UNIVERSITY OF TWENTE.

ALTERNATIVE FARMING PRACTICES AND THE POTENTIAL CONTRIBUTIONS TOWARDS A BIO-BASED ECONOMY:

Case Study of Dutch Dairy Farming Practices

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FINAL DRAFT

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PREFACE

This thesis is in partial fulfilment of my Master's degree programme, Environmental and Energy Management with specialization in the Energy Stream, at the University of Twente, The Netherlands.

I wish to thank my first supervisor, Dr Maarten J. Arentsen, a senior lecturer at the University of Twente. Your doors were always open to me to ask questions when I had any form of doubts about the report. I really appreciate your feedbacks on my progress reports. I would also like to thank Dr Frans H.J.M. Coenen, my second supervisor.

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Finally, I am grateful for the valuable ideas and advise from colleague's course mates, it was really a wonderful experience to meet you all. Special thanks go to Ms. Fiona Eudora Gomez for everything during the thesis period. I am grateful to my family for their prayers and words of encouragements throughout this journey. To my dad, Mr. Joseph Awelimba ASAMBO (late), I dedicate this to you. I remember every bit of advice you gave me before I embarked on this journey.

Through this opportunity, I gained a valuable, realistic and truly enriching experience and further developed myself.

Enjoy reading!

University of Twente, The Netherlands

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Table of Contents

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AD – ANAEROBIC DIGESTION

CH_4 – METHNAE

CO_2 – CARBON DIOXIDE

DAF – DISSOLVED AIR FILTRATION

DBC – DUTCH BIOREFINERY CLUSTER

ECM – ENERGY CORRECTED MILK

FAO – FOOD AND AGRICULTURE ORGANISATION OF THE UNITED NATION

GHG – GREENHOUSE GAS

KG – KILOGRAM

LSU – LIVESTOCK UNIT

NH_3 – AMMONIA

NO_3 – NITRATE

N_2O – NITROUS OXIDE

NPK – NITROGEN, PHOSPHORUS, POTASSIUM

RO – REVERSED OSMOSIS

SDE+ - STIMULATION OF SUSTAINABLE ENERGY PRODUCTION

ABSTRACT

Global developments such as European Union environmental policies, growth of the bio-based economy, the increase in energy prices, the increase in sustainability demands and the continuous growth of the dairy sector, demands a second consideration into current dairy farming. One key issue for sustainable development is the establishment of a bio-based economy. The bio-based economy can provide energy in the 21st century just as fossil-based economy was to the 20th century. To achieve this, agriculture will be core to the bio-based economy as a major supplier of raw materials (feedstocks) for commodities like liquid fuels and value-added products (such as chemicals and materials). "For example, a hectare (2.47 acres) of biomass crop converted to 16,800 L (4,450 gallons) of ethanol at a cost of USD 0.13 /L (USD 0.50/gallon), grown on 20Mha 950 million acres) of non-prime agricultural land would, along with domestic petroleum, enable national self -sufficiency in gasoline" (Hardy R.W.F, 2002 p.11). Agriculture will at the same time continue in the production of its core objective i.e. food and feed, that are even more healthy and safe.

This thesis, analysis the current Dutch dairy production practices and its potential of being a major feedstock supplier to the bio-based economy. The main research question is;

Is it possible to combine food production with feedstock production for the bio-based economy in Dutch dairy farming and if yes, what adjustments are needed in the current farm routines and processes?

Based on an extensive literature review, a theoretical framework was constituted by the researcher for approaching the complexity of the research questions.

Although the Dutch Dairy sector is one of the leading in the world in respect to milk production, the sector is also faced with residues (manure, crops) management challenges. The bio-based economy provides a fantastic opportunity for the Dutch dairy sector to convert these residues into feedstocks to feed the bio-based economy. This can be done through the adoption of a new production route that incorporates feedstocks production with food (milk), while simultaneously benefiting people, planet and profit (for business). The Dairy Campus farm was studied to know the process flow of inputs (feed intake) and outputs and recommendations made based on the scientific literature reviewed from different sources.

Keywords: Bio-based economy, feedstocks, sustainability, Dutch dairy farming, bioenergy conversion techniques and nutrients recovery techniques.

1.0 INTRODUCTION

1.1 PROJECT CONTENT

With the continuous increase in the global population, rapid depletion of many resources, increasing environmental pressures and climate change, the world need to radically change its approach to production, consumption, processing storage, recycling and disposal. The Europe 2020 Strategy identifies bio-economy as the key element for smart and green growth in Europe. The establishment of bio-economy would lead to; maintenance and creation of economic growth and jobs in rural, coastal and industrial areas, reduce fossil fuel dependence and improve the economic and environmental sustainability of primary production and processing industries.

The Dutch dairy sector is one sector that can tap into the bio economy prospects due to its high inputs of feed (maize, wheat, soya, chemical fertilizers and concentrates) and the high output of residues (manure etc) associated with it. The Dutch dairy sector produced a total of 78,211m/n kg of manure in 2016 (Statistics Netherlands). The bio-based economy as explained above, provides an opportunity for Dutch dairy farming to take advantage and produce feedstocks from these residues (manure etc.) while solving the challenging environmental concerns. If the current dairy production processes could be modified to incorporate feedstocks production, this would end or minimize the high challenges associated with the high manure output. Also, this will help provide feedstock to supply the bio-based economy and help provide a contribution towards achieving the Europe 2020 Strategy.

1.2 PROBLEM STATEMENT

The number of dairy cattle in the Netherlands continues to increase and thus changed manure from being a valuable ouput product into an environmental nuisance. Environmental challenges caused by the excess manure from dairy farming over the years have led to: "(1) eutrophication of surface water by phosphate emissions; (2) pollution of ground water by nitrate emissions; and (3) acidification by ammonia emissions" (Dietz and Hoogervorst, 1991. p 313).

Most of the attempts over the last 30 years to solve these challenges have been focused on addressing the environmental challenges caused by these excess manures and this approach have been proven not to be successful hence the need to find a newer approach on how dairy farming should be operationalized. The bio-based economy concepts seem to provide a business opportunity for dairy farmers to adopt to solve this residue problems in a more sustainable way. It is at the backdrop of this that dairy farming in the Netherlands requires a more sustainable new production route(s) where the whole agricultural production system could serve as a valuable source for feedstock for the bio-based economy.

1.3 RESEARCH OBJECTIVE

Inferred from the previous section, the research objective is formulated as follows:

To find and design a new production route that would see dairy production as an important producer of milk for food and feedstocks for bio-based economy in a sustainable way.

33To achieve this research objective, the researcher conducted literature reviews into the Dutch dairy farming and the available biotechnologies that can be incorporated into the process. The research considered the possibilities available for the combination of food and feedstocks with the aim of supplying raw materials to the bio-based economy while solving environmental challenges associated with dairy farming. The Netherlands is explicitly chosen as area of research given it widely claimed potential for developing bio-based economy (Nova institute, 2014; Deloitte, 2014; Bruggink, Hoeven & Reinshagen, 2014; WTC, 2014).

1.4 RESEARCH FRAMEWORK

Verschuren and Doorewaard (2010) defined research framework as a "schematic presentation of the research objective and includes the appropriate step that need to be taken to achieve it". In this study, the research framework consists of seven different but related steps and is presented below:

Step 1: Characterizing briefly the objective of the research project

The aim of this research is to find and design a new dairy production route aimed at making the production system a major supplier of feedstock for the bio-based economy in a more sustainable way.

Step 2: Determining the research object

The research object in this research are the current dairy farming practices in the Netherlands.

Step 3: Establishing the nature of research perspective

The research deals with a design-oriented research, thus the research perspective considers the current dairy farming practices that leads to nutrients loses and pollutions and designing a new system that would be based on making it an important producer of feedstock for the bio-based economy in a sustainable way. The research concerns the causal relationships between several factors on the one hand, which affect the success of the production outcome on the other. The research perspective would be presented in a conceptual model showing the relation between the current Dutch dairy farming practices and the potential of producing feedstocks for the bio-based economy. This is achieved by the reviewing of relevant literatures.

Step 4: Determining the sources of the research perspective

The research uses scientific literatures to develop a conceptual model. Theories used in this research are:

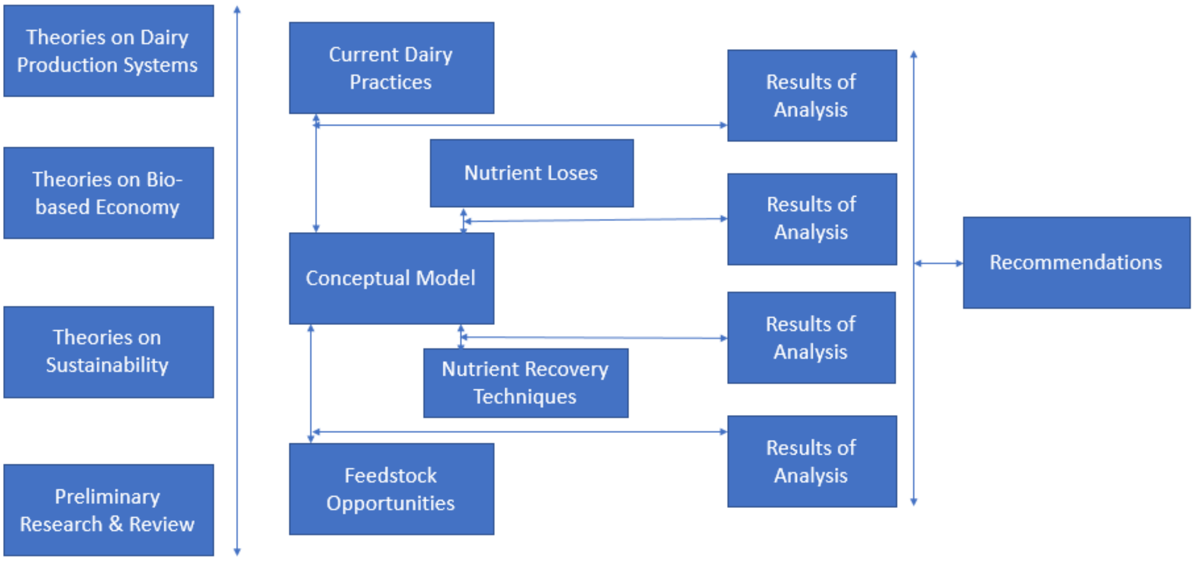
Figure 1: SOURCES OF THE RESEARCH PERSPECTIVE

Current dairy production systems	Theories on Dairy Production Systems
Bio-based economy	Theories on bio-based economy
Sustainability	Theories on sustainability
	Preliminary Research & Review

Step 5: Making a schematic presentation of the research framework

The research framework is schematically described through the following flow charts:

Figure 2: MAKING A SCHEMATIC PRESENTATION OF THE RESEARCH FRAMEWORK



Step 6: Formulating the research framework in the form of arguments are elaborated as follows:

(a) A study of the theories of dairy production management systems, sustainability principles, bio-based economy concepts and preliminary research results in a conceptual model;
(b) To help in clearly identifying the research object;
(c) A confrontation of these evaluation results in;
(d) Designing a new alternative farming routes for dairy production to combine food and feedstocks production in the dairy sector.

Step 7: Checking whether the model requires any change

There is no indication that any change is required.

1.5 RESEARCH QUESTION

To achieve the research objective a general research question is formulated as stated below:

Is it possible to combine food production with feedstock production for the bio-based economy in Dutch dairy farming and if yes, what adjustments are needed in the current farm routines and processes?

To answer the general research question, the following sub-questions are formulated:

1. *What is the current practice of dairy farming with respect to inputs, conversion and outputs?*
2. *Which adjustments in the current practice are needed to effectively combine and balance food production with feedstock production for the bio-based economy?*

1.6 RESEARCH METHOD

LITERATURE REVIEW

To be able to build a theoretical framework and examine dairy farming practices and the potential of incorporating feedstocks production in the Netherlands, a critical review of existing literature is done and scientific articles and books from various scholars is used. The literature has been retrieved via scholarly databases (Google Scholar, Web of Science, Scopus) and the libraries of Wageningen and the

University of Twente. Some of the terms searched for includes for example 'Dutch dairy farming', 'bio-based economy', nutrients recovery techniques and bioenergy technologies. I also made use of the snowball-method by reading articles and books others referred to. The literature is predominantly from academic journals and books, but also reports from (government) institutions like European Union or the Netherlands have been consultant for information. Furthermore, the statistical databanks of Statistics Netherlands and EUROSTAT were used for up-to-date numbers and figures.

1.7 REPORT STRUCTURE

The report is structured as follows: chapter 2 presents the literature review outlining the state of the art features in dairy farming practices and the bio-based economy of the Netherlands. Chapter 3 analyses the bio-based economy idea and its implications for the agriculture sector. Chapter 4 provides the empirical research of the studies. It analyses the flow sheets of the Dutch dairy sector and the possibilities to change the process to combine food and feedstock production. Lastly, in chapter 5, a summary of conclusions is drawn from the findings discussed to answer the research questions, and recommendations for further studies formulated.

2.0 LITERATURE REVIEW

INTRODUCTION

This chapter begins with a review of relevant literatures and documents on the global dairy farming practices and ends with core emphasis on the Dutch dairy farming. This chapter seeks to elaborate in detail the dominant features associated with dairy farming as well as talk about bio-based economy in the Netherlands.

2.1. GLOBAL DAIRY FARMING

Dairy production systems in many parts of the world continue to move towards a more intensive approach over the years because of the high global milk demands. According to FAO (2014), the global consumption of dairy products in milk equivalent in developing countries is expected to slow from 2.3% to 1.8% per annum in 2013-2022, reflecting growing shortages of water and suitable land. Developing countries is expected to account for 74 percent of new demand and this demand would grow at an estimated annual rate of 2% percent (FAO,2014). In the quest of dairy farmers to maximize annual milk production per cow, to meet demands, the dairy industry in many regions of the world have evolved from the pasture based dairy system towards a confinement or high-input/high-output system of production. As more and more dairy production moves towards this system of production the more the issues of environmental, sustainability, animal welfare and food security are asked by the society.

2.1.1. PASTURE-BASED SYSTEM VERSUS CONFINEMENT OR HIGH-INPUT/HIGH-OUTPUT SYSTEM

According to Blum et al., (2010), the percentage of the earth surface suitable for agriculture is only 36% and one third of this constitute arable land, while two thirds are suitable only for grazing. When ruminants were first domesticated by humans, these animals could easily digest fibrous feedstuffs (i.e. grass) due to their evolutionary adaptation (Engelhardt W. von, et al. 1985), which meant ruminants were never in competition with humans for food sources (Hofmann R.R. et al. 1989). Pasture-based system of dairy production involves the growing of grasses to feed dairy animals in carefully rotational managed paddocks. This system is aimed at maximizing milk yield per unit of pasture consumed and is always associated with usage of large areas of lands for growing grasses.

However, despite the abundance of grassland and pastures as a sustainable and cost-effective resource in climate zones and the unique evolutionary ability of ruminants to turn this resource into food for humans, the practice of feeding mainly grain -based concentrate rations to large dairy herds indoors year-round has been on the increase in North America and Europe since 1950s (Thomet P. et al., 2011). In a Confinement or high-input/high-output system of dairy production, dairy animals are kept in a confined structure and fed throughout the year with the sole aim of maximizing annual milk yield. Dairy animals are put on specific quantities of concentrate feeds aimed at optimizing milk production. This form of production system has been enhanced over the years because of the progressive mechanization of agriculture, which has seen grain prices drop because of being able to use machines to replace human labour and making it time and cost effective for feed harvest, conservation, storage and dairy feed provision indoors (Wilhelm K. 2015)

A study conducted by Belflower J. B (2010) on the ‘potential environmental impacts of Pasture-based and Confined Dairy Farms in Georgia’ found that the choice of production systems in dairy production has a significant impact on the milk production and the environment. Firstly, the study revealed that milk production in a confinement based dairy system was as high as two times that of pasture-based dairy system. According to Chianese et al., (2009b), the higher the percentage of fibre fed in diets the higher the emission of enteric methane per cow. Secondly, on the emission of gases, the study showed that higher forage diets on the pasture-based dairy increased the emission of enteric methane. Also, confinement dairy farms were found to be associated with long-term manure storage at the farm resulting to considerable emission of methane and this emission source together with other animal and manure handling differences, resulted to 70% greater methane emission per cow in confinement system (Belflower J. B et al. (2012). The pasture-based farm was found to have 30% more methane emission expressed per unit of Energy Corrected Milk (ECM) than that of the confinement farm (Belflower J. B et al. (2012) (Table 2).

Table 1: MAJOR CHARACTERISTICS OF THE TWO SIMULATED FARMS

Farm characteristics	Pasuture-based dairy	Confinement dairy
Number of cattle	500	700
Average body weight (kg)	500	590
Breed	Holstein and Jersey Crosses	Holstein and Holstein, Jersey and Swedish Red Crosses
Housing	Young calves in bedded barn All cows on pasture	Lactating cows in two free-stall barns Dry cows and older on pasture
Milk production		
Total (kg/cow/year)	5,000	10,700
Milk fat concentration (%)	3.6	3.8
ECM (kg/year)	2,538,000	7,872,000
Feed production and use		
Harvested silage (t DM)	0	3,372
Grazed forage (t DM)	2,045	685
Purhcased feed (t DM)	595	2,719

Source: Belflower J. B et al. (2012)

Table 2: SIMULATED ANNUAL GREENHOUSE GAS EMISSIONS FROM THE TWO DAIRY FARMS IN GEORGIA

Greenhouse gas emission	Unit	Pasuture-based dairy	Confinement dairy
Energy Corrected Milk production (ECM)	kg	2,548,000	7,872,000
Methane oxide	kg CH_4/cow	119	202
	kg CO_2 equiv.	1,482,900	3,525,700
	kg CO_2 equiv./t ECM	582	448
Nitrous oxide	kg N_20/cow	1.3	6.7
	kg CO_2 equiv.	200,600	1,402,700
	kg CO_2 equiv./t ECM	79	178
Carbon dioxide from fuel combustion	kg CO_2/cow	229	684
	kg CO_2 equiv.	114,300	478,500
	kg CO_2 equiv./t ECM	46	63.9
Total greenhouse gas			
Primary sources	kg CO_2 equiv.	1,797,800	5,406,900
Secondary sources	kg CO_2 equiv.	552,900	1,492,500
Net biogenic CO_2	kg CO_2 equiv.	-750,700	-2,329,200
Net allocated to milk	kg CO_2 equiv.	-158,300	-405,700
Total net	kg CO_2 equiv.	1,441,700	4,164,500
Potential carbon sequestration	kg	230,000	0

Source: Belflower J. B et al. (2012)

2.1.2. ANIMAL WELFARE

According to Hofmann R.R. (1989), cattle can be described as herd and social animals as well as eaters of grass and roughage. Considering this, feeding cattle with pasture is the ideal environment to exhibit their natural grazing, locomotion, resting, social and explorative behaviour (Wilhelm K. 2016). This nevertheless, the last 65 years have witnessed milk production potential of dairy cows increased significantly through research developments (Knaus W. 2009). This means the nutrient and energy requirements of cattle have also increased to an extent that if pasture continue to be the sole source of feed offered, a massive energy deficiency can be the result, as cows are limited in their daily feed intake in pasture-based system as compared to confinement based system, where cows are provided with highly concentrated rations. This is not to suggest that, a low milk production as observed in the study above (Belflower J. B et al., 2012) is a sign of low animal welfare, neither can a high level of milk performance as observed in the confinement system guarantee a high animal welfare status (Mag K.W. et al., 2012). Freedom from hunger cannot be guaranteed when high-yielding dairy cows are fed with pasture only (Charlton GL. Et al., 2011). The high milk demands from dairy cows over the years had led to significant problems like infertility (Lucy G.L. et al. 2011; Remnant J.G. et al., 2015) and reduced the productive life span of cows to only 2.63 years or 31.6 months (De Vries A., et al., 2013). The reduced life expectancy being witnessed is an indication that the animal's welfare has been impaired at some time or times during its life according to Broom (1991). Burow et al. (2011) concluded from an extensive study conducted in Denmark that 'the more time the cows spend on pasture, the lower the mortality.' The more cows are kept indoors the more likely detrimental effects on the hock joint integument of the animals are to be expected because of structural changes, larger dairy herds, and reduction in pasture use (Burow et al., 2013).

To determine the preferences of animals regarding their housing and feeding systems, free-choice experiments are probably the simplest method to conduct (Fraser D. 2008). A study conducted by Legrand A.L. et al. (2009), concluded that the pattern of cow's preferences regarding location is complex and is under certain conditions that pasture is preferred by cows. The study observed that in the absence of shade on pasture or when TMR (total mixed ration) was only provided indoors, the motivation of cows to stay inside was high (Legrand A.L. et al., 2009). In a further study conducted by Charlton G.L. et al. (2011) it was proven that when cows were offered same TMR indoors or on pasture, the animals showed preference for pasture. Generally, it can be concluded that, cows on pasture enjoys more animal welfare than when kept indoors and freedom from hunger can also be ensured in cows on pasture if the cows are of a type suitable for pasture.

2.1.3. SUSTAINABILITY

The term sustainability has been defined by several authors but the original definition of sustainability development is usually known to be: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs", (Bruntland Report for the World Commission on Environmental and Development, 1992). For any agriculture system to be sustainable its needs to respect the ecological conditions that it is based on for it to be truly practiced in a long term and those forms of agriculture that do not require external energy inputs to function is included (Heitschmidt R.K. et al 1996). He further explains that the grazing of indigenous grassland, adapted to local conditions, serves as a striking example of this, as no other form of agriculture depends less on external resources.

New Zealand is one country that have shown that a sustainable dairy production on pasture-based is possible. An investigation conducted by Basset-Mens C. et al (2009) in New Zealand's low-input pasture -based conditions (i.e. no use of nitrogen fertilizer, no brought-in feed supplement, stocking rate of 2.3 cows' ha^{-1}) concluded that any intensification of the dairy production system is detrimental to the system's eco-efficiency, regardless of which functional basis was used (per kg of milk or per ha land use). Generally, pasture is also perceived as being ecologically questionable due to its methane production but per Shibata and Terada (2010) this can be reduced by selection of suitable livestock and good pasture management. They observed that by feeding dairy cows with higher quality pasture of high generic merit results in improvement in milk production efficiency (kg milk kg^{-1} pasture intake) and thereby reduces the amount of methane released per kg of milk produced. According to Tilman D. et al. (2002). these data confirm it is possible to manage grassland-ruminant ecosystems to be highly eco-efficient compared to intensified systems. This therefore represent a sustainable method of producing high-quality protein at minimal environmental impact when stocking rate and pasture management are appropriate (Tilman D. et al. 2002).

The use of land scape conservation especially in the Alpine regions, were a site-adapted pasture feeding and management system contributes to the preservation of the cultural landscape (Wilhelm K. 2016). Abandonment of grassland use after pasturing and allowing this cultivated grassland area to revert to forest are among the most significant losses of biological diversity on agriculturally used lands (Holzner W. 2013)

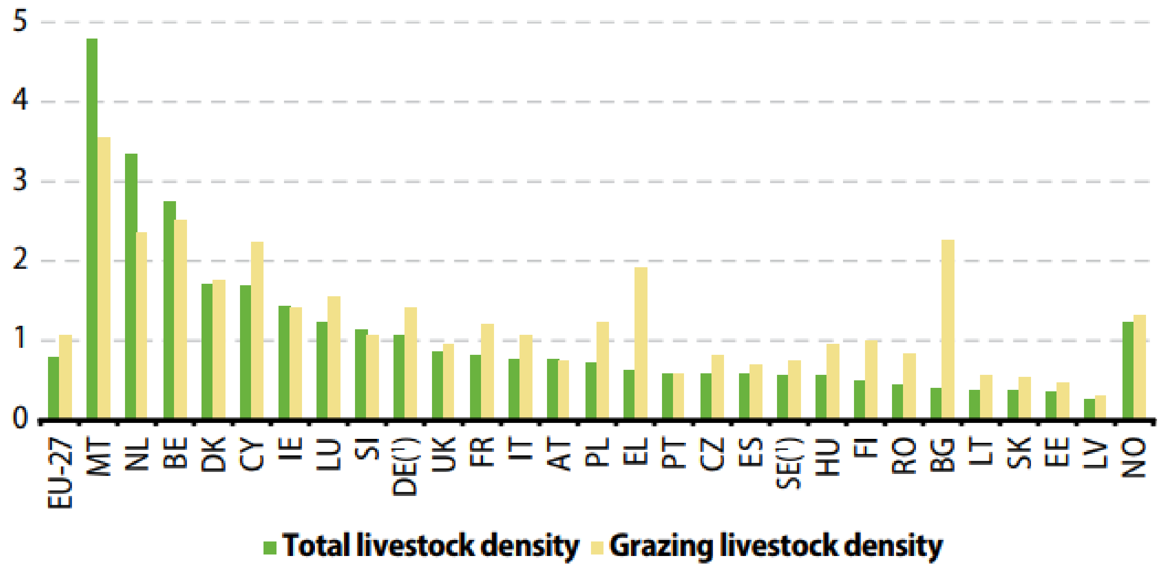
2.1.4. FOOD SECURITY

The food security of man cannot be guaranteed when ruminants are fed with substantial amounts grain-based concentrates indoors instead of pasture. Foley J.A. et al (2011) stated that depending on the method used, the production of meat and milk can either improve or impair the global food situation. Grazing systems based on the use of permanent grassland unsuitable for human food purposes and a mixed crop-livestock system could increase food supply globally and ensure food security. 'However, using highly productive croplands to produce animal feed, no matter how efficiently, represents a net drain on the world's potential food supply' (Foley J.A. et al 2011). The practice of high-input/high-output dairy production system is mostly dependent on grain and pulses thereby competing with humans for food. The use of potentially human-edible components such as grains and pulses to feed animals has led to unprecedented acceleration of the intensification of dairy productions systems. However, the converting of plant foods into animal products has been a very inefficient way of producing human food (Cassidy E.S. et al. 2013; FAO 2011). To achieve a more sustainable livestock production system, the amount of potentially human-edible food fed to animals would have to be reduced (Eisler M.C. et al. 2014; Herrero M. et al. 2013).

2.2. DUTCH DAIRY FARMING

The dairy sector is the most vital livestock in the Netherlands, and it is highly productive regarding both animal and land productivity. The dry matter yield of grass and maize are high due to high organic and inorganic fertilizer inputs (CBS, 2009a). The Netherlands is an important player in dairy production over the years and the Dutch dairy sector over the years are known for producing milk, cheese and yogurt. Despite achieving great successes in dairy production through investment in research, the Dutch dairy farming is faced with several challenges. Dairy farming has been characterized by a production system that engages in high stocking densities (see Table 3), high inputs of chemical fertilizers (for grass and forage growing) and concentrates. These have led to multiple challenges on environment, landscape and animal welfare. These challenges can be categorized as water quality (nitrate and phosphorus leaching; (European Union, 1991; MINLNV, 2008) in some cases water use for irrigation (Hellegers and Van Ierland, 2003)), air quality (ammonia, odour, particulate matter, greenhouse gasses); (MINVROM, 2007; MNP et al., 2006), the conservation of existing landscapes and natural ecosystems, as well as cattle welfare issues (grazing, housing conditions, health) (MINLNV, 2007).

Table 3: STOCKING DENSITIES, 2007 (LSU/ha)



Source: EUROSTAT: http://ec.europa.eu/eurostat/product?code=ef_ov_lssum&mode=view&language=en (Last Updated 28-04-2015)

Based on the number of cows present in a farm the Dutch dairy farms could be categorized as small, medium or large. The table below shows the number of dairy farms and dairy cows available in the Netherlands classified according to the number of dairy cows per farm.

Table 4: CLASSIFICATIONS OF DAIRY FARMS ACCORDING TO DAIRY COWS POPULATION

POPULATION CLASSES	NUMBER OF FARMS	NUMBER OF DAIRY COWS
	2015	**2015**
1 - ‹ 30	1,761	25,122
30 - ‹ 70	5,700	299,581
70 - ‹ 100	4,788	400,065
100 - ‹ 150	4,092	488,659
150 and more	1,924	408,340
Total =	**18,265**	**1,621,767**

Source: ZuivelNL, 2015.

From the table above, it can be deduced that dairy farms with less than 30 cows and more than 150 cows contribute to 9.6% and 10.5% of total dairy farms in the Netherlands respectively in 2015. Dairy farms with 30 or more cows but less than 150 makes up 79.9% of total cows in the Netherlands in 2015. The total number of dairy cows in the Netherlands in 2016 is 1,794,000 according to the Statistical Netherlands data.

2.2.2. GRAZING

Dairy cattle grazing in the Netherlands has seen a declining trend over the periods for several reasons. The average herd size of dairy farms has increased recently together with the number of automatic milking systems. The grazing of large herds is often perceived to be difficult to manage by the dairy farmers. This is because increasing in herd size implies larger walking distance from pasture to milking parlour. A longer walking distance is considered to negatively affect milking frequency of cows (Spörndly and Wredle, 2004). There is a possibility to combine grazing with automatic milking system but this is difficult to manage. The controlling of diets, dietary composition and feed intake by farmers is more difficult in grazing systems. Many Dutch farmers consider labour productivity as important. Between 1990 and 2006, the percentage of cattle grazing in the Netherlands gradually decreased from 95% to 85% of the total number of dairy cows. This percentage however, stabilized at about 80% from 2006 onwards (see Table 4 below).

Table 5: PERCENTAGE OF DAIRY COWS GRAZING DAY AND NIGHT, GRAZING ONLY DURING THE DAY AND PERMANENTLY HOUSED (CBS, 2009A). DURING THE PERIOD NOVEMBER-APRIL, ALL CATTLE IN THE NETHERLANDS ARE NORMALLY HOUSED

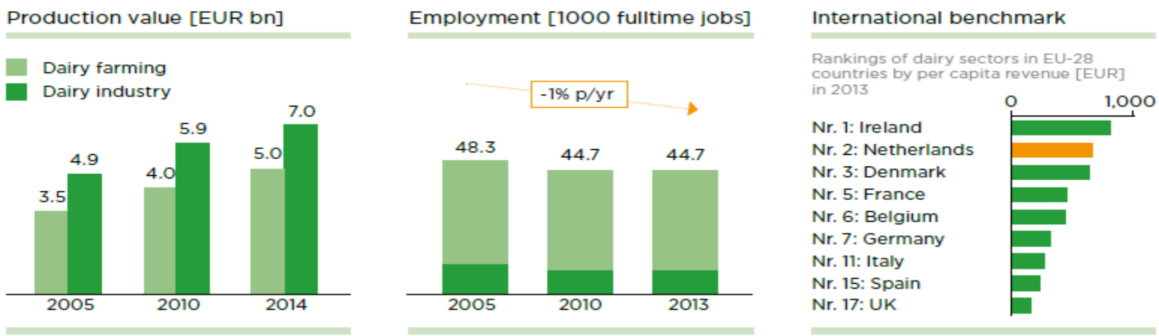
	1992	1997	2001	2004	2006	2007	2008
Day and night	47	48	36	31	34	23	38
Day only	47	45	54	55	46	57	41
Housed	6	8	10	15	20	20	21

Source: CBS, 2009a

2.2.3. ECONOMY

Agriculture is an integral part of the Dutch economy of which the dairy sector pays a significant role. In 2014, the Dutch dairy farming and the dairy industry had a productive value of EUR 5 billion, and EUR 7 billion respectively. Figure '3' shows the production value trend between 2005 and 2014. The industry employs about 45,000 fulltime jobs (see figure '3'). The introduction of automation however, has brought the numbers down but on the other hand improved the sector's competitiveness. As shown in figure 3 below, the Netherlands, is second to Ireland in the international rankings of dairy sectors in the EU-28 countries by per capita revenue (EUR) in 2013. Friesland Campina is one of the world's five largest companies in the dairy industry with a cooperative of 19,000-member dairy farms in the Netherlands and abroad. Appendix '1' gives further information on the trade balance between import and export for agricultural and dairy products in the Netherlands for 2015.

Figure 3: ECONOMIC CONTRIBUTION OF DUTCH DAIRY SECTOR



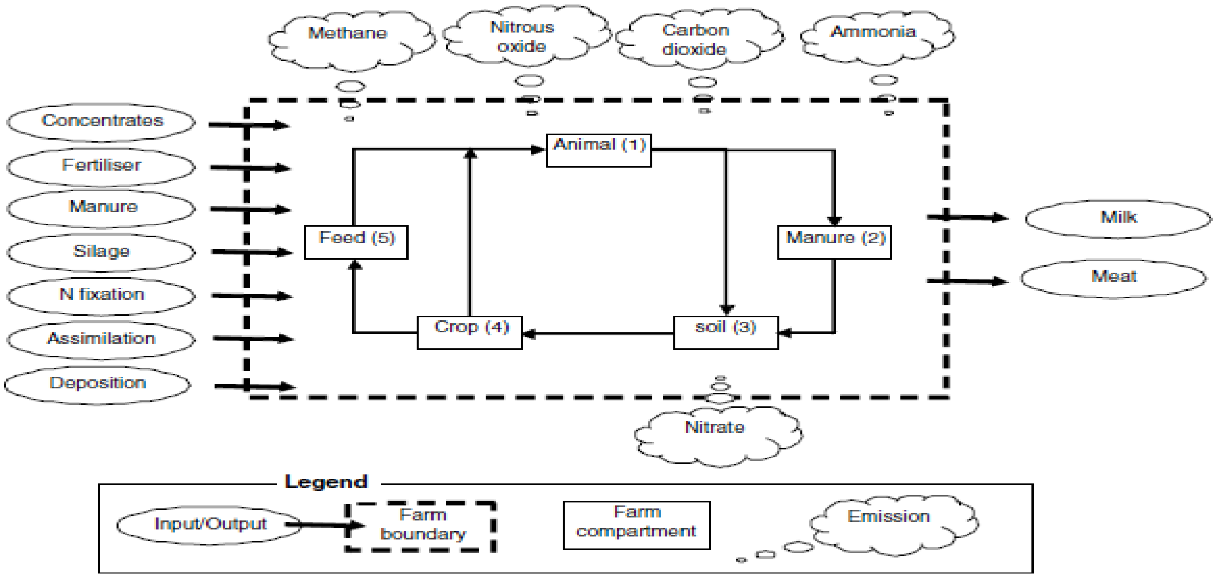
Source: Roland Berger and Dutch Dairy Association (NZO), DairyNL. (2015)

2.2.4. INPUT/OUTPUT FLOWS OF A TYPICAL DUTCH FARM

The Dutch dairy farming is characterized by high-input and high-output regime that sees farmers use high volumes of inputs. These inputs often lead to high output in terms of products and residues (emissions and manure). Figure '4' below provides a flow diagram elaborating the typical Dutch dairy farming process showing the inputs, conversion and output streams.

Figure 4: MAIN NUTRIENT FLOWS WITHIN THE BOUNDARIES OF THE FARMING SYSTEM AND THE INPUT, OUTPUTS AND LOSSES

(Carbon and nitrogen flow diagram of a ruminant livestock system. Numbers in farm compartments correspond with the explanation in the text).



Source: Schils et al., 2004

DIRECT EMISSIONS

(1) There is conversion of carbon and nitrogen from imported concentrates and forages and home-grown grass and forage crops to produce milk and meat. The relevant GHG emission here is methane, due to enteric fermentation. Other minor emissions like nitrous oxide coming from the rumen may also occur. Faeces and urine excretion from both in the field and or the stable lead to methane, nitrous oxide and ammonia emissions because of fermentation, nitrification, denitrification and ammonia volatilization respectively. Additionally, there is a direct emissions of carbon dioxide and nitrous emissions due to silage feeding which involves the use of fuel operated machinery.

(2) Manure and urine from farms are generally not used direct but stored first before field application. Emissions of methane, nitrous oxide and ammonia may occur during the storage period depending on the type of manure, storage system and duration. Emissions are higher in a stable storage system than pasture due the direct contact of urine and faeces in the stable and storage. Losses in ammonia, nitrous and carbon dioxide are mainly associated with manure application and these depends on application method, application time and manure type.

(3) By far, the soil pool is considered the largest carbon and nitrogen stock within a dairy farm. Within a soil pool, there is a diverse range of organic and inorganic nutrients that is cycled. The management type used for the soil and crop as a relation to soil type and climate, determine whether a net carbon sequestration or net carbon loss would be.

(4) The soil pool and the atmosphere contains nutrients which grass and forage take up, these nutrients are then withdrawn from the crop pool through either grazing or mechanized

harvests. Some levels of ammonia volatilization occur within the pathway when harvest and grazing losses are returned to the soil pool.

(5) Conservation losses occur during the storage of harvested grass and forage crops together with imported feeds. Variety of nitrogen losses among other ammonia and nitrous oxide emanates from the conservation losses.

INDIRECT EMISSIONS

Indirect emissions of nitrous oxide occur outside the system boundaries after nitrogen is emitted through volatilization, leaching or runoff. Additionally, indirect emissions of carbon dioxide, nitrous oxide and methane occurs during energy usage. Energy is lost during purchasing of goods (i.e. fertilizer, concentrate, silage and manure), services, e.g. contractors and buildings and machinery.

2.2.5. MANURE PRODUCTION AND NUTRIENT EXCRETION

Since 1990, considerable progress has been achieved in the tackling of the various challenges related to Dutch dairy farming. Progress in this regard has been made possible via several management adjustments. These management adjustments are improved techniques of storing manure and manure application, lower fertilizer inputs and higher milk production per cow (CBS, 2009a). These management adjustments resulted from detailed factorial experiments combining with formal experimental farms and partly on commercial farms. However, dairy production in the Netherlands have not achieved its environmental goals despite the several management adjustments over the last 15 years. The concentration of NO_3 of groundwater are still 70mg L^{-1} (Vellinga T.V., et al 2011), as against the set standards of 50ml L^{-1} (European Union, 1991).

The standard factors for manure production and nutrient excretion per livestock category is determined by the Working group on the Uniformisation of the calculation of Manure and minerals figures (WUM). The WUM comprises of representatives of the Ministry of Economic affairs, Agriculture and Innovation, LEI Wageningen UR, Netherlands Environmental Assessment Agency (PBL), Livestock Research (Wageningen UR-LR), National Institute for Public Health and the Environment (RIVM) and Statistics Netherlands (CBS).

The manure challenge in the Netherlands is a crucial one and if the country is unable to resolve the challenge, European Union Environmental rules would mean about half a million dairy cows would have to be killed. If these dairy cows are culled, it will mean about one-third of the total population would be taken out and that would have national economic consequences. In 2006 the Dutch government secured a 11-year exemption from the European Union rules on the amount of nitrate from fertilizers that can seep through to the soil. The exemption period is scheduled to end on 31st December, 2017 with signs indicating Brussels would not renew it due to concerns of another chemical called phosphate. The continuous spreading of fresh manure on farmlands largely is to be blamed for this phenomenon.

Dutch dairy groups have suggested among other things that, feed producing companies reformulate their feeds to contain fewer phosphate to ensure optimal growth, fertility and bone development. The Dutch Government on the other hand have plans to offer 25m euros as an incentive for the dairy sector to export or slaughter an estimated 200,000 cows. This plan when implemented would see a significant cut in milk supplied and possibly lead to high milk prices for the consumers.

Tables '5' and '6' provides information on the quantity of manure produced and the nutrients excreted in dairy farming and these leave this research with the question, could the bio-based economy provide an answer to the manure challenge as discussed above?

Table 6: MANURE PRODUCED VS MANURE PROCESSED

Subjects		Periods	1950	1970	1980	1990	2000	2002	2014	2015	2016
Manure production		*mln kg*	49 019	68 192	85 634	87 445	75 560	71 529	74 089	76 326	78 211
Manure processing	Processed nitrogen (N)		.	.	.	5.4	3.8	4.9	20.5	21.4	.
	Processed phosphate (P_2O_5)		.	.	.	2.1	. 1.7	2.7	9.7	9.7	.

Manure production is defined as the amount of manure present in animal housing and in storage outside housing after a few months of storage. These contains residuals from feed, cleaning water and spilled drinking water. It also includes the amount of manure produced while grazing outside.

Table 7: NITROGEN & PHOSPHORUS EXCRETIONS

Subjects		Periods	1950	1970	1980	1990	2000	2002	2014	2015	2016
Nitrogen excretion (N)	Nitrogen excretion	*mln kg*	.	.	565.1	691.2	549.1	504.4	486.7	497.5	504.3
Phosphate excretion (P_2O_5)			117.1	181.3	231.6	229.1	190.9	172.9	171.7	180.1	175.2

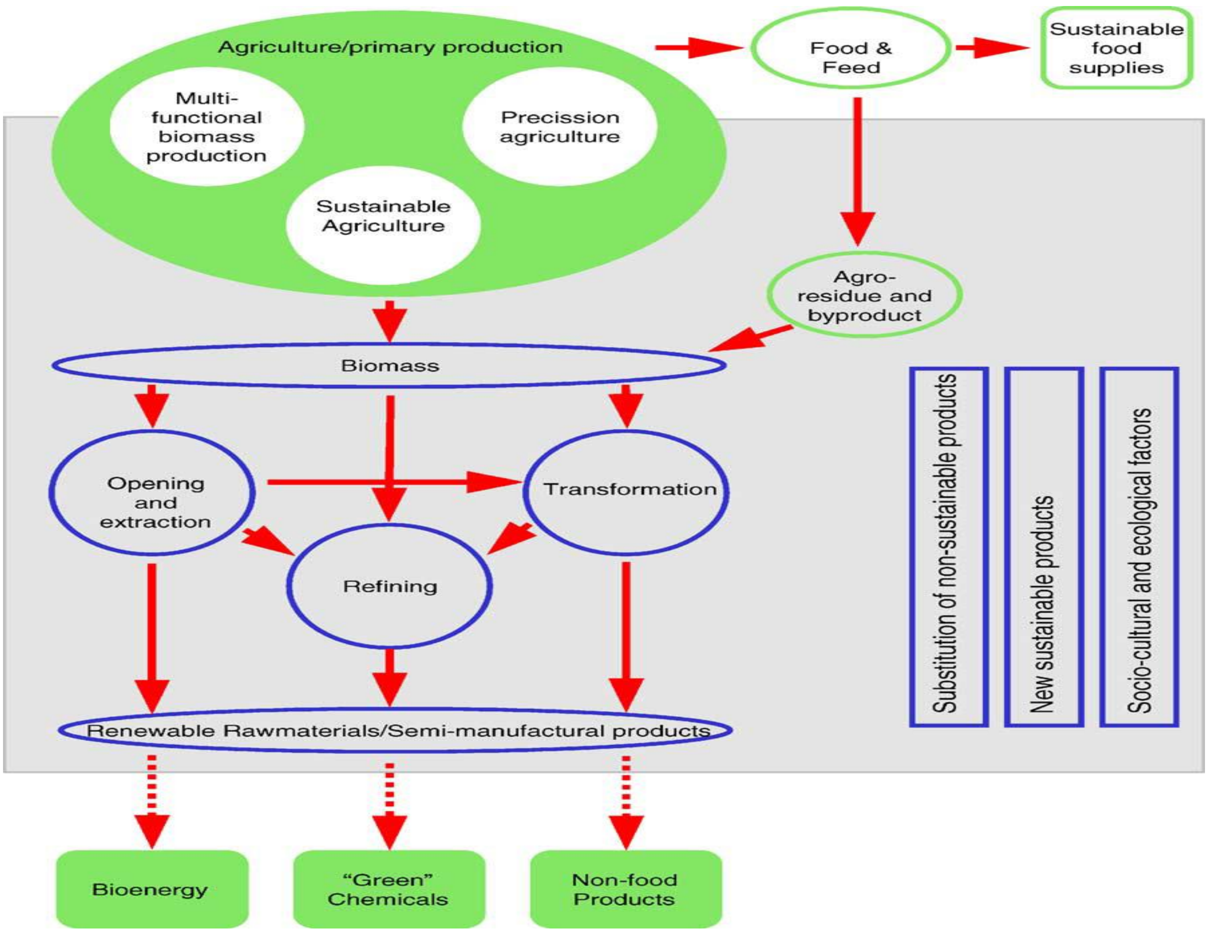
Nitrogen excretion consists of the excreted amount of nitrogen (N-total) without deduction of gaseous losses of NH_3, NO, N_2O, N_2. Calculation of mineral excretion is based on a balance per animal: intake of N and P with animal feed, minus retention in animal products (milk, meat, eggs) = excretion of N and P.

3.0. BIO-BASED ECONOMY IN THE NETHERLANDS

INTRODUCTION

The bio-based economy can be historically traced to between 1920s and 1930s in the chemurgic movement. Henry Ford envisaged and predicted that ethanol, not gasoline, would fuel the automobile. Agricultural raw material usage in industry is not new, even before the introduction of agriculture, man used plant resources to cover his needs for clothing, energy, medicines, and shelter (Spelman, 1994; Hardy, 2002). Renewable resources are alternative for fossil based products due to its environmental friendliness. For future developments, renewable resources will play a vital role as it tend to be neutral towards production of greenhouse gasses (closed $C0_2$ cycle) and potential carbon sequestration. To fully exploit the potential of these renewable resources as industrial chemical feedstock, will imply different interdependent routes ranging from the traditional 'complex route' via chemical conversion, to shifting to a glucose-based economy (C6) or transformation of biomass into C1 or C2 chemical building blocks, following the approach of the petrochemical industries. An integrated chain approach is essential for each scenario stated and must be addressed from a food security, food safety, 'green' energy production and development of sustainable non-food products for industry to waste management, recycling and disposal (van Dam et al, 2005) (see figure 5). Any emerging strategies will require a combination of efforts from science and commercial enterprise and facilitated by governmental legislation and public support.

Figure 5: COHERENCE OF FOOD AND NON-FOOD MARKETS AND THE NECESSARY DEVELOPMENT OF THE NON-FOOD PRODUCTION CHAIN



Source: J.E.G. van Dam et al. / Industrial Crops and Products 21 (2005) 129–144

For the last 10 years, the Netherlands has widely adopted the bio-based economy. The adoptions were made having some important motives behind, such as: Striving for more sustainability (reduction of CO2 emissions, circular economy), the awareness of the finite nature of fossil fuels, and the economic opportunities offered to Dutch businesses using renewable biological resources and residues. The agri-food-chemical sector in the Netherlands is on par with global industry leaders. For example, the Netherlands is the second largest exporter of agricultural and food products worldwide (http://www.nwo.nl). Over the past 10 years, the Dutch chemical sector has expanded its turnover by 30% by introducing new products in the market, increasing labour productivity by more than 30%, and reducing energy consumption per ton of product by 25% (http://www.shell.nl). The energy sector in the Netherlands is also well-developed. The Netherlands is strongly positioned to make the bio-based success due to: the several number of innovative small and medium enterprises, an international port linked to a close-knit logistics network, a sizeable hinterland, and a high-quality education and knowledge institutes. As a result, the Dutch government together with the business world have made the bio-based economy a priority.

BIOREFINERY

The practice of adding value to residues within the agricultural sector is increasingly improving. Residues has been possible sources of feed for livestock over the years. The new focus now is that, various consortia are seeking to know if the protein-rich residues can be extracted for human food. They also are analysing to find out the possibility of extracting enzymes from residues and use by the chemical industry. Below are examples of consortia activities within the Netherlands:

- Grassa consortium has developed a mobile system for grass refinery, that upgrades the protein and produces fibres for the paper and cardboard industry (www.grassnederland.nl).

- HarvestaGG (www.harvesagg.nl) consortium is active in this field, analysing to grow grass as a rotating crop. Its business case is based on a combination of protein upgrades and green gas.

- NewFoss (www.newfoss.com) already developed an aerobic treatment suitable for harvesting fibres from low-value residues such as grass and foliage.

- Solidpack (www.solidpack.eu/nl/index.html) is a cardboard manufacturer that has built a pilot plant to refine natural grass, in which the fibre is used as a raw material in the production of cardboard.

- Avebe produces a high-quality protein for human food from residues generated in processing starch potatoes(http://solanic.eu/).

- Consu in Roosendaal, has built a pilot plant for upgrading beet pulp. Resulting in a few successful business cases, for which the preparations for commercial production have now been initiated.

- The Dutch Grown Polymers consortium, consisting of Synbra, Purac, and Suikerunie, is investigating the feasibility of a production chain in the Netherlands for the conversion of sugar beets into PLA bioplastics.

The fermentation of biomasses such as animal manure, residues from food industry, silt from water treatment, KGW and energy crops like corn is an important theme in the agricultural sector.

Biogas is the main product obtained from fermentation and this consists mainly of CH4 (approx. 60%) and CO_2. To inject the biogas into the natural gas network, a (large) part of the CO_2 remains to be removed from the biogas. Technologies are commercially available for this biogas upgrade in the Netherlands. As at 2012, approximately 130 digestion plants were in operation, of which approximately 100 at agricultural companies. These are made possible by the subsides offered by government. The Dutch Biorefinery Cluster (DBC) is an organisation with the objective of jointly developing new high-quality, bio-based products and to close cycles. They comprise of the Dutch paper industry and four large processors of agricultural crops. Together, they represent 18,000 crop farmers and 18,000 dairy farmers, and process 10 million tons of sugar beets (Cosun), more than 8 million tons of milk (FrieslandCampina), 3 million tons of starch potatoes (Avebe), 1 million tons of potatoes for consumption (LambWeston/Meijer), and 3.2 million tons of biomass to produce paper and cardboard (20 companies) *(Engelen E. et al., 2013*).

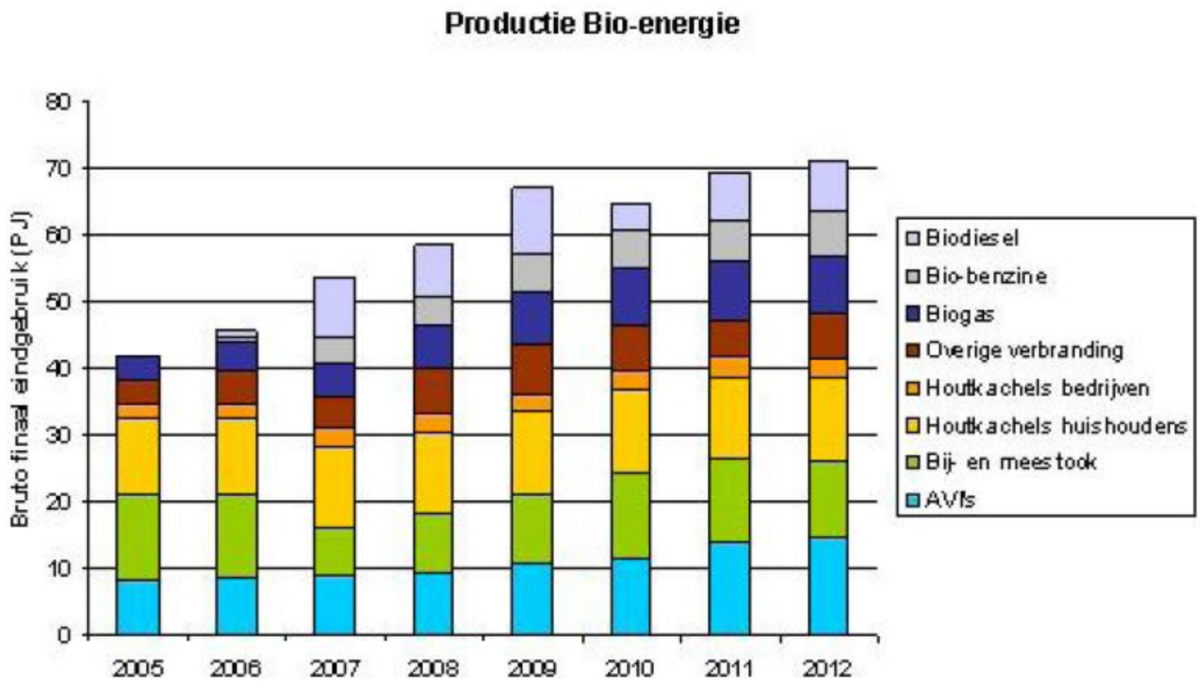
BIOENERGY AND BIOFUELS

The large-scale use of biomass in the energy sector is already ongoing in the Netherlands. The major drive for this agenda is the European objective of 14% renewable energy (EU, 2009) in 2020 and the raised objective of 16% of the Dutch government. Biomass has been anticipated to contribute significantly to this objective in 2020 (ECN, 2012). It is known that, green energy, whether with biomass or not, cannot be produced in the Netherlands in an economically viable way. As a result, the Dutch government is encouraging the generation of renewable electricity, heat, and green gas with subsidies. With the introduction of the Renewable Energy Directive (2009/28/EC), energy producers in the Netherlands anticipates their obligations, resulting in companies building their power stations to conform. New power stations are however, being built to run exclusively on biomass. Delta has plans of converting its coal-fired power plant in Borssele, to run entirely on biomass in the future (*PZC, 2013*).

Within the transport sector, fuel suppliers are required to blend fuels with biofuel to attain renewable energy usage. In 2012, the Netherlands achieved a 4.50% of mandatory share of renewable energy. This share is expected to continue to expand in the next years (*Decree on renewable energy in transport*). Several biofuel projects exist in the Netherlands either in the idea or start-up phase some of which are stated below:

- Woodspirit, a joint venture between BioMCN, Siemens Nederland, Linde, and Visser & Smit Hanab, received a commitment of 199 million euros in European Union subsidies for the construction of a biomethanol plant in Delfzijl (EU 2012) in the end of the year 2012.
- DSM signed a joint venture with POET to produce second-generation ethanol (DSM-Poet, 2012).
- KLM flight from New York to Amsterdam uses kerosene containing a portion of bio-kerosene derived from used frying oil (http://nieuws.klm.com). Figure '6' shows the development of bioenergy production in the Netherlands since 2005.

Figure 6: THE DEVELOPMENT OF BIOENERGY (PJ) FROM VARIOUS COURCES IN THE NETHERLANDS (2005-2012). (AVI= WASTE INCINERATION PLANT)



Source: (NL Agency, 2012)

BIO-BASED CHEMICALS AND MATERIALS

An important development in the chemical sector is the substitution of fossil resources with biomass. Fossil fuels sources are non- renewable and limited to certain regions of the world while biomass is renewable and available in all regions of the world. There is a set target of consuming 50% less fossil fuels in the chemical industry for the next 20 - 25 years. Actively involved in the development and production of bio-based chemicals in the Netherlands are global players such as Shell, DSM, and AkzoNobel. Examples of such involvements are:

- Production of bio-based building blocks by DSM -based building blocks (Reverdia, a joint venture with Roquette to produce succinic acid),
- bio-based polymers and resins and bioethanol (joint venture with POET).
- BioMCN produces bio-methanol, for the biofuels market.
- Latest in this is Avantium, which has a pilot plant in Geleen to produce bio-based FDCA, a chemical building block to produce terephthalic acid, often used in the production of PET. Avantium has entered into partnerships with Coca-Cola, Danone, Solvay, Rhodia, and Tejin-Aramid for these developments.
- Others includes are CRODA, Nuplex Resins, and PURAC etc.

KNOWLEDGE INFRASTRUCTURE

The Netherlands can boast of many public-private joint ventures that conduct targeted research programmes. Several partnerships have been achieved or initiated in the bio-based economy. Table '8' outlines some of these initiatives.

Table 8: LIST OF PUBLIC-PRIVATE COOPERATION PROGRAMMES IN THE NETHERLANDS.

PPP	Focus	Partners
ACCRES	Applied research centre for sustainable energy and green resources since 2007. Application-oriented research, testing site for prototypes, space for demonstration projects.	Wageningen University and Research Centre Plant and Environment Field Studies (WUR Praktijkonderzoek Plant & Omgeving), WUR Animal Sciences Group
AlgaeParc	Research centre for aquatic biomass. Comparative research among various photobioreactors.	WUR - open to the business world
BioSolar Cells (21)	Research programme for the production of energy carriers and raw materials. Research into photochemical and phototropic processes in micro-organisms.	Leiden University, WUR, 19 companies from the food, chemical, and biofuel sectors.
Green Genetics Centre of Excellence (Topinstituut Groene Genetica,TGG)	TGG promotes the cooperation between research institutions and the processing sector.	Technological centre of excellence, established in 2007.
Knowledge Centre of Vegetable Substances (Kenniscentrum Plantenstoffen, KP)	Knowledge centre focused on upgrading residues from horticulture and the production of high-quality extractives in horticultural crops. KP provides incentives for innovation projects, scans, and provides assistance in regulations (certification and admission).	Knowledge centre established by the government and the Commodity Board for Horticulture (Productschap Tuinbouw, PT) in 2011.
CatchBio	Research programme for biocatalysis. Research into catalytic processes for the production of chemicals, biofuels, and pharmaceutics.	WUR, UvA, UU, TUD, TU/e, UT, Radboud University, ECN, 11 companies (UU coordinates CatchBio)
BE-Basic	Industrial and environmental biotechnology focused on the development of biochemicals and biomaterials. Research programme and Bioprocess Pilot Facility (multipurpose facility for research into scaling up bioprocesses).	12 Dutch and 3 foreign knowledge institutes, 14 companies (TUD coordinates BE-Basic)
Dutch Polymer Institute & DPI Value Centre	Pre-competitive research into polymers and their applications. DPI promotes demand-driven research and the Value Centre promotes upgrading and network-building.	Technological centre of excellence, established in 1997.
Bio-based Performance Materials	Application-oriented research into new polymers and improving the performance of existing polymers.	WUR, TU/e, UU, RUG, approx. 40 companies (WUR coordinates BPM).
Carbohydrate Competence Centre (CCC)	CCC promotes research into synthesis, modification and/or degradation of carbohydrates for healthy nutrition and conversion into chemicals, materials, and biofuels.	19 companies and 6 knowledge institutes.
BIOCAB	Cooperative project in the Northern Netherlands, focused on the development of technology for the production of fibres (BIOFIB), chemicals (BIOSYN), and minerals (BIONPK) from agricultural residues.	WUR, RUG, and approx. 10 companies.
ISPT	Promotes research and innovation concerning sustainable process technology, such as upgrading residues that contain ligno-cellulosic material and proteins from agricultural residues.	Joint venture between the process industry and knowledge institutes.
AMIBM *currently being established*	Research institute for bio-based materials. Key focus: cellulose fibres, starch, bio-based additives, rubber, chemical building blocks, and medical applications.	Chemelot Campus, Maastricht University, RWTH Aachen, Fraunhofer
Chemelot Institute for Science and Technology *Currently being established*	Research institute focused on biomedical materials and process technology for the production of chemical building blocks.	DSM and TU Eindhoven.
Shared Research Centre Biobased Aromatics *Currently being established*	Application-oriented research into bio-based aromatics.	Green Chemistry Campus, TNO, VITO

Source: Engelen E. et al., 2013

POLICY

For more than 10 years now, the Dutch government has been closely involved in the promotion of the bio-based economy, with the initial role of mainly limited to setting the agenda and establishing relationships. For example, under the leadership of Roel Bol, the Ministry of Economic Affairs, a specific Bio-Based Economy Programme Management was set up. This program has a coordinating role in respect of “bio-based policy” at the various Dutch ministries. The Netherlands together with France and Germany has also been closely working with the European Union on an EU-wide approach to the bio-based economy. The result of this collaboration led to the publication of the EU Vision document “Strategy for a Sustainable Bio-economy in Europe”.

The Netherlands has nine (9) top sectors within which its encourages knowledge development and innovation through its policy. The nine (9) top sectors are: agriculture and food, chemical, energy, life sciences and health, horticulture and seed stock, logistics, high-tech systems and materials, creative industry and headquarters. Bio-based economy has been designated as the common theme with its own programme and a Knowledge & Innovation Top Consortium (Topconsortium voor Kennis en Innovatie, TKI).

Additionally, the Ministry of Economic Affairs has always promoted the cooperation in the “golden triangle”: the business world, knowledge institutes, and the government. The ministry achieves this by the facilitation of two platforms focused on generating new bio-based business cases: the Biorenewables Business Platform and the Agri-Paper-Chemical Platform. The government is able to supports the implementation of the bio-based economy by removing bottlenecks through the so-called ‘green deals’ (agreements between the government and the business world). The bottlenecks often are in areas of laws and regulations, the joint creation of pilots for sustainable procurement or the creation of room for experiments. One of such bottleneck removed by the Dutch government is the certification of the use of biomass as a raw material for the production of polymers within the polymer chemistry sector. Finally, the use of subsidies and tax instruments are ways the Dutch government uses to encourage the implementation of bio-energy.

In conclusion, the Netherlands is no doubt in a strong initial position for a bio-based economy, in areas such as agriculture and industry as well as the knowledge infrastructure is concerned. To be able to resolve the environmental challenges within dairy farming, the agricultural sector would have to connect to the idea of the bio-based economy. This will require changes in the dairy farming routes to make it more sustainable. This provides a reason to find if dairy farming could be combined with feedstock production for the bio-based economy in a more sustainable way.

4.0. CURRENT AND ALTERNATIVE PRACTICES IN DUTCH DAIRY PRODUCTION

This empirical part elaborates on the findings and discussions of the Dutch dairy farming practices with respect to inputs and outputs at the farm levels. It seeks to answer the research sub-question: 1. *What is the current practice of dairy farming with respect to input, conversion and outputs? and 2. Which adjustments in the current practice are needed to effectively combine and balance food production with feedstock production for the bio-based economy?* The results of the findings and analyses are presented below in chapter 4.1. to 4.2.1.3 of this thesis.

4.1. CURRENT DAIRY FARMING PRACTICES

In this part of the paper, findings are made into the current practices in the dairy farming sector based on data obtained from Dairy Campus farm in Leeuwarden, the Netherlands. The findings took into accounts the inputs, conversion and outputs involved in the dairy farming chain. The Dairy Campus farm was selected for this study primarily for two main reasons: 1. the readily availability of adequate data for use and; 2. their readiness to give access to the farm facilities for observations.

INPUTS

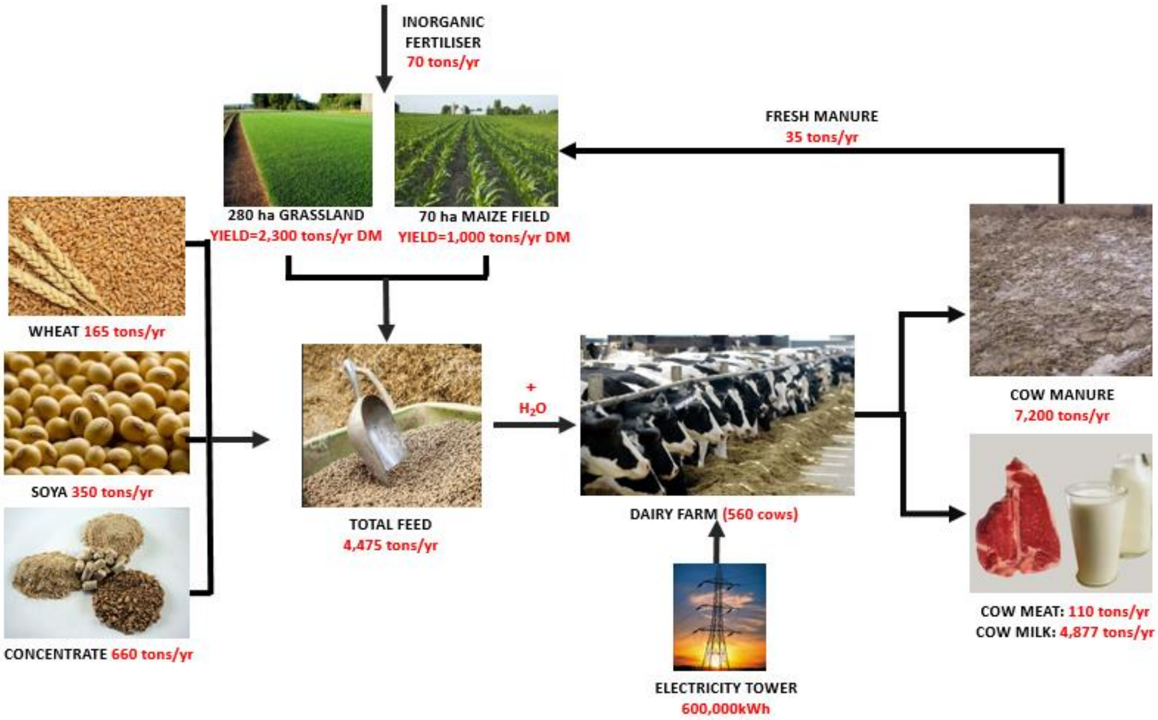
The dairy farm has a total of 560 dairy cows in the farm. The research found that, the composition of feed for these cows involves the cultivation of grass and maize on land areas of 280 ha and 70 ha respectively. At harvest, the grass and maize are harvested and stored as silage and combined with soybean meal, wheat and other concentrates mostly imported to formulate feed for the cows. The silage preparations involve the harvesting of maize (corn and straws) and grass in their fresh state and the swaths are left to wilt down for close to a day. This allows the moisture content of the harvested grass to reduce. The crops are then collected by help of a combined harvester and chopped into considerable sizes and pile up for storage. The grass and maize fields relies on inorganic fertilizers and manure as nutrient sources. Fertilizers are applied on these fields at a rate of 300kg N/ha (i.e. 200 kg N/ha of inorganic fertilizer and approx. 50 m3 manure / hectare x 2 kg inorganic N: 100 kg N from the manure). Additionally, high volumes of water are used throughout the farming processes in the farm for drinking and or cleaning of the farm. The electricity consumption of the farm is 6000,000kWh as this is known to be higher than the national average of 300,000kWh. This is so primarily because the farm is an experimental farm and is more mechanized than an average farm.

OUTPUTS

The primary focus of the dairy farm is research and milk production, and the farm produces 4,877,000kg of milk annually. In addition to the milk production, the farm also serves as a source for meat production. Dairy cows that are deemed not to be economically viable in milk production are sold out for meat. Approximately, a total of 110 tons of meat are produced for the market annually by the farm. In the process of making cows produce milk, dairy cows are made pregnant by means of artificial insemination. When the cows deliver their calves, the bull calves are sold out in the market while the females calves are raised to be used as replacements for aged and non-productive cows.

Another major output of relevance in the dairy sector is the manure production. Dairy campus produces 7,200 tons of manure annually. The farm is a high-inputs and high-outputs type and this is evident in the high quantities of milk and manure produced annually. Approximately, 35 tons of the fresh manures are used as fertilizers annually in their fresh state by spreading it over the soil surface to serve as fertilizers. Manure in it fresh state cannot be readily utilized by plants when applied as fertilizers and so this may lead to nutrients leaching down the soils. To dispose off the remaining larger proportion of the fresh manure remains a challenge as European Union laws limits the amount of manure a farm unit can dispose on surface soils. Figure 7 below gives a schematic view of the dairy farming route as explained above. It uses data obtained from Dairy Campus and shows the inputs/outputs relationship.

Figure 7: PRODUCTION FLOW SHEET OF INPUTS & OUTPUTS IN DAIRY FARMING



Manure produced 18,000m³ equivalents to 7200tons (http://www.aqua-calc.com/calculate/volume-to-weight)

Source: Figures Obtained from Dairy Campus.

SUMMARY

Nutrients in feed are either used by the dairy cow to produce milk, growth or excreted in the manure. It is estimated that, more than half of the nutrients in feed are said to be excreted in manure. That is, a 635.6kg lactating cow producing 31.78kg of milk per day excretes annually; 136.2kg of Nitrogen (N), 20.45kg of Phosphorus (P) and 74.91kg of Potassium (K) out as manure (faeces and urine) (Hart J. et al, 1997) (see also appendix '2'). Fresh grass and maize contains high levels of proteins usually in higher quantities than cows require in their diets.

The next chapter, chapter 4.2., examines the possible adjustments that could occur in the current farming practice to combine food and feedstocks production in a more sustainable way. To achieve this, current farm practices will have to be redesigned to incorporate technologies either at the inputs stage of the process or at the output stage or both.

4.2. ALTERNATIVE DAIRY FARMING ROUTES

The development of alternative dairy farming routes is important because of the feedstock potentials identified in biomass (fresh feed and manure) and its prospects to feed the bio-based economy while ameliorating the rising environmental challenges (pollution of the air and underground water) posed by the current farming practices. Dairy farming activities involves the handling of huge volumes of biomass either in their green state or processed state. These biomasses contain vital chemicals and nutrients in higher quantities than required by dairy cows. These nutrients and or chemicals can be extracted from the biomass by the help of technology and used by man, animals and industry (bio-economy). To do this, dairy farming should be adjusted in a way that feedstocks production would be incorporated into the production cycle.

To design an alternative route to the conventional dairy farming to combine food and feedstocks production, would require an adjustment in the farming processes by two approaches. The first approach, is finding the means to extract excess nutrients/chemicals that the cows would not utilize from the fresh feed (input) before feeding it to the cows. The extracted nutrients can then be used for food for man, feed for animals or chemicals for industry. By doing so, this will reduce the level of nutrients /chemicals that goes unutilized and ends up in the under-ground water pollution. The second approach would be to consider utilizing the manure into producing useful products. Manure as discussed in the concluding part of chapter 4.1., contains lots of nutrients that can be extracted and used again either in the farm or by industries.

To adjust the conventional farming route, will require incorporating scientific technologies in the farming processes. Several technologies already exist at various stages of developments for the conversion of biomass into energy products and the extraction of nutrients or minerals for industrial uses. For the purposes of this thesis, the focus would be on two main techniques i.e. bioenergy conversion techniques (namely: anaerobic digesters and fermentation by fungi) and nutrients recovery technique (grass-refinery). These techniques were chosen for the thesis because of the availability of adequate literature on their various stages of developments and the believe that they possibly hold the key to answering the thesis objective.

4.2.1. BIOENERGY CONVERSION AND NUTRIENTS RECOVERY TECHNIQUES

This section presents some detailed descriptions of the bioenergy conversion and the nutrients recovery techniques mentioned above and how these could be designed into alternative routes for dairy farming to effectively combine food and feedstocks production in a sustainable way.

4.2.1.1. ANAEROBIC DIGESTER (AD) PLANT

Anaerobic digestion is a biological process that occurs in the absence of oxygen, where organic matter is reduced mainly to methane and carbon dioxide by a microbial compound. The production of methane during the process and the possibility of recovering it as bio-gas and biodiesel to be used as fuel makes anaerobic digestion an interesting technique for consideration. The use of AD in the production of biogas is a widespread practice in the Netherlands. The AD-sector in the Netherlands has continued to see growth during this last years. This growth has been supported by several initiatives of the Dutch Government (e.g. MEP, OVMEP and SDE subsidy).

The AD technique has been proven over the years to be useful in converting biomass, most commonly manure into biogas. Synergy is most realized at AD facilities that tend to have access to sizable quantities of organic feedstock at little to no cost, require electricity and heat that can be provided by a biogas-powered combined heat and power unit (CHP) or through the direct use of biogas (such as boilers), and can utilize or market the digester effluent as compost and liquid fertilizer. This technology has proven to be instrumental in providing renewable energy to industry and the farming community while closing the loop on the nutrient cycle. The AD also helps in odour control as this is beneficial in improving the air environment of the farm.

Conventional dairy farming involves the usage of chemical fertilizers together with fresh manure. Since fresh manure takes longer time to be readily available for plants use, most of these nutrients leached. This could be avoided using the AD technique. The AD technique produces digestates which has the same nutrient values as the inorganic fertilizers (*Nkoa R., 2014)* and is readily available for plants usage unlike fresh manure. This would address the nutrient leaching problems associated with the fresh manure application. The incorporation of the AD technique to the farm process could reduce the usage of inorganic fertilizers as well as increase renewable energy production and usage for farm activities. Excess digestate could serve as nutrients (NPK etc.) extraction source for industries. A generator could be added to the AD process to convert the biogas produced to electricity (see figure 8). The electricity produced could be used to operate electrical equipment and machinery at the farm. Any excess electricity could be sold out to the grid.

An example of a similar AD technique is in Leeuwarden, Friesland. This AD is operated by a company called Biogas Leeuwarden with the capacity to produce in less than five hours enough electricity to power a household for an entire year and produces 7 million m^3 gas annually. The equivalent of this 7 million m^3 of gas produced to natural gas using the Dutch Slochteren heating value is 5,400,000 m^3 (www.biogasleeuwarden.nl).

Figure 8: ANAEROBIC DIGESTER PLANT

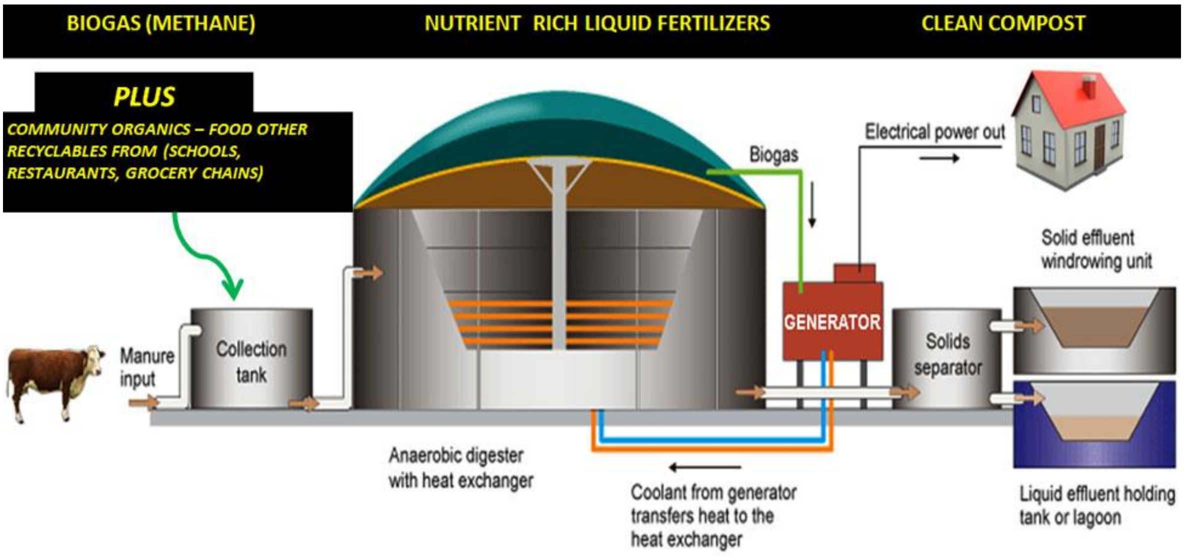


Figure '8' above shows the various processes involved in the conversion of manure (biomass) to useful products such biogas, electricity, and digestates (solid and liquid) as discussed above. Below are illustrations on how this technique could be incorporated in the farming process to combine food production and feedstocks in a more sustainable way.

ALTERNATIVE DAIRY FARMING ROUTE '1'

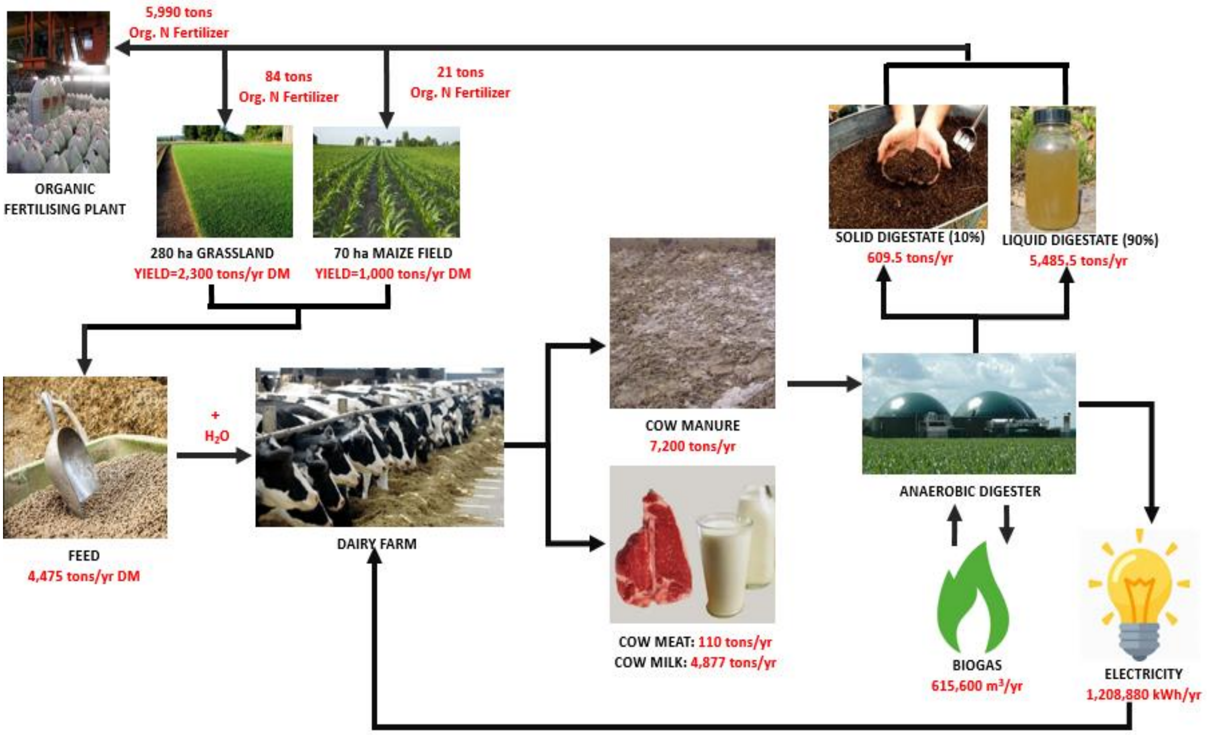
Alternative '1' seeks to focus on how the manure challenge could be turned around to be a major supplier of biogas and digestates and serve as feedstocks to the chemical industries by use of AD. The idea is to use AD technique to process manure into useful products such as biogas, electricity and digestates.

To implement the AD technique, the current farming processes must be slightly changed at the manure handling point. This means the input side of the farming process remains relatively unchanged. This requires the establishment of an AD plant close to the farm site with the capacity to handle the volume of manure produced by the farm. The AD plant now would serve as an intermediary between the point of manure collection and the usage/disposal of manure from the farm. The collected manure is conveyed to the AD plant to undergo anaerobic digestion process. This process results in the production of biogas, electricity (if generators are included), and digestates.

To be able to be more economical in this process, the AD plant selected must be able to use parts of the biogas produced to power its operations. Electricity from the AD is available for use by the farm to operate machines and offices. Any excess electricity produced in the process is sold out to the grid. The digestates could be useful in two ways: as fertilizers for use at the farm level and feedstock for the chemical industries to extract nutrients. Digestates contains high levels of nutrients *(Drosg B., et al, 2015)* useful for the chemical industry.

Figure '9' provides a schematic presentation of the processes discussed above showing the expected amount of electricity, biogas and digestates that would be produced using the farm's input discussed earlier on. Appendix '3' gives further details on the formulas and assumptions used in calculating the expected by-products and the expected revenue from the AD.

Figure 9: SHOWS ALTERNATIVE DAIRY FARMING ROUTE '1' WITH FEEDSTOCK PRODUCTION USING ANAEROBIC DIGESTER



**A typical separation performance of a screw press separators on digestates, produces: 10% solid components and 90% liquid components. Liquid components averagely contain 4.9 g/kg of Nitrogen, 3.0 g/kg of NH_4-N, 2.3 g/kg of P_2O_5 and 6.2 g/kg of K_2O. The solid fraction contains 5.8 g/kg of Nitrogen, 2.7 g/kg of NH_4-N, 5.0 g/kg of P_2O_5 and 5.8 g/kg of K_2O (Drosg B., et al, 2015). Anaerobic digestates are at least as effective as mineral fertilizers (Nkoa R., 2014), the nutrients are readily available for plants usage. The quantities of inorganic + manure fertilizers used on the grassland and maize farm is the same quantity that will be required for the digestates.*

The total expected electricity production using alternative '1' would be 1,208,880 kWh/yr. This is far more than the current electricity requirements of 600,000 kWh/yr on the farm and this offers the opportunity for the farm to sell part of the electricity produced to the grid. Another important feedstock produced in the process is the digestates. A total of 6,095 tons/yr production of digestates is huge and part could serve as substitute for the inorganic fertilizers currently being used on the farms. The remainder of the digestate which is the most part, can be sold to the chemical industry as raw materials for extracting vital plants chemicals like NPK.

Several techniques exist that are suitable for digestate processing, but not all of them is considered as a nutrient recovery technique. Table '9' outlines nutrient recovery techniques already being used at various levels of development stages in anaerobic digestion plants to recover nutrients.

Table 9: OVERVIEW OF DIFFERENT NUTRIENT RECOVERY TECHNIQUES AND THEIR END-PRODUCTS

NUTRIENT RECOVERY TECHNIQUE	STARTING FROM	END-PRODUCT(S)	CHARACTERISTICS OF END-PRODUCTS	STATE OF DEVELOPMENT FOR DIGESTATE
Acid air washer	Strip gas	$(NH_4)_2SO_4$ solution	$(NH_4)_2SO_4$ solution : N-content 30-70 kg/m³, pH 3-7[1,2]	Full scale
P-extraction	Ashes/biochar	Acid P-extract/$CaHPO_4$	Acid P-extract: Ptot: 0.192 g/kg[3]	Full scale for ashes from incinerated sludge from wastewater treatment Lab scale for digestate treatment
Reversed osmosis	UF/MF/DAF-permeate	RO-concentrate (NK-fertilizer)	Ntot: 7.3 g/kg[4] Ktot: 2.9 g/kg[4] Ptot: 0.42 g/kg[4]	Full scale
Forward osmosis	Further research needed	FO-concentrate (NK-fertilizer)	Further research needed	Full scale for desalination, food processing,... Starting interest for digestate treatment
Electrodialysis	LF	NK-fertilizer	Further research needed	Lab scale
TMCS	Tested on urine	NK-fertilizer	Further research needed	Pilot scale
P-crystallisation	Acidified RD/LF	$MgNH_4PO_4$/$MgKPO_4$/$CaNH_4PO_4$	-	Full scale for veal manure & wastewater treatment Lab scale for digestate treatment
NH_3-stripping & acid air washing	(Decarbonated) LF	$(NH_4)_2SO_4$ solution	N-content: 350 kg/m³ pH: 3-4[5]	Full scale
Biomass production	Diluted LF	Biomass	Further research needed	Pilot scale

Source: Vaneeckhaute C., et al., 2012

The nutrient recovery techniques outlined in table '9' are techniques currently at various levels of developments ranging from pilot level to full-scale implementation level. The acid air washers, membrane filtration plants and ammonia stripping plants are currently working full scale at anaerobic digestion plants in Flanders, Belgium. Appendix '4' provides detailed information on how the above-mentioned nutrients techniques works.

CONVENTIONAL DAIRY FARMING vs ALTERNATIVE '1'

Conventional farming route involves the spreading of fresh manure on surface of soils. This has several environmental consequences and environmental restrictions. These restrictions often lead to manure disposal challenges. Alternative '1' on the other hand, makes use of manure as a valuable feedstock for producing valuable bioenergy products and industry raw materials. This helps the process to be void of manure handling associated challenges since manure is processed into environmentally friendly products. A comparison between the conventional farming and the alternative '1' have been summarized below;

CONVENTIONAL	ALTERNATIVE ‘1’
❖ Releases unpleasant odour from manure into the environment.	❖ Significantly reduce odour from manure.
❖ Manure disposal is a big challenge	❖ Manure is a beneficial feedstock with bioenergy and nutrients recovery opportunities.
❖ Leads to pollution of underground water	❖ Reduces underground water pollution
❖ Increases greenhouse gases emissions	❖ Reduces greenhouse gases emissions: has less heat trapping potential than original methane.
❖ Relatively cheaper but could be expensive to dispose excess manure.	❖ More expensive and sometimes not economically viable if biomass size is too small.

SUMMARY

In summary, alternative ‘1’ could be a very useful addition to dairy farming for combining food and feedstock production in a sustainable manner. Several known technologies for this already exist in Europe and the Netherlands for readily implementation. This could positively impact on the bio-economy and the environment. Biogas production is still dependent on subsidies to attract investors to establish a substantial scale and with the SDE+, it establishment could be attractive in the Netherlands. Feedstock costs have a large impact on the economic viability of a biogas plant. Depending on the type of feedstock, they could account for up to 50% of production costs *(Foreest F. v., 2012).* The continues decline in the availability of chemicals used for preparing inorganic fertilizers and its high-cost, makes digestates a more sustainable raw material substitute for the chemical industry.

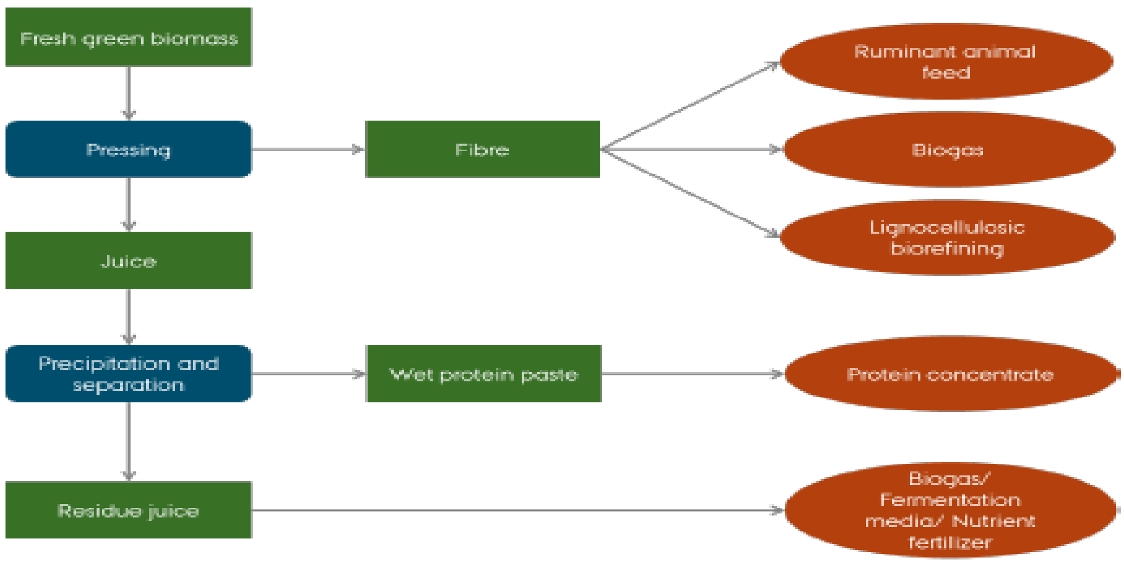
4.2.1.2. GRASS REFINING

This process involves the fractionating of fresh grass into juice and a fibre fractions. High quality protein concentrates for the monogastric livestock sector such as pigs, chickens etc can be extracted from the juice extracts, while the fibre fraction can be used for ruminant feed, biogas, or further refined into chemical building blocks or used for biomaterials. Since the residual fibre can be considered as a lignocellulosic biomass, the application is like any other such biomass that can be converted to produce bioethanol, other fuels, bio-chemicals and so on (Amore et al. 2016).

This technology has the potential of addressing the high nutrient volumes excreted out by cows in the manure. Incorporating this technology would mean, fresh biomass (grass, maize, etc) are first refined to extract the proteins. Green biomasses are known to contain high level quality soluble proteins (*Ambye-Jensen M., 2015)*. Ruminants do not need all the high quality soluble proteins and so most of these end up in the manure produced. To prevent this from occurring, the farming route must be adjusted from the inputs side. The aim here is to ensure the high soluble proteins in the green biomass are extracted and the remainder in the dry matter fibre used to feed cows. After refinery, two main products come out: fibre fraction and the protein juice. The fibre content which contains adequate levels of proteins would be used to feed cows (*Ambye-Jensen M., 2015)*. The extracted proteins juice can then be processed and used for feeding monogastric animals like pigs or even human beings (more research still required for human).

Recently, the Dutch company named Grassa! has developed and introduced grass refinery installations which are more efficient and mobile (Ingenieur, 2016). A photo of the newest installation is presented in appendix ‘5’. The big advantage of these mobile installations is that the biorefinery can take place wherever it is needed. This means movement of the installation is not restricted and small amounts of grass can be refined in an economically attractive way. While a vast amount of knowledge may exist, or is in progress on these issues, the full operational cost involved in this technology are not known since no large-scale bio-refinery plants for green biomass have been established (Hermasen J.E., et al 2017). Figure '10' shows the schematic overview of possible products from the biorefinery of green biomass as discussed above. The process involves the mechanical pressing of green biomass to produce fibre and liquid fractions. The fibre fraction is then ready and can be used to feed cows. The liquid fraction further goes through precipitation and separation process to produce wet protein paste and residue juice. The wet protein is then used as protein concentrates while the residue juice could serve as feedstock for biogas production or fertilizer on farms.

Figure 10: SCHEMATIC OVERVIEW OF POSSIBLE PRODUCTS FROM BIOREFINING OF FRESH GREEN BIOMASS



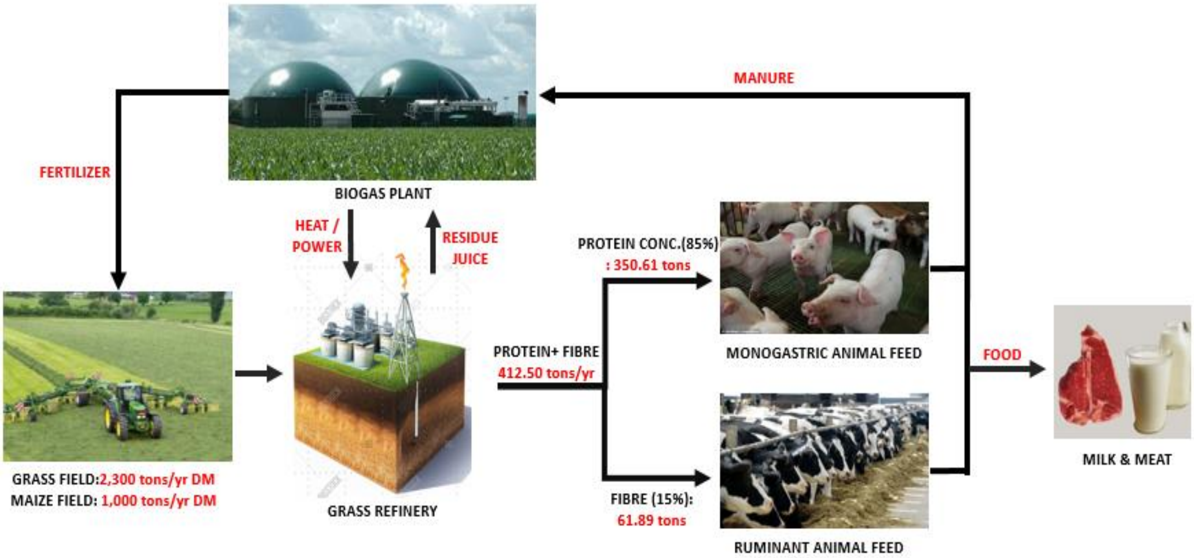
Source: Hermansen J.E., et al, 2017

ALTERNATIVE DAIRY FARMING ROUTE '2'

Alternative '2' significantly focus on an alternative route that can extract the high soluble proteins in green biomass. The aim is to extract these proteins from the biomass to a level where the protein left in the fibres are adequate for feeding cows. The extractable soluble proteins can then be processed into concentrates by the chemical industry.

To implement this, a change in the current feeding mode is required. This would require the establishment of a grass refinery situated between the feed and the animals. Meaning the grass and maize feed components would first be refined to extract the soluble proteins juice as shown in figure '10' and the remainder fibres with protein content of approximately 17% (Hermansen J.E., 2017) used to feed the cows. These extracted proteins juice serves as a major feedstock supply for the chemical industry to process and use as protein concentrates for monogastric animals, or man. Globally, demands for proteins continue to be high as animals continue to compete with man for protein diets. This makes alternative '2' an interesting option for solving the protein deficit. Figure '11' provides a schematic presentation of the processes discussed above showing the introduction of a grass refinery into the farming route and the expected protein production.

Figure 11: SHOWS ALTERNATIVE DAIRY FARMING PROCESS ROUTE '2' WITH FEEDSTOCK PRODUCTION USING GRASS REFINERY



In general, it is assumed that there is a direct correlation between the nitrogen content and the crude protein content of biomass. The crude protein content is, therefore, often calculated from an analysis of the total N-content (generally by the Kjeldahl method) (FAO, 2003). To estimate the total potential protein production from fresh grass, the following assumptions were made:

- Protein content is calculated by multiplying the total N-content by 6.25, assuming 16 % N in the protein.
- N-content in grasslands is between 1.8-2.2% in DM; in this calculation, 2.0% is used.
- Fibre content is 15% and Liquid Protein Concentrate 85% of total solution.
- Potential Protein Production (P)= Green biomass (ton DM) x 2.0% N x 6.25

Using the inputs from Dairy Campus farm of 2,300 tons/yr and 1000 tons/yr dry matter content of grass and maize respectively will yield a total of 412.50 tons of grass protein after refinery. These quantities of protein produced could substitute for imported soybean meal for feeding pigs or other animals.

CONVENTIONAL DAIRY FARMING vs ALTERNATIVE '2'

Conventional dairy farming heavily depends on imported soybean meals to reach the protein demands in animal feed. The soybean industry in these countries mainly in South America is growing and causing social and environmental problems, an example being deforestation and violence. Alternative '2' proposes the use of green biomass such as grass and maize to produce proteins which can supplement or replace the soybean importation to the Netherlands. While the conventional dairy farming practices results in loss of huge volumes of vital nutrients, alternative '2' will help in the reduction of nutrients and additionally, offer the opportunity to make proteins for used by other animals in the chain.

A comparison between the conventional farming and the alternative '2' have been summarized below;

CONVENTIONAL	ALTERNATIVE '2'
❖ Depends highly on imported soybean meal. ❖ Results in nutrients excretion in manure. ❖ Involves competition between man and animal for protein source. ❖ The process is known not to be environmentally friendly.	❖ Depends on locally produced proteins. ❖ Ensures efficient utilization of nutrients. ❖ Avoids man-animal food competition in respect to protein source. ❖ The process is known to be environmentally friendly.

SUMMARY

The replacement of protein rich soy products with grass protein can be a sustainable solution. This can be largely achieved if the price for grass protein is economically cheaper than soybean protein. According to *Ros N.J., 2017*, the tipping point at the price of soybean meal that the grass protein product becomes more economically attractive is allocated around €330,00 per tonne soybean meal. The price trend for soybean meal between March and August 2017 has been between €250.53 and €298.09 (Nasdaq website). This shows that although grass proteins have the potential of being economically viable much more is required. Strategic level decisions related to facilities and streams of materials must be optimised and logistical structures must be evaluated to improve the performance of the whole circular grass refinery supply chain.

4.2.1.3. LIGNIN DEGRADING FUNGI

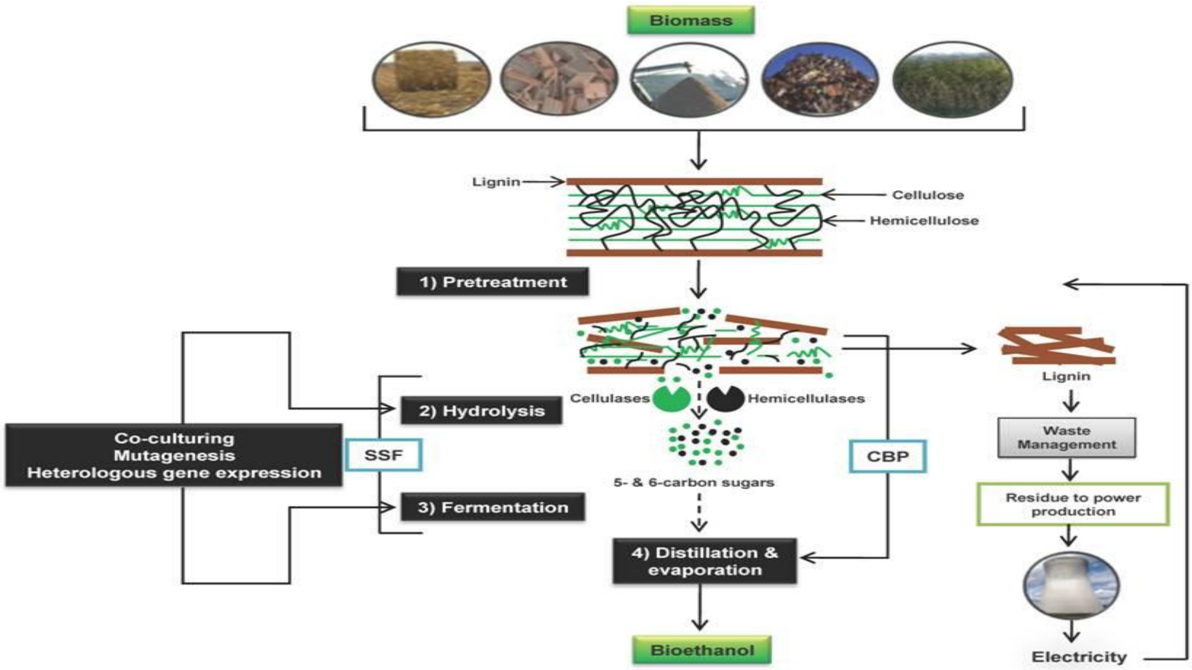
Organic waste streams such as manure, cereal straws from maize, wheat and grass contains high-levels of cellulose. These cellulose (and hemicellulose), can be converted into glucose and sugars and used for different purposes like energy production (ethanol), chemicals (lactic acid) or animal feed, especially for ruminants. However, the presence of lignin in these waste streams hampers the utilization process. Lignin is a recalcitrant aromatic polymer which provides plants rigidity and protection against pathogens and these lignin forms complexes with cellulose and hemicellulose hampering the utilization of carbohydrates in the process.

The white rot fungi are predominantly known to degrade lignocellulose and some species are selective lignin degraders. The use of fungi offers a safer and energy friendly alternative to the present chemical and physical treatment (steam explosion) since the latter results in high energy cost and production of new (toxic) waste streams. The lignin degrading fungi is an emerging biotechnology with prospects of solving manure waste and could be a vital intervention in Dutch dairy farming. Appendix '6' provides detailed information on some known methods used to improve fungal lignocellulolytic activity or stability.

This technique provides a more environmentally friendly way of converting manure into more useful products. This technology would imply, manure conversion to bio-based products would be done through a fermentation process by use of selective fungi after the manure has undergone pre-treatments and hydrolysis. The feedstock production would be focused on the manure produced from the farm. It would require the installation of a lignin degrading fungi unit at the farm. Manure plus all biomass waste in the farm containing lignin would be sent to the unit for processing. Bioethanol produced could be used in operating farm machines. The remaining un-degraded lignin can also serve as feedstock for biogas production and or electricity.

Figure '12' shows the systematic overview of the conversion of manure into bio-based products using the lignin degrading fungi processes as discussed above. Hydrolysis and fermentation can be performed separately (SHF, indicated by broken arrows) or as simultaneous saccharification and fermentation (SSF). In consolidated bioprocessing (CBP) however, all bioconversion steps are minimized to one step in a single reactor using one or more microorganisms. Different techniques such as mutagenesis, co-culturing and heterologous gene expression have been used to improve sugars utilization of the microbial biocatalyst as well as activity and/or stability of hydrolytic fungal-derived enzymes in order to improve the overall yields. For reduction of production cost, ethanol production can be integrated with a combined heat and power plant using lignin.

Figure 12: SCHEMATIC PICTURE FOR THE CONVERSION OF LIGNOCELLULOSIC BIOMASS TO ETHANOL, INCLUDING THE MAJOR STEPS



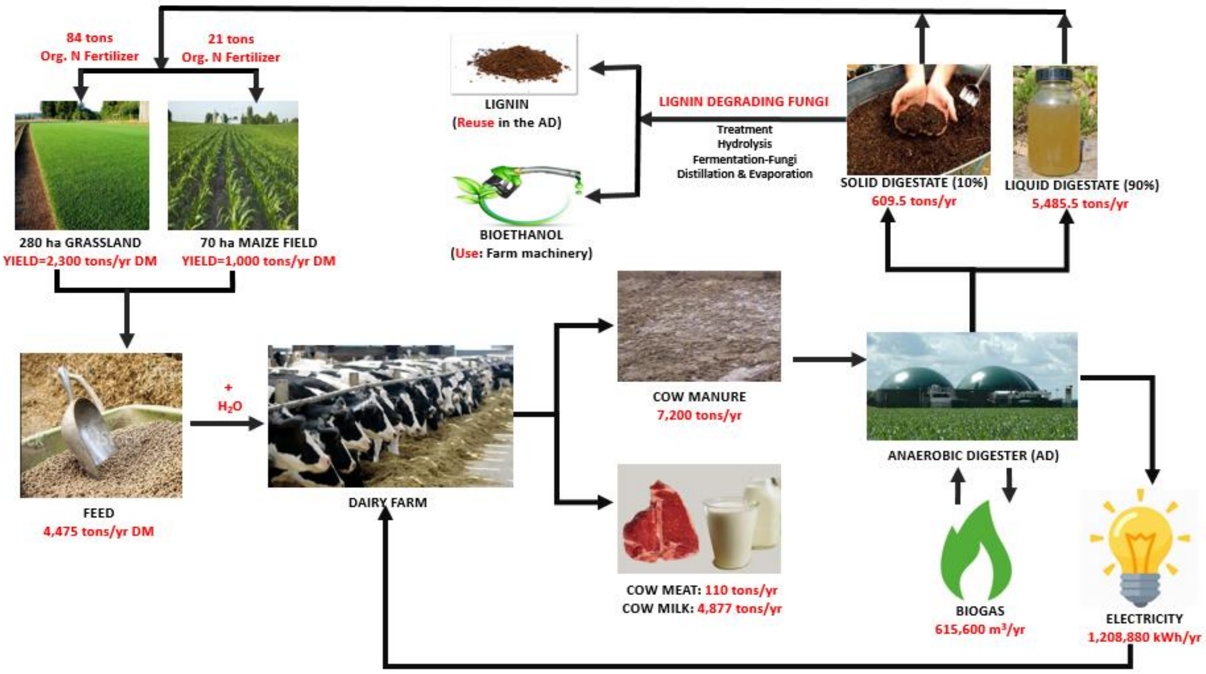
Source: Dashtban M. et al, 2009.

Alternative Dairy Farming Route '3'

The primary focus of alternative '3' is to utilize digestates from cow manure at the farm level to produced bioethanol in a more safer and energy efficient manner. Manure as already discussed above contains nutrients as well as fibre. These fibres content (celluloses and hemicellulose) continue to remain after an AD process as digestates. Through pre-treatments, hydrolysis, fermentation, distillation and evaporation of digestates, lignin content in the digestates are significantly reduced and bioethanol produced. This alternative route could reintroduce the left-over lignin back to the AD process or apply to the soil.

Figure '13' presents a diagram showing the alternative '3' farming route as discussed above showing how digestates could play a vital role in bioethanol production. The diagram also shows how digestates produced can also be used as substitute for inorganic fertilizers usage on the farm.

Figure 13: SHOWS ALTERNATIVE DAIRY FARMING PROCESS ROUTE '3' WITH FEEDSTOCK PRODUCTION USING ANAEROBIC DIGESTION PLUS LIGNIN DEGRADING FUNGI



CONVENTIONAL DAIRY FARMING vs ALTERNATIVE '3'

CONVENTIONAL	ALTERNATIVE '3'
❖ Not environmentally friendly.	❖ More environmentally friendly and less energy required than using steam explosion method.
❖ Releases greenhouse gas	❖ Reduces greenhouse gas effect
❖ An existing practice	❖ Full scale implementation cost unknown
❖ High residues handling	❖ Reduces volume of residues

SUMMARY

The fibre content of manure which includes cellulose and hemicellulose has about 52.6% (dry biomass basis) (*Dastban M., et al., 2009*). Sugars from the fibres can be hydrolysed and fermented to produce ethanol. However, the utilization of animal manure are known to be more complicated due to the high protein content (Champagne P., 2007 & Wen Z., et al., 2004), hence would require a nutrient recovery process between the point of receiving digestates from the AD and the lignin degrading process. Scaling up the production of lignocellulosic ethanol, would however requires production cost to further reduce. To be able to improve the technology and reduce the production cost, two key issues have to be addressed: i) improving technologies to overcome the recalcitrance of cellulosic biomass conversion (pre-treatment, hydrolysis and fermentation) and ii) sustainable production of biomass in very large amounts (*Dastban M., et al., 2009*). In the case of large scale biomass production, in addition to forest and crop residues, energy crops such as switchgrass and *Miscanthus* can be grown to meet the needs.

5.0. CONCLUSIONS

This concluding chapter of the thesis is aimed at making the findings of this study conclusive. It seeks to answer the general research question: *"is it possible to combine food production with feedstock production for the bio-based economy in Dutch dairy farming and if yes, what adjustments are needed in the current farm routines and processes?* The research objective is to find and design a new production route that would see dairy production as an important producer of milk for food and feedstocks for the bio-based economy in a more sustainable way. Firstly, conclusions are drawn upon the sub and main questions. Finally, recommendations for further studies are provided.

5.1. CONCLUSIONS ON SUB-RESEARCH QUESTIONS

This part presents the answers to the two sub-research questions. For detailed answers, the reader will be referred to the accompanying chapters. The sub-questions are answered below:

SQ 1: What is the current practice of dairy farming with respect to inputs, conversion and outputs?

Dutch dairy farming is associated with feeding cows with maize, grass, soybean meal, wheat and concentrates. Imported soybean meal is the primary protein source in the diet of the cows. Cultivated grass and maize are harvested and stored as silage and used as feeds. The conventional dairy farm produces milk, meat and manure with milk being the primary product. The current practice is associated with high usage of both inorganic fertilizers and fresh manure as nutrients sources for the grass and maize fields. Because fresh manure is not readily available for plants use, this often results in nutrients leaching. This leads to the acidification of underground water. The Dutch dairy farming is also faced with manure handling challenges. Due to the intensive nature of farming, manure production is high. The existing EU environmental policies restrict the quantity of manure that can be spread over a land surface. An overview of the current dairy farm practice showing the inputs and outputs is found in figure '7'of this thesis (section 4.1).

SQ 2: *Which adjustments in the current practice are needed to effectively combine and balance food production with feedstock production for the bio-based economy?*

Based on broad literature review, three alternative farming routes are suggested as the adjustments that can be made into the current farming practice for an effective combination of food and feedstock production. These alternatives in the view of the researcher could effectively make dairy production a source for food and feedstock production. The three alternative routes are summarized below;

ANAEROBIC DIGESTER (AD) PLANT

The alternative '1' route is to incorporate an anaerobic digester plant in the farm to convert the manure into environmentally friendly products such as digestates, biogas and electricity. This can further be made more efficient by introducing nutrient recovery techniques outlined in table '9' of this thesis, to recover all the essential nutrients in the digestates. Acid air washers, membrane filtration plants and ammonia stripping plants are all proven techniques being used to recover nutrient from digestates at full scale at anaerobic digestion plants in Flanders, Belgium.

GRASS REFINING

Protein is a large and expensive component of livestock feed and over reliance on imported soybean meal leaves businesses vulnerable to price volatility and supply. Greater use of homegrown protein is therefore desirable. Alternative '2' suggests the refinery of fresh grass and maize (whole plant) to extract soluble proteins otherwise not utilized by cows as seen in the conventional farming practice. The extracted proteins would then be a major feedstock source serving as substitute for imported soybean meal. However, for grass protein to be economically competitive now, soybean prices must be at €330,00 per tonne minimum. Large acres of grassland in the Netherlands together with advancement in grass refinery technologies could give grass refinery technique some positive prospects.

LIGNIN DEGRADING FUNGI

The main feedstock production of alternative ‘3’ is the production of bioethanol from manure digestates. This alternative would require an anaerobic digester plant incorporated between the manure produced and the bioethanol production unit. It offers the opportunity to produce biogas and electricity from the anaerobic digestion process and bioethanol from the lignin degradation process. Figure ‘13’ shows farming alternative ‘3’ route and the feedstock production potential.

5.2. CONCLUSION

Yes, it is possible to combine food production with feedstock production for the bio-based economy in Dutch dairy farming. It will, however, require some adjustments in the current farm routines and processes. These adjustments should be focused on incorporating nutrients recovery and bioenergy conversion techniques into the current farming practices to produce feedstocks. This has the potential of being a major feedstock supply source for the bio-based economy and a possible means to reduce the environmental challenges associated with cow manure handling in the Netherlands.

5.3 RECOMMENDATIONS FOR FURTHER RESEARCH

The following recommendations are offered for further studies

- Although grass protein has the prospects of becoming a major source of protein for animal feed, its survival may also largely depend on its uses for human food. It would be necessary to have more research focused on how grass protein can be formulated for human food, as this would increase its economic value for businesses.
- The Dutch dairy farming is in various farm sizes ranging from farms with 1-30 cows to 150 cows and more. Unfortunately, not adequate literature exist on the inputs/outputs flows of the various categories of farms. Further studies would be required to know the viability of these suggested alternative farming routes on other farm sizes.

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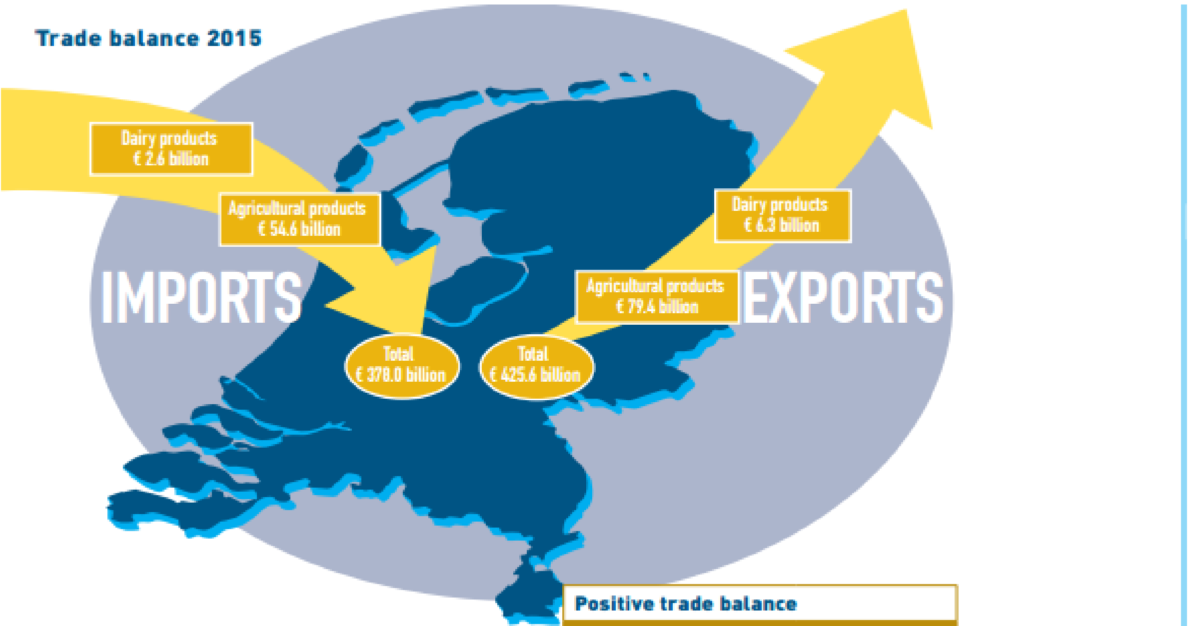
APPENDIX 1.0. TRADE BALANCE 2015



Positive trade balance	
Total	**€ 47.5 billion**
Agricultural products	€ 24.9 billion
Dairy products	€ 3.7 billion

source: Statistics Netherlands (CBS)

According to the Statistical Service Netherlands 2015 trade balance figure, the Netherlands is a net exporter of dairy products

APPENDIX 2: ESTIMATED DAILY NITROGEN (N) AND PHOSPHORUS (P) EXCRETION FROM LACTATING COW

Milk Production	100 lb/day	70 lb/day	50 lb/day	Dry
Intake/Day	56 lb	46 lb	39 lb	25 lb
Total N, lb/day waste	0.9 lb/day	0.8 lb/day	0.65 lb/day	0.4 lb/day
Total P, lb/day (diet 0.45% P)	0.151 lb/day	0.138 lb/day	0.126 lb/day	0.113 lb/day

Source: Downing T., 2001

APPENDIX 3: CALCULATIONS ON EXPECTED PRODUCTS AND REVENUE FROM AD

Based on available data obtained from the Dairy Campus on input/output flow, below are how the other figures where extrapolated and used:

BIOGAS PLANT SPECIFICATIONS ❖ Feedstocks: 7200 tons/year of Cow manure ❖ Digester Type: Wet ❖ Contaminants Levels: 5% ❖ Biogas Usage: CHP (Combined heat and power) ❖ Digestates Usage: Directly to land ❖ Solid Content Before Digestion: 25%TS (solid content should be adjusted for the digester type
RESULTS ❖ Biogas Production: 615,600 m^3/yr or 70m^3/hour ❖ Electricity Production: 1,208,880 kWh with a CHP OF 138 kWe. And Thermal Energy Production: 5,236 GJ per year. ❖ Total Digestate: 6,095 tons/year ❖ Contaminants to Landfill: 360 tons/year ❖ Greenhouse Gas (GHG) reduction will be around 1,135 tons CO_2 eq./yr for landfill diversion and 262 tons CO_2 eq./yr for renewable energy production.
POTENTIAL REVENUE PER YEAR 83,137.76 euros from electricity sales and 113,475.18 euros from heat sales.
PLANT COST ESTIMATION Estimated initial investment cost, +/-30%, is 1,186331.42 euro for this farm type.

Note: ***The calculation above, estimated energy costs for biogas plant to be at: Diesel= 1.25 Euro/L; Electricity=0.06652 euro /kWh; Gas= 21.6500 euro/GJ. Calculations were made by help of a 'biogas calculator' from the Biogas World (https://www.biogasworld.com/biogas-calculations/).***

APPENDIX 4: NUTRIENT RECOVERY TECHNIQUES FOR LIQUID DIGESTATES

Source: Vaneeckhaute C., Meers E., Christiaens P., Tack F.M.G., 2013, *"Nutrient Recovery from Digestate: Techniques and End-Products".* Conference Paper, November 2012. Pp 12-19.

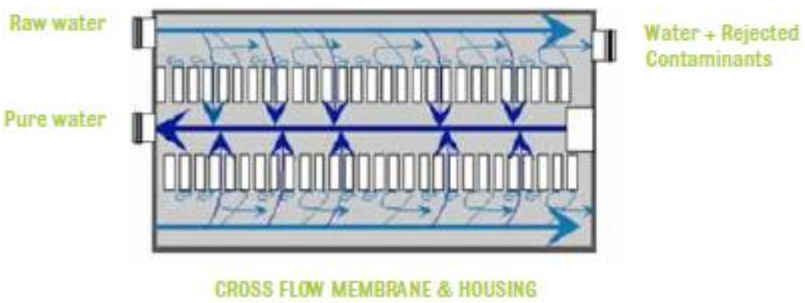
LIQUID DIGESTATES

a. Pressurised Membrane Filtration

i. Technique & end-product

The liquid fraction of the digestate or a pre-processed stream, such as the condensate of the evaporator is the input stream for membrane filtration. Pressure is used to force the input stream through the membrane. Several types of membranes used in manure/digestate processing exist, and categorised according to pore size: MF- (pores > 0,1 µm, 0,1-3 bar), UF- (pores > nm, 2-10 bar) and RO-membranes (no pores, 10-100 bar). Suspended solids are retained in a MF concentrate, while in a UF-concentrate also macromolecules are retained. Both filtration steps can be used as a pre-treatment for reversed osmosis, to prevent that either suspended solids or macromolecules block the RO membrane. Dissolved air flotation (DAF), is another technique that can be used prior to RO. DAF is a technique that consists of blowing small air bubbles through the liquid fraction, entraining suspended solids to the surface where they form a crust. This crust is then scraped off. Coagulants and flocculants are often added when using DAF. The permeate of RO, which consists mainly of water and small ions, can be discharged, if necessary after a 'polishing' step, or used as process water.

Clogging and fouling of the membrane remains the biggest reported problem in membrane filtration and this increases the hydraulic resistance. During MF and UF, this is mainly caused by suspended solids that form a cake on the surface of the membrane. Higher tangential velocities on the cross-flow stream can prevent the membranes from blocking but imply higher operational costs. Waeger F. et al. (2010) stress that blocking of the pores is strongly correlated to particle size distribution.
A decrease in the efficiency of RO-membranes can because of several reasons: 1) low-soluble salts can precipitate on the membrane surface (scaling), 2) suspended solids can adsorb to the membrane surface (fouling) or 3) bacteria can colonise the membrane (biofouling). The regulating of pH and use of anti-scalants help prevent scaling. Membrane cleaning is however required once too many pores are blocked. The membrane should be cleaned using chemicals such as NaOH and H_2SO_4. Some examples of these technique in the available in the commercial stage in the Netherlands are: VP Systems (NL), AquaPurga International (NL).



Source: www.filterwater.com

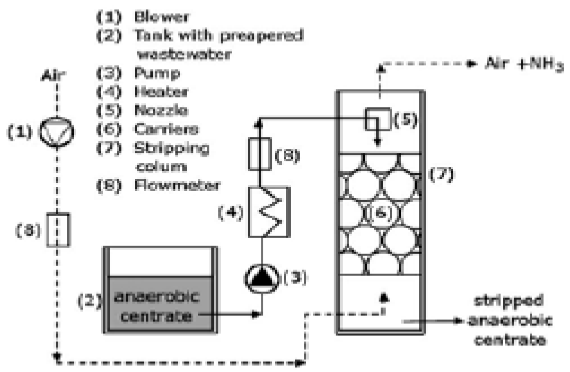
b. Ammonia stripping and scrubbing

i. Technique and end-product

To stripped ammonia, the blowing of air or steam through the liquid fraction in a packed tower is required. The pH of the liquid fraction should be around 10 and the temperature around 70°C to achieve optimal ammonia removal (Lemmens B. et al., 2006). Liao et al. (1995), however, observed that at a pH of 9,5 and 10,5 ammonia removal efficiency was directly dependent upon the air and liquid influent temperatures, whereas at a pH of 11,5 and a temperature of 22°C there was no appreciable improvement with a rise in air and influent temperatures. This led them to the conclusion that a pH of 10,5 is most optimal, as very high levels of nitrogen removal were obtained without incurring problems of excess lime. Gustin and Marinsek- Logar (2011), also confirmed that a high pH has the most significant effect on stripping, whilst temperature had the least significant effect. Bonmatí and Flotats (2003), however, also stated that complete ammonia removal without pH modification is possible at a temperature of 80°C.

A significant risk of scaling and fouling of the packing material exist during aeration of the digestate. The installation of a lime softening step before stripping, which removes a large part of the Ca, Mg, carbonic acids and carbonates and increases the pH, can be used to avoid scaling. To avoid fouling, it is important that during separation as many suspended solids as possible are retained in the solid fraction. Nonetheless, it is unavoidable that the packing material will have to be cleaned periodically. The stripgas, which is charged with ammonia and volatile organic matter, is then put in contact with a strong acid solution (H_2SO_4), which produces ammonium sulphate.

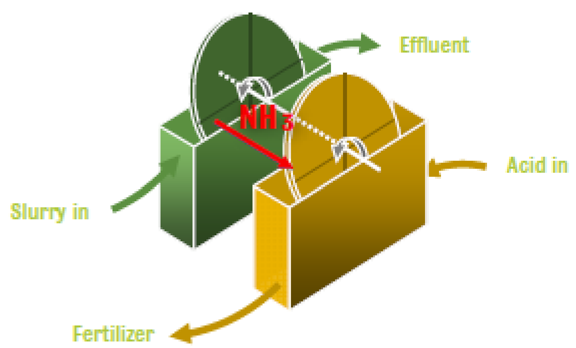
Ammonia stripping tower



Source: Gustin S. and Marinsek-Logar, 2011.

Another type of ammonia stripping system for manure and digestate without air recirculation or ventilation has been developed by the Dutch company Dorset. The system consists of rotating disks that are partly submerged in either the liquid manure or the receiving sulphuric acid solution. The rotating disks are close to each other so the ammonia coming from the gas phase is absorbed at the other disc with the sulphuric acid (Dorset GM).

Dorset LGL Ammonia Stripper



Source: www.dorset.nl

c. Precipitation of phosphorus

i. Technique and end-product

To induce a precipitation reaction forming phosphate salts, the addition of several ions to a solution containing soluble phosphate (orthophosphate) can be done. Addition of calcium to a phosphate solution will form calcium phosphate. By adding magnesium or potassium and adjusting pH to 9-11, MgNH4PO4.6H2O, K2NH4PO4.6H2O or MgKPO4.6H2O precipitates. Struvite is a slow-release fertilizer.

Recently, interest is shifting to the potential of struvite for P-recovery from waste streams, slurries and digestate. The formation of fine particles that are hard to separate remains an important bottleneck but this can be avoided by adjusting reactor design and process parameters (Anonymous, 2006). This is further confirmed by Wang et al. (2006), that proper seeding materials increase crystal size and improve settling ability. The University of Ghent is currently evaluating how chemical modelling can predict optimal struvite crystallizing parameters.

Struvite is mostly formed by adding MgO or $MgCl_2$. The main merit involved with the use of $MgCl_2$ is that, its production requires less energy. But is known to be slower with less complete reaction as well as the presence of chloride ions in the remaining solution. Meaning the solution can only be valorised as a fertiliser for chloride ions tolerant crops, e.g. grass (Sanders, 2010).

d. Biomass production and harvest

i. Technique and end-product

The economic and practical feasibility of growing algae on the liquid fraction of pig slurry is feasible if a polymer is added that precipitated the suspended solids, thereby allowing light penetration (The Flemish RENUWAL-project, 2013). Macrophytes have also been identified as alternative for nutrients recovery from digestates besides algae. The production of algae/macrophytes could be a major feedstock source for chemical and biofuel industries. The produced algae/macrophytes can be used as animal feed (provided that the necessary amendments in legislation are made) or spread out as a fertilizer on the fields. Compared to alternative sources of biomass, the production of algae is too high and not economically (Muylaert and Sanders, 2010). The high energy consumption associated with the algal production process still makes it not economically feasible even if the algae were sold to the animal feed industry.

However, an integration of biological and thermal-based conversion technologies by: (1) recapturing the evolved CO2 to promote algal growth and (2) utilizing wet gasification as the algal energy recovery component holds promise for a highly efficient and resource sustainable waste-to-bioenergy scheme (Vaneeckhaute C et al., 2012).

Algal growth on decoloured slurry

Source: RENUWAL, 2013

SOLID DIGESTATES

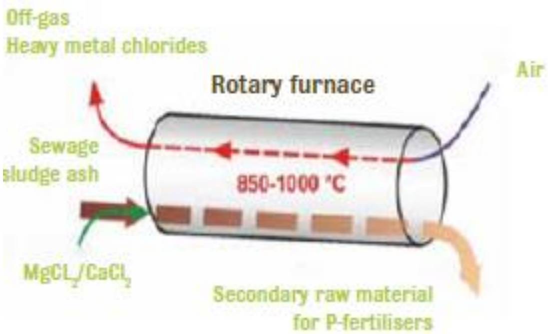
a. Extraction of phosphorus

i. Technique & end-product

There has been an extensive test conducted for the extraction of phosphorus has from dried or dewatered sludge and ashes from sludge incineration. Animal manure, which is not subject to the waste legislation, can be combusted, considering the emission standards (Art. 4.5.2., VLAREMA, 2012). The combustion of digestates generates electricity from the released energy and nutrients (mainly P) from the ashes. Small-scale combustion tends to be difficult because the process requires a thorough flue gas cleaning system. The remaining ashes after combusting digestate/manure contain up to 20-25% P2O5, next to K-, Al-, Mg- and Si-compounds and possibly also some heavy metals such as Cu, Zn and Cd (Vaneeckhaute C et al., 2012). Currently, more companies have designed different processes to extract phosphorus from combustion ashes (Schoumans et al., 2010). These techniques can be subdivided into thermochemical and wet-chemical techniques.

Pyrolysis exposes the digestate to a temperature of 150-900°C in the absence of oxygen. Organic matter fractionates into syngas, bio-oil and biochar (Lemmens et al., 2006). Preliminary pyrolysis tests on digestate revealed that oil yield and quality (very viscous) were suboptimal (K. Smets, pers. comm.). Experiments with pyrolysis of manure cakes have been conducted. The fraction of nutrients recovered in biochar is larger than in ashes and the plant-availability of the nutrients tends to be higher, especially for phosphorus (Schoumans et al., 2010).

Schematic overview of a possible P-recovery process



Source: www.outotec.com

APPENDIX 5: GRASSA! MOBILE INSTALLATION FOR BIOREFINERY; INTRODUCED IN 2016 (INGENIEUR, 2016)

APPENDIX 6: SOME METHODS WHICH HAVE BEEN USED TO IMPROVE FUNGAL LIGNOCELLULOLYTIC ACTIVITY OR STABILITY.

Methods	Fungal strain	Enzyme	Altered feature	Technique
Mutagenesis	*T. reesei* RUT-C30	Cellulases	Activity	UV treatment followed by 2 rounds of NTG treatment
	T. atroviride TUB F-1724	β-glucosidase	Activity	2 rounds of NTG treatment followed by UV treatment
	P. verruculosum 28K mutants	Cellulases and xylanases	Activity	Four cycles of UV mutagenesis followed by two-stage fermentation process
	T. reesei P9	Thermophilic endo-1,4-β-xylanase (XynII)	pH stability (alkalinity), Thermostability	SDM (using PCR and synthetic oligonucleotide primers) (N97R+F93W+H144K)
	T. reesei (Variants L218H, Q139R/N342T)	Endo-β-1,4-glucanase II	Catalytic efficiency, pH optimum	Saturation mutagenesis followed by random mutagenesis and two rounds of DNA shuffling
	T. reesei (T2C:T28C mutant)	Endo-1,4-β-xylanases II (XynII)	Thermostability	PCR and synthetic oligonucleotide primers (Engineering a disulfide bridge at N-terminal region)
Co-culturing	*T. reesei* RUT-C30 and *A. niger* LMA	β-glucosidase	Activity	Fed-batch fermentor on a Cellulose-Yeast extract medium
	T. reesei RUT-C30 and *A. phoenicis*	β-glucosidase	Activity	Shake flask culture
	A. ellipticus and *A. fumigatus*	β-glucosidase	Activity	Solid state fermentation using pretreated sugarcane bagasse
	T. reesei D1-6 and *A. wentii* Pt 2804	Cellulases, xylanases	Activity	Mixed culture medium (M3) supplemented with trace metal & vitamin solutions
	T. reesei LM-UC4 and *A. phoenicis* QM329	Cellulases, hemicellulases	Activity	Solid state fermentation using ammonia-treated bagasse
Heterologous gene expression	*T. reesei* RUT-C30	Thermostable β-glucosidase (*cel3a*) from thermophilic fungus *T. emersonii*	Activity	Heterologous gene expression using *T. reesei cbh1*promoter
	T. reesei	Cellobiohydrolase (I & II)	Activity	Overexpression using *T. reesei cbh1* promoter
	Acidothermus cellulolyticus and *T. reesei*	Endoglucanase & cellobiohydrolase	Bi-functional endo- & exo-acting cellulase	Chimeric protein, expressed in *T. reesei*
	H. jecorina (P201C)	Cel12 A	Thermostability	Mutation followed by heterologous expression in *A. niger*

Source: Dashtban M. et al, 2009.