oct 19	15
28			den Bosch	4 days	Wed Oct 14	Mon Oct 19	16
29			Vinkel and Dinther	6 days	Wed Oct 21	Wed Oct 28	17
30			SNB	2 days	Thu Oct 22	Fri Oct 23	18
31			Bart Verberkt	2 days	Thu Oct 29	Mon Nov 02	19
32			Oijen	2 days	Tue Nov 24	Wed Nov 25	23
33			Pipe	3 days	Fri Nov 13	Wed Nov 18	24
34			IVECO	4 days	Tue Oct 27	Mon Nov 02	20
35			Scania	5 days	Tue Oct 27	Tue Nov 03	21
36			Heeren Transport	4 days	Mon Nov 09	Thu Nov 12	22
37			**Execution**	**70 days**	**Mon Nov 02**	**Tue Jan 26**	
38			**Scenarios**	**24 days**	**Mon Nov 02**	**Tue Dec 01**	**26**
39			**Aarle Rixtel digester**	**24 days**	**Mon Nov 02**	**Tue Dec 01**	**27**
40			**Pipeline Vinkel-Dinther**	**24 days**	**Mon Nov 02**	**Tue Dec 01**	**33**
41			**Den Bosch digester**	**24 days**	**Mon Nov 02**	**Tue Dec 01**	**28**
42			**Trucks**	**41 days**	**Mon Nov 02**	**Mon Dec 21**	
43			CNG	39 days	Tue Nov 03	Mon Dec 21	35;34
44			LNG	39 days	Tue Nov 03	Mon Dec 21	35;34

7 '15 Aug 31 '15 Sep 14 '15 Sep 28
S T M F T S W S T M F

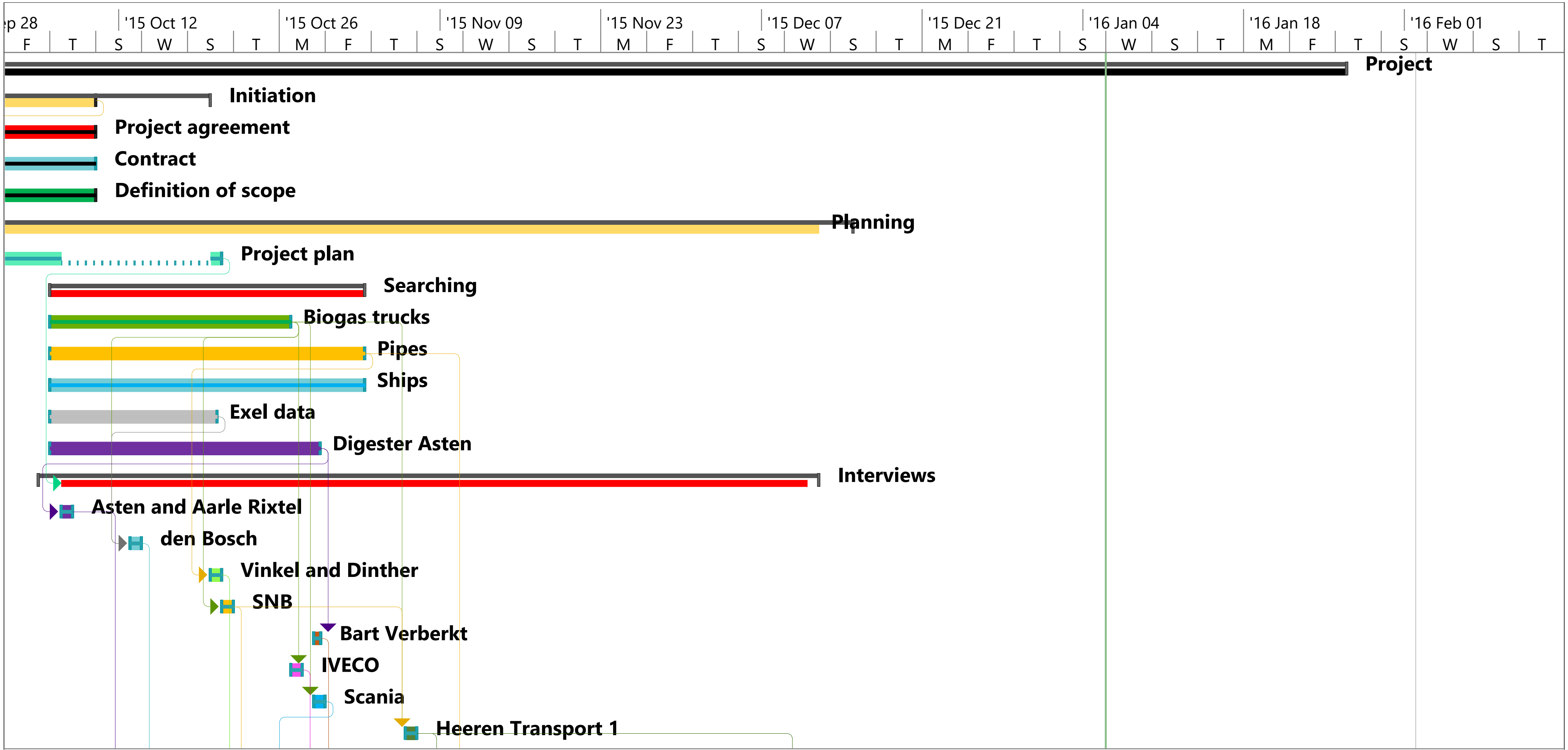
Project: MS Project
Date: Wed Jan 06

Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
Milestone	Duration-only	Deadline
Summary	Manual Summary Rollup	Progress
Project Summary	Manual Summary	Manual Progress
Inactive Task	Start-only	
Inactive Milestone	Finish-only	

ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors
45			**Performance**	**59,14 days**	**Mon Nov 16**	**Tue Jan 26**	**37**
46	✓		Company mid-term presentation	1 day	Mon Nov 23	Mon Nov 23	
47			Report	1 day	Mon Jan 18	Mon Jan 18	
48			Final Presentation	0,86 days	Tue Jan 26	Tue Jan 26	47
49			**Company meetings**	**110 days**	**Fri Sep 04**	**Mon Jan 18**	
70			**Avans**	**126 days**	**Mon Aug 31**	**Mon Feb 01**	
71	✓		Introduction to the company	1 day	Tue Sep 01	Tue Sep 01	
72	✓		Mid-term presentation	1 day	Tue Nov 03	Tue Nov 03	71
73	✓		Christmas Break	13 days	Mon Dec 21	Tue Jan 05	
74			Final Report Delivery	1 day	Mon Jan 18	Mon Jan 18	
75			Last Presentation Performance	1 day	Tue Jan 26	Tue Jan 26	74
76			**Tutor meeting**	**100 days**	**Thu Sep 17**	**Mon Jan 18**	
85							
86							

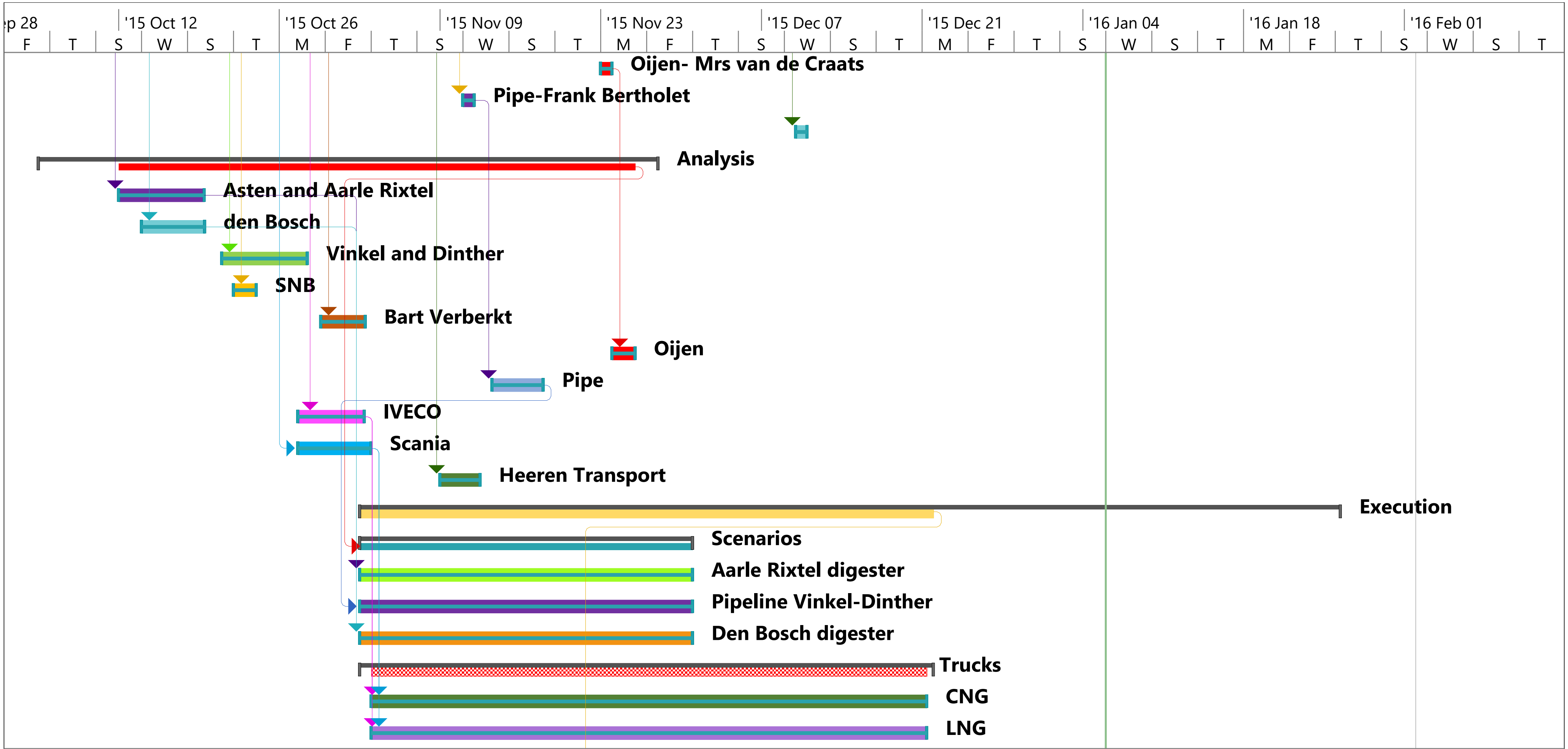
Project: MS Project
Date: Wed Jan 06

Task		Inactive Summary		External Tasks	
Split		Manual Task		External Milestone	
Milestone		Duration-only		Deadline	
Summary		Manual Summary Rollup		Progress	
Project Summary		Manual Summary		Manual Progress	
Inactive Task		Start-only			
Inactive Milestone		Finish-only			



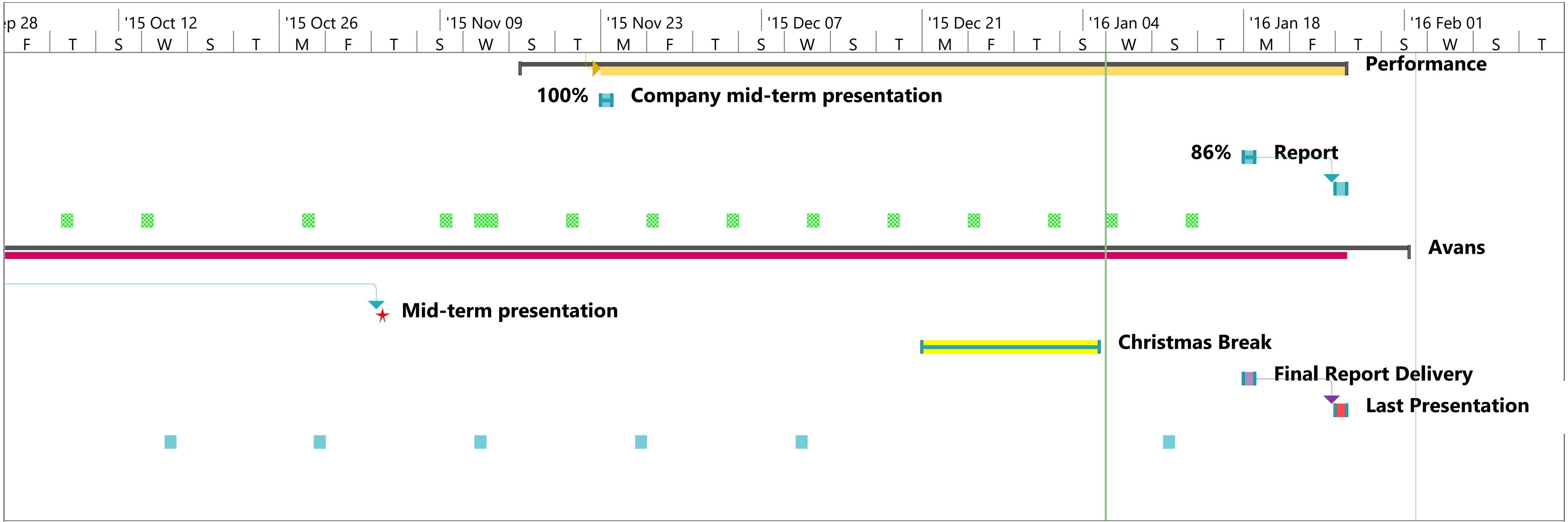
Project: MS Project
Date: Wed Jan 06

Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
Milestone	Duration-only	Deadline
Summary	Manual Summary Rollup	Progress
Project Summary	Manual Summary	Manual Progress
Inactive Task	Start-only	
Inactive Milestone	Finish-only	



Project: MS Project
Date: Wed Jan 06

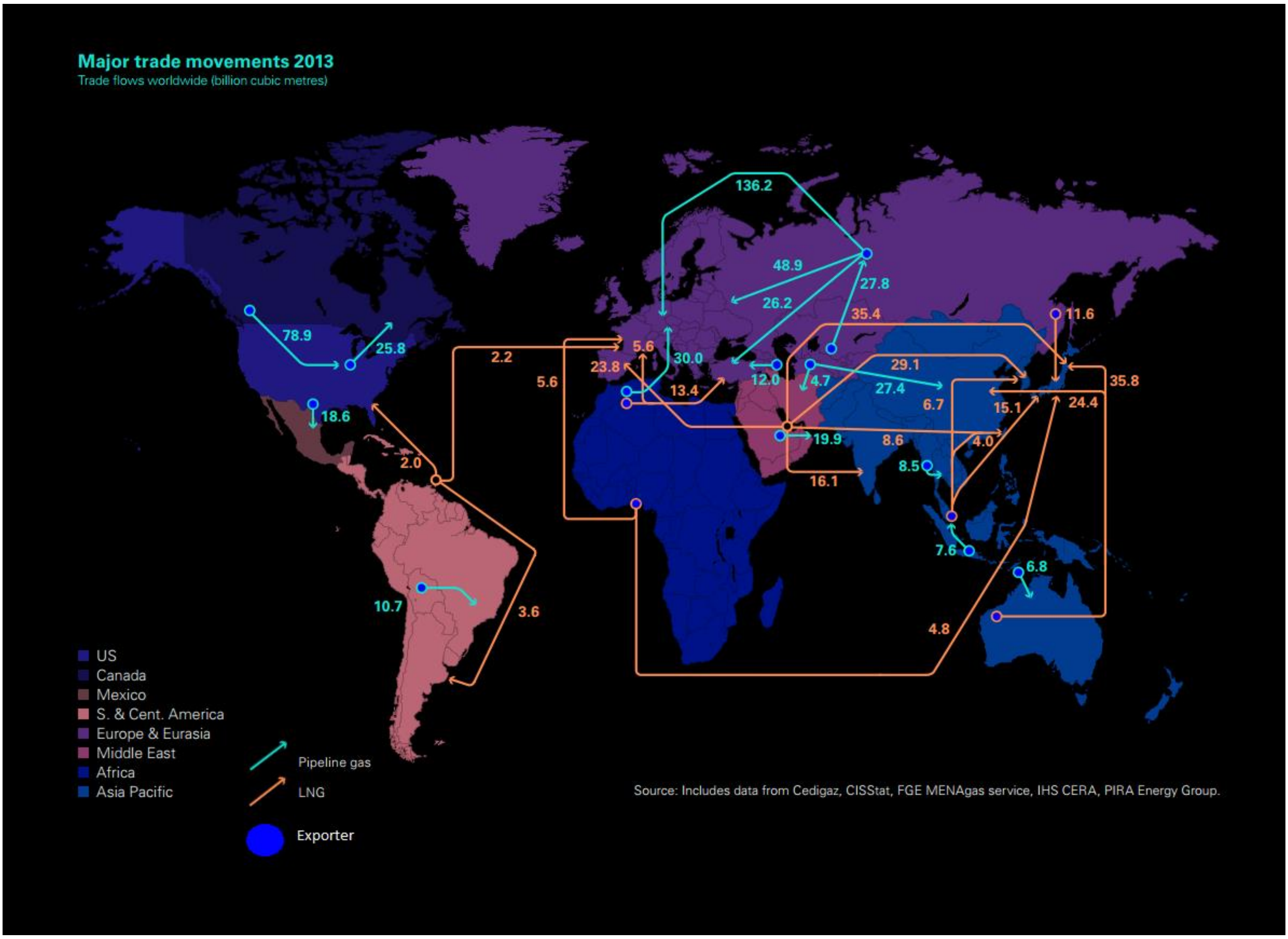
Task		Inactive Summary		External Tasks	
Split		Manual Task		External Milestone	
Milestone		Duration-only		Deadline	
Summary		Manual Summary Rollup		Progress	
Project Summary		Manual Summary		Manual Progress	
Inactive Task		Start-only			
Inactive Milestone		Finish-only			



Project: MS Project
Date: Wed Jan 06

Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
Milestone	Duration-only	Deadline
Summary	Manual Summary Rollup	Progress
Project Summary	Manual Summary	Manual Progress
Inactive Task	Start-only	
Inactive Milestone	Finish-only	

Appendix 2 - The global Natural Gas Trade in 2013



* numbers are in billion cubic meters per year

Appendix 3 – Fuel tank position of CNG trucks

Behind the cabin

On the sides

Appendix 4

Distances between the water treatment plants

	Roosendaal	Moerdjk	Den Bosch	Oijen	Land van Cuijk	Dinther	Vinkel	Aarle Rixtel	Asten
Roosendaal	0	25	80	100	130	100	87	100	110
Moerdijk	25	0	60	83	120	82	75	100	115
Den Bosch	80	60	0	25	55	30	18	40	70
Oijen	100	83	25	0	40	35	20	50	70
Land van Cuijk	130	120	55	40	0	30	45	35	50
Dinther	100	82	30	35	30	0	13	20	40
Vinkel	87	75	18	20	45	13	0	33	50
Aarle Rixtel	100	100	40	50	35	20	30	0	18
Asten	110	115	70	70	50	40	50	18	0

all of the values are expressed in *km*

Appendix 5

CBG Trucks Logistics

`	Number of loads	From	To	Distance	Tank endpoint	Load	Unload	Upload	Refilling	Driving time	Total time
				km	*km*	*y/n*	*hours*	*hours*	*hours*	*hours*	*hours*

Scenario I

Aarle Rixtel - Den Bosch

Truck	1
Capacity [t]	33
Tank at the beginning [km]	270
Drives from Aarle Rixtel to Den Bosch	2
Number of drivers	1

1		Roosendaal	Aarle Rixtel	100	170	0	0	0.5		1.54		
2	1	Aarle Rixtel	Den Bosch	40	130	1	0.5	0		0.62		
3		Den Bosch	Aarle Rixtel	40	90	0	0	0.5		0.62		
4	2	Aarle Rixtel	Den Bosch	40	50	1	0.5	0	**0.5**	0.62		**Break**
5		Den Bosch	Roosendaal	80	270	0	0	0		1.23		0.75
				300		**2**	**1**	**1**	**0.5**	**4.62**	**7.12**	**7.87**

Dinther - Den Bosch

Truck	1
Capacity [t]	33
Tank at the beginning [km]	270
Drives from Dinther to Den Bosch	3
Number of drivers	1

1		Roosendaal	Dinther	100	170	0	0	0.5		1.54		
2	1	Dinther	Den Bosch	30	140	1	0.5	0		0.46		
3		Den Bosch	Dinther	30	110	0	0	0.5		0.46		
4	2	Dinther	Den Bosch	30	80	1	0.5	0		0.46		
5		Den Bosch	Dinther	30	50	0	0	0.5		0.46		
6	3	Dinther	Den Bosch	30	20	1	0.5	0	0.25	0.46		**Break**
7		Den Bosch	Roosendaal	80	270	0	0	0		1.23		0.75
				330		**3**	**1.5**	**1.5**	**0.25**	**5.08**	**8.33**	**9.08**

Oijen - Moerdijk

Truck	1
Capacity [t]	33
Tank at the beginning [km]	265
Drives from Oijen to Moerdijk	2
Number of drivers	1

1		Roosendaal	Oijen	100	165	0	0	0.5		1.54		
2	1	Oijen	Den Bosch	25	140	1	0	0	0.25	0.38		
2	1	Den Bosch	Moerdijk	60	290	0	0.5	0		0.92		
3		Moerdijk	Oijen	83	207	0	0	0.5		1.28		
4	2	Oijen	Den Bosch	25	182	1	0	0	0.25	0.38		
4	2	Den Bosch	Moerdijk	60	290	0	0.5	0		0.92		**Break**
5		Moerdijk	Roosendaal	25	265	0	0	0		0.38		0.75
				378		**2**	**1**	**1**	**0.5**	**5.82**	**8.32**	**9.07**

Land van Cuijk - Moerdijk

Truck	1
Capacity [t]	33
Tank at the beginning [km]	265
Drives from LvC to Moerdijk	1
Number of drivers	1

1		Roosendaal	LvC	130	135	0	0	0		2.00		
2	1	LvC	Den Bosch	55	80	1	0	0.5	0.25	0.85		
2	1	Den Bosch	Moerdijk	60	290	0	0.5	0		0.92		**Break**
3		Moerdijk	Roosendaal	25	265	0	0	0		0.38		0.75
				270		**1**	**0.5**	**0.5**	**0.25**	**4.15**	**5.40**	**6.15**

Appendix 5

CBG Trucks Logistics

`	Number of loads	From	To	Distance	Tank endpoint	Load	Unload	Upload	Refilling	Driving time	Total time	
				km	km	y/n	hours	hours	hours	hours	hours	

Den Bosch - Moerdijk

Truck	1
Capacity [t]	33
Tank at the beginning [km]	265
Drives from Den Bosch to Moerdijk	5
Number of drivers	2

1		Roosendaal	Den Bosch	80	185	0	0	0.5	0.25	1.23		
2	1	Den Bosch	Moerdijk	60	290	1	0.5	0		0.92		
3		Moerdijk	Den Bosch	60	230	0	0	0.5		0.92		
4	2	Den Bosch	Moerdijk	60	170	1	0.5	0		0.92		
5		Moerdijk	Den Bosch	60	110	0	0	0.5	0.25	0.92		
6	3	Den Bosch	Moerdijk	60	290	1	0.5	0		0.92		
7		Moerdijk	Den Bosch	60	230	0	0	0.5		0.92		
8	4	Den Bosch	Moerdijk	60	170	1	0.5	0		0.92		
9		Moerdijk	Den Bosch	60	110	0	0	0.5	0.25	0.92		
10	5	Den Bosch	Moerdijk	60	290	1	0.5	0		0.92		**Break**
11		Moerdijk	Roosendaal	25	265	0	0	0		0.38		2.25
				645		**5**	**2.5**	**2.5**	**0.75**	**9.92**	**15.67**	**17.92**

Vinkel - Den Bosch

Truck	1
Capacity [t]	36
Tank at the beginning [km]	270
Drives from Vinkel to Den Bosch	4
Number of drivers	1

1		Roosendaal	Vinkel	87	183	0	0	0.16		1.34		
2	1	Vinkel	Den Bosch	18	165	1	0.16	0		0.28		
3		Den Bosch	Vinkel	18	147	0	0	0.16		0.28		
4	2	Vinkel	Den Bosch	18	129	1	0.16	0		0.28		
5		Den Bosch	Vinkel	18	111	0	0	0.16		0.28		
6	3	Vinkel	Den Bosch	18	93	1	0.16	0		0.28		
7		Den Bosch	Vinkel	18	75	0	0	0.16		0.28		
8	4	Vinkel	Den Bosch	18	57	1	0.16	0	0.25	0.28		**Break**
9		Den Bosch	Roosendaal	80	270	0	0	0		1.23		0.75
				293		**4**	**0.64**	**0.64**	**0.25**	**4.51**	**6.04**	**6.79**

Asten - Aarle Rixtel

Truck	1
Capacity [t]	36
Tank at the beginning [km]	250
Drives from Asten to Aarle Rixtel	3
Number of drivers	1

1		Roosendaal	Asten	110	140	0	0	0		1.69		
2	1	Asten	Aarle Rixtel	18	122	1	0	0.16		0.28		
3		Aarle Rixtel	Asten	18	104	0	0.16	0		0.28		
4	2	Asten	Aarle Rixtel	18	86	1	0	0.16		0.28		
5		Aarle Rixtel	Asten	18	68	0	0.16	0		0.28		
6	3	Asten	Aarle Rixtel	18	50	1	0	0.16	0.25	0.28		**Break**
7		Aarle Rixtel	Roosendaal	100	250	0	0.16	0		1.54		0.75
				300		**3**	**0.48**	**0.48**	**0.25**	**4.62**	**5.83**	**6.58**

Appendix 5

CBG Trucks Logistics

	Number of loads	From	To	Distance	Tank endpoint	Load	Unload	Upload	Refilling	Driving time	Total time	
				km	km	y/n	hours	hours	hours	hours	hours	

Scenario II

Oijen - Den Bosch

Truck	1
Capacity [t]	33
Tank at the beginning [km]	270
Drives from Oijen to Den Bosch	2
Number of drivers	1

	Number of loads	From	To	Distance	Tank endpoint	Load	Unload	Upload	Refilling	Driving time	Total time	
1		Roosendaal	Oijen	100	170	0	0	0.5		1.54		
2	1	Oijen	Den Bosch	25	145	1	0.5	0		0.38		
3		Den Bosch	Oijen	25	120	0	0	0.5		0.38		
4	2	Oijen	Den Bosch	25	95	1	0.5	0	0.25	0.38		**Break**
5		Den Bosch	Roosendaal	80	270	0	0	0		1.23		0.75
				255		**2**	**1**	**1**	**0.25**	**3.92**	**6.17**	**6.92**

Dinther - Den Bosch

Truck	1
Capacity [t]	33
Tank at the beginning [km]	270
Drives from Dinther to Den Bosch	3
Number of drivers	1

	Number of loads	From	To	Distance	Tank endpoint	Load	Unload	Upload	Refilling	Driving time	Total time	
1		Roosendaal	Dinther	100	170	0	0	0.5		1.54		
2	1	Dinther	Den Bosch	30	140	1	0.5	0		0.46		
3		Den Bosch	Dinther	30	110	0	0	0.5		0.46		
4	2	Dinther	Den Bosch	30	80	1	0.5	0		0.46		
5		Den Bosch	Dinther	30	50	0	0	0.5		0.46		
6	3	Dinther	Den Bosch	30	20	1	0.5	0	0.25	0.46		**Break**
7		Den Bosch	Roosendaal	80	270	0	0	0		1.23		0.75
				330		**3**	**1.5**	**1.5**	**0.25**	**5.08**	**8.33**	**9.08**

Aarle Rixtel - Moerdijk

Truck	1
Capacity [t]	33
Tank at the beginning [km]	225
Drives from Aarle Rixtel to Moerdjk	2
Number of drivers	1

	Number of loads	From	To	Distance	Tank endpoint	Load	Unload	Upload	Refilling	Driving time	Total time	
1		Roosendaal	Aarle Rixtel	100	125	0	0	0.5	0.25	1.54		
2	1	Aarle Rixtel	Moerdijk	100	250	1	0.5	0		1.54		
3		Moerdijk	Aarle Rixtel	100	150	0	0	0.5	0.25	1.54		
4	2	Aarle Rixtel	Moerdijk	100	250	1	0.5	0		1.54		**Break**
5		Moerdijk	Roosendaal	25	225	0	0	0		0.38		1.5
				425		**2**	**1**	**1**	**0.5**	**6.54**	**9.04**	**10.54**

Land van Cuijk - Moerdijk

Truck	1
Capacity [t]	33
Tank at the beginning [km]	265
Drives from LvC to Moerdijk	1
Number of drivers	1

	Number of loads	From	To	Distance	Tank endpoint	Load	Unload	Upload	Refilling	Driving time	Total time	
1		Roosendaal	LvC	130	135	0	0	0		2.00		
2	1	LvC	Den Bosch	55	80	1	0	0.5	0.25	0.85		
2	1	Den Bosch	Moerdijk	60	290	0	0.5	0		0.92		**Break**
3		Moerdijk	Roosendaal	25	265	0	0	0.5		0.38		0.75
				270		**1**	**0.5**	**1**	**0.25**	**4.15**	**5.90**	**6.65**

Appendix 5

CBG Trucks Logistics

Number of loads	From	To	Distance	Tank endpoint	Load	Unload	Upload	Refilling	Driving time	Total time
			km	*km*	*y/n*	*hours*	*hours*	*hours*	*hours*	*hours*

Den Bosch - Moerdijk

Truck	1
Capacity [t]	33
Tank at the beginning [km]	265
Drives from Den Bosch to Moerdijk	5
Number of drivers	2

	Number of loads	From	To	Distance	Tank endpoint	Load	Unload	Upload	Refilling	Driving time	Total time	
1		Roosendaal	Den Bosch	80	185	0	0	0.5	0.25	1.23		
2	1	Den Bosch	Moerdijk	60	290	1	0.5	0		0.92		
3		Moerdijk	Den Bosch	60	230	0	0	0.5		0.92		
4	2	Den Bosch	Moerdijk	60	170	1	0.5	0		0.92		
5		Moerdijk	Den Bosch	60	110	0	0	0.5	0.25	0.92		
6	3	Den Bosch	Moerdijk	60	290	1	0.5	0		0.92		
7		Moerdijk	Den Bosch	60	230	0	0	0.5		0.92		
8	4	Den Bosch	Moerdijk	60	170	1	0.5	0		0.92		
9		Moerdijk	Den Bosch	60	110	0	0	0.5	0.25	0.92		
10	5	Den Bosch	Moerdijk	60	290	1	0.5	0		0.92		**Break**
11		Moerdijk	Roosendaal	25	265	0	0	0		0.38		2.25
				645		**5**	**2.5**	**2.5**	**0.75**	**9.92**	**15.67**	**17.92**

Vinkel - Den Bosch

Truck	1
Capacity [t]	36
Tank at the beginning [km]	270
Drives from Vinkel to Den Bosch	4
Number of drivers	1

	Number of loads	From	To	Distance	Tank endpoint	Load	Unload	Upload	Refilling	Driving time	Total time	
1		Roosendaal	Vinkel	87	183	0	0	0.16		1.34		
2	1	Vinkel	Den Bosch	18	165	1	0.16	0		0.28		
3		Den Bosch	Vinkel	18	147	0	0	0.16		0.28		
4	2	Vinkel	Den Bosch	18	129	1	0.16	0		0.28		
5		Den Bosch	Vinkel	18	111	0	0	0.16		0.28		
6	3	Vinkel	Den Bosch	18	93	1	0.16	0		0.28		
7		Den Bosch	Vinkel	18	75	0	0	0.16		0.28		
8	4	Vinkel	Den Bosch	18	57	1	0.16	0	0.25	0.28		**Break**
9		Den Bosch	Roosendaal	80	270	0	0	0		1.23		0.75
				293		**4**	**0.64**	**0.64**	**0.25**	**4.51**	**6.04**	**6.79**

Asten - Aarle Rixtel

Truck	1
Capacity [t]	36
Tank at the beginning [km]	250
Drives from Asten to Aarle Rixtel	3
Number of drivers	1

	Number of loads	From	To	Distance	Tank endpoint	Load	Unload	Upload	Refilling	Driving time	Total time	
1		Roosendaal	Asten	110	140	0	0	0		1.69		
2	1	Asten	Aarle Rixtel	18	122	1	0	0.16		0.28		
3		Aarle Rixtel	Asten	18	104	0	0.16	0		0.28		
4	2	Asten	Aarle Rixtel	18	86	1		0.16		0.28		
5		Aarle Rixtel	Asten	18	68	0	0.16	0		0.28		
6	3	Asten	Aarle Rixtel	18	50	1		0.16	0.25	0.28		**Break**
7		Aarle Rixtel	Roosendaal	100	250	0	0.16	0		1.54		0.75
				300		**3**	**0.48**	**0.48**	**0.25**	**4.62**	**5.83**	**6.58**

Appendix 6

European Driving Regulations

Driving hours without break	4,5 h
Driving hours in	
one day	9 h
	10-12 h (only twice a week)
one week	56 h
two weeks	90 h
Rest in one day	11h
Rest splitted	3 h + 9 h
Rest shortened	9 hours, only 3 times a week
	with 2 drivers 9 hours in 30 hours

Break for driving	45 min for every 4,5 hours
	45 min can be split into at least 15 min

(Regulation (EC) No. 561/2006)

Appendix 7

Model sludge digestion - Scenario I

Input		
Primary sludge		
Amount	96	m3 per day
DM%	10%	
OM%	78%	of DM
Biogasproduction	900	L/kg OM converted
Secundary sludge		
Amount	338	m3 per day
DM%	10.0%	
OM%	78%	of DM
Biogas production	900	L/kg OM converted
Total pr. sludge in	**9.6**	tonnes of DM per day
Total sc. sludge in	**33.8**	tonnes of DM per day
Total sludge in	**43.4**	tonnes of DM per day

Digestion		
Residence time	18	days
Temperature	55	degrees
Contents of tanks	**7812**	m3

Output		
Biogas production	**4,809,579**	Nm3 / jaar
Energy content biogas	22	MJ/Nm3
Total pr. sludge out	**4.9**	tonnes of DM per day
Total sc. sludge out	**23.8**	tonnes of DM per day
Total sludge out	**28.8**	tonnes of DM per day

Economics: revenu		
Biogas value	€ 0.16	per Nm3
Biogas value total	**€ 769,532.7**	

pr.	primary
sc.	secondary

Vugt, Peter van:
Factor 1,2 t.o.v. kaalprijs

Appendix 7

Formula for organic matter conversion Chen Hashimot

Residence time	18	dagen
Sludge temperature	55	graden
Minimal sludge age	1.31	

	Primair slib	Secundair slib
Minimal sludge age	1.31	1.31
Maximum reduction	65%	40%
Break down constant	0.5	0.75
Conversion of organic matter	62.54%	37.77%

$$\frac{R}{B} = \frac{\Theta - 1}{\Theta - 1 + K}$$

waarin:
R = het percentage afbraak van de organische stof
B = het maximum haalbare percentage afbraak
Θ = de relatieve slibleeftijd (slibleeftijd gedeeld door minimum slibleeftijd voor methaangisting)
K = de afbraakconstante

De temperatuursafhankelijke minimale slibleeftijd wordt als volgt berekend [23]:

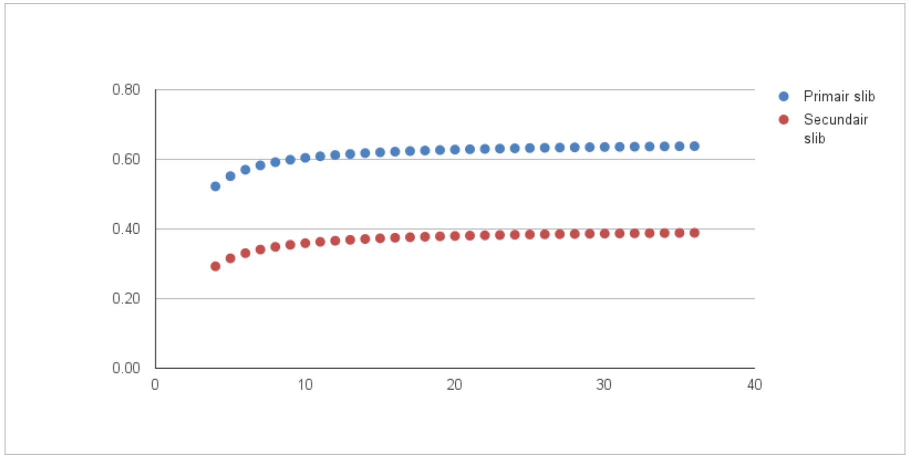
$$SLT_T = 2.85 * MAX((1.08^{(T-30)} - 1.35^{(T-40)}), (1.08^{(T-42)} - 1.35^{(T-57)}))^{-1}$$

De functies tussen de haken beschrijft de afbraakcurve voor het mesofiele (links) en het thermofiele bereik.

PARAMETERS VOOR DE BEREKENING VAN HET PERCENTAGE AFBRAAK VAN ORGANISCHE STOF VOOR MESOFIELE VERGISTING [4]

parameter	eenheid	primair slib	secundair slib
minimale slibleeftijd bij 30°C	d	2,9	2,9
maximale reductie	%	65	40
afbraakconstante	-	1,0	1,5

Dag	Primair slib	Secundair slib
4	0.52	0.29
5	0.55	0.32
6	0.57	0.33
7	0.58	0.34
8	0.59	0.35
9	0.60	0.35
10	0.60	0.36
11	0.61	0.36
12	0.61	0.37
13	0.62	0.37
14	0.62	0.37
15	0.62	0.37
16	0.62	0.37
17	0.62	0.38
18	0.63	0.38
19	0.63	0.38
20	0.63	0.38
21	0.63	0.38
22	0.63	0.38
23	0.63	0.38
24	0.63	0.38
25	0.63	0.38
26	0.63	0.38
27	0.63	0.39
28	0.63	0.39
29	0.63	0.39
30	0.64	0.39
31	0.64	0.39
32	0.64	0.39
33	0.64	0.39
34	0.64	0.39
35	0.64	0.39
36	0.64	0.39
37	0.64	0.39
38	0.64	0.39
39	0.64	0.39
40	0.64	0.39
41	0.64	0.39
42	0.64	0.39
43	0.64	0.39
44	0.64	0.39
45	0.64	0.39



Appendix 8

Comparison of the Scenarios

Costs Comparison							
	Destination	Sludge	Drive / day	Distance	Transport costs	Total costs	Incineration costs*
Scenario I		*t/year*		*km/year*	*€/t*	*€/year*	*€/year*
to SNB							
Land van Cuijk	Moerdijk	9,205	1.07	33472.73	8.75	80,544	285,355
Oijen	Moerdijk	16,037	1.86	40335.48	8.75	140,324	497,147
Den Bosch	Moerdijk	42,048	4.89	76450.91	8.75	367,920	1,303,488
Internal							**2,085,990**
Aalre Rixtel	Den Bosch	20,571	2.39	24934.34	5.95	122,396	
Dinther	Den Bosch	26,769	3.11	24335.45	5.95	159,276	
		114,630	**13.32**	**199528.92**	**7.63**	**870,460**	
Scenario II							
to SNB							
Land van Cuijk	Moerdijk	9,205	1.07	33472.73	8.75	80,544	285,355
Aalre Rixtel	Moerdijk	15,123	1.76	45826.67	8.75	132,325	468,807
Den Bosch	Moerdijk	40,004	4.65	72734.55	8.75	350,035	1,240,124
Internal							**1,994,286**
Oijen	Den Bosch	16,037	1.86	12149.24	5.95	95,420	
Dinther	Den Bosch	26,769	3.11	24335.45	5.95	159,276	
		107,138	**12.45**	**188518.64**	**7.63**	**817,599**	
Difference		**7,492**	**0.87**	**11010.28**		**52,861**	**91,704**

*including transport

Appendix 9

CBG Trucks Combined Logistics

	Number of loads	From	To	Distance	Tank endpoint	Load	Unload	Upload	Refilling	Driving time	Total time	
				km	km	y/n	hours	hours	hours	hours	hours	

Scenario I

Drives from LvC to Moerdijk	1
Drives from Aarle Rixtel to Den Bosch	2
Drives from Dinther to Den Bosch	3
Drives from Den Bosch to Moerdijk	5
Drives from Oijen to Moerdijk	2
Drives from Asten to Aarle Rixtel	3
Drives from Vinkel to Den Bosch	4

Land van Cuijk - Moerdijk

Truck	1
Capacity [t]	33
Tank at the beginning [km]	265
Number of drivers	1

	Number of loads	From	To	Distance	Tank endpoint	Load	Unload	Upload	Refilling	Driving time	Total time	
1		Roosendaal	LvC	130	135	0	0	0		2.00		
2	1	LvC	Den Bosch	55	80	1	0	0.5	0.25	0.85		
2	1	Den Bosch	Moerdijk	60	290	0	0.5	0		0.92		
3		Moerdijk	Den Bosch	60	230	0	0	0.5	0.25	0.92		
4	1	Den Bosch	Moerdijk	60	290	1	0.5	0		0.92		**Break**
5		Moerdijk	Roosendaal	25	265	0	0	0		0.38		0.75
				390		**2**	**1**	**1**	**0.5**	**6.00**	**8.50**	**9.25**

Aarle Rixtel - Den Bosch

Truck	1
Capacity [t]	33
Tank at the beginning [km]	270
Number of drivers	1

	Number of loads	From	To	Distance	Tank endpoint	Load	Unload	Upload	Refilling	Driving time	Total time	
1		Roosendaal	Aarle Rixtel	100	170	0	0	0.5		1.54		
2	1	Aarle Rixtel	Den Bosch	40	130	1	0.5	0		0.62		
3		Den Bosch	Aarle Rixtel	40	90	0	0	0.5		0.62		
4	2	Aarle Rixtel	Den Bosch	40	50	1	0.5	0.5	0.25	0.62		**Break**
5	2	Den Bosch	Moerdijk	60	290	1	0.5	0		0.92		
6		Moerdijk	Roosendaal	25	265	0	0	0		0.38		0.75
				305		**3**	**1.5**	**1.5**	**0.25**	**4.69**	**7.94**	**8.69**

Dinther - Den Bosch

Truck	1
Capacity [t]	33
Tank at the beginning [km]	270
Number of drivers	1

	Number of loads	From	To	Distance	Tank endpoint	Load	Unload	Upload	Refilling	Driving time	Total time	
1		Roosendaal	Dinther	100	170	0	0	0.5		1.54		
2	1	Dinther	Den Bosch	30	140	1	0.5	0		0.46		
3		Den Bosch	Dinther	30	110	0	0	0.5		0.46		
4	2	Dinther	Den Bosch	30	80	1	0.5	0		0.46		
5		Den Bosch	Dinther	30	50	0	0	0.5		0.46		
6	3	Dinther	Den Bosch	30	20	1	0.5	0	0.25	0.46		**Break**
7		Den Bosch	Roosendaal	80	270	0	0	0		1.23		0.75
				330		**3**	**1.5**	**1.5**	**0.25**	**5.08**	**8.33**	**9.08**

Den Bosch - Moerdijk

Truck	1
Capacity [t]	33
Tank at the beginning [km]	265
Number of drivers	1

	Number of loads	From	To	Distance	Tank endpoint	Load	Unload	Upload	Refilling	Driving time	Total time	
1		Roosendaal	Den Bosch	80	185	0	0	0.5		1.23		
2	3	Den Bosch	Moerdijk	60	125	1	0.5	0		0.92		
3		Moerdijk	Den Bosch	60	65	0	0	0.5	0.25	0.92		
4	4	Den Bosch	Moerdijk	60	290	1	0.5	0		0.92		
5		Moerdijk	Den Bosch	60	230	0	0	0.5		0.92		
6	5	Den Bosch	Moerdijk	60	290	1	0.5	0	0.25	0.92		**Break**
7		Moerdijk	Roosendaal	25	265	0	0	0		0.38		1.5
				405		**3**	**1.5**	**1.5**	**0.5**	**6.23**	**9.73**	**11.23**

Appendix 9

CBG Trucks Combined Logistics

	Number of loads	From	To	Distance	Tank endpoint	Load	Unload	Upload	Refilling	Driving time	Total time	
				km	*km*	*y/n*	*hours*	*hours*	*hours*	*hours*	*hours*	

Oijen - Moerdijk

Truck	1
Capacity [t]	33
Tank at the beginning [km]	265
Number of drivers	1

	Number of loads	From	To	Distance	Tank endpoint	Load	Unload	Upload	Refilling	Driving time	Total time	
1		Roosendaal	Oijen	100	165	0	0	0.5		1.54		
2	1	Oijen	Den Bosch	25	140	1	0	0	0.25	0.38		
2	1	Den Bosch	Moerdijk	60	290	0	0.5	0		0.92		
3		Moerdijk	Oijen	83	207	0	0	0.5		1.28		
4	2	Oijen	Den Bosch	25	182	1	0	0	0.25	0.38		
4	2	Den Bosch	Moerdijk	60	290	0	0.5	0		0.92		**Break**
5		Moerdijk	Roosendaal	25	265	0	0	0		0.38		0.75
				378		**2**	**1**	**1**	**0.5**	**5.82**	**8.32**	**9.07**

Asten - Aarle Rixtel

Truck	1
Capacity [t]	36
Tank at the beginning [km]	250
Number of drivers	1

	Number of loads	From	To	Distance	Tank endpoint	Load	Unload	Upload	Refilling	Driving time	Total time	
1		Roosendaal	Asten	110	140	0	0	0		1.69		
2	1	Asten	Aarle Rixtel	18	122	1	0	0.16		0.28		
3		Aarle Rixtel	Asten	18	104	0	0.16	0		0.28		
4	2	Asten	Aarle Rixtel	18	86	1		0.16		0.28		
5		Aarle Rixtel	Asten	18	68	0	0.16	0		0.28		
6	3	Asten	Aarle Rixtel	18	50	1		0.16	0.25	0.28		**Break**
7		Aarle Rixtel	Roosendaal	100	250	0	0.16	0		1.54		0.75
				300		**3**	**0.48**	**0.48**	**0.25**	**4.62**	**5.83**	**6.58**

Vinkel - Den Bosch

Truck	1
Capacity [t]	36
Tank at the beginning [km]	270
Number of drivers	1

	Number of loads	From	To	Distance	Tank endpoint	Load	Unload	Upload	Refilling	Driving time	Total time	
1		Roosendaal	Vinkel	87	183	0	0	0.16		1.34		
2	1	Vinkel	Den Bosch	18	165	1	0.16	0		0.28		
3		Den Bosch	Vinkel	18	147	0	0	0.16		0.28		
4	2	Vinkel	Den Bosch	18	129	1	0.16	0		0.28		
5		Den Bosch	Vinkel	18	111	0	0	0.16		0.28		
6	3	Vinkel	Den Bosch	18	93	1	0.16	0		0.28		
7		Den Bosch	Vinkel	18	75	0	0	0.16		0.28		
8	4	Vinkel	Den Bosch	18	57	1	0.16	0	0.25	0.28		**Break**
9		Den Bosch	Roosendaal	80	270	0	0	0		1.23		0.75
				293		**4**	**0.64**	**0.64**	**0.25**	**4.51**	**6.04**	**6.79**

Appendix 9

CBG Trucks Combined Logistics

	Number of loads	From	To	Distance	Tank endpoint	Load	Unload	Upload	Refilling	Driving time	Total time	
				km	*km*	*y/n*	*hours*	*hours*	*hours*	*hours*	*hours*	

Scenario II

Drives from LvC to Moerdijk	1
Drives from Aarle Rixtel to Moerdijk	2
Drives from Dinther to Den Bosch	3
Drives from Den Bosch to Moerdijk	5
Drives from Oijen to Den Bosch	2
Drives from Asten to Aarle Rixtel	3
Drives from Vinkel to Den Bosch	4

Land van Cuijk - Moerdijk

Truck	1
Capacity [t]	33
Tank at the beginning [km]	265
Number of drivers	1

	Number of loads	From	To	Distance	Tank endpoint	Load	Unload	Upload	Refilling	Driving time	Total time	
1		Roosendaal	LvC	130	135	0	0	0		2.00		
2	1	LvC	Den Bosch	55	80	1	0	0.5	0.25	0.85		
2	1	Den Bosch	Moerdijk	60	290	0	0.5	0		0.92		
3		Moerdijk	Den Bosch	60	230	0	0	0.5	0.25	0.92		
4	1	Den Bosch	Moerdijk	60	290	1	0.5	0		0.92		**Break**
5		Moerdijk	Roosendaal	25	265	0	0	0.5		0.38		0.75
				390		**2**	**1**	**1.5**	**0.5**	**6.00**	**9.00**	**9.75**

Asten - Aarle Rixtel

Truck	1
Capacity [t]	36
Tank at the beginning [km]	250
Number of drivers	1

	Number of loads	From	To	Distance	Tank endpoint	Load	Unload	Upload	Refilling	Driving time	Total time	
1		Roosendaal	Asten	110	140	0	0	0.16		1.69		
2	1	Asten	Aarle Rixtel	18	122	1	0.16	0		0.28		
3		Aarle Rixtel	Asten	18	104	0	0	0.16		0.28		
4	2	Asten	Aarle Rixtel	18	86	1	0.16	0		0.28		
5		Aarle Rixtel	Asten	18	68	0	0	0.16		0.28		
6	3	Asten	Aarle Rixtel	18	50	1	0.16	0	0.25	0.28		**Break**
7		Aarle Rixtel	Roosendaal	100	250	0	0	0		1.54		0.75
				300		**3**	**0.48**	**0.48**	**0.25**	**4.62**	**5.83**	**6.58**

Aarle Rixtel - Moerdijk

Truck	1
Capacity [t]	33
Tank at the beginning [km]	225
Number of drivers	1

	Number of loads	From	To	Distance	Tank endpoint	Load	Unload	Upload	Refilling	Driving time	Total time	
1		Roosendaal	Aarle Rixtel	100	125	0	0	0.5	0.25	1.54		
2	1	Aarle Rixtel	Moerdijk	100	250	1	0.5	0		1.54		
3		Moerdijk	Aarle Rixtel	100	150	0	0	0.5	0.25	1.54		
4	2	Aarle Rixtel	Moerdijk	100	250	1	0.5	0		1.54		**Break**
5		Moerdijk	Roosendaal	25	225	0	0	0		0.38		1.5
				425		**2**	**1**	**1**	**0.5**	**6.54**	**9.04**	**10.54**

Appendix 9

CBG Trucks Combined Logistics

#	Number of loads	From	To	Distance	Tank endpoint	Load	Unload	Upload	Refilling	Driving time	Total time	Break
				km	km	y/n	hours	hours	hours	hours	hours	

Dinther - Den Bosch

Truck	1
Capacity [t]	33
Tank at the beginning [km]	270
Number of drivers	1

#	Number of loads	From	To	Distance	Tank endpoint	Load	Unload	Upload	Refilling	Driving time	Total time	Break
1		Roosendaal	Dinther	100	170	0	0	0.5		1.54		
2	1	Dinther	Den Bosch	30	140	1	0.5	0		0.46		
3		Den Bosch	Dinther	30	110	0	0	0.5		0.46		
4	2	Dinther	Den Bosch	30	80	1	0.5	0		0.46		
5		Den Bosch	Dinther	30	50	0	0	0.5		0.46		
6	3	Dinther	Den Bosch	30	20	1	0.5	0	0.25	0.46		**Break**
7		Den Bosch	Roosendaal	80	270	0	0	0		1.23		0.75
				330		**3**	**1.5**	**1.5**	**0.25**	**5.08**	**8.33**	**9.08**

Oijen - Den Bosch

Truck	1
Capacity [t]	33
Tank at the beginning [km]	265
Number of drivers	1

#	Number of loads	From	To	Distance	Tank endpoint	Load	Unload	Upload	Refilling	Driving time	Total time	Break
1		Roosendaal	Oijen	100	170	0	0	0.5		1.54		
2	1	Oijen	Den Bosch	25	145	1	0.5	0		0.38		
3		Den Bosch	Oijen	25	120	0	0	0.5		0.38		
4	2	Oijen	Den Bosch	25	95	1	0.5	0.5	0.25	0.38		
5	2	Den Bosch	Moerdijk	60	290	1	0.5	0		0.92		**Break**
6		Moerdijk	Roosendaal	25	265	0	0	0		0.38		0.75
				260		**3**	**1.5**	**1.5**	**0.25**	**4.00**	**7.25**	**8.00**

Den Bosch- Moerdijk

Truck	1
Capacity [t]	33
Tank at the beginning [km]	265
Number of drivers	1

#	Number of loads	From	To	Distance	Tank endpoint	Load	Unload	Upload	Refilling	Driving time	Total time	Break
1		Roosendaal	Den Bosch	80	185	0	0	0.5	0.25	1.23		
2	1	Den Bosch	Moerdijk	60	290	1	0.5	0		0.92		
3		Moerdijk	Den Bosch	60	230	0	0	0.5		0.92		
4	2	Den Bosch	Moerdijk	60	170	1	0.5	0		0.92		
5		Moerdijk	Den Bosch	60	110	0	0	0.5	0.25	0.92		
6	3	Den Bosch	Moerdijk	60	290	1	0.5	0		0.92		**Break**
7		Moerdijk	Roosendaal	25	265	0	0	0		0.38		1.5
				405		**3**	**1.5**	**1.5**	**0.5**	**6.23**	**9.73**	**11.23**

Vinkel - Den Bosch

Truck	1
Capacity [t]	36
Tank at the beginning [km]	270
Number of drivers	1

#	Number of loads	From	To	Distance	Tank endpoint	Load	Unload	Upload	Refilling	Driving time	Total time	Break
1		Roosendaal	Vinkel	87	183	0	0	0.16		1.34		
2	1	Vinkel	Den Bosch	18	165	1	0.16	0		0.28		
3		Den Bosch	Vinkel	18	147	0	0	0.16		0.28		
4	2	Vinkel	Den Bosch	18	129	1	0.16	0		0.28		
5		Den Bosch	Vinkel	18	111	0	0	0.16		0.28		
6	3	Vinkel	Den Bosch	18	93	1	0.16	0		0.28		
7		Den Bosch	Vinkel	18	75	0	0	0.16		0.28		
8	4	Vinkel	Den Bosch	18	57	1	0.16	0	0.25	0.28		**Break**
9		Den Bosch	Roosendaal	80	270	0	0	0		1.23		0.75
				293		**4**	**0.64**	**0.64**	**0.25**	**4.51**	**6.04**	**6.79**

Appendix 10

Model sludge digestion - Asten

Input		
Primary sludge		
Amount	0	m3 per day
DM%	9%	
OM%	78%	of DM
Biogasproduction	900	L/kg OM converted
Secundary sludge		
Amount	255	m3 per day
DM%	9.0%	
OM%	78%	of DM
Biogas production	900	L/kg OM converted
Total sludge in	23.0	tonnes of DM per day

Digestion		
Residence time	18	days
Temperature	55	degrees
Contents of tanks	4590	m3

Output		
Biogas production	2,221,137	Nm3 / jaar
Energy content biogas	22	MJ/Nm3
Total sludge out	16.2	tonnes of DM per day

Economics: revenu

Biogas value	€ 0.16	per Nm3
Biogas value total	**€ 355,381.9**	per year

Biogas

		Present	Scenario I	Scenario II
Biogas production	*m3/year*	294,972	604,216	2,221,137
Consumption	*m3/year*	294,972	604,216	3,208
Overproduction	*m3/year*	/	/	2,217,929
Self-supplyment	*%*	24	50	100
Profit 1 year	*€*	/	/	354,869
Profit 10 years	*€*	/	/	3,548,686
Value	*€/m3*	0.16	0.16	0.16

Vugt, Peter van:
Factor 1,2 t.o.v. kaalprijs

Appendix 10

Formula for organic matter conversion Chen Hashimot

Residence time	18	dagen
Sludge temperature	55	graden
Minimal sludge age	1.31	

	Primair slib	Secundair slib
Minimal sludge age	1.31	1.31
Maximum reduction	65%	40%
Break down constant	0.5	0.75
Conversion of organic matter	62.54%	37.77%

$$\frac{R}{B} = \frac{\Theta - 1}{\Theta - 1 + K}$$

waarin:

R = het percentage afbraak van de organische stof
B = het maximum haalbare percentage afbraak
Θ = de relatieve slibleeftijd (slibleeftijd gedeeld door minimum slibleeftijd voor methaangisting)
K = de afbraakconstante

De temperatuursafhankelijke minimale slibleeftijd wordt als volgt berekend [23]:

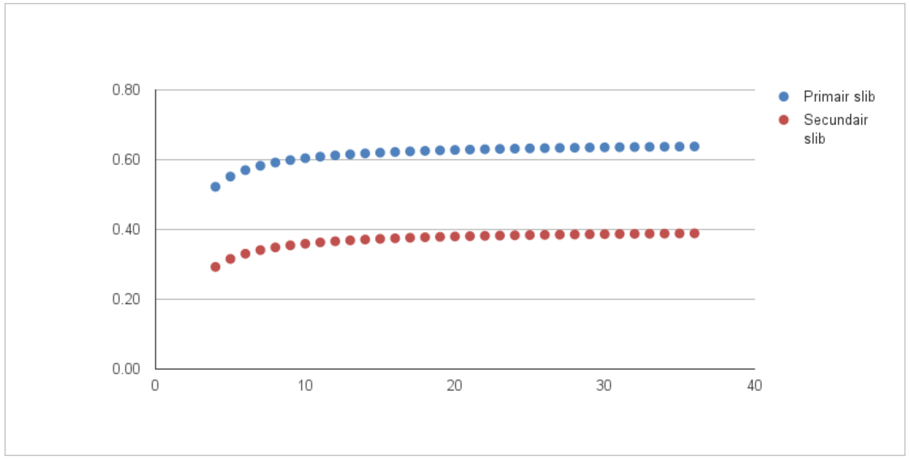
$$SLT_T = 2.85 * MAX((1.08^{(T-30)} - 1.35^{(T-40)}), (1.08^{(T-42)} - 1.35^{(T-57)}))^{-1}$$

De functies tussen de haken beschrijft de afbraakcurve voor het mesofiele (links) en het thermofiele bereik.

PARAMETERS VOOR DE BEREKENING VAN HET PERCENTAGE AFBRAAK VAN ORGANISCHE STOF VOOR MESOFIELE VERGISTING [4]

parameter	eenheid	primair slib	secundair slib
minimale slibleeftijd bij 30°C	d	2,9	2,9
maximale reductie	%	65	40
afbraakconstante	-	1,0	1,5

Dag	Primair slib	Secundair slib
4	0.52	0.29
5	0.55	0.32
6	0.57	0.33
7	0.58	0.34
8	0.59	0.35
9	0.60	0.35
10	0.60	0.36
11	0.61	0.36
12	0.61	0.37
13	0.62	0.37
14	0.62	0.37
15	0.62	0.37
16	0.62	0.37
17	0.62	0.38
18	0.63	0.38
19	0.63	0.38
20	0.63	0.38
21	0.63	0.38
22	0.63	0.38
23	0.63	0.38
24	0.63	0.38
25	0.63	0.38
26	0.63	0.38
27	0.63	0.39
28	0.63	0.39
29	0.63	0.39
30	0.64	0.39
31	0.64	0.39
32	0.64	0.39
33	0.64	0.39
34	0.64	0.39
35	0.64	0.39
36	0.64	0.39
37	0.64	0.39
38	0.64	0.39
39	0.64	0.39
40	0.64	0.39
41	0.64	0.39
42	0.64	0.39
43	0.64	0.39
44	0.64	0.39
45	0.64	0.39



Appendix 11

Waterboard Aa en Maas
Dewatering system WWTP Asten

Description	Unit	Quantity	Price per Unit	Total price
Civil construction sludge processing	Euro	1	500,000.00	500,000.00
Adapt infrastructure	Euro	1	100,000.00	100,000.00
Centrifuges	stuks	2	300,000.00	600,000.00
Sludge transportation (screws)	stuks	1	100,000.00	100,000.00
E-installation (consumers)	stuks	10	10,000.00	100,000.00
Sludgebuffer / loading	Euro	1	1,400,000.00	1,400,000.00
				2,800,000.00
Execution	%	5		140,000.00
General costs	%	7.5		210,000.00
Profit and risiko	%	5		140,000.00
Contract price				3,290,000.00
VAT	%	21		690,900.00
Total incl. VAT				3,980,900.00
General costs	%	5		199,045.00
Third-party consultancy costs				
Authoriastion				
Insurance				
Adjusting utility lines				
Private compensation				
Preperation- and supervision costs	%	15		597,135.00
				4,777,080.00
Unexpected costs	%	10		477,708.00
				5,254,788.00
Interests	%	5		262,739.40
Total				5,517,527.40
Rounded				**5,500,000.00**

Source: Frank Bertholet, Coördinator elektrotechniek en werktuigbouw, Waterschap Aa en Maas

Appendix 12

Model sludge digestion - Aarle Rixtel

Input		
Primary sludge		
Amount	0	m3 per day
DM%	10%	
OM%	78%	of DM
Biogasproduction	900	L/kg OM converted
Secundary sludge		
Amount	135	m3 per day
DM%	9.0%	
OM%	78%	of DM
Biogas production	900	L/kg OM converted
Total sludge in	12.2	tonnes of DM per day

Digestion		
Residence time	18	days
Temperature	55	degrees
Contents of tanks	2430	m3

Output		
Biogas production	1,175,896	Nm3 / jaar
Energy content biogas	22	MJ/Nm3
Total sludge out	8.6	tonnes of DM per day

Economics: revenu		
Biogas value	€ 0.16	per Nm3
Biogas value total	**€ 188,143.3**	per year

Vugt, Peter van:
Factor 1,2 t.o.v. kaalprijs

Appendix 12

Formula for organic matter conversion Chen Hashimot

Residence time	18	dagen
Sludge temperature	55	graden
Minimal sludge age	1.31	

	Primair slib	Secundair slib
Minimal sludge age	1.31	1.31
Maximum reduction	65%	40%
Break down constant	0.5	0.75
Conversion of organic matter	62.54%	37.77%

$$\frac{R}{B} = \frac{\Theta - 1}{\Theta - 1 + K}$$

waarin:

R = het percentage afbraak van de organische stof
B = het maximum haalbare percentage afbraak
Θ = de relatieve slibleeftijd (slibleeftijd gedeeld door minimum slibleeftijd voor methaangisting)
K = de afbraakconstante

De temperatuursafhankelijke minimale slibleeftijd wordt als volgt berekend [23]:

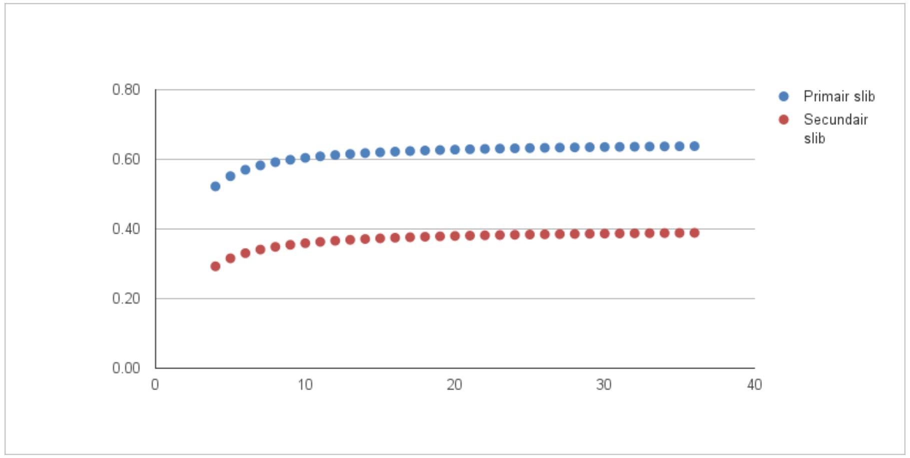
$$SLT_T = 2.85 * MAX((1.08^{(T-30)} - 1.35^{(T-40)}), (1.08^{(T-42)} - 1.35^{(T-57)}))^{-1}$$

De functies tussen de haken beschrijft de afbraakcurve voor het mesofiele (links) en het thermofiele bereik.

PARAMETERS VOOR DE BEREKENING VAN HET PERCENTAGE AFBRAAK VAN ORGANISCHE STOF VOOR MESOFIELE VERGISTING [4]

parameter	eenheid	primair slib	secundair slib
minimale slibleeftijd bij 30°C	d	2,9	2,9
maximale reductie	%	65	40
afbraakconstante	-	1,0	1,5

Dag	Primair slib	Secundair slib
4	0.52	0.29
5	0.55	0.32
6	0.57	0.33
7	0.58	0.34
8	0.59	0.35
9	0.60	0.35
10	0.60	0.36
11	0.61	0.36
12	0.61	0.37
13	0.62	0.37
14	0.62	0.37
15	0.62	0.37
16	0.62	0.37
17	0.62	0.38
18	0.63	0.38
19	0.63	0.38
20	0.63	0.38
21	0.63	0.38
22	0.63	0.38
23	0.63	0.38
24	0.63	0.38
25	0.63	0.38
26	0.63	0.38
27	0.63	0.39
28	0.63	0.39
29	0.63	0.39
30	0.64	0.39
31	0.64	0.39
32	0.64	0.39
33	0.64	0.39
34	0.64	0.39
35	0.64	0.39
36	0.64	0.39
37	0.64	0.39
38	0.64	0.39
39	0.64	0.39
40	0.64	0.39
41	0.64	0.39
42	0.64	0.39
43	0.64	0.39
44	0.64	0.39
45	0.64	0.39



Appendix 13

Digester and self-sufficiency overview

Aarle Rixtel

1 digester thermophilic methode

TDM*	DM	Volume	Capacity
t	*%*	*m3*	*m3*
5741	9	63789	3200

* 1500 ton/year less because of the new filter

Digester capacity						
DM (tdm/year)	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Asten	1195	1152	1222	1191	1083	1144
Aarle Rixtel	5442	4409	5357	5325	5072	5293
Total	**6637**	**5561**	**6579**	**6516**	**6155**	**6437**

Digesting scenarios		**Scenario II**
Tonnes of DM per day	*tdm/day*	15.8
Total DM out per day	*tdm/day*	11.1
DM%	*%*	9
Residence time	*day*	18
Temperature	*°C*	55
Contents of tank	*m3*	3200
Biogas production	*m3/year*	1,175,896
Biogas value	*€*	**188,143**
Energy content	*kWh/year*	7,186,031

Energy		**Scenario II**
Consumption	*kWh*	5,478,355
Energy content of the biogas	*MJ/m3/year*	25,767,896
Energy content of the biogas*	*kWh/m3/year*	7,157,749
Efficiency	*%*	38
Production	*kWh*	2,719,945
Difference	*kWh*	-2,758,410
Self-sufficiency	*%*	50
Profit 1 year	*€*	/
Profit 10 years	*€*	/
Value	*€/kWh*	0.05

*1kWh=3,6 MJ

Appendix 14

Sludge amount 2014

Plant	Sign	DM	tdm	Total amount
		%	*tonnes*	*(m3/year)*
Land van Cuijk	LVC	23,4	2,158	9,205
Oijen	O	27	4,333	16,037
Asten	A	3.50	804	23,198
Asten - *dewatered*	A-d	25.00	804	3,216
Aarle Rixtel	AR	3.1	6,097	194,779
Aarle Rixtel - *dewatered*	AR-d	21.6	6,097	28227
Vinkel	V	2,8	793	27,097
Dinther	DI	3,1	5,450	322,494
Dinther - *dewatered*	Di-d	22	5,450	24,773
Den Bosch	DB	4,6	5,782	124,513
Den Bosch - dewatered	DB-d	25,5	3,408	13,361

Dewatered sludge from Den Bosch to Moerdijk

	tdm/day	tdm/year	DM%	Volume
Scenario I	28.8	10512	25	**42,048**
Scenario II	27.4	10001	25	**40,004**

Source: Jaarverslag rwzi´s 2014, Waterschap Aa en Maas

Appendix 15

Model sludge digestion - Scenario II

Input		
Primary sludge		
Amount	150	m3 per day
DM%	10.0%	
OM%	78%	of DM
Biogasproduction	900	L/kg OM converted
Secundary sludge		
Amount	280	m3 per day
DM%	10.0%	
OM%	78%	of DM
Biogas production	900	L/kg OM converted
Total pr. sludge in	**15.0**	tonnes of DM per day
Total sc. sludge in	**28.0**	tonnes of DM per day
Total sludge in	43.0	tonnes of DM per day

Digestion		
Residence time	18	days
Temperature	55	degrees
Contents of tanks	7740	m3

Output		
Biogas production	5,113,575	Nm3 / jaar
Energy content biogas	22	MJ/Nm3
Total pr. sludge out	**7.7**	tonnes of DM per day
Total sc. sludge out	**19.8**	tonnes of DM per day
Total sludge out	27.4	tonnes of DM per day

Economics: revenu

Biogas value	€ 0.16	per Nm3
Biogas value total	**€ 818,172.0**	

pr.	primary
sc.	secondary

Vugt, Peter van:
Factor 1,2 t.o.v. kaalprijs

Appendix 15

Formula for organic matter conversion Chen Hashimot

Residence time	18	dagen
Sludge temperature	55	graden
Minimal sludge age	1.31	

	Primair slib	Secundair slib
Minimal sludge age	1.31	1.31
Maximum reduction	65%	40%
Break down constant	0.5	0.75
Conversion of organic matter	62.54%	37.77%

$$\frac{R}{B} = \frac{\Theta - 1}{\Theta - 1 + K}$$

waarin:

R = het percentage afbraak van de organische stof
B = het maximum haalbare percentage afbraak
Θ = de relatieve slibleeftijd (slibleeftijd gedeeld door minimum slibleeftijd voor methaangisting)
K = de afbraakconstante

De temperatuursafhankelijke minimale slibleeftijd wordt als volgt berekend [23]:

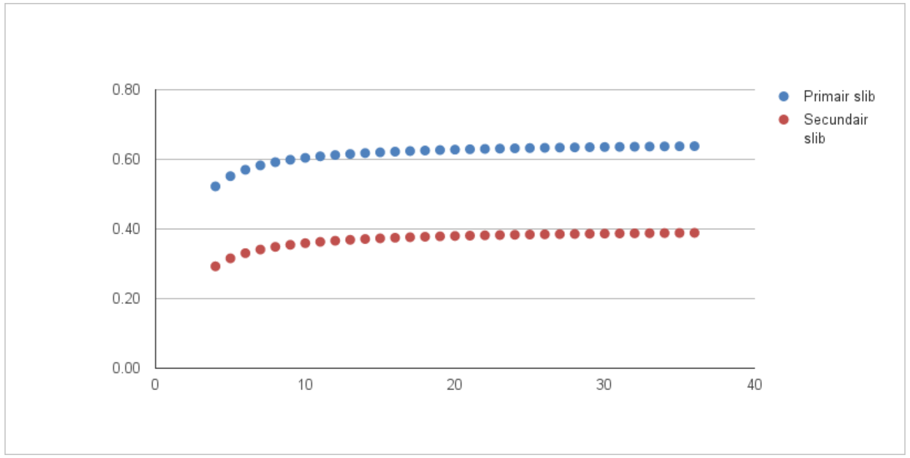
$$SLT_T = 2.85 * MAX((1.08^{(T-30)} - 1.35^{(T-40)}),(1.08^{(T-42)} - 1.35^{(T-57)}))^{-1}$$

De functies tussen de haken beschrijft de afbraakcurve voor het mesofiele (links) en het thermofiele bereik.

PARAMETERS VOOR DE BEREKENING VAN HET PERCENTAGE AFBRAAK VAN ORGANISCHE STOF VOOR MESOFIELE VERGISTING [4]

parameter	eenheid	primair slib	secundair slib
minimale slibleeftijd bij 30°C	d	2,9	2,9
maximale reductie	%	65	40
afbraakconstante	-	1,0	1,5

Dag	Primair slib	Secundair slib
4	0.52	0.29
5	0.55	0.32
6	0.57	0.33
7	0.58	0.34
8	0.59	0.35
9	0.60	0.35
10	0.60	0.36
11	0.61	0.36
12	0.61	0.37
13	0.62	0.37
14	0.62	0.37
15	0.62	0.37
16	0.62	0.37
17	0.62	0.38
18	0.63	0.38
19	0.63	0.38
20	0.63	0.38
21	0.63	0.38
22	0.63	0.38
23	0.63	0.38
24	0.63	0.38
25	0.63	0.38
26	0.63	0.38
27	0.63	0.39
28	0.63	0.39
29	0.63	0.39
30	0.64	0.39
31	0.64	0.39
32	0.64	0.39
33	0.64	0.39
34	0.64	0.39
35	0.64	0.39
36	0.64	0.39
37	0.64	0.39
38	0.64	0.39
39	0.64	0.39
40	0.64	0.39
41	0.64	0.39
42	0.64	0.39
43	0.64	0.39
44	0.64	0.39
45	0.64	0.39



Appendix 16

Digester and self-sufficiency overview

´s-Hertogenbosch	
Scenario I	sludge transported from Vinkel, Dinther, Aarle Rixtel, Asten
Scenario II	sludge transported from Vinkel, Dinther, Oijen

Digester capacity

Scenario I

DM (tdm/year)	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Dinther	6241	6214	6291	6118	6143	5629
Oijen	4845	4322	4405	4326	4260	4333
Den Bosch	6282	5552	6070	6370	5979	5782
Total	17368	16088	16766	16814	16382	15744
Max. capacity	**20440**	**20440**	**20440**	**20440**	**20440**	**20440**
Difference	3072	4352	3674	3626	4058	4696

Scenario II

DM (tdm/year)	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Dinther	6241	6214	6291	6118	6143	5629
Aarle Rixtel	5693	5296	5847	5729	5498	5344
Den Bosch	6282	5552	6070	6370	5979	5782
Total	18216	17062	18208	18217	17620	16755
Max. capacity	**20440**	**20440**	**20440**	**20440**	**20440**	**20440**
Difference	2224	3378	2232	2223	2820	3685

Digesting scenarios

		Present	**Scenario I**	**Scenario II**
Tonnes of DM per day	*tdm/day*	15,9	43,2	46,3
Total DM out per day	*tdm/day*	10,4	27,6	29,5
DM%	*%*	4 and 5,2	10	10.5
Residence time	*day*	23	18	18
Temperature	*°C*	37,6	55	55
Contents of tank	*m3*	7843	7920	7938
Biogas production	*m3/year*	2,381,935	4,809,579	5,113,575
Biogas value	*€*	**381,110**	**769,533**	**818,172**
Energy content	*kWh/year*	14,556,269	29,391,872	31,249,625

Appendix 16

Digester and self-sufficiency overview

Electricity

Assuming the same electricity consumption as in 2015

		Present	Scenario I	Scenario II
Consumption	*kWh*	5,228,487	5,228,487	5,228,487
Energy content of biogas*	*MJ/m3/year*	48,723,180	102,131,348	108,819,260
Energy content of biogas	*kWh/m3/year*	13,534,217	28,369,819	30,227,572
Production	*kWh*	4,620,102	10,780,531	11,486,477
Efficiency	*%*	34	38	38
Difference	*kWh*	-608,385	5,552,044	6,257,990
Self-supply	*%*	88	206	220
Profit 1 year	*€*	/	277,602	312,900
Profit 10 years	*€*	/	2,776,022	3,128,995
Value	*€/kWh*	0.05	0.05	0.05

* it is excluded natural gas production

Biogas

		Present	Scenario I	Scenario II
Biogas production	*m3/year*	2,381,935	4,809,579	5,113,575
Consumption	*m3/year*	167,245	167,245	167,245
Consumption electricity*	*m3/year*	2,381,935	2,251,502	2,251,502
Overproduction	*m3/year*	/	2,390,832	2,694,828
Self-supplyment	*%*	88	100	100
Profit 1 year	*€*	/	382,533	431,173
Profit 10 years	*€*	/	3,825,332	4,311,725
Value	*€/m3*	0.16	0.16	0.16

*amount of biogas for producing electrictiy

**requirement of the Energy Agreement 2020

Profit

comparing the profit of electricity and biogas

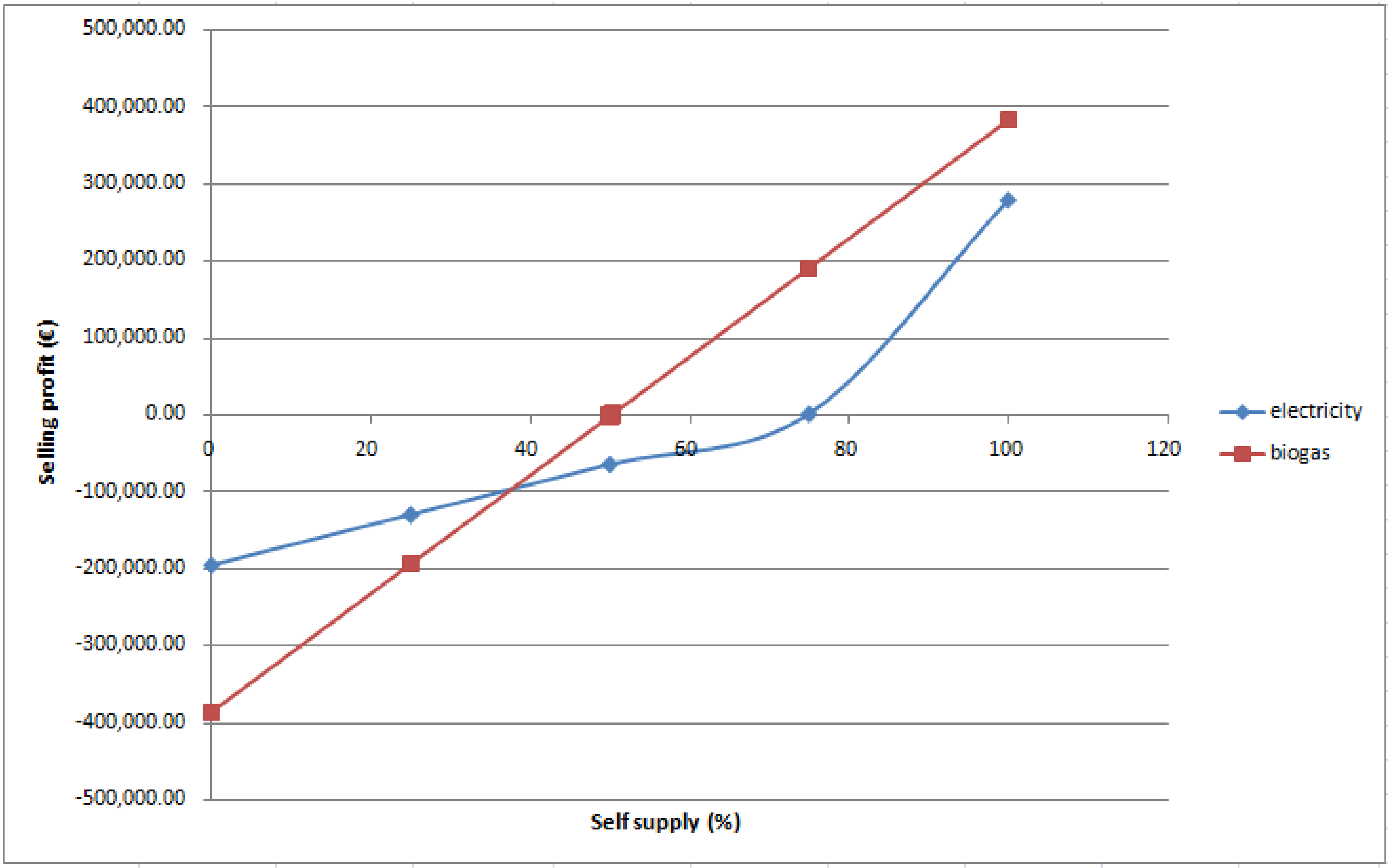
	Scenario I	Scenario I
Self-supplyment	40	100
Profit biogas	382,533	431,173
Profit electricity	434,457	277,602
Costs electricity	282,338	0
Difference elecricity	152,119	327,756
Difference biogas	100,195	431,173

Appendix 17

Biogas Production Comparison

Biogas production		*Scenario I*	*Scenario II*
Land van Cuijk	*m3/year*	397,032	397,032
Den Bosch	*m3/year*	5,113,575	4,809,579
Aarle Rixtel	*m3/year*	0	1,175,896
Total	*m3/year*	5,510,607	6,382,507
Biogas consumption			
For CNG fuel	*m3/year*	237,990	238,238
For electricity LVC	*m3/year*	397,032	397,032
Self-supply LVC	*%*	17	17
For electricity Den Bosch	*m3/year*	2,251,502	2,251,502
Self-supply Den Bosch	*%*	100	100
For electricity Aarle Rixtel	*m3/year*	0	1,175,896
Self-supply Aarle Rixtel	*%*	0	50
Total	*m3/year*	2,886,524	4,062,668
Remaining biogas	*m3/year*	2,624,083	2,319,839

Appendix 18 – Profit comparison of electrictiy and biogas



Appendix 19

Profit comparison of the scenarios

Scenario I	AR, A, DI, VI --> DB	digester in Asten is closed
Scenario II	A --> AR and VI, DI, O -->DB	digester in Aarle Rixtel is placed

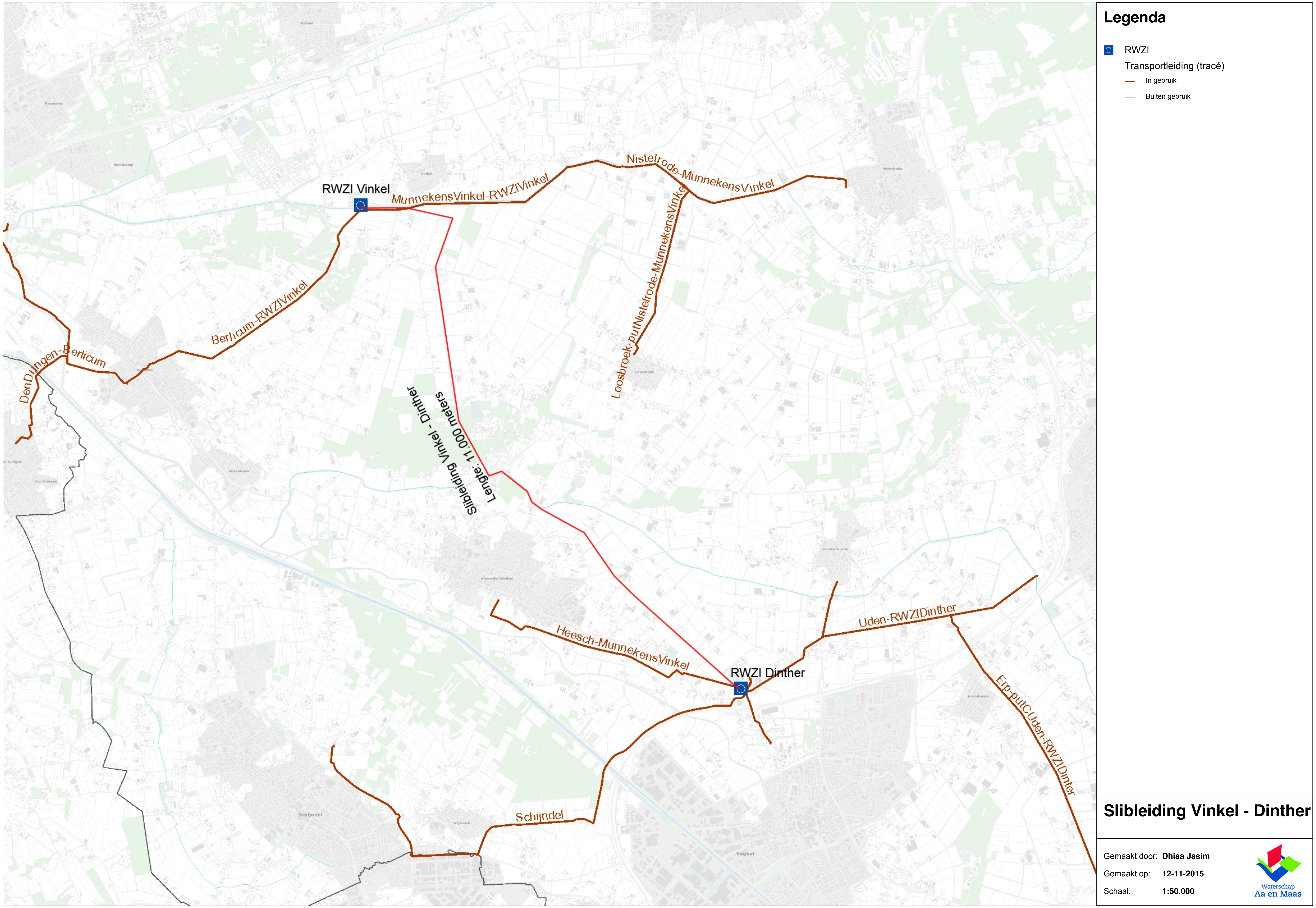
		Aarle Rixtel		´s-Hertogenbosch	
		digester	*no digester*	*Scenario I*	*Scenario II*
Electricity produced	*kWh*	2,719,945	0	5,228,487	5,228,487
Electricity consumption	*kWh*	5,478,355	5,478,355	5,228,487	5,228,487
Electricity consumption	€	493,052	493,052	470,564	470,564
Self-supplyment	%	**50**	0	**100**	**100**
Electricity costs	€	248,257	493,052	0	0
Profit 1 year (biogas)	€	0	0	382,533	431,173

		Total costs electricity	Income	Savings electrictiy	Savings SNB	Profit	For investment	Year of payoff for the new digester
Scenario I	€	493,052	382,533	0	0	-110,519	/	/
Scenario II	€	248,257	431,173	244,795	91,704	182,916	519,415	9.63

Appendix 20

Routes efficieny Comparison											
	Trucks	Drivers	Total distance	Total driving hours	CBG		Biogas		All runs	Empty runs	Relation
			km/day	*hours/day*	*kg/day*	*kg/year*	*m3/day*	*m3/year*	*per day*	*per day*	
Normal routes											
Scenario I	5	6	**1923**	**50.08**	538	139,994	915	**237,990**	31	18	0.58
Vinkel, Asten	2	2	593	13.36	166	43,170	282	73,390	16	9	0.56
Scenario II	5	6	**1925**	**51.12**	539	140,140	916	**238,238**	31	18	0.58
Vinkel, Asten	2	2	593	13.36	166	43,170	282	73,390	16	9	
Combined routes											
Scenario I	5	5	**1808**	**47.32**	506	131,622	861	**223,758**	30	17	0.57
Vinkel, Asten	2	2	593	13.36	166	43,170	282	73,390	16	9	0.56
Scenario II	5	5	**1810**	**48.60**	507	131,768	862	**224,006**	30	17	0.57
Vinkel, Asten	2	2	593	13.36	166	43,170	282	73,390	16	9	0.56

Appendix 21



Source: Dhiaa Jasim, Tekenaar bouwkunde en civiele techniek, Waterschap Aa en Maas

Appendix 22

Waterboard Aa en Maas
Sludge Pipeline WWTP Vinkel - WWTP Dinther
Length 11.000 m
HPPE 150

Descrition	Unit	Quantity	Price per Unit	Total price
Construction pressure pipe HDPE 150 mm	m	11000	150.00	1,650,000.00
Civil construction sludge pumping station	Euro	1	250,000.00	200,000.00
Adapt infrastructure	Euro	1	50,000.00	50,000.00
Pumpstations W&E	Euro	1	100,000.00	100,000.00
				2,000,000.00
Execution	%	5		100,000.00
General costs	%	7.5		150,000.00
Profit and risiko	%	5		100,000.00
Aanneemsom				2,350,000.00
VAT	%	21		493,500.00
Total incl. VAT				2,843,500.00
General costs	%	5		142,175.00
Third-party consultancy costs				
Authoriastion				
Insurance				
Adjusting utility lines				
Private compensation				
Preperation- and supervision costs	%	15		426,525.00
				3,412,200.00
Unexpected costs	%	10		341,220.00
				3,753,420.00
Interests	%	5		187,671.00
Total				3,941,091.00
Rounded				**4,000,000.00**

Source: Frank Bertholet, Coördinator elektrotechniek en werktuigbouw, Waterschap Aa en Maas

Appendix 23 - Map of digesters in Noord-Brabant