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Taking Western U.S. bio-based technologies to the Netherlands (and visa versa)

An U.S. and Dutch analysis of the current knowledge and technology base for a bio-based economy.

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M.Sc. Thesis

Taking Western U.S. bio-based technologies to the Netherlands; an U.S. and Dutch analysis of the current knowledge and technology base for a bio-based economy.

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Preface

Our bio-based economy sector is subject to a lot of changes, with the end not yet in sight. Technological innovations are developed every day, which will lead to a lot of changes in the way life is organized. In the field of bio-based economy these changes are sometimes yet to happen. Therefore this is the theme of my Master Thesis, with which I finalize my Master Business Administration at the University of Twente.

Looking back at the process of graduating and writing this report, there is still one thing I would like to do: Thanking all people who made a contribution to this process:

I would like to thank Dr. ir. De Boer, Prof. dr. ir. Van der Meer, and Prof. dr. ir. De Bruijn at the University of Twente for their contribution, critical remarks and helpful directions.

A special thanks to my colleagues at the Netherlands Office for Science and Technology; Bianca Oudshoff, Mark Nellen, Cees van der Zon, and Anushka Koeldiep. Also special thanks to Ella van Gool and Peter Laanen!

I would also like to express my appreciation to all of the people who generously made themselves available for interviews for this research. Although not all people have been cited in this report, without their help I could not have completed this research.

And finally, some words of thanks to my family and friends; thank you for your interest and support during my graduation period!

Enschede. June 12, 2009

Frank Roeloffzen

EXECUTIVE SUMMARY

Economical growth, rising world population and the demand for a higher standard of living are increasing the global demand for fossil fuels. However, the fossil-energy-based economy is not sustainable over time. To meet the global energy needs and to force back global pollution, a global movement towards a plant-based, or bio-based, economy is considered as one of several solutions. In the last decade bio-based products have increased in popularity. Current market shares are increasing rapidly and are expected to increase even more in the future.

This research was conducted in order to provide an overview of current actors, knowledge and technologies, as well as an overview of future expectations of these subjects. Next to this descriptive character this research also has a more exploratory character. It was also conducted in order to identify U.S. knowledge and technologies relevant for the Netherlands and to analyze the transfer potential, in order to support the development of a bio-based economy.

Hence, the central research question of this research is: *"What available knowledge and technologies in the field of bio-based economy in the West Coast of the U.S. are relevant for Dutch industries (and vice versa) and how could Dutch Government encourage the transfer of these U.S. technologies to Dutch industries (and vice versa) in order to support the development of the bio-based economy?"*

Definition bio-based economy

The term bio-based economy is a relatively new phenomenon, although it has its roots in the 1920s and 1930s. In the early 20th century bio-based economy was represented in e.g. lamp fuels. Nowadays the term bio-based economy encapsulates the vision of a future society no longer fully dependent on fossil fuels for energy and industrial raw materials. In this research the term bio-based economy "*encapsulates the use of renewable green resources to produce chemicals, materials, products and transport fuels as well as to generate energy*."

Methodology

A comparative study between the United States and the Netherlands is executed so that the central question can be answered in a broader perspective. In order to provide an overview of the current situation and to compare both countries in a scientific manner, a theoretical starting point was chosen. In this research the so-called '*innovation system approach'* is used. The innovation system approach places technological development in a larger system, the so-called 'innovation system'. Additionally, '*the system function approach*' and the '*Product Life Cycle*' are applied.

Next to an extensive literature study different individuals in the field of bio-based technologies were interviewed in the Netherlands and in the United States. Various conferences and trade shows concerning bio-based economy were also visited.

Results

In the West Coast of the U.S. the government plays a vital role in the development, introduction and growth of innovative technologies. The universities, intermediate organizations, laboratories and private organizations also contribute to the growth, by applying their knowledge concerning agriculture, genomics, plant science and biotechnology. A strong research focus exists on plant science, genetics, genomics, and synthetic biology that result in lower feedstock production costs and also benefits the development of advanced conversion technologies such as enzymatic hydrolysis and fermentation. Synthetic biology is a notable combination of genomics, genetics, and biology that is increasing of interest; engineering the right enzymes to produce low-cost second-generation bio fuels by cloning microbes. Research effort on algae production and

conversion into bio fuels are increasing in popularity by scientists and the industry and are often referred to as the third generation bio fuels. Next to a broad range of knowledge, *conversion technologies* are strongly in development in the West Coast area. While bio chemical conversion technologies are more developed, thermochemical biomass conversion technologies are applied on a large scale and can be considered to be in the mature stage of development. Bio chemical conversion technologies, such as enzymatic hydrolyses and synthetic biotechnology, receive a relatively large amount of financial support by government and large industrial companies (e.g. BP, GE and Toyota).

In The Netherlands the government also plays a vital role in the development, introduction and growth of innovative technologies. Universities mostly conduct fundamental research, which is not easily applied by organizations. Large multinationals, such as Shell, DSM and Purac, are involved with research, development and production of byproducts, especially bio chemicals and bio fuels. Consequently, the long-term government policy is focused on the development of second-generation bio fuels. However, no second-generation bio fuels are commercially available, primarily due to the fact that costs are too high. More maturely developed technologies are biomass pyrolysis and gasification. ECN and Essent commercially apply biomass gasification for power generation. The University of Twente can be considered as one of the important research institutes on both gasification and pyrolysis. They conduct ongoing research on pyrolysis and gasification.

Conclusions

This research showed that knowledge and technologies are equally available in both countries. The research also shows that there are differences in the lifecycle stages of these technologies. This research showed that *pyrolysis, fermentation, enzymatic hydrolysis, chemical hydrolysis, and simultaneous saccharification and fermentation* are considered as more developed technologies in the U.S. These technologies are all considered as relevant to transfer to Dutch industries. Especially the transfer of *pyrolysis* knowledge to the Netherlands is considered as relevant due to the favorable functions in the Netherlands. The research furthermore showed that with respect to feedstock production technologies, *resource availability and costs, genetics genomics & plant science,* and *algae feedstock* are considered as further developed in the U.S. Knowledge sharing around *algae feedstock* is considered as relevant to transfer.

The lack of bio fuel production incentives in the Netherlands is considered as prime imperfection that hinders the large-scale application of bio fuels related technologies in the Netherlands. The Dutch government can encourage the knowledge transfer of these technologies by adopting distinct bio fuel production incentives and incentives for consumers on alternative fuel vehicles. These incentives reduce the risk for technology users and allow effective knowledge transfer. These measure are expected to create significant opportunities for Dutch industries.

Recommendations

This research led to many insights, however for further research the following can be recommended:

- Apply a more narrow focus area with respect to technologies and technology-product combinations;
- Use a technology based model rather than a market based model;
- Conduct more academic research on the Innovation System Approach in combination with the System Function Approach;
- Study the position of Venture Capital within the Innovation System Approach.

TABLE OF CONTENTS

DEFINITIONS

Term	Definition
BIOMASS	Biomass refers to animal or vegetable material. Biomass has two advantages compared to fossil feedstock; biomass is a renewable feedstock, in contrast to fossil feedstock that is finite. Secondly, biomass is - so called - carbon neutral. Biomass combustion does not result in a net carbon dioxide increase to the atmosphere. (LNV, 2007)
BIO-PRODUCTS	Bio-products are products that are made from renewable 'green' resources. Bio-products can be divided into five categories: 1) Chemicals, 2) Materials, 3) Products, 4) Transportation 5) Fuels Energy. In this research we refer to bio-products solely as (bio)chemicals, (bio)transportation fuels, and (bio)energy.
BIO-BASED ECONOMY	A bio-based economy uses renewable green resources to produce chemicals, materials, products and transport fuels as well as to generate energy. (LNV, 2007)
PROCESSING AND CONVERSION TECHNOLOGIES	Processing and conversion technologies include a variety of techniques that convert feedstock into cost-competitive bio-products (DOE/OBP, 2007).
FEEDSTOCK PRODUCTION TECHNOLOGIES	Feedstock production includes all the steps required to sustainable produce biomass feedstock up to the collection of harvesting from the field or forest (DOE/OBP, 2007)
FIRST GENERATION BIO FUELS	Refers to liquid transportation fuels made from sugar, starch or lipid containing crops with conventional technologies. These crops often can be easily fermented into bio ethanol, or are seeds that can simply be pressed to manufacture bio diesel. These crops are usually agriculture crops used in food production. First generation bio fuels therefore compete with the food chain. First generation bio fuels emit between 30 and 50 percent lower green house gasses compared with fossil fuels. (LNV, 2007)
SECOND-GENERATION BIO FUELS	Second-generation bio fuels are made from ligno-cellulosic, or woody, resources that do not compete with food. This feedstock includes special dedicated energy crops, agriculture and forestry wastes and other ligno-cellulosic residues. Second-generation bio fuels are expected to emit 50 to 90 percent lower green house gasses than fossil-based fuels. (LNV, 2007)
VENTURE CAPITALISTS (VC)	Venture capital is an actor group of investors (venture capitalists) that invest in early-stage high-potential companies mainly in exchange for shares in the company. Venture capital is a type of private equity capital pooled together by individuals or by institutional investors.

FIGURES, TEXTBOXES AND TABLES

1 INTRODUCTION

1.1 MOTIVE AND RELEVANCE

Economical growth, rising world population and the demand for a higher standard of living are increasing the global demand for fossil fuels that are not sustainable over time. Less than half of the world's total oil reserves is expected to be exhausted by 2025 (IEO, 2007). The human addiction to oil has several negative side effects that become clearer every year: increasing greenhouse gasses, a shrinking ozone shield, increasing climate change and pollution from air and waterways. Most of these effects are caused by the combustion of fossil fuel in order to generate electricity, heat and to power vehicles. To meet the global energy needs and force back global pollution, a global movement towards a plant-based, or bio-based, economy might be a solution.

Central in this bio-based economy are renewable green resources, or biomass. Biomass includes all plant and plant-derived materials. Essentially all energy originally captured by photosynthesis (non-fossil), like wood, plants, and plant residues that can be used to produce 'green' products and materials such as plastics, lubricants, fertilizers, transportation fuels and energy.

"A bio-based economy uses renewable green resources to produce chemicals, materials, products and transport fuels as well as to generate energy"

Textbox 1 Definition bio-based economy (LNV, 2007)

Bio-products are increasing in popularity. Current market shares are increasing rapidly and are suspected to increase even more in the future. To achieve these future market shares a large variety of new innovative cutting-edge technologies are needed since most existing technologies cannot manufacture bio-products in a sustainable, environment friendly and, most of all, cost effective way. The latter can be considered as the major barrier in commercializing bio-products on large scale. New advanced technologies should overcome this hurdle.

Since the bio-based economy is a relative new phenomenon, the NOST Silicon Valley (this research is carried out for the NOST Silicon Valley, see next chapter for more information) did not conduct earlier research on this subject. There is also a lack of overview of the present initiatives, in terms of knowledge, technologies and actors, because the bio-based economy is emerging. Due to the growing importance of this subject, NOST Silicon Valley wishes to have an overview of the current bio-based initiatives, in terms of knowledge and technology. Twice a year the NOST organizes a conference in the Netherlands with a specific subject; the 'NOST Network' has chosen 'bio-based economy' as theme for its conference in April 2008.

Together the high pace of technology developments and the NOST's annual conference are the motivations for conducting this research.

The results of this research are relevant for the NOST and the Dutch Ministry of Economic Affairs. It provides a current up-to-date situation of technological developments, government policy, and an overview of the most important actors in the technological landscape. This research also is relevant for Dutch and American entrepreneurs, universities, branch organizations, and other persons interested in the technological dynamics of the U.S. and Dutch bio-based economy. The results can supplement their knowledge and can strengthen the Dutch renewable energy policy in order to stimulate a bio-based economy.

1.2 ABOUT NOST SILICON VALLEY

The research is carried out for The Netherlands Offices for Science and Technology in Silicon Valley, California, United States. (NOST Silicon Valley). The NOST is part of the Dutch Ministry of Economic Affairs, Agency for International Business Cooperation (EVD). The NOST Silicon Valley's main activity is information collection about technology and science, and about the technology and science policy within the West Coast of America and Canada. The NOST Silicon Valley is supporting Dutch companies, knowledge institutes, universities and the government by putting information at their disposal. Besides this, they are concerned with the start-up and execution of exchange programs orientated at stimulating alliances between Dutch and U.S. parties. The NOST Silicon Valley has several fields of attention, which are: renewable energy, Clean Tech, IT, nanotechnology and Life Sciences but also innovation policy and the collaboration with universities and businesses, start-ups and incubators.

The NOST Silicon Valley has undertaken many activities in the field of bio-products and sustainability in general. For instance in October 2006, NOST Silicon Valley organized a conference in San Francisco in the field of renewable energy. The NOST Silicon Valley also is working on a cooperation concerning climate change with The State of California.

1.3 OBJECTIVES AND CENTRAL RESEARCH QUESTION

The objectives of this research are formulated as following: Within the field of bio-based economy at the U.S. West Coast,

- to provide an overview of the current actors and their objectives. Attention has to be paid to government policy and –programs as well as companies and private initiatives;
- to provide an overview of the current knowledge and technology base in the U.S. and in the Netherlands;
- to provide an overview of the future expectations of these initiatives;
- to distinguish U.S. knowledge or technologies that can be relevant for Dutch industries, and vice versa;
- to analyze in what way the Dutch government can encourage the transfer of potential technology or knowledge to Dutch industries and vice versa, in order to support the developments of a bio-based economy.

In order to find a solution for the objectives stated above, the central question to be answered in this research is:

> What current available knowledge and technologies in the field of bio-based economy in the West Coast of the U.S. are relevant for Dutch industries (and vice versa) and how could the Dutch Government encourage the transfer of these U.S. technologies to Dutch industries (and vice versa) in order to support the development of the bio-based economy?

Textbox 2 Central research question

In order to address this central research question several research questions are formulated. Each will deal with a manageable component of the central question. The various research questions to be solved are:

First an overview of the subject and the technological and product domains needs to be gained by asking the first question:

1. *What is a bio-based economy and what different product and technological domains can be distinguished?*

Next a theoretical framework and methodology is developed in order to solve the central research question.

2. *What theoretical framework and methodology are appropriate to apply in this research?*

After the theoretical framework is made-up an overview of the currently available knowledge and technologies in the West Coast U.S. and in the Netherlands is desired. The following questions are formulated:

3a. What is the current situation in the U.S.?

3b. What is the current situation in the Netherlands?

In order to distinguish technologies and knowledge that can be relevant for Dutch industries both situations need to be compared. The following question is asked:

4. *How do the current situations in the U.S. and in the Netherlands compare?*

Finally, insight needs to be gained in what way the Dutch government can encourage the transfer of these technologies in order to support the development of the bio-based economy. The following question will be answered:

5. *In what way can the Dutch government encourage the transfer of U.S. technologies to the Netherlands in order to support the development of a bio-based economy?*

1.4 GEOGRAPHICAL DELINEATION

Because the NOST Silicon Valley has its orientation on the U.S. West Coast, the geographical focus in this study is on the states Washington, Oregon, California, Nevada, Idaho, Utah and Arizona. The research also encapsulated the Canadian Province of British Columbia. In The Netherlands the whole country is analyzed.

Figure 1 Geogriphical delineation Netherlands

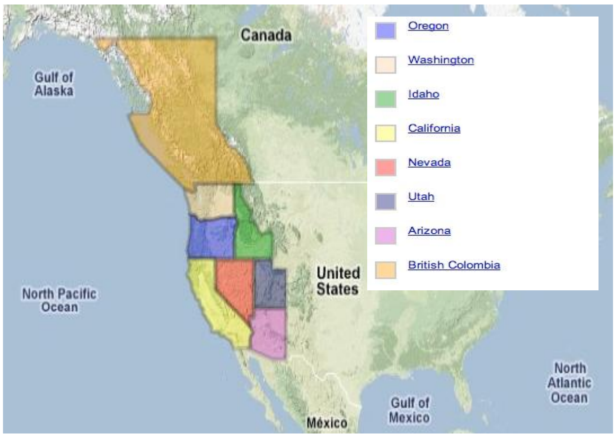


Figure 2 Geographical delineation in the USA

1.5 RESEARCH STRUCTURE

The figure below represents the research structure. It presents a clear overview of the steps that have been taken in the research. Each window element is consistent with the questions stated in section 1.3 at the previous pages.

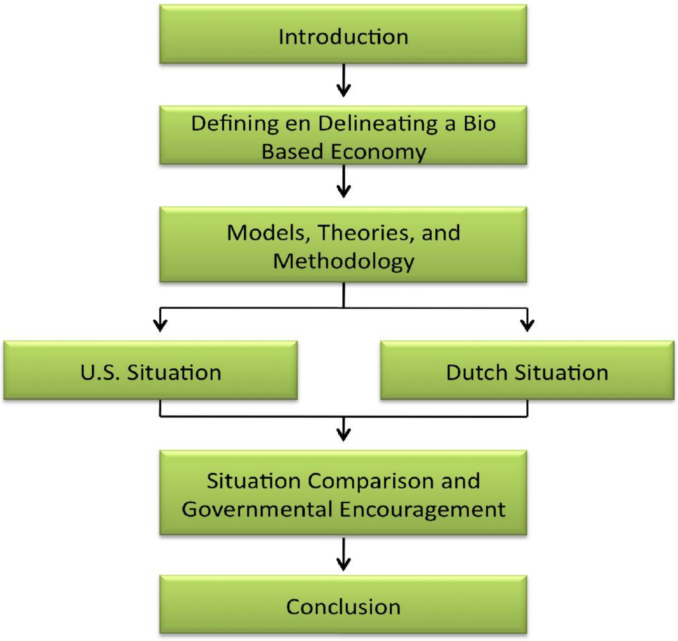


Table 1. Structure of the Research

1.6 READING GUIDE

This report comprises seven chapters that include methods, analysis, and answers in order to address the central question that is stated at page 11. The central question is addressed according to the answers to the various research questions. The first part of the research is the theoretical and methodological part. The second part comprises an analysis of the U.S. West Coast and the Netherlands. This part includes (i) an analysis based on the innovation system approach, (ii) a technical analysis of available technologies, and, (iii) an analysis based on the system function approach. The third part of the study has a comparative and advisory set up. The following subsections provide an overview of chapters and the information that is given in the next chapters.

Chapter 2.

This chapter provides an introduction into the main subject of this research. The definition of a bio-based economy is elaborated as well as what technologies and products are analyzed. Finally the concept of a bio-based economy in relation with people, profit, and planet is elaborated.

Chapter 3.

After the main subject of this research is elaborated the theoretical framework and research methodology is elaborated. It is elaborated in what way the *innovation system approach, system function approach,* and *the product life cycle model* are applied. The chapter furthermore elaborates the steps that are taken in order to gather the research data.

CHAPTER 4.
In chapter four the U.S. West Coast is analyzed according to the models, theories, and research methodology discussed in the previous chapter. In this chapter the important actors in the political-, educational-, research-, and industrial system are identified. The second part of the chapter describes the available knowledge and technologies. Finally, the system functioning of both countries are analyzed according four most important functions. In this section it is analyzed how they are fulfilled.

CHAPTER 5.
In this chapter an overview of the Dutch situation is provided. The composition of this chapter is similar to chapter four.

CHAPTER 6.
After in chapter four and five an overview is provided from both countries, this chapter compares both situations. It provides the difference in knowledge and technology availabilities and discusses the relation with differences in the system functions. Finally, the chapter includes an recommendation in what way the government can encourage this technology transfer.

CHAPTER 7.
The final chapter shows the research conclusions, reflections, and recommendations. The reflections include a brief reflection towards the results versus the research objectives, it reflects the research process and criticizes the suitability of the models and theories used in this study.

The next chapter elaborates the term 'bio-based economy' in more detail and provides an overview of the technologies and products within this bio-based economy. Further it explains the importance and benefits of a transition towards a bio-based economy.

2 BIO-BASED ECONOMY AND ITS TECHNOLOGIES

2.1 INTRODUCTION

A bio-based economy is a broad definition. It encapsulates a broad range of products and technologies. In this chapter the answer to the next research question is given:

What is a bio-based economy and what different product and technological domains can be distinguished?

In order to find a solution the term bio-based economy is described in more detail. Secondly the boundaries of this research are addressed according to the main products and technological areas that can be distinguished in a bio-based economy. Finally the most important benefit of a bio-based economy is elaborated; sustainability.

2.2 A BIO-BASED ECONOMY

The term *'bio-based economy'* is a relative new phenomenon although it has its roots in the 1920's and 1930's. In the early 19^{th} century a variety of lamp fuels made from vegetable oils, animal oils, turpentine from pine trees, wood- and grain alcohols were common in the US as well as in Europe. In 1925 Henry Ford advocated that ethyl alcohol (ethanol) was *'the fuel of the future'* (Kovarik, 1998). Later, Ford designed his first T-Ford automobile to run on ethanol (alcohol) produced from agriculture crops. However, a bio-based economy includes more products.

The term '*bio-based economy'* encapsulates our vision of a future society no longer wholly dependent on fossil fuels for energy and industrial raw materials (BBE, 2007). Although there are many definitions of a bio -based economy, the definition as stated by the Dutch Ministry of Agriculture, nature and Food Quality is used in this study *'A bio-based economy encapsulates the use of renewable green resources to produce chemicals, materials, products and transport fuels as well as to generate energy'.*

The most important drivers in the transition towards a bio-based economy are declining oil supplies, the dependency of foreign oil, and increasing social awareness of the growing environmental problems caused by consuming fossil fuels.

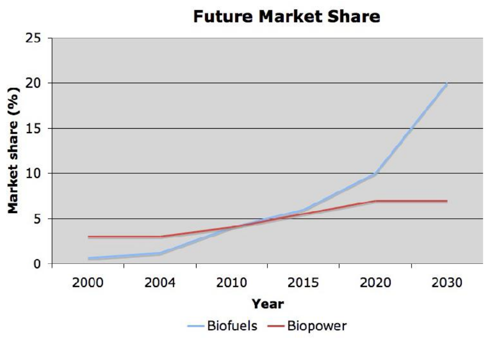
A transition to a bio-based economy possesses the ingredients to solve important global problems. Probably the most important one is that it possesses the ability of reducing carbon emissions from fossil-based energy production and consumption since bio products are consumed carbon neutral. Secondly, it possesses the ability to reduce the dependency of (currently very expensive) foreign oil due to the domestic production of biomass derived fuels and energy. It furthermore promotes the use of more diverse, domestic and sustainable energy resource and finally it creates new domestic industries in developed and developing areas al throughout the world. (Biomass, 2007; Biomass, 2007)

2.2.1 BIO PRODUCTS

In a bio-based economy renewable green resources are used to produce a range of bio-based products. These products can be divided into five categories (NRC, 2000):

- Chemicals
- Materials
- Products
- Transportation Fuels
- Energy

Some of these products result from the direct physical or chemical processing of renewable green recourses. Others are indirectly processed from carbohydrates by applying biotechnologies such as microbial processing. Market shares of these bio-based products are expected to grow significantly in the next twenty years. The category Transportation fuels and Chemicals, Materials and Products together are expected to grow most rapidly and will obtain a significant market share by 2020. Figure 3 (stated below) represents the expected future bio fuels market (Transportation fuels) and market for bio-power (Energy). The market for bio fuels is expected to grow solidly from a 4.0 percent market share in 2010 until 20 percent in 2030. Biopower market share is envisioned to grow less rapidly. Figure 4 illustrates the expected production of bio products, including Chemicals and Materials, from the year 2000 through 2030; production is expected to more than quadruple in those thirty years.



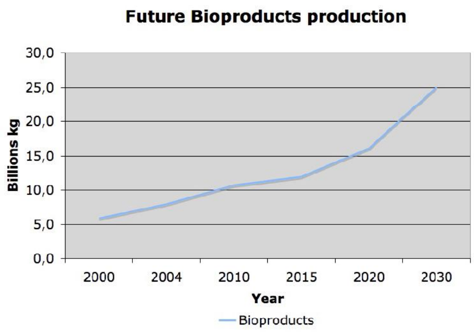


Figure 3 (left) Envisioned future market share of bio fuels and biopower (Source: DRDi Vission)
Figure 4 (right) Envisioned future production of bio products (Source: BRDi Vission)

At request from the NOST Silicon Valley this research covers solely initiatives and developments in the production of *Chemicals, Transportation Fuels,* and *Energy* derived from biomass.

When referring to 'bio-products' in this report, it refers to these three product categories.

Table 2 Delineation Bio-Products in a Bio-Based Economy

2.3 TECHNOLOGICAL DELINEATION

The production of bio-products derived from biomass embraces many different technologies within several technological areas. These technological areas can be visualized in a biomass-to-bio products supply chain, as demonstrated in Figure 5. The production pathway of these bio-products consists of five technology fields. The amount and difficulty of current technological barriers variate within all five fields in the supply chain.

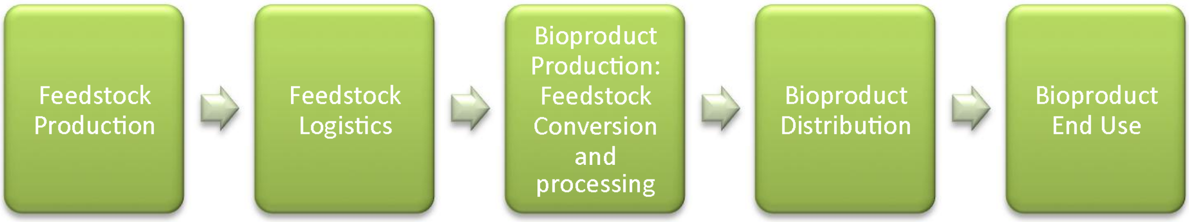


Figure 5 Biomass-to-bio products Supply Chain (Biomass, 2007) (Modified by author)

Some of these technological areas are needed to develop more drastically than other fields. In this study the emphasis will be on analyzing those technical areas with most urgent need for development. The barriers in these areas mainly cope with 'quantity', 'quality', 'sustainability' and most of all 'costs' of biomass and the bio products. Currently less bio-based products can be produced in large quantities with maximum energy yields, grown in a 'sustainable' way against low prices. Current bio products are not cost-competitive with fossil fuel-based products. R&D advances should increase this financial gap and make bio-products more cost-competitive.

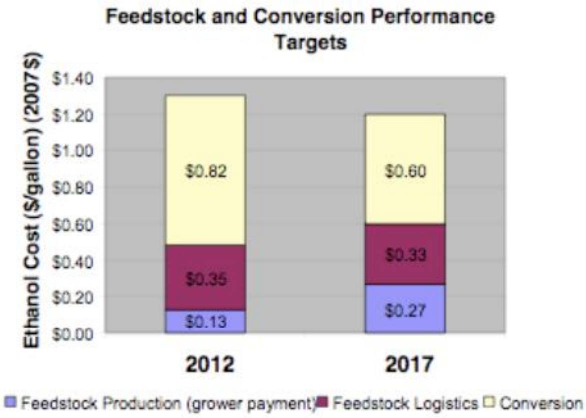


Figure 6 Feedstock and Conversion Performance Targets (Biomass, 2007)

Figure 6 shows the projected production cost reductions through research and development advances between the year 2012 and 2017 for the most common bio fuel, ethanol. The figure shows that 'feedstock production' and 'feedstock conversion cost' are the cost components that are expected to drop most significantly as a result of technology advances. Therefore the focus in this study is solely on these two technological areas.

2.3.1 FEEDSTOCK PRODUCTION TECHNOLOGIES

Feedstock is essential in the biomass supply chain. Feedstock production includes all the steps required to sustainable produce biomass feedstock up to the collection of harvesting from the field or forest (Biomass, 2007). Relevant topics that form major problems and are in need for research efforts are *'resource availability and costs', 'sustainable production'* and *'crop genetics'.*

2.3.2 PROCESSING AND CONVERSION TECHNOLOGIES

Processing and conversion technologies include a variety of techniques that convert feedstock into cost-competitive bio-products (Biomass, 2007). The diversity of feedstock types leads to the development of multiple conversion pathways that can efficiently deal with the diverse feedstock characteristics. Two primary conversion pathways can be distinguished; *thermo chemical-* and *bio chemical conversion*. Thermo Chemical Conversion covers heat, chemical and pressure-based conversions (EERE, 2007; Biomass, 2007) whereas Bio chemical Conversion technologies include biological processes (the use of living organisms such as enzymes or microorganisms) in addition to heat and chemical catalysts, to process renewable feedstock into bio-products (EERE, 2007; Biomass, 2007)

2.4 BIO-BASED ECONOMY AND SUSTAINABILITY

A last important subject to acknowledge is 'sustainability'. Central in a bio-based economy are renewable green resources, or biomass. Biomass includes all plant and plant-derived materials, essentially all energy originally captured by photosynthesis (non-fossil). The main benefit from biomass-derived products is that they generate no net carbon dioxide during combustion regarding fossil fuel based products. An important criterion for biomass use is that it may not negatively affect important human, environmental and economical aspects. These aspects are conceptualized in the Triple-P model where the P's stand for *'People', 'Planet'* and *'Profit'.*

'People' stands for the social wellbeing of the human. The use of bioproduct, i.e. bioplastics, in the food and packaging industry may not cause threats on the human wellbeing. Or the production of biomass may not result in bad working and living conditions for humans in for instance the developing countries.

'Profit' includes the economical part of the production of biomass with subjects like competition with other crops resulting in increasing (food) prices and economical prosperity of rural economies due to local crop production.

'Planet' can be considered as the most important sustainability aspect. It includes carbon dioxide and other emissions to water and atmosphere, effective soil usage, water usage and balancing ecosystems.

Textbox 3. Triple-P model; People, Profit, Planet.

In February 2007 the Dutch government presented the 'testing framework for sustainable biomass' (SenterNovem, 2007) in which they presented their methodology to analyze the sustainability degree of biomass. In this report they distinguished six themes that individually include several sustainability 'testing criteria'. All six themes are all more or less linked dimensions to the 'Triple-P' model. They include: (SenterNovem, 2007)

1. **Greenhouse gas emissions.** Measured over the whole biomass-to-bio product supply chain, the use of biomass must result in net lower greenhouse gas emissions than the use of conventional fossil feedstock.
2. **Competitiveness with food and other local applications.** The production of biomass may not negatively affect the food supply and other local applications of biomass.
3. **Biodiversity.** Biomass production may not harm protected or delicate biodiversity in any case. If possible it will strengthen the current biodiversity.

4. **Environment.** The quality of ground water, surface water and air needs to be maintained or improved during the production and processing of biomass.
5. **Prosperity.** The production of biomass must contribute to increasing domestic prosperity.
6. **Social wellbeing.** The production of biomass must contribute to the social wellbeing of employers and the local population.

2.5 CONCLUSION

In this chapter answers to one of the first research questions were found;

What is a bio-based economy and what different product and technological domains can be distinguished?

The idea of a bio-based economy is not new. Already in the 1920s and 1930s lamps were fueled with vegetable- and animal oils. Even the first mass produced vehicle was engineered to run on corn-derived ethanol.

The term *bio-based economy* encapsulates our vision of a future society no longer wholly dependent on fossil fuels for energy and industrial raw materials (BBE, 2007). The definition of a bio-based economy as adopted in this research is: A bio-based economy uses renewable green resources to produce chemicals, materials, products and transportation fuels as well as to generate energy (LNV, 2007).

A transition towards a bio-based economy is driven by declining oil supplies, the dependency of foreign oil, and the social awareness of the increasing environmental problems caused by consuming fossil fuels.

A bio-based economy distinguishes the products *Chemicals, Materials, Products, Transportation fuels* and *Energy*. This study is delineated by focusing solely on the bio-products: *Chemicals, Transportation fuels* and *Energy.*

The biomass-to-bio-product supply chain distinguishes five steps in the production pathway from biomass to bio-product; 1) feedstock production, 2) feedstock logistics, 3) feedstock conversion and processing, 4) bio product distribution, and 5) bio product end-use. The scope in this research is on the first and third step, *feedstock production* and *feedstock conversion and processing,* since most benefits are expected to take place through technological advances in these steps.

Technological development towards a bio-based economy embraces a large contextual landscape consisting of a large variety of players in various technological fields and innumerable external elements influencing developments towards a bio-based economy.

An important element in the transition towards a bio-based economy is 'sustainability'. The sustainability of the production and use of renewable feedstock deals with three dimensions; the social, the environmental, and the economical aspect. This means that the production and use of renewable feedstock should benefit all these three dimensions optimally.

In the next chapter the theoretical framework and research methodology are elaborate in more detail.

3 THEORETICAL FRAMEWORK AND RESEARCH METHODOLOGY

3.1 INTRODUCTION

In this chapter an overview of the theories and models is provided which are used as a framework to find a solution to the problem formulation in a scientific way. In the last part of this chapter the steps that have been taken in this study, from gathering data until data processing, are elaborated.
In this part of the research answers to the following question are given:

What theoretical framework and methodology is appropriate to adopt in this research?

Since developments towards a bio-based economy take place in a wide contextual landscape composed of various actor groups and innumerable external influencing factors, the central approach of this framework is the so-called *'innovation system approach'*. The innovation system approach can be used as a heuristic tool to analyze all the important actors in a technological landscape. Additional to the innovation system approach the *'system function approach'* is used in order to assess in what way the important external influencing elements, i.e. providing financial resources or creating and stimulating new markets, have been fulfilled. Finally, the use of this model, in order to analyze the feasibility for adopting U.S technologies to the Netherlands and vice versa is elaborated.
This chapter also elaborates briefly an additional model, the product life cycle. According to this model the maturity of identified technologies is analyzed.

3.2 WHAT ARE INNOVATIONS?

In this research the emphasis lies on exploring new technologies and existing technologies with new applications. In several studies technological development is analyzed by using innovation theories and models. Then the reasonable question arises: what are innovations?

In literature several different explanations of innovations can be found. Edquist (2001), one of the pioneers in innovation theories, writes; "Innovations are new creations of economic significance normally carried out by firms. They may be brand new, but are more often new combinations of existing elements. It is a matter of *what* is produced by firms and *how*". According to Edquist's definition innovations do not have to exist out of new technologies but can also exist out of combinations of existing technologies. A Dutch innovation expert Van Ex (1999) writes; *"whit a technological innovation we mean the creation of a new, or improved, process or product, of which the application achieves a better performances (Production, commercial or financial performance) than before."*
Edquist (2001) provides a clear taxonomy of innovations (Figure 7); he categorizes innovations in product innovations (*what* is produced) and process innovations (*how* goods and services are produced). Product innovations may be goods or services. Process innovations may be *organizational* or *technological innovations*. In this research the emphasis is on *technological innovations.*

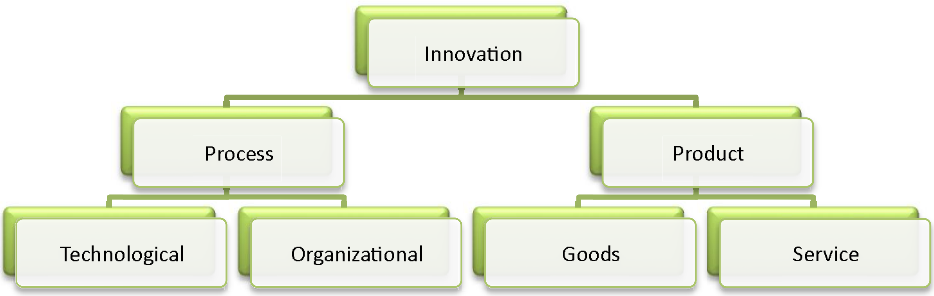


Figure 7 Taxonomy of innovations (Edquist, 2001)

3.3 CENTRAL MODEL: THE INNOVATION SYSTEM APPROACH

Technological development cannot be seen as an isolated phenomenon it has to be studied as a part of a larger system, a so called 'innovation system' (Johnson, 2001). A large number of articles about the dynamics of technological development have been published in the last decades. For a long time researchers and scientist considered technological progress as an exogenous factor, the environment in which technological progress took place was not or barely studied. Currently, parts of the scientific research, concerning technological progress, focus on determining the so-called 'blackbox' mechanisms (van Ex, 1999). Today the dynamics of technological developments are examined by analyzing the relations between companies, sectors, regions and countries among themselves. It has been proven that innovations emerge within a network of universities, organizations, research centers, governments etc. (Edquist, 1997). All these actors are influenced by each other and depend on each other (Edquist, 1997). A common approach to analyze the development, use, and change of technological innovations is the so-called *Innovation System approach* (IS, or 'System of Innovation'). This approach can be considered as a conceptual framework rather than a theory and therefore it can be used as a heuristic tool to analyze technological change. It can also be used as a descriptive tool to identify actors, infrastructure, and the relations between them in a structured way. In this study the innovation system approach is used as central model.

In the many scientific articles published concerning innovation systems several authors agree that innovation systems contain three main elements 1) *organizations* 2) *institutions,* and 3) *relations* (Jacobsson & Johnson, 2000; Van Ex, 1999; Negro, Hekkert & Smits, 2004; Carlsson et al., 2002; Edquist, 2001). These elements are described below.

ORGANIZATIONS

Organizations are formal structures with an explicit purpose, which are consciously created and have an explicit purpose. They are players or actors and can be of a variety of types (Edquist, 2004). Some examples are: individuals, business firms, banks, venture capital, universities, research institutes, and public policy agencies (Carlsson et al., 2002). Jacobson and Johnson (2001) say that in order to analyze the innovation system it is especially important to identify the '*prime movers'*. Prime movers are the key actors in the creation of new technological systems. They can perform four important tasks to promote their new technology: *they raise awareness*, *undertake investments*, *provide legitimacy*, and *diffuse the new technology* (Jacobson and Johnson, 2001).

INSTITUTIONS

Institutions are sets of common habits, norms, routines, established practices, rules, or laws that regulate the relations and interactions between individuals, groups and organizations (Edquist, 1997). They are also called 'the rules of the game'. Institutions differ from system to system and therefore need to be analyzed separately for each of these systems.

RELATIONSHIPS

Relationships are the mutual linkages between organizations and institutions. The speed of diffusion of new technologies depends on the quality of the actors and the relationships between the several actors (Edquist, 1997). Several different types of relationships exist among actors, which take care of the diffusion of information and knowledge. The quality of mutual relationships determines the direction and speed of the technological development (van Ex, 1999).

Since 1995, when the first person, Bengt-Ake Lundvall, used the word 'national system of innovation', several different innovation system approaches have been developed. These approaches are made on basis of a perception of affinity between authors with regard to the level of analysis of the system. The most common approaches are the national, regional, sectoral and technological approach (Carlsson et al.,2002; Edquist, 1997; Breschi en Malerba, 1997). The national and regional approaches both are delineated geographically, whereas the sectoral end technological approaches are delineated in a physical dimension.

In the national approach the analysis is carried out on national level: R&D activities and the role played by universities, research institutes, government agencies, and government policies are viewed as components of a single national system (Carlsson *et al.,* 2002). In the regional approach the analysis is carried out focusing on the regional level with regional policies, actors etc.

In the sectoral approach they talk about generic technologies or technology fields and this can be restricted to an industrial branch (Edquist, 1997). These systems include a part of a regional, national, or even international system and can also be geographically delimited. According to Breschi en Malerba (1997) "a sectoral IS can be defined as that system of firms active in developing and making a sector's products and in generating and utilizing a sector's technologies". Edquist (1997) says 'specific technologies or product areas are used to define the boundaries of the sectoral system'. So, the basic elements of a sectoral approach consist of *products* and *basic technologies*. For a sectoral system a technology-product matrix can be build that links products to a range of technologies. The latter approach, the technological approach, is more focused to one specific technology, and since it is also physically delineated it can be considered as sectoral in this way.
In this study the sectoral system of innovation is considered as the most suitable approach to identify the players in the system and to analyze technological development later on in this study.

The innovation system as reproduced by Kuhlmann and Arnold represents an integral overview of important aspects in the creation and diffusion of innovations. This model is used to analyze the important actors in both biomass-to-bio-products supply chain areas *feedstock production* and *feedstock conversion and processing technologies* together.
However, one important actor group that is visualized as a minor actor group, which is Venture Capital (VC). VC is expected to contribute significantly to the development of innovations. Therefore this group is supplemented to the model.

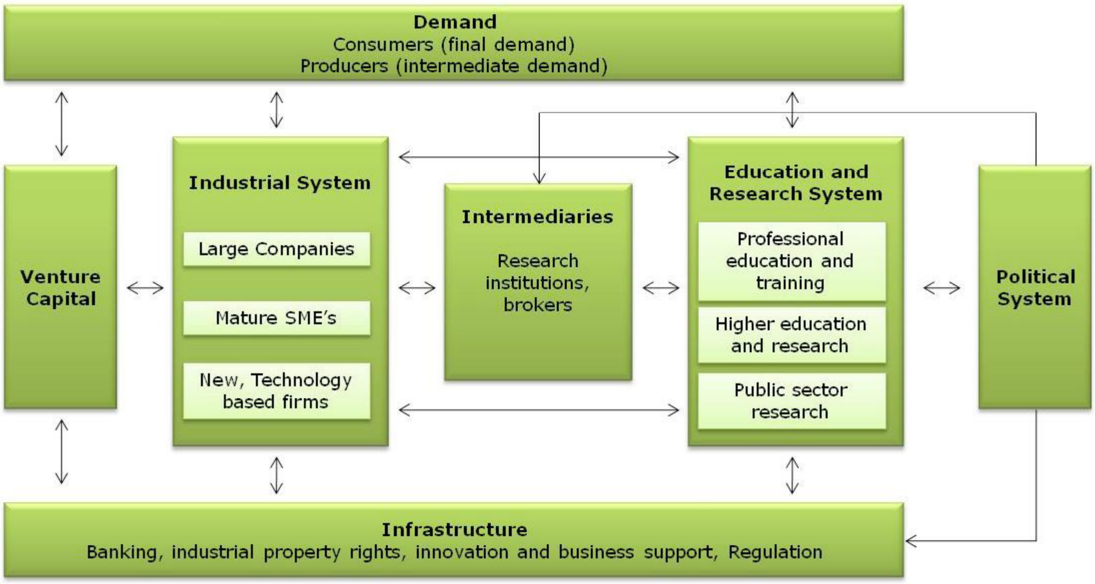


Figure 8 Central model in this study: 'The Innovation System'. Based on the Innovation System model by Kuhlmann & Arnold (Kuhlmann, 2001)

In the next sections the elements, *industrial system, intermediaries, education and research system, and political system,* of Kuhlman & Arnolds Innovation System are elaborated. The boxes *demand* and *infrastructure* will *not* be elaborated and analyzed in this research. Analyzing *demand* is not an objective of this study; a specific in-depth study can be devoted to analyze the demand for bio-based technologies and/or products. The non-physical *infrastructure* such as banking, business support, regulation and standards are intertwined with the 'system functions' as elaborated later on in the research.

The industrial system

This group contains the main companies that play a key role in technological development. It includes all companies that develop or apply feedstock production and processing & conversion technologies for the production of bio-based products, limited to the production of bio-chemicals, bio-transportation fuels and bio-energy.

Intermediaries

Intermediaries are groups of persons that offer intermediation between two ore more actors. They mainly offer intermediation between companies and the educational and research system. They also fulfill an important role in the knowledge diffusion among different actors. Examples of these actors are organized interest groups, NGO's, environmental and industry organizations. Again, only intermediaries for the product groups Chemicals, Transportation fuels and Energy are distinguished.

Education and Research system

Research activities in the innovation system mainly take place in the education and research system. Research in the education and research system mostly includes basic research; the industrial system is mostly concerned with applied research. Through this, the education and research system will have a significant influence on innovation system functioning. This part of the system is represented by universities, non-university public research institutes and, national or private laboratories.

Political system

The government is another actor with a central role in the innovation system. The role of the government is of importance concerning its regulations and policy, subsidies, grants, etc. The role of the government, among other things, is to stimulate markets, provide infrastructure and education and give companies incentives to invest or innovate (Johnson, 2001). Hence the government significantly influences the institutions of the system, and consequently its functions (see section 3.4.1. on page 23). In this research only the most important governmental ministries and ministerial offices are identified: those who have actual influence on the development of technologies and innovations.

Venture Capital

Venture capital is an actor group of investors (venture capitalists) that invest in early-stage high-potential companies mainly in exchange for shares in the company. Venture capital is a type of private equity capital pooled together by individuals or by institutional investors.

3.4 TECHNOLOGIES AND KNOWLEDGE

In this research available technologies and knowledge are identified both in the U.S. West Coast and in the Netherlands. Technologies and knowledge are identified that fall within the technological delineation: *feedstock production technologies* and *processing & conversion technologies.* Within feedstock production technologies the focus is mainly on tangible aspects, like research on *availability and cost of biomass*, *sustainable production, etc.* Processing & conversion technologies are identified according input and output. When technologies use renewable green resources (biomass) for input, and have bio products as output, these technologies are analyzed. Bio products as output are delineated in bio-fuels, bio-energy, and bio-chemicals. The identified technologies are analyzed and compared according a technology-market based model: the Product Life Cycle.

3.4.1 PRODUCT LIFE CYCLE

The Product Life Cycle (PLC) is a conceptual market-based model that visualizes the stages that a product, or service, goes through, starting from market introduction until the product eventually 'dies' in the market (Levitt, 1966). Since the focus technologies in this study have a constant input (biomass) and generally have one output we consider these technologies as a 'product'. Although the PLC model reflects the market position of a specific product, the model does not comprise the degree of technological superiority. Per example, a technology can be technically superior after twenty years of intensive research and development although it never established as a mature technology applied on a large scale in the market. The success of market adoption was perhaps determined then by other factors such as economical factors. Nevertheless, analyzing technologies from a market perspective can be used for this research purpose to analyze technologies in both the U.S. and The Netherlands.

The PLC model distinguishes four stages (Levitt, 1965; Wood, 1996): 1) *Introduction*. A product is first brought to market, no proven market demand, almost fully technically proven, sales are low, and costs are high. 2) *Growth*. Market demand begins to accelerate, market expands, sales volumes increase significantly, costs reduces, public awareness. 3) *Maturity*. Sales volumes start to peak, profits starts to decline, increasing competitive offerings. 4*) Decline.* Drop in consumer appeal, sales volumes drift downward or stabilize.

Levitt (1965) and *Wood (1996)* discuss four stages. Their model will be extended with a fifth important stage, the *product development* stage. Prior to the 'Introduction' phase it can be considered as the product is in *development*. Fundamental or applied research is conducted, and a first proof of concept is initiated.

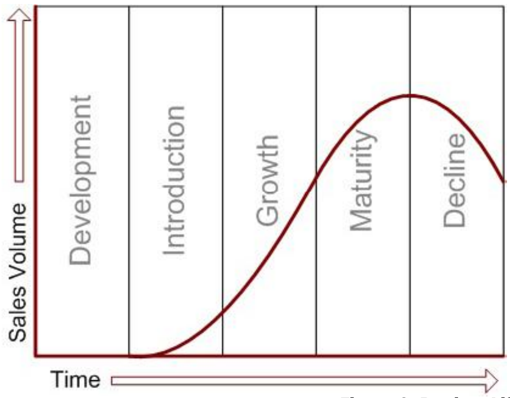


Figure 9. Product Life Cycle (Published by Samuel J. Scott)

3.5 COMPARING TWO CURRENT TECHNOLOGICAL SITUATIONS

In order to compare two situations the so-called *System Function (SF) approach* is used as additional approach to the Innovation System approach. Hence, this approach can be seen as an extension of the *Innovation System approach* and is used to analyze the external factors of the innovation system. The development, use, and spreading of new technologies is affected by many economic, social, political, organizational, and other determining factors (Edquist, 2001). These external factors can be seen as individual *'functions of the system'* that need to be fulfilled to a certain extend. The better these functions are fulfilled, the better the performance of the system.

The reason to use the system function approach is that this perspective makes comparison between innovations systems (The U.S. vs. the Dutch innovation system) with different institutional set-ups more feasible (Hekkert et al., 2007). It is assumable that some technologies will be developed or applied in one system more difficult than in another system, due to the lack of financial support, incentives, regulations, or other functions in the other system.
A disadvantage of creating insight in innovation system dynamics is that *many* functions take place in innovation systems; to map all of them is not feasible (Hekkert et al., 2007).

Therefore it is necessary to map only the most relevant functions. In literature several different functions are identified. According to the objectives of this research and NOST's preferences, the following functions are adopted and analyzed:

1. *Create incentives*

Carlsson and Jacobsson (2004) write that one of the functions of the system should be providing incentives (main drivers) that make firms want to enter the market or expand its activities, either as user or supplier of the technology. A key feature in innovation systems is creating incentives in order to stimulate the development and spread of new technologies. Incentives can be provided to producers (producer incentives) or to consumers (consumer incentives).
This element is operationalized as follow: *What incentives are available for the particular product resulting from a specific technology?* During the data gathering these question are asked to the interviewees in order to get insight how incentives are created.

2. *Regulation/ formation of markets*

Markets do not develop spontaneously (Negro et al., 2004). New technologies often have difficulty to compete with existing technologies. When new technologies are invented they are not always efficient. They might be badly adapted to their ultimate uses and they might offer very small advantages over existing technologies. Because of this, it's important to create a protected space for new technologies. Besides the formation of new markets it is also important to create favorable institutional regulations (Negro et al., 2004). The government has a critical role in influencing the creation and diffusion of technologies with regulations and market formations.
This function is operationalized as: *What is the market attractiveness for a specific technology?*

3. *Creating financial resources*

Financial resources are necessary as a basic input for all activities within the innovation system. For specific technologies, the allocation of sufficient financial resources is necessary to make knowledge production possible. Examples are funds made available for long-term R&D programs set up by the industry or government and the availability of venture capital. This function excludes financial incentives.
This function is operationalized as: *What financial resources are available for a specific technology?*

4. *Knowledge development*

According to Hekkert *et al.* (2005) mechanisms of learning are at the heart of any innovation process. The development of new knowledge is a key aspect in the innovation process. Lundvall (1992) writes; *"the most fundamental resource in the modern economy is knowledge and, accordingly, the most important process is learning"*. Thus, in the creation of new innovative technologies it is important to maximize knowledge development. Knowledge development can be achieved by various actors but is mainly fulfilled by research institutions like laboratories, universities and research centers.
This function is operationalized as: *To what extent is knowledge available for certain technologies?*

3.6 RESEARCH METHOD

In this section we will elaborate the research approach. It specifies what research methods, sources, and analysis instruments are used in order to obtain the answers to the research questions.

3.6.1 RESEARCH APPROACH

The research that is conducted can be considered as applied research. The purpose is to increase understanding of a particular problem, which will result in a solution to the problem. The research strategy applied is a multiple case study in which both the U.S. and Dutch situation are analyzed and compared. The research is carried out in the U.S. and partly in the Netherlands.

In this research a choice has to be made between the use of primary and secondary data. Secondary data is *'data that has already been collected for some other purposes'* (Saunders et al., 2007). The main advantage of using secondary data is the enormous savings in resources, in particular time and money. A disadvantage of using secondary data is aggregations meeting the requirements of the original research may not be quite so suitable for this research. Primary data is *'data collected specially for the research project being undertaken'* (Saunders et al., 2007). Primary data collection tends to entail high costs relative to its perceived nature. Nevertheless, in this research it is important to identify the current up-to-date situation. Therefore the use of primary data is favorable in some parts of the study.

Data used for the first research question (*What is a bio-based economy and what different product and technological domains can be distinguished?)* is mostly collected in the Netherlands and partly in the U.S. This part of the research has an explorative but mostly a descriptive character. An exploratory study is a valuable means of finding out 'what is happening; to seek new insights; to ask questions and to assess phenomena in a new light' (Saunders et al., 2007). Robson (2002) describes that the object of descriptive research is 'to portray an accurate profile of persons, events or situations'. Data involved in this part is qualitative and both secondary and primary. Gradually, experts on the subject are interviewed. The objective is to gain sufficient insight in the subject bio-based economy and its different technological and knowledge fields prior to answering the next research questions. The literature study is continued in the U.S. and includes the use of mainly subject specific books and governmental publications.

The second question (*What methodology is appropriate to apply in this research?)* is answered by conducting a literature study. Comparative scientific studies and scientific articles are studied in order to find the most suitable methodology.

The third research question *(What is the current situation in the U.S. and in the Netherlands?)* has an explorative purpose and is conducted in the U.S. These questions are answered by executing a multi-method qualitative study. It involves qualitative primary and secondary data, which are analyzed qualitatively. Secondary data is collected by conducting a literature and an Internet search. Primary data is collected by visiting symposia, forums, and exhibitions and by conducting interviews.

Regarding the fourth research question *(How do the current situations in the U.S. and in the Netherlands compare?)* the results of research question three are compared. Additionally, primary and secondary data is collected in order to analyze in what way the current system functions are fulfilled in both countries. To collect primary data interviews are conducted and forums, symposiums and conferences are visited. Most of the effort is made by collecting secondary data by conducting an Internet and literature search. Additionally subject related journals, governmental reports and other publications are used.

The last research question *(In what way can the Dutch government encourage the transfer of U.S. technologies to the Netherlands in order to support the development of a bio-based economy?)* is answered by using the data collected for research question three and the results of chapter four.

3.7 SELECTION OF THE INTERVIEWEES

The interviews that are conducted were semi-structured. In both the Netherlands and the U.S. interviewees are questioned. According to the first part of the literature study experts were interviewed in the Netherlands. A list with experts created by the NOST Silicon Valley formed the starting point of selecting informants to be interviewed in the Netherlands. Due to the limited available time before departure to the U.S. half of the number of selected persons were interviewed.

In the U.S. a similar list composed by the NOST has been used as a starting point to select interviewees in the U.S. Additional the 'snowball method' has been used to select other participants in the Netherlands. According to Saunders *et al.* (2007) *'sampling procedure in which subsequent respondents are obtained from information provided by initial respondents'.* This means that each expert is asked to point out further experts as participants. The method assumes that participants are aware of at least some other participants.
In the U.S. several congresses and seminars have been visited. People were met during these meetings also have been added to the participants list. These people also have been asked to point to further experts as participants.
The topics that have been of influence on composing the interview questions are:

1. *What can be considered as the current important technological developments in a' bio-based economy'?*
2. *Who are the main actors in the bio-based economy in the U.S. West Coast/ in the Netherlands?*
3. *What technologies and knowledge are these actors currently developing and applying?*
4. *What factors influencing the development of new knowledge and technologies in the U.S./ Netherlands? How do these factors look like?*

A list of interviewees and visited conferences and seminars can be found in the appendices.

3.8 COLLECTING, PROCESSING AND ANALYSING DATA

Prior to the interviews a desk research is carried out in order to collect background information from the interviewee using the Internet, newspapers, and other documentary. The interviews have mainly been carried out face-to-face, when informants where not able to be interviewed face-to-face, an interview has been conducted by telephone.
In all cases information was sent to the interviewees preliminary to the interview. Since the interviews were semi-structured the questionnaire solely included general questions and questioning topics. During the interview more specific questions were asked.
Most of the interviews have been recorded on tape, authorized by the interviewee. Directly after the interviews took taken place a summary transcript has been made. By doing so important findings could be found easily afterwards.
The meetings, conferences and seminars visited, have been selected very carefully by studying the conference program and conference topics. During these meetings several persons have been 'interviewed' as well. Although these 'interviews' were mainly briefly, they led to relevant information.

4 TECHNOLOGICAL SITUATION IN THE U.S.

4.1 INTRODUCTION

In this part of the research an overview is provided from the U.S. innovation system and from the available technologies in the U.S. in order to answer the following question:

What is the current situation in the U.S.?

The previous model and theories showed that technological development cannot be seen as isolated phenomenon, the actors and functions of the innovation system need to be analyzed as well.
The actor landscape in the U.S. covers a strong political system, leading educational and research institutions including universities and laboratories, a strongly developed industrial system consisting of technology developers and bio-products manufactures, and various important intermediaries. The larger industrial players have an influential role in creating knowledge and bringing developing technologies to the market through the funding of basic and especially applied research. Often they provide large amounts of investments to research development and demonstration collaborations between universities, local or state governments, and SME's. Intermediaries fulfill a strong information providing role between the industrial-, educational and research-, and political system. Finally, a group of influential venture capitalist is responsible for originating various sophisticated leading U.S. tech-companies mainly in the early stage of development.

4.2 POLITICAL SYSTEM

The American political system contains two important levels, the federal and state level. On the federal level three branches carry out governmental power and functions; a legislative, a judicial, and an executive branch. The legislative branch is responsible for the development and maintenance of legislation on behalf of their constituencies. These legislations are explained and applied by the judicial branch and enforced by the executive branch.

4.2.1 FEDERAL EXECUTIVE DEPARTMENTS

From the total of fifteen federal executive departments the *Department of Energy (DOE), Department of Agriculture (USDA)*, *Department of Defense (DOD)*, and the independent *Environmental Protection Agency (EPA)* are the governmental bodies that run most important programs and other initiatives affecting bio-products and its related technology development. DOE is the department that runs most important supporting programs related to bio-energy, transportation fuels and its related technological development, whereas the USDA is concerned with agriculture and other natural resources issues and strongly focuses on qualities and quantities of biomass resources nation wide.

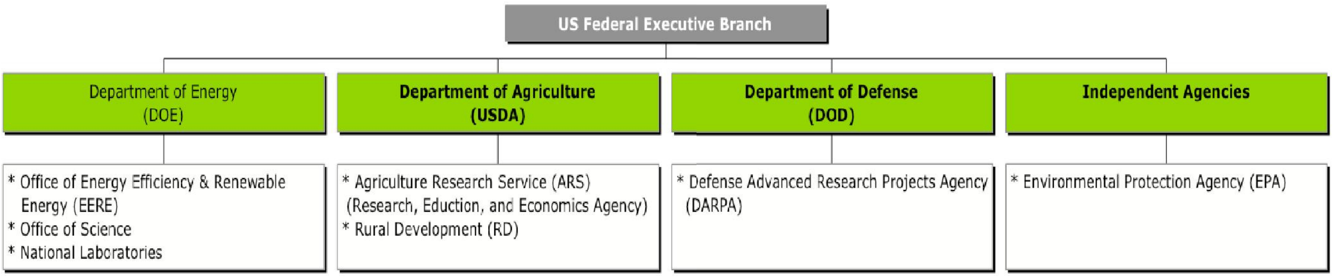


Figure 10 Overview federal executive departments, agencies and under-offices

Department of Energy (DOE)

DOE was established in 1977 after the 1973 energy crisis. Its overarching mission is to advance the national, economic, and energy security of the United States; to promote scientific and technological innovation in support of that mission (DOE, 2008). Compared with the other fourteen executive departments DOE sponsors the most basic and applied scientific research in a broad range of scientific areas, most of which is funded through DOE's chain of National Laboratories (elaborated in detail on page 32). DOE stimulates research development and demonstration projects on i.e. biomass, bio energy, cellulosic ethanol, system biology, solar and wind energy, and other types of renewable energy. Important DOE program offices are the Office of Science, and the Office of Energy Efficiency and Renewable Energy (EERE).

To execute its strategy and accomplish its goals DOE had a funding budget of approximately $ 24.3 billion over fiscal year 2008, representing 2.6 percent of the total President's budget.

Department of Agriculture (USDA)

The U.S. Department of Agriculture is responsible for regulating the safety and development of food, agriculture, and natural resources. USDA employs a variety of funding, research and supporting programs on agricultural development and improvement. USDA conducts studies in national biomass qualities and quantities, future feedstock estimations, agricultural crop improvement through genetic modification, the development of dedicated energy crops, biomass cultivation in rural areas, and researches the potential from various biomass types for the production of bio products. Influencing USDA offices are *Rural Development* and the *Agriculture Research Service.*

To carry out its policies the USDA requested a budget of $ 19.7 billion US (fiscal year 2007), representing 2.3 percent of the total President's budget (Budget of the US, 2008).

Department of Defense (DOD)

The Defense Advanced Research Projects Agency (DARPA) is DOD's research and development agency and carries out basic and applied research and development projects for military purposes. DARPA's contribution towards a bio-based economy is conduction of research into, mainly, bio or synthetic fuels for military (aviation) purposes. One notable initiative is DARPA's Bio fuel Program. The goal of the program is to develop an affordable and highly efficient process of converting cellulosic and algae feedstock to JP-8 aviation fuel, which is currently fossil fuel derived. In December 2007 DARPA organized a solicitation calling for the exploration of energy alternatives and fuel efficiency efforts. The organization has set strict quality and price goals on the conversion process and JP-8 aviation fuel. DARPA's *Strategic Technology Office* (STO) has been directed to carry out the Bio fuel Program. (DARPA, 2008)

USDA & DOE

The multi-year *Biomass Research and Development Initiative (BRDi)* is a multi agency initiative established and carried out by the USDA and DOE. The BRDi provides grants and financial assistance to private companies, universities, national laboratories, and non-profit organizations to carry out research, development and demonstrations of bio products, and technologies for their production. (BRDA, 2000)

EPA

The U.S. Environmental Protection Agency is a federal government agency of the United States charged to regulate chemicals and protect human health by safeguarding the natural environment: air, water, and land. EPA sets environmental protection legislation that may also apply to other governmental departments including the USDA, and often also affects the development of bio-based products. (EPA, 2008)

4.2.2 STATE LEVEL

State of California

With its progressive greenhouse gas (GHG) emission targets and Renewable Portfolio Standards (RPS) the State of California can be considered America's leading state concerning climate-related subjects. Governor Schwarzenegger's established RPS is intended to increase the percentage of renewable energy - derived from various sources with various technologies like anaerobic digestion, biomass, bio diesel, tidal energy, photovoltaic, municipal solid waste, or landfill gas –used in the state's electricity mix to 20 percent by 2010. Regarding bio fuels the state of California shall produce a minimum of 20 percent of its bio fuels within California by 2010. In the future both targets will be significantly higher. Early 2007 the Governor established the world's first and strictest greenhouse gas emission standard for transportation fuels; the Low-Carbon Fuel Standard (LCFS). The LCFS sparks research in alternative fuels and reduces carbon dioxide emissions. A statewide goal has been established of reducing carbon dioxide produced by transportation fuels by at least 10% by 2020.
The State of California runs a progressive policy stimulating the use of renewable energy and the development of related technologies to achieve these ambitious targets.

THE CALIFORNIA ENERGY COMMISSION (CEC)
California's Energy Commission is California's primary energy policy and planning agency. The Commission's activities include forecasting future energy needs, promoting energy efficiency, and supporting renewable energy technologies. Important initiatives running are the *Renewable Energy Program, PIER Program,* and the *Bio energy Action Plan.* (CEC, 2008)

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY
The California Environmental Protection Agency (CalEPA) is California's agency concerning environmental research, administering and regulating environmental protection programs. CalEPA coordinates the Governors *Low Carbon Fuels Standards, California's Climate Action Team & Climate Action Initiative,* and the *Hydrogen Highway Initiative*, which aims to develop infrastructure for a hydrogen transportation economy. (CalEPA, 2008)

CALIFORNIA BIOMASS COLLABORATIVE
The Biomass Collaboration is a statewide partnership of government, industry, academia, environmental organizations, and educational institutions. The collaborative works to enhance the sustainable management and development of biomass in California for the production of renewable energy, bio fuels, and bio products. The Collaborative carries out technology research and development, conducts studies of policy issues and implications, develops standards, and supports education and training. (CBC, 2008)

4.3 EDUCATIONAL AND RESEARCH SYSTEM

The education and research system consists mainly of universities and laboratories. In the U.S. a strong competition exists between state and private universities as well as a strong mutual competition between universities in general. The state universities are state funded and carry out fundamental research within a broad range of topics. They often administer and manage multi-actor research initiatives set up by the state or federal government composed of other universities, private companies (large, medium and small), private persons, and/or laboratories.
Laboratories are mainly federal funded. Most of the federal, National, laboratories are coordinated and funded by the U.S Department of Energy and have an energy related research history. This actor group conducts fundamental as well as applied research. National laboratories closely collaborate between all the actors in the system; companies, government, and universities. Therefore the U.S. National Laboratories can be considered as an influential actor group in the technological innovational landscape.

4.3.1 UNIVERSITIES

The prime universities that carry out research activities with respect to the development of bio products are visualized in Figure 11.

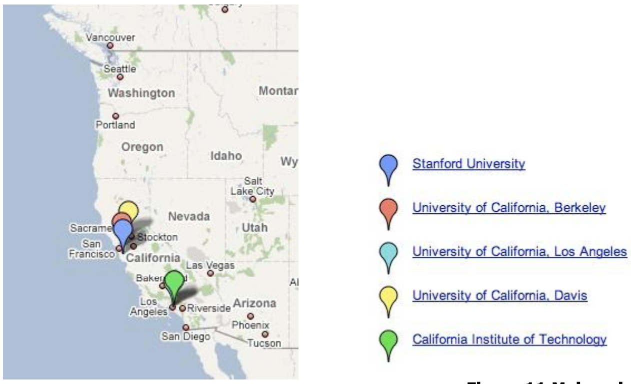


Figure 11 Main universities in Western United States

Stanford University

The private Stanford University (Palo Alto, CA) is the world's leading university. The university offers a broad range of academic and research programs and facilitates interdisciplinary research in its schools and departments, but also in its laboratories, institutes and research centers.
Several academic departments carry out basic research activities related to bio-based products, like the department of Biochemistry, Bioengineering, Biological Science, System Biology, Energy Resource Engineering, Genetics, and Chemical Engineering.
Stanford's Carnegie Institution Department of Plant Biology can be considered as one of the U.S. West Coast most prominent institutes with respect to the study of plants and other living organisms; an important scientific area within a bio-based economy. The Department of Plant Biology engages in basic research in modern plant science and has research interests in plant wall polysaccharide synthesis, mechanisms of Disease Resistance, Plant Molecular Biology, and Plant Cell Development. (Stanford, 2008) Stanford furthermore runs the Global Climate and Energy Project (GCEP). This collaboration (sponsored with $250 million by ExxonMobile, general Electric, Schlumberger, and Toyota) between research institutions and private industry seeks new solutions in sustainable green energy supply. (Stanford, 2008)

University of California, Berkeley

The prestigious UC Berkeley, third in the list of Top 500 World Universities, can be considered as leading public university regarding basic research into various bio products, sustainability of resources, biosciences, and greenhouse gas emissions. Various departments and institutes work to find solutions to several challenges in the field of new and existing energy recourses. One of these is the Energy and Resources Group (ERG) that performs programs issuing energy, energy resources, governance, global climate change, and new approaches to think about economics and consumption. Important institutions at UC Berkeley are the California Institute for Quantitative Bioscience (QB3), the Synthetic Biology Engineering Research Center (SynBERC), HELIOS, the Environmental Combustion Group, and the Renewable and Appropriate Energy Laboratory (RAEL).
UC Berkeley houses the Lawrence Berkeley National Laboratory, the Joint Bio energy Institute and the Energy Bioscience Institute. (UCBerkeley, 2007)

University of California, Los Angeles

Public research university Los Angeles (UCLA) is one of the oldest campus universities in the University of California system.

UCLA’s department of Chemical and Biomolecular Engineering is the department that makes contributions to environmental chemical engineering. They conduct research related to environmental protection and clean technologies of the future. Current research programs include biomolecular engineering, systems engineering, energy, and environment. UCLA furthermore houses the Hydrogen Engineering Research Consortium, Metabolic Engineering and System Biology Laboratory, the Combustion Research Laboratory, and the Bio chemical Engineering Laboratory. (UCLA, 2007)

University of California, Davis

UC Davis (Davis, California) is one of US’ top-4 public state universities. The university facilitates a broad range of academic and (multidisciplinary) research programs, research centers and institutes. The university has a strong focus on agricultural & environmental science, and especially on biological sciences. Research is carried out into plant science, biotechnology, microbial ecology, environmental science and policy, agriculture and resource economics, (bio) energy systems, organic residue conversion systems, and assessment studies to dairy manure technologies and products. The university facilitates several laboratories. Two of them are the Biomass Utilization Lab and the Bioprocess Engineering Lab.
Recently UC Davis established the Energy Institute, focusing on sustainable energy, energy efficiency, bio fuels, solar energy, waste-to-energy, and carbon dioxide emissions, and the Bio Energy Resource Group (BERG), seeking solutions for the development of heat, power and fuels from biomass.
UC Davis also administers the Californian Biomass Collaborative, a state-wide collaboration between government, industry, environmental groups, and educational institutions. (UC Davis, 2008)

California Institute of Technology

California Institute of Technology, or *Caltech*, is ranked sixth in the list of Top 500 World Universities. The private university (Pasadena, CA) offers academic programs including biology, chemistry and chemical engineering, engineering and applied science, and interdisciplinary programs like biochemistry, bioengineering, and environmental science & engineering.
The research area of the biology department includes structural, molecular and cell biology. The chemistry and chemical engineering department works on subjects covering protein engineering, bio catalysis, bio energy, bio materials, bio molecular cell engineering, and combustion.

4.3.2 NATIONAL LABORATORIES AND RESEARCH INSTITUTES

The figure below represents the important National laboratories and Research Institutes located at the U.S. West Coast states.

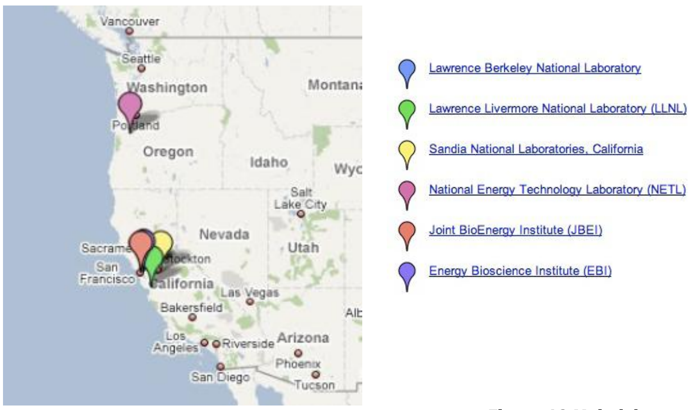


Figure 12 Main laboratories in Western United States

Lawrence Berkeley National Laboratory (LBNL)

LBNL, or the Berkeley Lab, is part of DOE's Office of Science. The laboratory is located, managed and coordinated by UC Berkeley. The laboratory conducts unclassified research across a wide range of scientific disciplines with key efforts in quantitative biology; nanoscience; material science, chemical science, new energy systems and environmental solutions.
At LBNL's Environmental Energy Technologies Division physical science research is conducted in support of energy technologies. Research is aimed at developing more environmentally friendly technologies for generating energy, including low-emission combustion, advanced materials and nanotechnology for cleaner energy, and biosythetic pathways for generating hydrocarbon fuels. Furthermore research includes climate assessment and modeling studies, studying energy policy, advanced transportation technologies, and studying the area of water and energy efficiency.

Lawrence Livermore National Laboratory (LLNL)

Lawrence Livermore National Laboratory (LLNL) is an applied science laboratory once started as an institute for nuclear weapon research. The Livermore based laboratory is owned by DOE's National Nuclear Security Administration (NNSA). Besides research into nuclear weapons and preventing the use of mass destruction weapons the laboratory utilizes programs in non-defense areas such as energy, environmental science, and biosciences. LLNL undertakes studies in the genetics and metabolism of microbes that produce long chain hydrocarbons to explore the possibilities of developing practical sources of non-ethanol liquid fuels. The lab LLNL is one of the six partners in DOE's Joint Bio energy Institute. (LLNL, 2008)

Sandia National Laboratories, California (SNL)

Sandia Laboratories, with facilities in New Mexico (Albuquerque) and California (Livermore), has its roots in research into defense, homeland security and nuclear weapons. The laboratory is one of DOE's (National Nuclear Security Administration) national research laboratories and is managed and operated by the Sandia Corporation. Beside Energy, Resources and Non-Proliferation Sandia's main area of interest is Renewable Energy. Sandia's purpose is to develop commercially viable renewable energy technologies based on solar, wind, and geothermal resources. Sandia runs the Water Initiative in which the objective is to increase the safety, security and sustainability of water infrastructure through the development of advanced technologies that create new water supplies, and decrease demand through water-use efficiency; the use of water heavily affects biomass cultivation and the manufacturing of bio products. (Sandia, 2008)

National Energy Technology Laboratory (NETL)

The National Energy Technology Laboratory is the only national laboratory in the U.S. mainly concerned with fossil energy research, although they also undertake efforts in renewable energy research. The lab has facilities spread out over five sites. The only West-U.S. site is located in Albany, OR. NETL's various key research issues are climate change, clean power generation (mainly coal power plants), hydrogen economy, and renewable energy and energy efficiency. The lab supports the DOE Office of Energy Efficiency and Renewable Energy's (EERE) mission by managing research and development projects for EERE. NTEL's contribution is supporting portions of the industrial technologies, biomass, and other federal energy programs. NETL is owned and coordinated by the Department of Energy. (NETL, 2008)

Joint Bio energy Institute (JBEI)

The recently founded Joint Bio energy Institute aims to develop basic science and technology needed to produce sustainable, carbon-neutral fuels from biomass. JBEI focuses on three main areas i) the production and development of plants that have been engineered to be feedstock for energy, ii) the breakdown of cellulose to sugars using enzymes (oa. Synthetic biology to 'engineer' microbes through genetics), and iii) the conversion of these sugars to fuels (Keasling, 2007). JBEI is one of the three DOE Bio energy Research Centers. DOE's Lawrence Berkeley National Laboratory will lead and facilitate this multi agency collaboration project. JBEI is expected to receive $125 million in DOE funding over five years. (JBEI, 2008)

Energy Bioscience Institute (EBI)

The Energy Bioscience Institute is a new collaboration between UC Berkeley, Lawrence Berkeley National Laboratory, University of Illinois at Urbana-Champaign, and BP, who will support the institute with a 10-year $500 million grant. EBI conducts research into problems that include the sustainable production of cellulosic ethanol fuels, enhanced biological carbon sequestration, bio processing of fossil fuels, and biologically-enhanced petroleum recovery. The institute will be led by UC Berkeley's California Institute for Quantitative Biosciences (QB3). (SF Business Times, 2007)

4.4 INDUSTRIAL SYSTEM

The industrial system consists of both small, medium enterprises (SME's), and large enterprises. An overview of the most important actors is provided for each bio product sector; the *bio fuel, bio chemical,* and *bio energy-sector*. The bio chemical sector also includes industrial biotechnology companies. These companies produce and/or use microorganisms (enzymes) that are used to catalyze industrial processes as they are applied in industrial, food, agriculture, and the bio fuel industry.
As demonstrated in Figure 3 and Figure 4 on page 16, the market share of bio products is growing, so are the number of companies. In the U.S. the two most rapidly growing renewable fuel types are ethanol and bio diesel. The bio diesel consumption between 2003 and 2005 grew more than 400 percent. In the same period ethanol (E85 as well as ethanol in gasohol) consumption grew with 44 percent, resulting that in this section the most interesting bio fuel players are the producers of ethanol and bio diesel.
Primary green renewable resources in America used for bio products are corn, soybean and switch grass. In the US these agriculture commodities are growing mainly in the area between the Great Plaines and the Great Lakes. This area includes the states Minnesota, Illinois, Wisconsin, Nebraska, Kansas, and Iowa. Because of this the most and the largest bio product producing companies like Cargill, DuPont, Archer Daniels Midland Company, Abengoa, POET Energy, and Verasun Energy Corporation are located in these states.

4.4.1 BIO FUELS- ETHANOL

In March 2009 there where nine operational bio refineries in the Western United states that produce ethanol with a gross annual capacity of 1,145 million liter. The five facilities that are currently under construction will increase annual capacity to 1,825 million liter. The largest US West-coast producers are Pacific Ethanol, Pinal Energy and Phoenix Bio fuels. In the appendices an overview is provided from plants in operation and plants that are under construction. (RFA, 2009)

Pacific Ethanol Inc.

Pacific Ethanol is the largest bio ethanol producer in the Western United States. Pacific Ethanol (NASDAQ: PEIX) has an annual capacity of 780 million liter, which represents more than 1 percent of the US national ethanol production. The firm has four plants in operation (Madera, California and Boardman, Oregon, Stockton, California and Burley, Idaho). (RFA, 2009)

Pinal Energy Processors

Pinal Energy is the second largest bio ethanol producer in the Western United States. Pinal Energy is Arizona's first ethanol production facility. (Pinal, 2008) (RFA, 2009)

Phoenix Bio fuels LLC

Phoenix Bio fuels is the Western United States third largest bio ethanol producer. The company is a subsidiary of Phoenix Consulting Group International LLC. The firm has one production plant in Goshen, California, with a capacity of 95 million liter a year. (Phoenix, 2007) (RFA, 2009)

4.4.2 BIO FUELS- BIO DIESEL

In the U.S. West Coast states twenty-five bio diesel production facilities are present in 2007. The state California represents the largest amount of plants (eleven), with a production of 162 million liter a year. The state Washington though, represents fewer facilities but represents a higher production rate; 500 million liter a year. The largest West Coast producers of bio diesel are *Imperium Renewables, Domestic Energy Partners, Imperial Western Products, Seattle Bio diesel,* and *Bio diesel of LasVegas. (NBB, 2007)*

Imperium Renewables.

The annual production of 380 million liter makes Imperium Renewables (Washington) the largest bio diesel producer in the United States. Imperium Renewables *(Imperium Grays Harbor)* produces its bio diesel from canola, soybeans and other crops. (NBB, 2007) (Imperium, 2007)

Domestic Energy Partners

Domestic Energy Partners (Utah) is the second largest bio diesel producer at the US West Coast. The company has an annual capacity of 34 million liter. (NBB, 2007)

Bio diesel of LasVegas

Bio diesel of LasVegas has currently one plant in operation and is constructing a new plant with a capacity of 227 million liter a year. This production facility will be one of the nations largest bio diesel plants, and will use waste vegetable oils that the company will collect at restaurants or import from abroad. (NBB, 2007) (Bio diesel Las Vegas, 2007)

4.4.3 BIO CHEMICALS

A second industrial sector is the bio chemical. Important bio chemical companies, including biotechnology businesses, are *DOW Chemical Company, Novozymes, Genencore, Codexis, and LS9 Inc.*

DOW Chemical Company

DOW (San Diego, CA) is one of the leading chemical producing companies in the world. The company's net sales of $ 53 billion (2007) is generated by its operating segments; performance plastics, basic plastics, performance chemicals, basic chemicals, agricultural sciences, and hydrocarbons & energy. In contradiction with other large chemical companies DOW has locations at West Coast States; it's corporate research and development (R&D) facility is located in San Diego (CA). Here, DOW conducts research into Industrial biotechnology: Applying biotechnology to produce chemicals and proteins from renewable resources. (DOW, 2007)

Novozymes

Novozymes is a Danish industrial biotechnology company with divisions all over the world. Novozymes focuses on research and development of enzymes and microorganisms for industrial and consumer product technologies. Net sales in 2007 were $ 1.2 billion. The company offers solutions in the business areas enzymes, biologicals, biopharma, and biopolymers. Enzyme development is expected to accelerate the production of bio fuels dramatically. The latter is one of the growing industries in which Novozymes is operating. The firm offers several enzyme products that accelerate and optimize biomass conversion processes. Novozymes has a fully owned research and development facility in Davis, CA. Here they conduct research and development in the fields of molecular biology, protein chemistry, chemical engineering and microbial physiology. (Novozymes, 2007)

Genencor

Genencor (Palo Alto, CA) is part of the Danish multinational Danisco. Genencor develops, discovers, manufactures, and delivers enzyme products for agricultural, industrial, and food & beverage industries, as well as consumer products, and bio fuels. Genencor develops its products through advanced technologies in gene expression, protein chemistry, and protein engineering. Genencor holds its only USA research facility in the centre of Silicon Valley, Palo Alto. Danisco's net sales were $ 3.2 billion in 2007 (Genencor, 2007)

Codexis

Codexis evolves enzymes for use in optimizing processes in a broad range of industries. Codexis (Redwood City, CA) offers products and services for two major branches, the pharmaceuticals and bio industrials. In the latter, Codexis serves several markets; bio fuels, industrial chemicals, air, and water treatment. In the bio fuels the firm is collaborating with Shell to develop next-generation bio fuels from biomass. Codexis is using bio catalytic approaches to find pathways for developing economically feasible transportation bio fuels from renewable resources. In industrial chemical manufacturing the corporation offers clean bio catalysis. (Codexis, 2007)

LS9 Inc.

LS9 Inc. is an industrial biotechnology company based in South San Francisco, California developing bio fuels made with the power of synthetic biology. LS9 is the market leader for hydrocarbon bio fuels and is rapidly commercializing and scaling up DesignerBio fuels™ products to meet market demands, including construction of a pilot facility leading to commercial availability. While initially focusing on fuels, LS9 also develops sustainable industrial chemicals for specialty applications. LS9 is supported by Khosla Ventures and by two other venture capital firms. LS9 is located in San Carlos, CA. (LS9, 2008)

4.4.4 BIO ENERGY

The industrial bio-energy actors can be separated in two groups: a) the developers (or suppliers) of conversion systems for energy generating purposes, and b) electricity and heat producers, or power plants.

4.4.4.1 DEVELOPERS

Dynamotive Energy Systems Corporation

Dynamotive Energy is a public traded company, founded in 1991, developing biomass-to-liquid technologies. Their fast pyrolysis technology converts dry waste biomass and energy crops into BioOil, char and gas. BioOil can be used as fossil fuel replacement in industrial applications to generate heat and electric power. The co-product char is used as fertilizer, as feedstock for heat production, and to manufacture charcoal briquettes. In fiscal year 2007 the firm made $15,4 million loss from operations. The firm has offices in the USA and Argentina. (Dynamotive, 2008)

Nexterra Energy

Vancouver (Canada) based private company Nexterra Energy develops gasification systems to produce syngas applied as major or additional renewable fuel in boilers, dryers, heating systems or in steam turbines for power generation. The firm constructed six plants with its technology, all for heat and electricity producing purposes in industrial and residential applications. (Nexterra, 2008)

4.4.4.2 POWER AND HEAT PRODUCING PLANTS

Wheelabrator Shasta Energy Company

Wheelabrator Shasta is a waste processing company that owns and operates California's (Anderson, Shasta) largest 100 percent biomass-fired power plant. The plant has a capacity of 58 MW and processes annually 750,000 short tons of mill waste en forest residues. The firm is a wholly owned Waste Management Inc. subsidiary. (Wheelabrator, 2008)

Colmac Energy Corporation

Colmac Energy operates the second largest biomass-fired electric power plant facility at the US West coast. The plant's capacity is 47 MW and uses agricultural residues, municipal and commercial wood-waste. The plant started operations in 1992. (Colmac, 2008)

4.5 INTERMEDIARIES

Intermediaries fulfill an interfering role between the various actors in the innovation system. They facilitate the exchange of knowledge, opinions, and developments between the industry, individual actors, venture capital firms, universities and laboratories. Intermediate organizations also fulfill an important advocate role between the industry and local or federal government. Together they work on new legislations or reform current legislations. Due to this advocate role the industry sector, individuals, venture capital firms, universities and laboratories are kept up-to-date about the latest developments. This report pointed out that the most important intermediary organizations in the U.S. are *Biotechnology Industry Organization (BIO), BayBio Northern California's Life Science Association, The Renewable Fuels Association, The National Bio diesel Board,* and *LifeSciences British Columbia.*

BIO, Biotechnology industry Organization

Bio is the world's largest biotechnology organization, providing advocacy, business development and communication services for more than 1200 members worldwide. Besides medical biotechnology (in Europe often referred to as red biotechnology) and agricultural biotechnology (often referred to as green biotechnology) BIO also emphasizes industrial biotechnology (white biotechnology) that finds a promising application in the manufacturing from various biomaterials. BIO is located in Washington, DC.

BayBio

Northern California has the largest cluster of life sciences companies. South San Francisco can be considered as the center of biotechnology, this is where BayBio is located. BayBio is Northern California's life science association. They support the regional bioscience community through advocacy, enterprise support, and the enhancement of research collaboration. Its members include organizations engaged in, or supportive of, research, development and commercialization of life science technologies. (BayBio, 2008)

Renewable Fuels Association (RFA)

The RFA is America's national trade association for the ethanol industry. RFA promotes policies, regulations and research and development initiatives that will lead to the increased production and use of fuel ethanol. The RFA producer members represent 90% of the U.S. ethanol production. The RFA is originated in 1981 and located in Washington, DC. (RFA, 2008)

National Bio diesel Board (NBB)

The NBB is the RFA for the bio diesel industry; they represent and support the U.S. bio diesel industry. NBB coordinates and interacts with industry, government, and academia. NBB is located in Jefferson City, Missouri. (NBB, 2007)

LifeSciences British Columbia.

British Columbia is the seventh largest biotechnology centre in North America by number of companies, and the fastest growing in Canada. LifeSciences British Columbia represents and supports the biotechnology, medical device, and greater life sciences community of British Columbia through advocacy and promotion. Its members include; academic and research institutions, associations, government, and industry.
The organization has a focus on several sectors; bio products & bio energy, industrial & environment biotechnology, bioinformatics, forest biotechnology, agricultural biotechnology, and marine biotechnology. (LSBC, 2008)

Clean Edge

Clean Edge is the market authority with a focus on the cleantech sector. They are a research and publishing company that tracks and analyzes clean-tech markets, trends, and opportunities. The organization runs several cleantech benchmark indexes and organizes summits for researchers, investors, governments, technology providers, and private persons. CleanEdge residens in the San Francisco Bay Area. (CleanEdge, 2009)

4.6 VENTURE CAPITAL

Venture Capital (VC) firms fulfill an important role in providing financial resources to the system of innovation. VC's create venture capital funds where mainly institutional and individual investors pool together investment. VC's mainly invest in early-stage, immature, high potential growth companies. They scout for start-ups or early-stage businesses to invest in and often are adding management or domain expertise to the company. VC's sometimes work closely together since sometimes investors are partners at other VC' as well.
Most of the important VC's (related to investments in firms involved in bio products, bio energy, and mainly bio fuels) are located at Menlo Park's Sand Hill Road. These firms are; Khosla Ventures, Kleiner Perkins Caufields & Byers, and Draper Fisher Jurvetson. One more firm is located in Fremont; BASF Venture Capital America.

Khosla Ventures (Menlo Park)

Khosla Ventures (Menlo Park, CA) has an investing focus on early-stage ventures. The firm was founded in 2004 by former Sun Microsystems co-founder Vinod Khosla. Kohsla Ventures is considered by many experts as leading VC in renewable energy. Its portfolio includes 26 renewable start-ups mainly bio fuel orientated. The firm is particularly interested in the sectors mobile, alternative energy, and bio refineries. Some of Khosla's investments to date are Amyris Biotechnology (synthetic biotechnology), LS9 Inc. (industrial biotechnology), Mascoma Corporation (bio fuels), and Gevo Inc. (bio fuels). Khosla Ventures works closely together with Kleiner Perkins Claufields & Byers, they share investments in companies like AltaRock and Mascoma. (Khosla, 2008)

Kleiner Perkins Caufields & Byers (KPCB, Menlo park)

KPCB is a venture capital firm founded in 1972 and investing in early-stage businesses. Since that time they contributed to the funding of leading companies like Amazon, Google, Sun, and Genentech. The firm seeks for investment opportunities in the greentech sector but also in information technology, life science, and pharmaceuticals. Current portfolio companies are Amyris Biotechnology, Altra Bio fuels, Mascoma Corporation (bio fuels), but also companies like Fisker Automotive (plug-in hybride vehicles), Alta Rock Energy (geothermical systems), and Bloomenergy (fuel cells). (KPCB, 2008)

Draper Fisher Jurvetson (Menlo Park)

DFJ, Menlo Park, was founded in 1985 and has been backing over 500 companies across many sectors. Some of the firm's successes were Hotmail, Skype, United Online, and TicketsNow. The firm seeks investment opportunities across the sectors consumer applications, media, energy, cleantech, hardware, mobile and nanotechnology. Currently the firm has participations in about 35 companies active in the energy/cleantech industry. Some current participations are Bio fuelBox (Modulair bio fuel production), EdenIQ (bio fuels), Coal Tech (clean coal technology). (DFJ, 2008)

BASF Venture Capital America Inc. (Fremont)

BASF Venture Capital is part of the German BASF Group. Besides its European activities the firm scouts for investment opportunities in Asia and in the U.S. BASF venture capital group has several hundred deals a year. Each year two or three firms are acquired in the U.S. Since 2001 BASF venture capital America has eight direct investments in North America and six fund investments; three in Canada and three in the U.S.
The company has an investment focus on five clusters; plant biotechnology, industrial biotechnology, raw material change, nanotechnology, and energy management. Some current participations are Luca Technologies (Golden (CO), Industrial biotechnology), and Arcadia Bioscience (Davis (CA), Agricultural/Industrial biotechnology). (Gillard, 2007)

4.7 AVAILABLE TECHNOLOGY AND KNOWLEDGE

In this section an overview of the current technology and knowledge base is provided. The first chapter already elaborated that the technological areas of interest in the biomass-to-bio product lifecycle are *feedstock production* and *processing and conversion technologies*. On the next pages the currently available technologies in both areas are summarized and assessed on current status and latest technological developments.

4.7.1 FEEDSTOCK PRODUCTION TECHNOLOGIES

Biomass feedstock is essential in the biomass supply chain. The size of our future bio-based economy will, to a large degree, be determined by the quality and quantity of biomass available (Biomass, 2007). The current developments in feedstock production technologies are concerned with three major barriers that need to be overcome concerning feedstock quality and quantity; *resource availability and costs, sustainable production,* and, *improved crop genetics.*

Since these areas mostly address scientific basic research, often no concrete technologies can be appointed.

Additionally, one extra theme is pointed out that has a growing public interest and offers a large potential for the production of bio fuels and bio energy, which is *algae.*

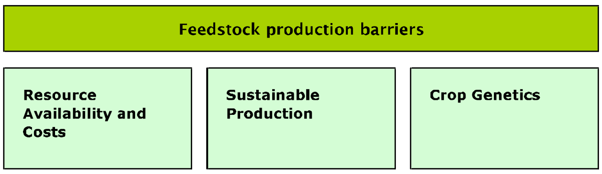


Figure 13 Feedstock production barriers (Biomass, 2007)

4.7.1.1 Resource Availability and Costs

Current estimates of feedstock resources are limited in scope, therefore it is necessary to gather information on price, location, yields, quality and quantity of different types of feedstock. Large research efforts are currently conducted at Oak Ridge National Laboratory on feedstock and environment research and development to improve yield, costs, and quality of biomass (EERE, 2009). Idaho National Laboratories is currently investigating methods to enhance cost-effective agricultural processes that can reduce the cost of feedstock. (EERE, 2009).

On state scale, agencies like the *California Energy Commission* and the *Oregon Biomass Coordination Group* gather data on inner state biomass availabilities and make this valuable data commercial available for many actors.

4.7.1.2 SUSTAINABLE PRODUCTION

Sustainable production copes with the limited knowledge on the environmental effects of feedstock production. The production and use of energy crops raises a number of sustainability questions concerning the impact on water, fertilizer, soil use and other related subjects. Characteristics of current and potential 'new' crops require to be improved. At Idaho National Laboratory, UC Berkeley, UC Davis, and EBI research and development is going on with respect to cost-effective harvesting, collection, utilization and sustainable production. The latter theme is also a point of focus at Oak Ridge National Laboratory. (EERE, 2009)

4.7.1.3 GENETICS, GENOMICS, AND PLANT SCIENCE

Genetics (1), genomics (2), and plant sciences (3) have the potential to have large impacts on the development of low-costs bio energy, bio chemicals, and especially bio fuels.
Crop genetics copes with the lack of information on plant genomics and metabolic data on many different potential crops for bio-product purposes. New information and more complete data can provide insights on the effects of genetic modification of 'bio-product'-crops; dedicated crops for the production of bio-products. (Biomass, 2007). Identifying and mapping the plants genomic characteristics allows further research in the engineering of 'new' plants with more favorable characteristics; higher energy yields, better resistance to temperatures, better resistance to insects and diseases, less water consumption, more easily convertible e.g. By doing so cost of bio products will drop significantly. Nevertheless, engineering 'new' plants requires a significant amount of work and time. Genetic modified crops are already on the market for a long time. Missouri based Monsanto Company sells a variety of modified crops that are resistant to specific pesticides and herbicides. Modified energy crops are not brought to the market yet. Hayward, CA based Mendel Biotechnology is a plant biotechnology firm that develops energy crops for second-generation bio fuel production with enhanced yield and quality and is expected to commercialize its products in the next decades (Mendel, 2008).

There is also a group of organizations that are combining genetics, genomics and biology to what is called *synthetic biology*. They conduct research in order to 'engineer' the right microbes (enzymes) to produce or future second-generation bio fuels. Firms like LS9, Amyris, Synthetic Genomics, Solazyme, Gevo and the research institutes UC Berkeley and JBEI try to find the perfect microbes (cellulases/ enzymes) that break down cellulose. There are many different cullulases but they need to be found, in termites, kettle and microbes that live under the ground for instance. When these are found these firms clone the genes and test them in order to find the best one (transgenetic modification). Some of these firms already demonstrated they could engineer interesting molecules that might make good bio fuels.

In 1997 the DOE Joint Genome Institute (JGI) has been established, a collaboration between six research institutions. JGI is specialized in genome mapping and DNA sequencing and already has been very successful by doing so. JGI for instance delivered the assembly and annotation of a soybean genome (soybeans form an important feedstock for bio diesel production.), found the first moss genome and sequenced genomes from a super fermenting fungus. The institute's target encompasses a rapidly expanding range of microbes, animals, and plants.

A last important research area is plant science; understanding the plant functions and chemical composition. Knowing the biochemistry of plant components lignin, cellulose, and lignocellulose are important to develop tomorrows advanced conversion methods for second-generation bio products. Stanford University is one of the important institutes that contribute to plant science as well as to plant genetics and genomics. Stanford's Carnegie Institution, the Department of Plant Biology, carries out basic research on the mechanisms involved in the growth and development of plants and algae. The department focuses on plant cell development, plant molecular biology, bioinformatics and system approaches in biology, cell wall polysaccharide synthesis, and mechanisms of disease resistance (Stanford, 2007). The recently established Joint Bio energy Institute (JBEI) also contributes to these knowledge areas. The institute develops the basic science and technology to create an array of environmentally friendly bio fuels using microbes as well as plant biomass. (JBEI, 2007) (JGI, 2007).

4.7.1.4 ALGAE FEEDSTOCK

Algae are considered as a promising renewable source for the production of transportation bio fuels, bio energy and various other bio products. Algae's ability of carbon dioxide capturing, ability to grow in brackish or saline water, high lipids (oil) content, and the fact that algae do not compete with food are the major characteristics that make algae a very attractive renewable resource. Commercial algae mass production, in an economical attractive way, still has several major technological limitations. Hence, the large-scale algae production for commercial fuels or energy purposes has not been realized yet.

SPECIE SELECTION

The first hurdle is the selection of the right algae specie. There are around a thousand different algae species, each containing different characteristics. Selecting the right algae specie with the preferable characteristics is a very expensive and time-consuming process. One of the developments is mapping algae specie characteristics for future efforts. Thirty years ago, NREL started to study about 3,000 algae species and documented their specific characteristics. The study was part of their *Aquatic Species Program.* To date NREL still poses very valuable algae specie knowledge and they are still studying more species. Another way to obtain the algae with the right characteristics is genetically modifying. Research in modifying algae is conducted by several companies and laboratories, including *NREL, Sandia Laboratories, Aurora Bio fuels (*Alameda, CA), and *Live Fuels Inc.* (Menlo Park, CA). Modifying algae is a very expensive process since the pathway of obligatory legislative approvals is very long. None of these companies have succeeded in creating the right algae for commercial large-scale cultivation yet.

HOMOGENEOUS CULTIVATION

A second barrier is the controlled and continuously homogeneous algae grow. Algae grow relatively fast. A colony of a selected algae strain is very easily 'infected' with other algae species. A large amount of companies, universities and laboratories are studying methods for efficient and controlled algae cultivation. Current methods are algae cultivation in open systems or in closed photovoltaic-bioreactors (bioreactors). Open systems, mostly raceway ponds, are relatively cheap but have a high chance of algae 'wild growth'. Companies studying algae cultivation in open raceway ponds are *Kent Seatech Bio energy Division* (San Diego, CA), *Aurora Bio fuels,* and *Live Fuels Inc.* Actors experimenting with bioreactors are *Global Green Solutions Inc. (Vancouver, BC), Solix Bio fuels, Ocean Technology and Environment Consultancy (San Francisco, CA), XL Renewables, Diversified Energy Corporation,* and several research institutions like *UC Berkeley,* and *NREL*. Bioreactors exist in a broad variety. *XL Renewables* is using an innovative patent-pending algae cultivation and production system called SIMGAE (licensed to *Diversified Energy Corp.).* The system utilizes a series of clear polyethylene tubes laid out parallel across an agriculture field. The tubes are buried in the soil for 50 percent for optimal warmth insulation. Other technologies are modular cultivation and harvesting systems, called Vertigro, developed by *Global Green Solutions*. The algae are grown in vertical bioreactors constructed from plastic sheeting.

HARVESTING

The third technological hurdle is algae harvesting and oil extraction. Since algae are aquatic species it is energy and time consuming to de-water the algae biomass. One of the methods is freeze-drying. The drying method is an energy consuming process and therefore relatively expensive. The oil extraction (about 50 percent of the algae body mass consists of oil) is a second difficult process, and also can be very expensive since it will be a very energy intensive process. An often-applied method is the use of solvents like hexane, benzene, methanol or acetone, to 'soak out' the oil. However, most of these solvents are flammable which makes this method a risky operation. Another disadvantage is the need to remove the solvents, which again, is an expensive process. Recently the South San Francisco based *Solazyme* announced its collaboration with United States largest bio diesel producer*, Imperium Renewables*, to deliver large quantities of algae crude (100% algae oil) for the first mass production of algae derived bio diesel. *Solazyme* uses synthetic biology principles to derive the algae oil.

4.7.2 PROCESSING AND CONVERSION TECHNOLOGIES

Processing and conversion technologies include a variety of techniques that convert renewable feedstock into bio products. Some of these techniques are uncomplicated like burning wood to produce heat and electricity. Other techniques can be quite complicated such as Bio chemical Conversion of hemi-cellulosic biomass to high-quality transportation fuels. The type of conversion method highly depends on the type of feedstock and the desired product. Often various different processing and conversion technologies supplement each other and are used sequentially during the production of bio products.
Two primary conversion pathways are *Thermo chemical-* and *Bio chemical Conversion*. Thermo chemical Conversion covers heat, chemical and pressure-based Conversions, whereas Bio chemical Conversion technologies include biological processes (the use of living organisms) that convert renewable feedstock into bio products. Many of the Thermochemical Conversion technologies are in the introduction or growth stage and widely applied and even more on large scales. Most of the technologies are already used for centuries and are started to be adapted for biomass conversion recently. Most of the current developments contribute to output-quality improvement, energy and production efficiency. Thermochemical Conversion technologies can be used to manufacture a wide range of products from an array of organic feedstock.
On the other hand, many Bio chemical Conversion technologies are far from mature and are still in development or in the introduction stage.

Appendix 1 and 2 represent the most common conversion pathways for various biomass types and the most common bio products. The blue boxes represent the commercial availability.

4.7.2.1 THERMOCHEMICAL CONVERSION TECHNOLOGIES

Thermochemical Conversion methods use heat and pressure in order to convert biomass into liquids or gasses. Most of the Thermochemical Conversion (TCC) technologies are already applied effectively on large scale to convert a variety of feedstock, fossil and renewables, into fuels, chemicals and energy. The combustion of wood can be considered as one of the earliest TCC technologies in human mankind, more advanced TCC technologies are gasification and fast-pyrolysis of wood to bio-liquids. Most of the thermochemical end-products are generally intermediate products (liquids and gasses) that can be further converted into more valuable bio products like chemicals, transportation fuels, heat and electricity.

Figure 14, on the next page, illustrates the major TCC pathways and its products. In the next sections we will briefly elaborate these technologies, the current initiatives employed, and the technology status.

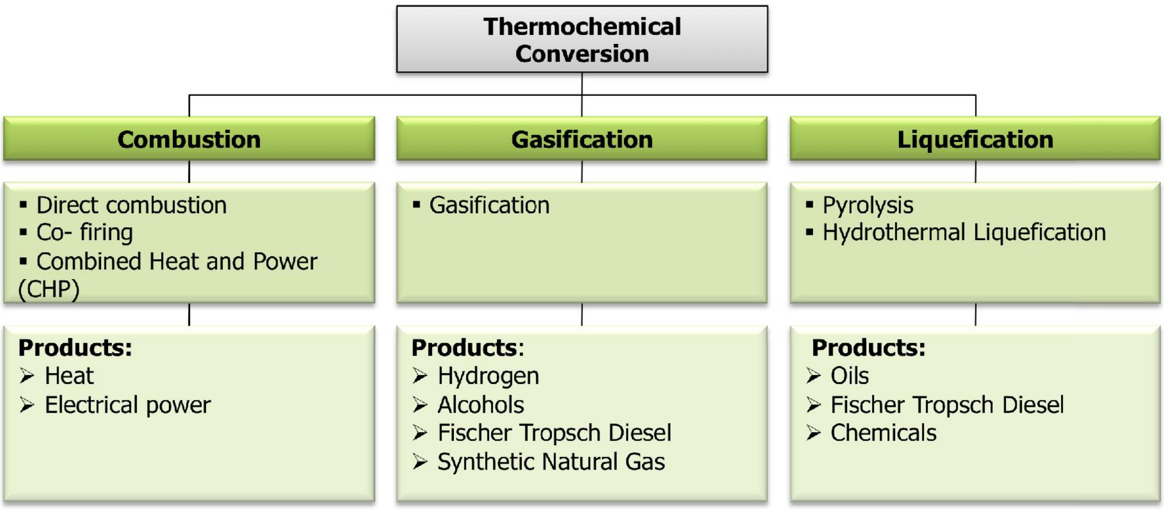


Figure 14 Thermo chemical conversion pathways

Combustion and Co-Firing

Combustion is the most common and oldest conversion technology worldwide. It is a mature technology and widely applied for heat and power production although it is mainly used for heat production. Direct combustion is used globally by millions of people in their homes to meet their energy needs. Combustion is applied on large scale for electricity and heat production. The state of California locates 21 operating biomass (direct) combustion facilities, which burn primarily forest wood/product residue, urban wood waste, and some agricultural residue (fruit pits, seed/grain shells or husks, and woody tree removal or pruning). Almost half of these are re-using heat for own industrial processes. Current biomass combustion power plants are relatively small. Capacities of these facilities range from ~10 MW to 50MW, whereas the largest Californian (natural gas fired) power plant's capacity is 2000 MW. Three more combustion plants in California directly burn municipal solid waste, or 'household garbage' (a.k.a. waste-to-energy). Biomass co-firing is often applied in coal-fired power plants. The driving force for generating power and heat by (co-) combustion is carbon dioxide (CO_2) reduction because of the 'carbon neutrality' of agriculture crops, and organic waste.

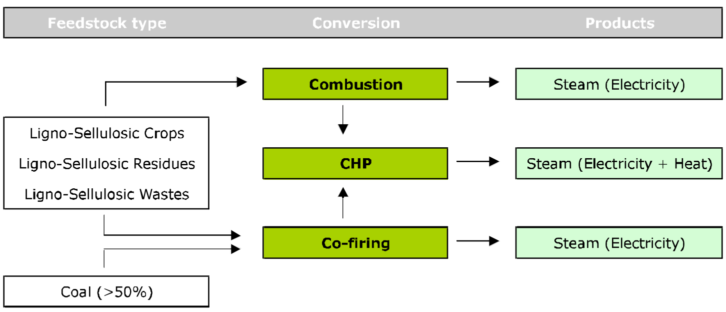


Figure 15 Combustion and Co-firing

Although direct combustion and co-firing are both mature technologies there is still need for improvement, mainly in terms of environmental impact. The reduction of CO_2, NO_x emissions and micro particles are major concerns. Other points of improvement are system optimization, adjustments of fuel to air ratio's, and optimizing heat distribution management (Nussbaumer, 2003).
In 2006 a new firm was established that produces biomass direct combustion systems. The Vancouver, BC, based company Global Green Solutions Inc. offers modular systems, named

'Global Greenstream', to convert animal manure, paper-, pulp-, forest-, crop-, and urban green waste to electricity and steam for industrial use. (GlobalGreenSolutions, 2007).

Combined Heat and Power

Whereas biomass combustion and co-firing systems use steam to generate electric power, Combined Heat and Power (CHP) systems utilize both electricity and heat from one single source. The system recovers heat that normally would be wasted in an electricity generator and is blown into the atmosphere. CHP systems offer dramatic advantages in efficiency and cause much less air pollution than conventional technologies. One of the barriers of the technology is the high capital investment even though operation costs are very low as the result of high efficiency (Hedman, 2007). CHP systems are used in combination with other power generating systems like gas-, steam- and micro turbines, but also in combination with fuel cells. The Vancouver (British Columbia, Canada) based Real Energy Corporation develops, builds, and operates small onsite CHP systems that are combined with these systems, but also in combination with micro turbines. In the last years the company has build about fifty systems in facilities all over the U.S., mainly at the U.S. West Coast (RealEnergy, 2008).
Currently a total of 294 power plants (coal, natural gas, biomass) in California are based on a CHP system in order to co-generate heat. These systems range in size and capacity. CHP is a proven and well-established technology, and can be considered in the mature stage. Nevertheless, there is still need for improvement and there is a need for more advanced applications.

Gasification Technology

Gasification is a process that heats carbon-containing material with presence of steam and a controlled amount of oxygen. The gasification process converts biomass, coal, crude oil, and refinery residuals into synthesis gas *(syngas*). Syngas is primarily composed of carbon mono oxide and hydrogen, which can be used to generate electricity and steam. It can also be used as a basic chemical building block for a large number of uses in the petrochemical and refining industries. (GTC, 2007)

One of the benefits of gaseous fuels is that they mix with oxygen more easily than liquid fuels, which in turn burns more easily than solid biomass. Syngas therefore burns more efficiently and cleaner than the solid biomass from which it was made. Another benefit is its ability to readily mix with chemical catalysts that enhance its ability to be converted to other valuable fuels and chemicals (State of California, 2008)

Coal gasification is a proven and well-established technology and has a long history of development and use. In the early eighteenth century some scientists already published about the production of gas derived from coal (Bain, 2008). One of the first commercial applications was the production of town gas for (street) lighting purposes in the end of the nineteenth century.

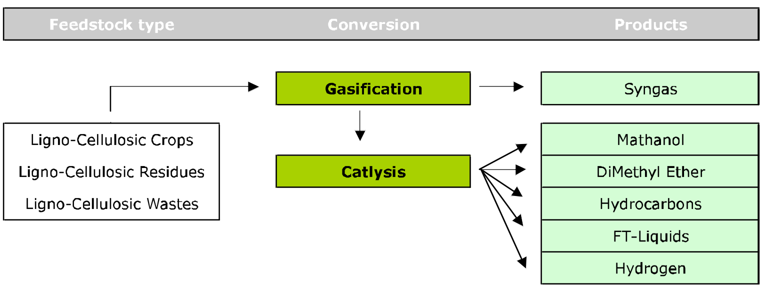


Figure 16 Gasification with catalysis step.

Even though coal gasification is a well-established technology, large scale biomass applications are still in development. It can be considered to be in the introduction stage. There are a few known research or demonstration efforts utilizing gasification for heat or power in Vancouver (by Nexterra Energy) Arizona and in British Columbia, Canada (both by Diversified Energy Corporation) (Nexterra, 2008) (Diversified Energy, 2008). Other biomass gasification developers are Arizona based Phoenix Energy, specialized in small modular systems, Energy Products of Idaho, and Syntec Bio fuel (Vancouver, BC).

Pyrolysis

Pyrolysis is the chemical decomposition of organic materials by heating at moderate temperatures in the absence of oxygen. The process converts lignocelluloses feedstock into pyrolysis-oil (a.k.a. bio oil or bio crude). Pyrolysis-oil can be used directly as fuel to generate heat and electricity but can also be used to derive chemicals and bio fuels through catalysis. Co-products are char, gas, ash and heat (steam). Char can be used as fertilizer and steam can be used in other industrial processes that require heat.

Pyrolysis technology is applied commercially for a long time in the production of liquid fuels from fossil fuels and mainly in the production of chemicals. Nevertheless, applications in biomass conversions are emerging. At the moment a few known biomass pyrolysis facilities at the U.S. West Coast area are operational, mainly pilot plants. Hence, the technology can be considered in the introduction/ growth stage.

Dynamotive Energy Systems Corporation (Vancouver, Canada, BC) can be considered as the world largest developer of biomass pyrolysis technologies. The organization operates six pilot plants and has built its first commercial plant in 2000. Since then, several large plants were build including a 12.2 million gallons per year plant in Toronto, and a plant in Ontario producing 3,8 million gallons bio-oil annually. Recently contracts were signed that envisions the construction of six plants in Argentina and a plant in China (Dynamotive, 2008).

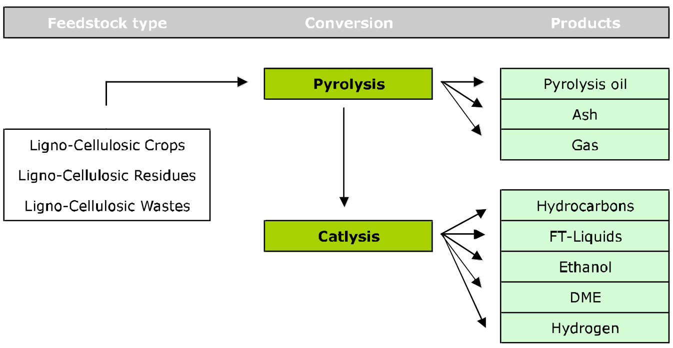


Figure 17 Pyrolysis with catalysis step

4.7.2.2 BIO CHEMICAL CONVERSION TECHNOLOGIES

Transesterification

Transesterification is the process used to convert vegetable oils (lipids) to bio diesel. The process exchanges the alkoxy group of an ester compound with another alcohol.
Transesterification is a proven technology that has been applied on large commercial scale in the production of bio diesel since the twentieths century. The technology can be considered as in the growth stage.
Transesterification is often used to convert vegetable oils, animal fats, and used oils (yellow and brown grease) into bio diesel. The by-product in this process is glycerol that can be used in the chemical and cosmetics industry. Bio diesel producing companies that apply the technology are for instance Imperium Renewables, Domestic Energy Partners, and Bio diesel of Las Vegas. Recently the Arizona based Diversified Energy developed a transesterification based technology that will replicate the chemical structure of their petroleum-derived counterparts, therefore enhancing performance and eliminating required modifications to distribution infrastructures, storage techniques, and combustion engines.

The process is currently being proved on a first small commercial scale in order to produce aviation fuel. (Diversified Energy, 2008)

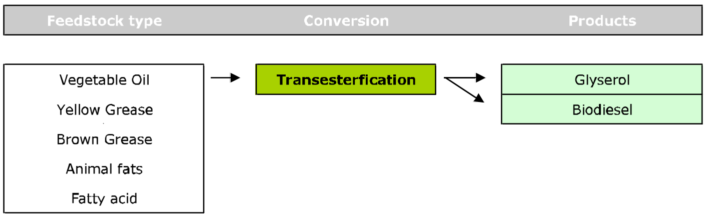


Figure 18. Transesterification process

Anaerobic Digestion

Anaerobic digestion (AD) is the breakdown of organic material by micro-organisms in the absence of oxygen. AD is of great interests in energy production since the major product of the process is methane. AD is primarily used as waste management technology to eliminate pathogens (microorganisms that can cause disease), reduce unpleasant smells, eliminate releases of methane, produce useful fertilizers, and prevent nutrient contamination of groundwater (Farrell, 2008). Current date AD technologies are more often used to produce gas that can be used for heat and electricity generation. A couple of digester gas fired power plants are operational at the West Coast area. Among others in San Francisco, LA, San Diego and Orange County in sizes varying from 0.25 until 25 online Mega Watts.
Unfortunately digester gas cannot yet be upgraded to natural gas in large quantities and injected into the regular gas grid. This development is expected to take place in the near future. Since AD was originally developed as a waste management technology, it is substantially more mature than other conversion technologies.

In October 2007 the Californian firm Onsite Power Systems (Davis) launched a joint venture project with University of California Davis using a commercial anaerobic digestion plant to convert kitchen and yard waste into methane, hydrogen, and fertilizers. In the future hydrogen gas will be separated for use in hydrogen fuel cells (SF Gate, 2006). In the state of Oregon (Port of Tillamook Bay) an AD system was installed in 2003 that converts cattle manure into methane used for electricity generation. The port delivers its electricity to the public network and is still in use.

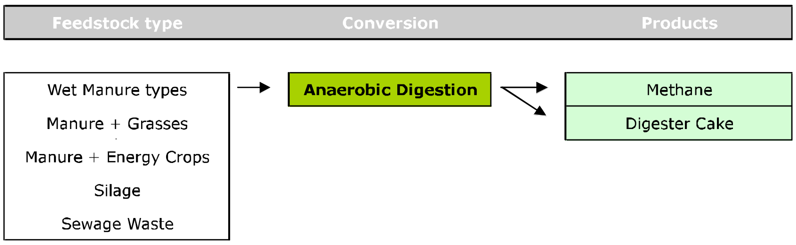


Figure 19 Anaerobic Digestion process

Fermentation

Fermentation has been applied by human mankind for thousands of years to process wine, beer, and other alcoholic beverages. Fermentation is the energy-yielding anaerobic metabolic breakdown of a nutrient molecule, such as glucose, without net oxidant (Bio News, 2007). Fermentation typically refers to the process of converting sugar (carbohydrates) to fuel ethanol (ethyl alcohol) or to lactic acid by using yeast.
Fermentation is a mature-stage technology. Firstly, fermentation is applied to manufacture first generation bio-fuels (mainly bio-ethanol) from sugar crops that is commonly applied in Brazil and is not applied in the U.S. Whereas sugar crops can be fermented directly into ethanol, starch-containing feedstock need to be converted into sugars first by using a hydrolysis process (elaborated in the next section) and then can be fermented into first generation ethanol fuel. Corn is the far most used starchy feedstock for ethanol production

via fermentation in the US, even though global social counter-pressure against the production of these first generation fuels is high. Companies that apply fermentation for ethanol production includes Pacific Ethanol, Pinal Energy Processors, Phoenix Bio fuels, Idaho Ethanol Producers.

The figure stated below represents the ethanol production route. Hydrolysis and pretreatment processes are elaborated in the next sections.

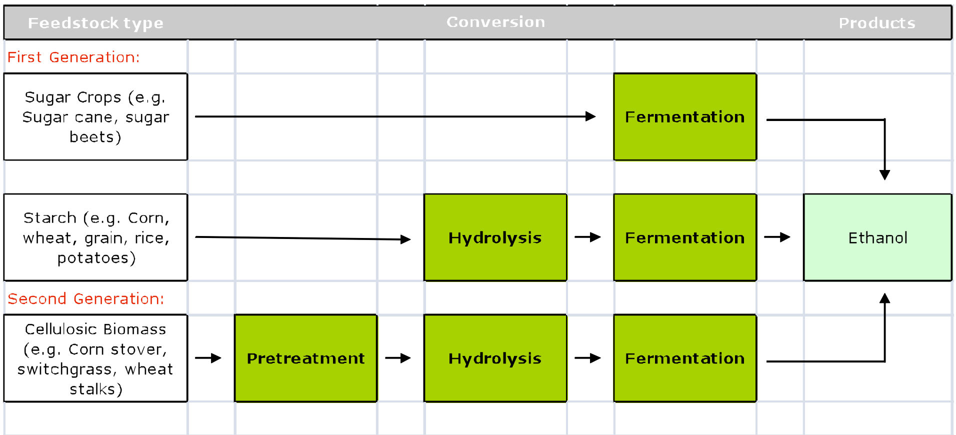


Figure 20. Ethanol production process from sugar, starch and ligno-cellulosic feedstock

A third type feedstock that can be converted into *second-generation* ethanol fuel is ligno-cellulosic biomass (e.g. wood, grasses, corn stover, switch grass). Compared with sugar and starch crops, lignocellulosic feedstock requires an additional pretreatment and hydrolysis in order to create sugars that can be fermentation to ethanol. Plant cell walls are composed of 35-50% cellulose, 20-35% hemicelluloses, and 10-25% lignin. These compounds form a complex matrix that provides the backbone for all plants. In order to convert this so-called (ligno- or hemi-) cellulosic biomass to ethanol or chemicals it is necessary to breakdown the complex matrix into simple sugars before converting into ethanol or chemicals. The breakdown is generally accomplished in two steps; pretreatment and hydrolysis. The pretreatment opens the biomass and makes the cellulose and hemicelluloses accessible for hydrolysis.

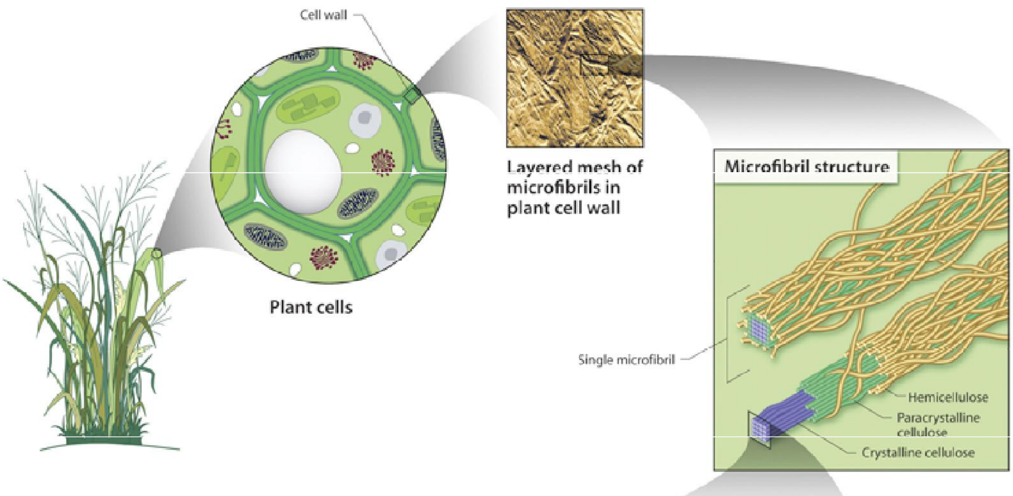


Figure 21 Plant cell wall composition. Lignin not represented. (source: http://www.genomics.energy.gov)

Hydrolysis (Saccharification)

Hydrolysis is the process of breakdown complex hydro carbonates (starch as in potato, corn starch, wheat, e.g.) into simple sugars that can be fermented into fuels and chemicals. Hydrolysis of cellulose into glucose is also known as saccharification.
In the US the most commonly used feedstock for ethanol production is corn. Various biomass hydrolysis technologies exist. The most common approaches are *concentrated acid*, *diluted acid* and *enzymatic hydrolysis.* Some approaches are used in a combination as pretreatment and actual hydrolysis treatment like both enzymatic and acid hydrolysis. Although hydrolysis technologies like concentrated acid and dilute acid hydrolysis have a long industrial history, enzymatic hydrolysis can be seen as the most promising for reducing the cost of producing fuel ethanol and enabling bio refinery developments. (EERE, 2007)

ENZYMATIC HYDROLYSIS

Most of the research efforts in commercializing cellulosic ethanol production are on the development of low-cost second-generation ethanol enzymes for hydrolysis. Enzymatic Hydrolysis is considered to be in the introduction stage. Historically these enzymes have been expensive, with a result that the U.S. government pays large attention and offers large financial funding to companies and research institutes in order to find cheap enzymes. Early 2009 Novozymes and Genencor both launched new second-generation cellulosic ethanol enzymes. These Enzymes are replacing their first-ever commercially available enzymes that were launched in 2007. Biotechnology firm Verenium (San Diego) claims to offer similar enzymes on commercial scale on the short term. Despite all current efforts, enzyme costs have not yet reached commercially-viable cost levels. (EPM, 2009)

CHEMICAL HYDROLYSIS

In this hydrolysis approach where biomass is exposed to chemicals, commonly diluted or concentrated sulfuric acid, and water to convert the substrate into sugar. This process is commonly based on concentrated acid decrystallization of cellulose followed by dilute acid hydrolysis to sugars at near theoretical yields (Kiplinger's, 2007). The first concentrated acid hydrolysis was discovered in 1883. The technology is nearly developed with little room for further cost saving. Nonetheless the technology is considered as profitable for the commercialization of cellulosic ethanol and bio refinery concepts. Arkenol (Mission Viejo, CA) holds most of the important patents for the concentrated acid hydrolysis technologies. In the 1990's they worked with NREL under a CRADA (Cooperative Research and Development Agreement) to develop and improve their technology. The technology has undergone several significant improvements such that the process is commercial implementable. The company has licensed its technology to BlueFire Ethanol Incorporated that has far going plans for the first U.S. West Coast second-generation cellulosic ethanol production facility (near Lanchaster, CA). The plant will be based on the acid hydrolysis technology. (BlueFire, 2007)

Simultaneous Saccharification and Fermentation (SSF)

An important improvement of cellulosic biomass conversion to ethanol fuel is the combination of hydrolysis and fermentation in one new process. In this so-called Simultaneous Saccharification and Fermentation (SSF) process, cellulase and fermenting microbes are combined. As sugars are produced, the fermentative organisms convert them to ethanol. Genencor (Palo Alto, CA) found a low-cost enzyme for hydrolyis of cellulosic biomass late 2007 that is able to operate in simultaneous saccharification and fermentation processes as well. The in 2009 launched second-generation cellulosic ethanol enzymes by Genencor and Novozymes are both claimed to be applicable in the SSF process. The development of more low-cost enzymes accelerates the commercialization of the Simultaneous Saccharification and Fermentation process significantly. (EPM, 2009)

4.8 SYSTEM FUNCTIONS

In this section an overview is provided from the four important external factors (in innovation theory literature called 'system functions') that influence the development, use, and diffuse of new technologies. The fulfillment of functions is highly important for well performing of the system in which technological innovations originates. Various types of actors can fulfill various functions. The U.S. federal government fulfills many functions in the U.S. The federal policies concerning the fulfillment of these functions can be found in various federal acts. The figure below represents the major federal acts that affect bio-based technologies.

U.S. Federal policies significantly effect the development, use and diffuse of technologies and technological knowledge. The Federal Government strongly foresee in the fulfillment of the functioning of the U.S. system aiming to create new innovative bio-based technologies. The most important acts that cover the system function fulfillments concerning technologies in a bio-based economy are:

- Biomass Research and Development Act of 2000 (BRDA 2000)
- Farm Security and Rural Investment Act of 2002 (Farm Bill 2002)
- Energy Policy Act of 2005 (EPAct 2005)
- Energy Independence and Security Act of 2007 (CLEAN Energy Act of 2007)
- Food, Conservation, and Energy Act of 2008 (Farm Bill 2007)

Figure 22 Overview of the major federal acts.

4.8.1 FUNCTION 1: CREATING INCENTIVES

Incentives are important for the creation of new innovative technologies since they can be considered as 'main drivers' that make firms wanting to enter a specific market or expand its activities, either as user or supplier of the technology. On the other hand, incentives drive customers to purchase products for which they are *rewarded*. Thus, governments can indirectly create supply *and* demand for new technologies and its products.

In the U.S. incentives are strongly provided on state and federal level in several forms. The most common incentive types provided by the federal government are *tax credits, production or purchase allowances,* and *customer rebates.* For industrial users and suppliers the most important incentives are; *The Renewable Energy Production Incentive* that foresees $ 1,5 cent per kilowatt-hour for producers of electricity generated by the facility through the use of solar, wind, biomass, landfill gas, livestock methane, tide, wave, or geothermal sources. The *Production Incentive for Cellulosic Bio fuels* authorizes incentives to ensure that annual production of one billion gallons of cellulosic bio fuels is achieved by 2015. The provision authorizes $250 million for 10 years. The *Small Ethanol Producer* Credit includes a production incentive of 10 cents per gallon on the first 15 million gallons of ethanol produced each year. The *Credit for Installation of Alternative Fueling Stations* foresees a 30% tax credit for installation of alternative fuel stations. The *Small Agri-Bio diesel Producer Credit* provides incentives for the production of bio diesel. Finally, the *Modification of Small Ethanol Producer Credit* that foresees a production incentive of 10 cents per gallon on the first 15 million gallons of ethanol produced each year.

An important incentive for consumers include the *Alternative Motor Vehicle Credit* that provides a tax credit to buyers of new alternative fuel vehicle.

The Federal Government provides most important incentives for technology users and consumers. They are:

- Renewable Energy Production Incentive — *Producer*
- Production Incentive for Cullulosic Bio fuels — *Producer*
- Small Ethanol Producer Credits — *Producer*
- Alternative Motor Vehicle Credits — Consumer
- Cellulosic Bio fuel Producer Credits — *Producer*
- Credit for Installation of Alternative Fuel Stations — *Producer*

4.8.2 FUNCTION 2: REGULATION AND FORMATION OF MARKETS

Markets do not develop spontaneously. New technology often has difficulty to compete with existing technologies. Because of this, it is important to create a protected space for new technologies. Besides the formation of new markets it is also important to create favorable institutional regulations (Negro et al., 2004). In the U.S. the government has a critical role in influencing the creation and diffusion of technologies and knowledge with regulations and market formations.

An important market-formation initiative is the state measurement *Renewable Portfolio Standard*. The state of California has been one of the first state that adopted the RPS. Currently, California applies to most progressive RPS in whole the United States. The standard is intended to increase the percentage of renewable energy (derived from various sources with various technologies like anaerobic digestion, biomass, tidal energy, photovoltaics, municipal solid waste, and landfill gas) used in the state's electricity mix. California's targets are 33 percent by 2020. Regarding bio fuels the state of California shall produce a minimum of 20 percent of its bio fuels by 2010, 40 percent by 2020, and 75 percent by 2050. The RPS had a positive effect on the use and production of bio energy and bio fuels in the several states that adopted this measurement. As a result, the Federal government adopted this measure concerning the production of bio-fuels in their CLEAN Energy Act of 2007 under the Renewable Fuel Standard (RFS).

The RFS (also known as the *Renewable Content of Gasoline*,) requires that gasoline sold by refiners, importers and blenders must contain an increasing amount of renewable fuel, such as ethanol or bio diesel, starting at 10.21 percent (11.1 billion gallons) in 2009, increasing to 36 billion gallons in 2022. This powerful provision already created a very large renewable fuels market. The total ethanol production in 2007 almost reached 6.5 billion gallon, that is 1.1 billion gallon more than the old RFS requirements for that same year, and ethanol production is expected to increase more in the future.

The state of California is not the only state that adopted RPS's to regulate and create a 'renewable' market. Together with the State of California the State of Nevada also established progressive standards. Other states that are creating markets through RPS include Oregon, Washington, and Arizona. Table 3 shows that the state of California applies the most progressive RPS targets within the US.

State	Amouth	Year	Organization Administrating RPS
Arizona	15%	2025	Arizona Corporate Commission
California	20%	2010	California Energy Commission
Nevada	20%	2015	Public Utilities Commission of Nevada
Oregon	25%	2025	Oregon Energy Office
Washington	15%	2020	Washington Secretary of State

Table 3 Renewable Portfolio Standards (RPS) by state. (source: www.eere.energy.gov)

Other measures include obligatory purchase of bio products by the federal governments and its agencies. These measurements include the use of renewable electrical energy, bio-fuels, and bio-products like bio-plactics. The legislations include: *The Purchase of Bio-Based Products by the Federal Government* that prescribes the purchase of bio-based products by Federal agencies, the *Federal Purchase Requirements* that says that 5 percent of the total amount of electric energy the Federal Government consumes shall be renewable energy in 2012, and 7,5 percent each year after 2013. The *Federal use of Alternative Fuels by Dual Fueled* Vehicles requires federal fleets to use alternative fuels in federal dual-fuel vehicles. Finally, the federal *Clean School Bus Program* foresees financial funding for retrofit or replacement of certain existing school buses through the country with school buses fueled by renewable fuels.

As mentioned at page 50, the federal *tax credit to buyers of new alternative fuel vehicles* is an major legislation that provides an incentive to customers in order to purchase a alternative powered vehicle, simultaneously it impacts the formation of a market for these vehicles and more important, it impacts the market of bio fuels.

Other legislative procurements are shown in Figure 23.

The most important market regulations and market formation initiatives are:

- Renewable Fuel Standard (RFS) (Federal)
- Renewable Portfolio Standard (RPS) (State)
- Federal Procurement of Bio-based Products
- Federal Purchase Requirements
- Federal use of Alternative Fuels by Dual Fueled Vehicles
- Clean School Bus Program
- Alternative Motor Vehicle Credits

Figure 23. Major Federal market regulation and market formation measures.

4.8.3 FUNCTION 3: CREATING FINANCIAL RESOURCES

Financial resources are necessary as a basic input for all activities within a system of innovation. For specific technologies, the allocation of sufficient financial resources is necessary to make knowledge production possible. Examples are loan guarantees, grants or investments made available for long-term research, development & demonstration (RD&D) projects. The federal government and venture capital firms are the most important providers of financial resources in the U.S.

Financial resources provided by the Federal Government

The federal government is providing approximately $ 544 million in grants and loans between 2000 and 2010 for various projects (BRDA, 2000; EPAct, 2005; FarmBill, 2002). The new American Recovery and Reinvestment Act of 2009 (signed by president Obama in February 2009) includes more than $ 70 billion in direct spending and tax credits for clean energy and transportation programs.

The CLEAN Energy Act provides a financial resources through grants, loans and loan guarantees. Generally these financial resources are provided in order to set up research, development, and demonstration projects in biology, feedstock harvesting, renewable energy systems,

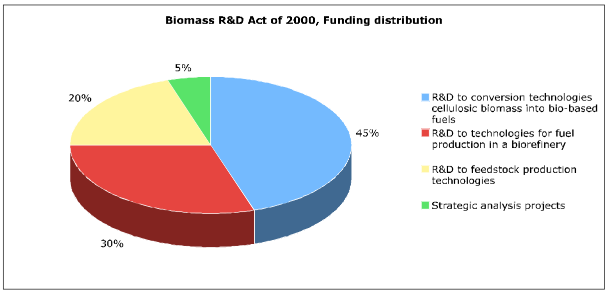


Figure 23 Biomass R&D Act of 2000 Funding distribution (BRDA, 2000)

the production of ethanol and the development of bio refineries.

The BRDA of 2000 has been one of the first federal legislations focusing on the stimulation of R&D of bio products solely through financial funding. The act provided a large amount of financial resources; a total funding of $214 million per year ($ 14 million annually from 2003 through 2007, additional $ 200 million annually from 2006 through 2015) (BRDA, 2000). As Figure 23 shows, almost half of the funds are dedicated to R&D to conversion technologies and one-third is dedicated to R&D to fuel production technologies in bio refineries.

The Energy Policy Act of 2005 provides the largest amount of financial resources; $ 306 million in grants and additional loan guarantee programs (EPAct, 2005). The act includes the *System Biology Program, Renewable Fuel Producers Grants, Sugar Ethanol Loan Guarantee Program,* and grants to improve the commercial value of forest biomass for electrical energy, heat, transportation fuels, and other commercial purposes.
In the Farm Bill of 2002 appoints approximately $ 24 million a year on biorefinery grants, education programs grants, a renewable energy systems and energy efficiency improvements program, and on loans and loan guarantees for renewable energy systems.

Financial resources provided by the Venture Capitalists

The regions studied in this research receive a relatively high amount of venture capital compared with VC investments in other U.S. regions. **Fout!Verwijzingsbron niet gevonden.** visualizes that most of regions that fall within the geographical boundaries of this study attracts 58 percent (!), or $ 17,4 billion, of the total venture capital investments (Total $ 30 billion) in all industrial sectors in the U.S in 2007. Silicon Valley is the region that is of most interest to investors, it attracted 35% of the total U.S. investments.

Even with respect to the cleantech industry (which also includes solar, wind, nuclear, and other renewable energy sources and environment technologies) California is an area of great interests to investors. California-based cleantech companies received approximately 64 percent of all cleantech investments in the U.S; $1.1 billion in 35 investments deals from a national total of $1.7 billion over the third quarter 2008 (Cleantech.com, 2008). The historical total U.S. venture capital investments and the total VC investments in the cleantech sector can be found in the apendixes.

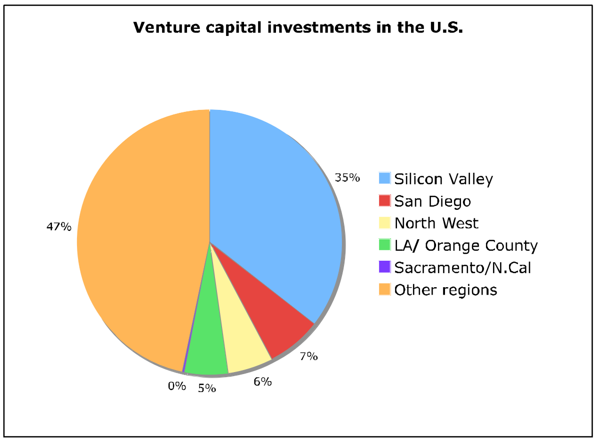


Figure 24. Venture capital investments in the U.S. by region (2007) (MoneyTree, 2008)

The most important federal initiative in order to provide financial resources are:

- Renewable Fuel Capital Investment Program — *Producers*
- Grants for Production of Advanced Bio fuels — *Producers*
- Loans and Loan Guarantees for Renewable Energy Systems — *Producers*
- Biorefinery Development Grants — *Producers*
- Grants for Production of Advanced Bio fuels — *Producers*
- Express Loans for Renewable Energy and Energy Efficiency — *Consumers*

The venture capital cleantech investments in California already amounted $1.1 billion in Q3 from 2008

Figure 25. Federal Initiatives Providing financial Resources

4.8.4 FUNCTION 4: KNOWLEDGE DEVELOPMENT

In the process of creating new innovative technologies it is important to maximize knowledge development. The most fundamental resource in the modern economy is knowledge and, accordingly, the most important process is learning (Lundvall, 1992). Knowledge development can be achieved by various actors but is mainly fulfilled by research institutions like laboratories, universities and research centers.
As mentioned before in this study, a large amount of prominent universities and laboratories are represented in the West Coast area that strongly contributes to the development of bio-product, feedstock, and conversion technology related knowledge. The larger part of, both the universities and laboratories, are funded by the federal or state government. Both institutions often lead and execute large government R&D programs.

Between 2003 and 2003 the U.S. Federal Government totally spend a total amount of $ 1,7 billion on several R&D projects concerning biomass and renewable energy (EPAct, 2005; FarmBill, 2002). An example is the recently started scientific partnership, Joint Bio energy Institute (page 33) that is funded by DOE for $125 million. JBEI is one of three DOE Bio energy Research Centers and studies among others synthetic biology; 'engineering' the right microbes that efficient convert cellulosic biomass to second generation bio fuels. A similar large collaborative scientific program is EBI and is funded by a large industrial actor (BP) EBI addresses several sustainability issues.

Other Major governmental programs are;
The sugarcane ethanol program is a program to study the production of ethanol from sugarcane and sugarcane byproducts. Among others, it deals with the development of cellulosic bio fuels and the development of catalytic enzymes for the second-generation bio fuels. *The Bio energy Program* focuses on renewable energy research, development, demonstration, and commercial application for bio energy including; bio power energy systems, bio fuels, bio products, integrated bio refineries, cross cutting research in feedstock, and economic analysis. *Science Program* that conducting several sub-programs of research, development, demonstration, and commercial application of several topics. Activities include the *Plant Genome Program* carried out by the National Science Foundation. The *Catalysis Research Program*, focusing on research and development in catalysis science. The *System Biology Program* on research, development and demonstration efforts in microbial and plant systems biology, protein science, and computational biology that benefit the U.S. synthetic biology related companies and research institutes. The program includes support of individual researchers and multidisciplinary teams through grants. The *Advanced Bio fuel Technologies Program* that focuses on advanced bio fuel technologies.

The most important federal initiatives on knowledge development are:

- Bio energy Program
- Catalysis Research Program
- System Biology Program
- Advanced Bio fuel Technologies Program
- Cellulosic Ethanol and Bio fuels Research
- Bio energy Research Centers
- Algal Biomass

Figure 26. Federal Initiatives Knowledge Develop

4.9 CONCLUSION

In this chapter the answer to the following research question is provided;

What is the current situation in the U.S.?

4.9.1 TECHNOLOGICAL SITUATION: MAIN ACTORS

The innovational landscape of the Western states consists of a large variety of actors. The political system can be considered as the most prominent and important actor group, as the federal and state executive departments fulfill a leading role in the development of new innovative technologies. They provide incentives, form new markets, provide financial resources, and strongly stimulate knowledge development. The federal and state government financially fund fundamental and applied research at state universities and national laboratories. Together with private universities these universities belong to the best in the world and are highly competitive and performance orientated. Universities and laboratories successfully collaborate with small, medium and large sized companies in order to share and apply their knowledge. The effective knowledge valorization can be explained by the focus on performance, by the entrepreneurial mindset, the willingness to take risk, and the availability of venture capital.

In the broad actor landscape both the federal government and large industrial actors often fund scientific collaborations between laboratories, universities and private companies, such as British Petrol (BP), General Electric (GE), ExxonMobile, and Toyota. Intermediate organizations have a strong influencing role and mainly operate independent and objective. They are strongly competitive and performance orientated, and they provide information towards the public, industrial organizations, the state and federal government, universities, research organizations and also towards lawyers, accountants, investors, and laboratories e.g.. The last important role is fulfilled by Venture Capital (VC) providers. The West Coast region residences many VC's especially in the Silicon Valley region. Silicon Valley receives almost half of all the venture capital investments in the U.S. Venture Capital firms. Sustainable energy, industrial biotechnology, synthetic biotechnology, and second-generation bio fuels currently receive large VC investments. The availability of large amounts of venture capital and other financial resources strongly contributes to the development of new technologies that contributes to a growing bio-based economy.

4.9.2 TECHNOLOGICAL SITUATION: FEEDSTOCK AND CONVERSION TECHNOLOGIES

The U.S. West Coast poses an outstanding knowledge base in the area of feedstock production technologies. Central California locates world's best universities with excellence in agriculture, biology, biotechnology, and chemistry. Current research efforts incorporate biomass availability, quality, resource costs, sustainable production, crop genetics, plant genomics and plant science. This enables the improvement of existing and new crosscutting conversion technologies for the production of second-generation bio-fuels and other bio-products. Hence, the U.S. West Coast industrial biotechnology sector was able to develop the first commercial available enzyme for the production of second-generation cellulosic ethanol recently. The excessive knowledge on sustainable feedstock production furthermore allows the government to shape its vision on the sustainable production from biomass. This contributes to create an unambiguous vision on what feedstock types, under what conditions, are sustainable and what feedstock types are not sustainable for bio product manufacturing.

The combination of genetics, genomics, and biology, often referred to as synthetic biology, is expected to play a crucial role in the future of bio fuels. Large extensive knowledge development initiatives are currently deployed at the U.S. West Coast in order to 'engineer' the right microbes that are able to convert cellulosic biomass into second-generation bio fuels in a cost effective way.

Algae face a growing attention as high-potential feedstock for bio products. The major barriers that hinder algae to be used on large scale at low-costs are being challenged at universities, laboratories and by industrial organizations. The U.S. federal government already started a large algae research program thirty years ago in which the characteristics from thousands algae species where identified and stored in a large database that to date is of high value for more successful genetic modification and for effective algae specie selection. Nowadays U.S. West Coast laboratories and SME's are still expending their knowledge around algae. Specie selection, homogeneous cultivation and algae harvesting are areas that are controlled in this region. Not for nothing two West Coast companies recently announced start producing algal bio-fuels on large commercial scale soon. Second-generation bio fuels will shape our future. Since these sustainable fuels offer dozen advantages over fossil fuels and the commercial low-cost availability on large-scale is expected to be feasible on the mid-long term, research efforts into production of these fuels are skyrocketing.

Traditional Thermochemical Conversion methods like biomass combustion, co-combustions en combined heat and power (CHP), are commonly applied and well developed technologies, the number of plants based on these technologies is growing. Biomass pyrolysis and biomass gasification on the other hand are less developed and less established technologies. Biomass pyrolysis technology can be considered to be in the introduction phase and is currently applied to generate oil for power and heat generation. Process costs and product qualities can be considered as major issues that need to be improved before the technology can be applied to produce more bio-fuels, and bio chemicals. Biomass gasification systems are also developed by several companies, but are only applied on pilot scale. Therefore this technology is in the late development/early market introduction stage. Anearobic Digestion (AD) and fermentation are regularly applied and can be considered as early mature technologies.

Enzyme advances claim they play a key role in conversion processes. In the last years many laboratories, universities, companies and research collaborations focused on both areas resulting in a solid knowledge base at the U.S. West Coast. Recently two West Coast firms had a breakthrough; the first commercial available hydrolysis enzymes where developed and launched to the market. The West Coast states have several first generation ethanol facilities using fermentation and the number is growing. Especially enzymatic and chemical hydrolysis advances will accelerate the application of fermentation technologies for second-generation bio fuels. Chemical hydrolysis is more developed. To date the first commercial scale second-generation cellulosic ethanol plant based on chemical hydrolysis is under construction and is expected to be in operation soon. Transesterification is a strong developed and often applied technology to produce bio diesel from fat-containing crops and waste streams.

	U.S. West Coast
Feedstock Production Technologies	
Resource Availability and Costs	***
Sustainable Production	***
Genetics, Genomics, and Plant Science	***
Algea	***
Processing and Conversion Technologies	
Thermo Chemical methods	
Combustion and Co-firing	*Mature*
Combined Heat and Power	*Mature*
Gasification	*Introduction*
Pyrolysis	*Growth*
Bio Chemical methods	
Transesterfication	*Growth*
Anaerobic Digestion	*Mature*
Fermentation	*Mature*
Enzymatic Hydrolysis	*Introduction*
Chemical Hydrolysis	*Introduction*
Simultaneous Saccharification and Fermentation	*Introduction*
(Technologies solely concerning the conversion of biomass)	

Figure 27. Technical situation, overview the U.S. West Coast

4.9.3 TECHNOLOGICAL SITUATION: SYSTEM FUNCTIONS

The United State government strongly focuses on the development of second generation bio fuels and bio energy on commercial scale. As a consequence, research, development and demonstration efforts in both TTC end BCC receive a relative large amount of financial support. Hence, the sector develops rapidly and large amounts venture capital are invested. In the U.S. incentives are strongly provided on state and federal level in several forms. The most common incentive types provided by the federal government are tax credits, production or purchase allowances, and customer rebates. The state of California adopted Renewable Portfolio Standards (RPS's) to regulate and create a 'renewable' market. Other measures include obligatory purchase of bio products by the federal governments and its agencies. These measurements include the use of renewable electrical energy, bio-fuels, and bio-products like bio-plastics. The federal government provides approximately $544 million in grants and loans annually for various projects. The large amount of prominent universities and laboratories strongly contribute to the knowledge development concerning bio-products, feedstock-, and conversion technology related knowledge.

5 TECHNOLOGICAL SITUATION IN THE NETHERLANDS

5.1 INTRODUCTION

In this part of the research an overview is provided from the Dutch innovation system and from the available technologies in the Netherlands in order to answer the following question:

What is the current technological situation in the Netherlands?

The previous model and theories showed that technological development cannot be seen as isolated phenomenon, the actors and functions of the innovation system need to be analyzed as well.
The Dutch innovation system comprises many different actors. The Netherlands has a strong political system that sets legislation and has an advisory role towards private companies. The research and education group exists of federal funded universities, and federal and private research centers. The industrial system comprises companies that develop and apply technologies in order to produce bio chemicals, bio energy, and bio fuels. Depending on the technology and bio products these companies are large and small of scale. Intermediates are not very common in the Netherlands. The Netherlands has several venture capital firms focusing on firms in bio product development.

5.2 POLITICAL SYSTEM

In contrast to the United States, The Kingdom of the Netherlands is administrated on the federal level only. The most important government departments that are involved with bio-based technologies are the *Ministry of Agriculture, Nature and Food Quality*, the *Ministry of Economic Affairs*, and the *Ministry of Housing, Spatial Planning, and the Environment.*

Minstry of Agriculture

This ministry's vision is 'working for a permanent quality of the living environment'. The ministry mainly stimulates innovation and knowledge research by providing granting programs. One of the prominent programs is the Small Business Innovation Research Program – Bio-based Economy – in which they provide research grants to SME entrepreneurs in order solve key problems in the bio-based economy. Other central research themes are biotechnology and crop modification.

Ministry of Economic Affairs

The Ministry of Economic Affairs (EZ) aims at a sustainable and an entrepreneurial country as part of an open global economy. The ministry's most important focus is economical growth, international entrepreneurship, and innovation. That is why the Ministry of Economic Affairs advocates technological developments towards a stronger bio-based economy and therefore employs many initiatives with a broad range of topics.
In cooperation with the Ministry of Education, Culture, and Science EZ started the Catchbio research program (year 2007-2015) aiming for the development of catalytic processes converting biomass into a range of bio products.

SENTERNOVEM

SenterNovem is one of the Dutch prominent agencies supporting sustainable development and innovation, and accelerating knowledge transfer from research institutions to industrial actors. SenterNovem provides knowhow and other support to Dutch actors as well as to the Dutch Government in setting its energy related policies. The agency's focus areas are innovation, energy and climate change, and environment and spatial planning. SenterNovem is furthermore the agency that provides most of the Dutch sustainable energy & energy efficiency subsidies.

Ministry of Housing, Spatial Planning, and the Environment

The Ministry of Housing, Spatial Planning, and the Environment (VROM) is another important governmental body that stimulates environmental research. VROM is addresses themes like climate change, bio-fuels, carbon emissions, and sustainable energy.

5.3 EDUCATIONAL AND RESEARCH SYSTEM

University of Twente

University of Twente is an entrepreneurial research university with a broad range of projects in technological, scientific, and social scientific disciplines. The research centers IMPACT, MESA+, and CSTM are the university's main institutes concerning bio-based economy related subjects. The university has a strong emphasis on research into *nano-technology* (*membrane technology* and *catalytic processes and materials*), *thermo chemical conversion of biomass* and *polymer chemistry and bio-materials.*
At IMPACT one of the two main research topics is *sustainable energy and greenhouse gas emissions*. Major research topics are on biomass conversion, bio-refinery, utilization of bio-fuels, sustainable production, and materials for sustainable energy.

Wageningen University and Research Centre

Wageningen University is a former agricultural university originated early 1900. As its name suggests Wageningen University and Research Centre consists of a research center and a scientific educational group. Both the educational part as the research center are focusing on five topics; agrotechnology & food sciences, animal sciences, environmental sciences, plant-, and social sciences. The research center includes several specialized research institutes such as 'The Food Technology Centre, 'Bio-based Products', 'Plant Research International', 'Alterra Institute' 'LEI' and the 'Central Veterinary Institute'.

Delft University of Technology

The Delft University of Technology consists of eight faculties concerning a broad range of technological studies. The university distinguishes itself from other Dutch universities by offering studies in aerospace, architecture and maritime engineering. Furthermore, the university has many research institutes participating in a variety of disciplines. Examples are 'Delft Centre for Aviation', 'Delft Centre for Sustainable Energy', 'Netherlands Institute for Material Research', 'Kavli Institute for Nanosciences', and the 'Delft Institute of Earth Observation and Space Systems'. Delft University furthermore accommodates and directs the B-Basic program. (Delft University, 2008)

B-Basic

B-Basic is a research consortium of universities, research centers, and industrial actors. The consortium's mission is "to provide the chemical industry with an advanced set of tools and concepts by approaching Bio-based Sustainable Industrial Chemistry in a fully integrated manner, combining functional genomics, intensified bioprocess technology and feedstock scenarios". Participants are Delft university of Technology (Coordinator), University of Groningen, Leiden University, Wageningen University and Research Centre, TNO, Agrotechnology and Food Science Group, DSM, AkzoNobel, Shell Global Solutions, Paques, and Organon. (B-Basic, 2008; NWO, 2008).

Energy Research Centre of the Netherlands (ECN)

ECN has its origin in 1955 when it was set up as a nuclear research centre and now is the largest energy research centre in the Netherlands. The institutions aim to develop excellent knowledge and technology for a sustainable national energy usage and intend to transfer this knowledge and technology to the market. ECN works in eight units among which 'Biomass, Coal & Environmental Research', 'Energy in the Built Environment', 'Hydrogen & Clean Fossil Fuels', and 'Policy Studies'. In fiscal year 2006 the centre had an income of € 122 million.

The Nuclear Research & consultancy Group (NRG), ECN's daughter company, accommodates and operates the nuclear reactor in Petten (Noord Holland), which is solely operational for research purposes.

Netherlands Genomic Initiative (NGI)

The NGI is a research institute coordinating and financing all the genomic research in The Netherlands. Research is carried out within large consortia operative within specific genomic areas like, health (red-biotechnology), agro-food (green-biotech), sustainability (white-biotech), enabling technologies, and on the genomic link with the society. After its first successful period from 2002-2007 the program has been extended by the Dutch government till the year 2012. The institute expects additional investments from academia, industry, and research institutions amounting to € 220 million. (NGI, 2008; NWO, 2008)

5.4 INDUSTRIAL SYSTEM

Royal Dutch Shell

Royal Dutch Shell is a Dutch-British multinational oil company and includes Exploration & Production, Gas & Power, Oil Products, Chemicals, and the business Oil Sands. Shell conducts research and development activities into various production pathways for renewable electricity and fuels. The corporation is engaged in the development of gas-to-liquid technologies, coal gasification technologies, bio fuels, solar and wind energy.
Shell is partnering in several research, development & demonstration initiatives. In 2004 the Canadian company Iogen opened a demonstration plant where enzymes are use to manufacture ethanol from straw. Together with the German firm Choren they plan to set up a demonstration plant to produce fuel from wood residues. In 2007 Shell started to work with Codexis to develop new "super enzymes" that can convert non-food biomass into bio fuels more efficiently. A new project with HRBiopetroleum includes the construction of a new demonstration plant in Hawaii to turn algae into biomass form fuel production purposes. Early 2008 Shell announced a new collaboration with U.S. company Virent to develop new technologies to turn sugar from plants directly into gasoline. (Shell, 2008)

5.4.1 BIO FUELS- ETHANOL

The most important Dutch industrial ethanol producers are Koninklijke Nedalco, Abengoa Bio energy Netherlands BV, and Maatschap Bosma. The appendixes provide an overview of all current and planed ethanol, bio diesel, ETBE, and bio energy facilities.

Koninklijke Nedalco

Koninklijke Nedalco (Nedalco) is one of Europe largest ethanol manufacturers (application in spirits, food, pharmaceutical products, cosmetical products, and industry) and has operations in more than 20 countries worldwide. Nedalco (Bergen op Zoom, Noord Brabant) has a strong focus on the development of second-generation bio fuels. Recently they patented a genetically modified yeast specie that is able to ferment C5 (xyalse) and C6 (glucose) sugars directly into second-generation ethanol fuel, eliminating the enzymatic hydrolysis process. Nedalco recently announced it freezes its plans to build the first second-generation ethanol plant in The Netherlands. (Nedalco, 2009)

Abengoa Bio energy Netherlands BV

Currently the Spanish multinational Abengoa is building a new bio ethanol production facility in the port of Rotterdam. The facility is expected to start operations in the end of 2009 and will produce 480 million first generation bio ethanol per annum from grain. (Abengoa, 2009)

Maatschap Bosma

Maatschap Bosma (Zuidvelde, Drenthe) started operation with a small ethanol fermentation installation (first generation fuels) based on potatoes in 2006. Currently they process 21.000 ton feedstock and manufacture 4.600 ton ethanol annually. (Dlvplant, 2009)

5.4.2 BIO FUELS- BIO DIESEL

Bio diesel can be considered as bio fuel that is mostly produced in the Netherlands. The Netherlands currently has four operational bio diesel manufacturing plants. Seven plants are currently in development. To date the Netherlands has a total capacity around 100 million liter annually. The largest producer is Sunoil Bio diesel. The first bio diesel production plant opened its doors in 2005. The appendixes provide an overview of all current and planed bio diesel, ethanol, ETBE, and bio energy facilities in the Netherlands. The largest bio diesel plants in The Netherlands are:

Bio diesel Kampen

Bio diesel Kampen (Kampen, Overijssel) is funded in 2006 by waste vegetable fat and oil trading firm Vierhouten Vet BV. Bio diesel Kampen uses waste vegetable oils as feedstock to produce bio diesel. The plants annual capacity is 50.000 metric tons. Early 2007 the firm stopped its plant operations because it is suffering from the growing import of cheaper, mainly heavily subsidized, bio diesel from other countries, including the USA. (De Stentor, 2008; Bio diesel Kampen, 2008).

Sunoil Bio diesel

Sunoil Bio diesel (Emmen, Drenthe) starts building the first bio diesel plant in the Netherlands in 2005. Early November 2006 the plant started operations. The plant uses domestic and imported rapeseed as feedstock as well as animal fat. The plant capacity is 80 million liters per annum. (Sun Oil Bio diesel, 2008)

Cooperatie Carnola

Cooperatie Carnola in Oirlo (Limburg) manufactures 2.8 million liter of bio diesel per annum produced from rapeseed. Together with Bio diesel Kampen, Cooperatie Carnola had the first bio diesel production facility in The Netherlands. (Cooperatie Carnola, 2008)

Noord-Nederlandse Oliemolen BV

Noord-Nederlandse Oliemolen BV (Located in Boijl, Friesland) opened its production plant in the summer of 2007. They manufacture around 3.5 million-liter bio diesel per annum, produced from domestic and imported rapeseed. (NNO, 2008)

5.4.3 BIO CHEMICALS

Purac

Purac is the world's largest producer of natural lactic acids for the food and chemical industry. Purac manufactures a range of naturally derived products to replace or reduce solvents, acids, and salts derived from fossil fuels. Purac’s lactic acid can be used as a monomer in various types of polymers, for instance Polylactic acid (PLA), which is a biodegradable and compostable polyester.

Purac is a subsidiary from multinational CSM. CSM is the largest supplier of bakery products worldwide and is global market leader in lactic acid and lactic acid derivatives CSM annual sales accounted € 2.5 billion over 2007. The company’s profits reached € 202 million in the same year. (CSM, 2008; Purac, 2008)

Royal DSM

DSM is a Dutch, public traded, multinational creating products and services in life and material sciences. DSM, located in Gorinchem (Zuid-Holland) works in five main clusters; nutrition, pharma, performance materials, polymer intermediates, and base chemicals & materials. Among others, DSM produces biopolymers, enzymes for bio fuel production, and DSM has activities and knowledge on fermentation, genomics and biocatalysis. DSM has annual sales of almost EUR 8.8 billion and employs some 23,000 people worldwide. (DSM, 2008)

Rodenburg Biopolymers

Rodenburg Biopolymers, located in Oosterhout (Noord Brabant), is a Dutch family-owned company founded in 1945. Rodenburg produces the patented and biodegradable plastic Solanyl, a potato starch based polymer. The bioplastic is applicable in various industrial sectors. Products made from the material are for instance CD and DVD trays, golf-tees, street cleaning brushes, and cup-holders. (Rodenburg, 2008)

PaperFoam

The Barneveld (Gelderland) based organization PaperFoam produces packaging trays and CD/DVD sleeves from starch based fiber-reinforced polymer. PaperFoam developed products for AMD and Motorola. (PaperFoam, 2008)

5.4.4 BIO ENERGY

The industrial bio-energy actors can be separated in two groups: a) the developers of conversion systems for energy generating purposes, and b) electricity and heat producers, or power plants. The most important actors in the first group are Biomass Technology Group, Kara Energy, and HoST Oosterveld Holman. The primary actors in the second group are Twence, Essent N.V., and Bio energy Twente B.V.

5.4.4.1 DEVELOPERS

Biomass Technology Group (BTG)

Biomass Technology Group (Enschede) is a consultancy, R&D and engineering firm specialized in conversion technologies of biomass into bio fuels and bio energy. The company conducts R&D into diverse technologies in different stages of development. Areas BGT is currently working on fast pyrolysis, gasification, super critical gasification, and anaerobic digestion. BTG develops and sells her own conversion systems.
BTL recently launched a new spin-off company, BTG-Bioliquids (BTG-BTL), which commercializes BTG's biomass-to-liquid fast pyrolysis technology. The company employs a demonstration plant in Malaysia. (BTG, 2008)

Kara Energy

Kara Energy (Almelo) is an organization specialized in the production and engineering of biomass combustion systems. Additionally, the firm offers CHP systems that produce heat as a secondary product from biomass combustion. Kara sells CHP systems varying from 500 kW till 2MWe. (Kara, 2008)

HoST

Engineering company HoST (Hengelo, Overijssel) develops, produces and sells digesters, wood fired CHP systems, and biomass/ waste gasification systems. The company has offices in Latvia, Romania, Slovakia, and in the Republic of Moldova. In cooperation with Oosterhof Holman the firm builds manure digesters. In a joint venture with Imtech-Vonk, HoST is able to design and also to build wood fired power plants and CHP systems. (HoST, 2008)

5.4.4.2 POWER AND HEAT PRODUCING PLANTS

Twence

Twence is a waste-processing firm located in Enschede, Overijssel. Twence produces electricity, heat and landfill gas from municipal wastes collected through a large part of the Netherlands. In 2006 the company started the construction of a new 100 percent biomass fired plant, which is in operation since 2008. On the nearby landfill the firm recovers landfill gas to generate its own electricity. Twence recovers about 1350 m^3 landfill-gas pro hour. Twence is owned by a group of local governments, Essent N.V, and by Vuilverwerkingsbedrijf Noord Groningen. (Twence, 2008)

Essent N.V.

Essent is one of the largest power supplying companies in the Netherlands. Currently, the firm is one of the two power companies in the Netherlands use a 100 percent biomass feeded power plant. Essent's bio-energy plant is located in Cuijck (Noord Brabant) and is in operation since 2000. The plant produces 170 million kW/h electricity annually and uses 250,000 metric tons of wood. The plant is mainly fired with mill and forestry residues. (Essent, 2008)

Bio energy Twente B.V.

Bio energy Twente B.V. is the name of a recently established company owned by Cogas (Gas and electricity infrastructure), Participatiemaatschappij Oost Nederland (PPM) (investment fund), and Bruins & Kwast (biomass recycling). Late 2006 the organization opened the doors of the new 100 percent biomass combustion plant in Goor (Overijssel). The plant uses nearly 17.000 metric tons wood annually and produces 14 million kWh electrical power and 33.500 GJ heat per annum. (Bio energy Twente, 2008)

5.5 INTERMEDIARIES

Cleantech Holland

Cleantech Holland is an export organization funded by several government ministries. The organizations aim to stimulate the exportation of Dutch sustainable technologies, products, and innovations to other countries in the world. CleantechHolland organizes seminars and provides information to Dutch companies throughout their network. (Cleantech Holland, 2009)

5.6 VENTURE CAPITAL

Eco Ventures

Eco Ventures is part of the Dutch firm Ecoconcern and focuses on sustainable energy companies in the early business development stage. Currently the company holds about ten portfolio firms in bio fuels, wind energy, solar energy, solar boilers, and electric powered vehicles. (Ecoventures, 2008)

Start Green Venture Capital

Start Green Venture Capital is a venture capital firm focusing on early stage businesses in the sectors sustainable energy, water treatment, and sustainable agro solutions. Currently the organization has eight firms in its portfolio. (Start Green, 2008)

5.7 TECHNOLOGY AND KNOWLEDGE

In this section an overview of the current technology and knowledge base is provided for the areas *feedstock production* and *processing and conversion technologies*. On the next pages the available technologies are clarified as well as the current status and current developments are elaborated briefly.

5.7.1 FEEDSTOCK PRODUCTION TECHNOLOGIES

5.7.1.1 Resource Availability and Costs

Although the Netherlands is small country they are globally the second largest agriculture products exporting country. SenterNovems *BioBased Raw Materials Platform* studied biomass availabilities in the Netherlands and showed that almost half of the biomass used in the Netherlands is imported from abroad. The same institute, that comprises various Dutch Governmental ministries and various research institutes, studied the effects from biomass usage on the Dutch economy. Early 2009 they presented the study findings of a research – conducted by Wageningen University and the University of Utrecht - that addressed the economical effects from biomass usage in the Netherlands. The research showed that large application of biomass results in large environmental benefits and has a significant long-term effect on the Dutch economy. The use of biomass for the production of bio-fuels, bio-chemicals, and bio-energy, offers the Dutch economy 7 billion Euros annually. (SenterNovem, 2009)

5.7.1.2 Sustainable Production

The Dutch Government pays large attention towards the sustainability of biomass. In 2007 the Dutch Government presented their vision on the sustainability of biomass for import as well as domestic production. Together with SenterNovem and Wageningen University sustainability criteria are developed. In April 2009 these criteria where concretized so the Dutch government can start developing a sustainable biomass certification system. According to the concrete sustainability criteria biomass types can be certified in the future as ‘produced sustainable’. (SenterNovem, 2009)
The effects from biomass production on water usage are increasing in popularity by researchers. University of Twente’s *Twente Water Centre* studies among others the waterfootprint of biomass and other energy carriers. Here, the disciplines of *Water* Engineering & Management and Thermal Engineering come together and additionally study the energyfootprint of water supply. (TWC, 2009)

5.7.1.3 Genetics, Genomics, and Plant Science

The Netherlands is a global leader in the cultivation of new plant varieties, seeds for sowing and young plants for potatoes and vegetables. The agricultural Wageningen University and Research Centre (WUR) can be considered as the pioneer in this area. Recently the Technological Top Institute, *Groene Genetica* was founded at the same university in order to bridge trade and industry’s fundamental genetics research and applied research. The program with a funded budget of EUR 40 million will take four years to complete. Another research program ran at WUR in the field of genetics aim to reduce the use of herbicides and amount of energy consumed in the cultivation of potatoes.

Under the Netherlands Genomic Initiative (NGI) multiple Genomic Centers were created focusing on NGI’s main research areas. The Kluyver Centre for Genomics of Industrial Fermentation is one of these centers and applies microbial genomics to improve micro-organisms for industrial fermentation processes. Fermentation is used in the production of food products and ingredients, pharmaceutical compounds and fine and bulk chemicals including bio-ethanol (Kluyver, 2008).

5.7.1.4 Algae Feedstock

Algae are considered as a promising renewable source for the production of transportation bio fuels, bio energy and various other bio products. Transportation fuels from algae are called already the third generation bio-fuels. Hence, the large-scale algae production for commercial fuels or energy purposes has not been realized jet in the Netherlands. (General information on algae can be found in section 4.7.1.4)

A Noord-Brabant based company LGem cultivates algae for the production of omega-3 fatty acids for the food production industry. Ingrepro BV located in Borculo (Gelderland) cultivates algae on large scale on three locations in the Netherlands solely for the food processing industry. Organizations involved in algae cultivation and harvesting are among others Econcern (plans for algae farm at Bonaire), Aquaphypto, and Algae Link. The latter company just signed a contract with Air France/KLM in order to produce algae on large scale for the production of bio-jet fuel. AlgeaLink manufactures algae cultivation equipment.
Other demonstration plans are made by Professor Wijffels and the Wageningen University and Research Centre. They intent to start building a proof of concept cultivation facility for algae production used for energy production. (WUR, 2009)

5.7.2 PROCESSING AND CONVERSION TECHNOLOGIES

5.7.2.1 THERMOCHEMICAL CONVERSION

Most of the Thermochemical Conversion (TCC) technologies are already applied effectively on large scale in the Netherlands in order to convert a variety of feedstock, fossil and renewable, to fuels, chemicals and energy. The Netherlands has a strong history in the development and use of Thermochemical Conversion technologies, especially in gasification and pyrolysis technology. Pyrolysis is a technology that is not applied on a commercial scale in the Netherlands nevertheless the technology is ready for commercialization. Hence, commercialization is expected to take place soon.

Combustion and Co-Firing

Combustion is a mature and common applied technology in the Netherlands and is mainly applied to burn natural gas and coal. Currently three 100-percent biomass fired plants (Twence Enschede (35 MW), Essent Cuijk (25 MW), and Bio energy Twente BV Goor) are operational, of which two combined heat and power facility (Twence, and Bio energy Twente BV). Additionally, The Netherlands counts twelve waste-to-energy combustion facilities that directly burn household waste (inorganic and organic fractions) in order to generate energy and heat.

Biomass co-firing is a more occurring technology mostly supplementing coal-fired power plants in order to neutralize the plant’s carbon emissions. Seven Dutch power plants are currently co-firing small percentages, around 10 percent, of biomass to their primary feedstock coal. One (Essent Amercentrale, Geertruidenberg) is co-firing woodgas to the coal plant. In the past years seven power companies have presented their plans to build a new power facility. From the seven companies three plan to build a co-firing facility based on 20%, and more, biomass co-firing.

In 2004 permits where provided by the local government for the poultry manure combustion facility Fibroned BV. A couple of months the permit was withdrawn because of increasing neighborhood complaints about bad odor.

Combined Heat and Power (CHP)

Combined Heat and Power (CHP) systems utilize both electricity and heat from one single source, whereas combustion systems solely utilize electricity from one source.
CHP systems are a well-developed and often applied technology. About one third of the operational power plants in the Netherlands are co-generating heat. Hence, CHP technology can be considered as mature technology.

In the small town Goor (Overijssel) the firm Bio energy Twente BV operates the only 100 percent biomass powered CHP power plant in the Netherlands. The facility primary uses forestry and other wood residue. The company is an initiative from a forestry waste management company Bruins&Kwast, energy company Cogas, and investment organization PPM Oost.

A firm based in Etten-Leur (Noord Brabant), I-Res, for instance develops modular CHP installations that convert biomass on a pyrolysis, gasification and combustion base into energy and heat. Combining these process steps utilize most efficient the energy from the biomass. (I-Res, 2009)

Gasification Technology

The Netherlands is globally one of the important developers of thermal conversion technologies and in specific the gasification technology. Gasification can be considered to be in the late introduction stage. The Twente region has a strong history in gasification technology. The University of Twente was one of the first (early seventies) institutes that started research in to gasification technology. In the eighties BTG developed out of the same institute and is nowadays a global leader in this area. In the meanwhile BTG developed several facilities all around the world. Another Dutch firm engaged in gasification is HosT. HosT develops, produces and sells digesters, wood fired CHP systems, and biomass/ waste gasification systems. The in 2007 established firm I-Res (Innovative Renewable Energy Solutions) in Etten-Leur develops modular CHP installations that convert biomass on a pyrolysis, gasification and combustion base into energy and heat. Combining these process steps utilize most efficient the energy from the biomass. The firm has not jet commercialized its process but has far going future plans.
Late 2008 ECN company in Petten (Noord Holland) took a new biomass gasification facility in use that converts grasses and wood chips into gas. An earlier build facility is operated by power company Essent. This power plant 'Amercentrale' in Geertruidenberg, two times 650 MW installed capacity, is co-fired with woodgas (Essent, 2008).

Pyrolysis

The Netherlands can be considered as a front-runner in the development of pyrolysis technology. Similar to the gasification technology, the University of Twente is one of the pioneers on the pyrolysis technology. Research started in the eighties. In the nineties the first small scale facility was operational producing ten liters of bio-oil per hour. In 1996 BTG started commercializing the technology. The firm built one commercial facility in Malaysia that converts empty fruit bunches into pyrolysis-oil. The firm has plans to build more facilities in the future, domestically as well as abroad. At the IMPACT research group at the University of Twente the flash-pyrolysis technology is further researched and developed as well as other thermal biomass conversion technologies.

I-Res in Etten-Leur (Noord Brabant) uses pyrolysis in their CHP installation in order to convert biomass, mainly woody feedstock, into electricity and heat. A pyrolysis step is complemented with gasification and combustion in order to utilize most energy from the feedstock. The technology is not commercially applied (I-Res, 2009).

In 2007 the Dutch firm BIOeCON formed a joint venture with the cleantech investor and former Sun Microsystems founder Vinod Khosla, named KiOR. The start-up uses a catalytic pyrolysis technology in order to convert ligno cellulosic material into second-generation bio-crude which is suitable for upgrading to transportation fuels. The firs technology is not commercially available jet. (KiOR, 2009).

Even though developments on the pyrolysis technology are ongoing the technology is not applied on commercial scale in the Netherlands. Hence it can be considered as a technology in the introduction stage.

5.7.2.2 Bio chemical Conversion

Transesterification

Transesterification is the process used to convert vegetable oils (lipids) to bio diesel. The process exchanges the alkoxy group of an ester compound with another alcohol. Transesterfication is a proven technology that is applied on commercial scale in the Netherlands by several companies. It can be considered as technology in the growth stage.

Some firms that apply the technology in order to produce bio diesel are Bio diesel Kampen, Sunoil Bio diesel, Cooperatie Carnola, and the Noord-Nederlandse Oliemolen. In the appendix a complete overview of current and future bio diesel production efforts is given.

Anaerobic Digestion

Anaerobic digestion (AD) is the breakdown of organic material by microorganisms in the absence of oxigen. AD is of great interests in energy production since the major product of the process is methane that can be used as renewable fuel for power and heat generation. Mainly wet feedstock fractions are converted via AD systems.
During the 70's and 80's the development of digester systems started in the Netherlands. In that period about twenty systems where build in which various feedstock, mainly wet manure, was tested. Early 2000 the development of digesters accelerated again and the technology became more and more efficient in the Netherlands. Currently the technology is a proven and mature technology that is applied often by agriculturists in the conversion of wet manure into gas. AD systems are commonly complemented with a CHP-system in order to produce heat and electricity for own use or the electricity is supplied to the power grid. Power and waste company Essent employs an AD facility in Groningen that converts wet waste fractions into gas for power generation. Co-digestion is an often-occurring process where other organic biomass (i.e. dedicated corn crops or grasses) is added to the wet manure in order to improve system output performance. Currently several developers of AD systems exist in the Netherlands; HosT (Hengelo, Overijssel), HosT Oosterman Holtman (manure digestors), Thecogas (Lochem, Gelderland) i.e.
Late 2007 an new installation started operations in Son (Noord Brabant) that converts meat residues from abattoirs through anaerobic digester into biogas used for electricity production. In the same plant, operated by the firm Ecoson, bio diesel is produced from other meat residue fractions.

Fermentation

Fermentation is the energy-yielding anaerobic metabolic breakdown of a nutrient molecule, such as glucose, without net oxidant (Bio News, 2007). Fermentation typically refers to the processing of converting sugar (carbohydrate) to ethanol (ethyl alcohol) and/ or lactic acid by using yeast. In the Netherlands fermentation is applied as alcoholic beverage processing technology as well as ethanol producing technology. Biomass fermentation can be considered to be in the growth stage. A new breakthrough on fermentation is the recently developed (on lab-scale by KUN TUDelft, and Bird Engineering) approach that converts lignocellulosic feedstock into second-generation bio fuel. This is accomplished by genetically modifying a specific yeast specie (patented by Nedalco) that is now able to ferment C6 (glucose) and C5 sugars (Xylose) directly into ethanol. This technology is expected to compete with enzymatic hydrolysis approaches to manufactured second-generation bio fuels.

Current developments on traditional fermentation processes, to produce first generation bio fuels, aim to increase process yields and productivity. WUR's Bio-based Products Institute has many research efforts in these fields. Fermentation is also applied to produce poly lactic acid from starch by companies like Rodenburg, Purac, DSM, and Paperfoam, which manufacture biodegradable bioplastics.
The Netherlands has four small-scale ethanol facilities that are all starch based and use fermentation as core technology. (Harvest Fuels BV 110 million liter annually from corn, Nedalco 200 million liters annually from starchy residues, Maatschap Bosma processes 4.600 tones of potatoes annually). In the future Bio-Ethanol Rotterdam (BER) plans to build an ethanol and biogas plant based on two fermentation stages with a capacity of 100 million liters ethanol per annum. The feedstock is wheat.

Hydrolysis

Enzymatic Hydrolysis

Wageningen Unversity and Research Center (WUR) is one of the leaders concerning research into enzymatic conversion processes for second-generation bio fuels in the Netherlands. Together with Royal Nedalco the WUR conducts research in finding the right enzymes that accomplish and accelerate the production of second-generation bio fuels. In 2005 WUR already manufactured second-generation ethanol on small lab scale through enzymatic hydrolysis (WUR, 2008). DSM can be considered as an important Dutch industrial biotech company. Recently the company received a DOE funding in order to conduct research to the development of second-generation bio fuels including enzymatic hydrolysis.

The recently established Catchbio research program is focusing on catalytic processes to converting biomass into bio fuels, bio chemicals and pharmaceuticals. The program runs from 2007 till 2015 and has a budget of EURO 29.2 million, 16.6 million is made available by the Dutch Ministry of Economical affairs and the Ministry of Education, Culture and Science. The program is managed by the Dutch Institute for Catalytic Research (NIOK). Catchbio is a consortium of companies, universities and research institutes. Partners are; Shell, DSM, DOW, Sabic, BIOeCON, Albemarle, Avantium, BASF, VibSpec, Hybrid Catalysis, Sasol, Organon, University of Utrecht, Wageningen, Twente, Groningen, Delft, Eindhoven, Leiden, Nijmegen, Amsterdam, and the Energy Research Centre of the Netherlands. (CatchBio, 2008)

The Netherlands has no commercial available cellulase enzymes for hydrolysis of woody biomass for second-generation bio fuels.

Chemical Hydrolysis

Chemical Hydrolysis is often applied as additional pretreatment step to enzymatic hydrolysis in cellulosic ethanol production. The technology is not well established in the Netherlands. Bio-Rights in Hardenberg is the only known company that applies the technology in order to produce second-generation ethanol fuel. The firm plans to start a new bio ethanol pilot plant in 2009. They are licensee for Europe of a diluted acid chemical hydrolysis technology patented by the U.S. company GeneSyst International Inc. (BioRights, 2009). WUR conducted various experiments with chemical pretreatment and chemical hydrolysis approaches to manufacture cellulosic ethanol (WUR, 2009)

Simultaneous Saccharification and Fermentation (SSF)

Wageningen University and Research Center conducts research into SSF processes for bio fuel production application within their Biobased Products program. (WUR, 2009)

5.8 SYSTEM FUNCTIONS

5.8.1 CREATING INCENTIVES

Incentives are commonly provided by the Dutch government. The most common incentives are grants and tax breaks. Grants are provided by the federal government as well as by local governments. The program *Stimulation Sustainable Energy Production* (SDE) can be considered as the most promising stimulation program that provides a total of EUR 2,585 million in incentives on bio-energy production, and stimulates the use of wind-, solar-energy, CHP systems, and energy derived from biomass. With respect to biomass an incentive on a kWh production bases (varying from 0,06-0,58 €/kWh) is provided and covers the difference in costs of production from bio-energy (electricity) and the costs of regular electrical. The program includes energy production through combustion, fermentation, anaerobic digestion and other thermochemical conversions technologies. In 2008 totally EURO 10 million is provided and is planned to increase to 336 million in 2015 (SenterNovem, 2008).

The Dutch has two primary tax breaks that stimulate the use of new technologies and products. The program *Tax Break for Energy Investments (Energie-investeringsaftrek, EIA)* foresees a tax break for Dutch companies that invest in energy saving systems and sustainable energy. The program *Tax Break for Environment Investments (Milieu-investeringsaftrek, MIA)* foresees an investment tax break in environment friendly systems and are able to receive a 40 percent tax discount over the total invested amount.

The most important Dutch federal incentives include:	
○ Program Stimulation Sustainable Energy Production (SDE)	*Producers*
○ Tax Break for Energy Investments	*Producers*
○ Tax Break for Environment Investments	*Producers*

Figure 28 Overview Dutch Federal Incentives

5.8.2 REGULATIONS AND FORMATION OF MARKETS

In 2003 the European Union required that all EU-states should use a minimum of 5,75 percent bio-energy from their total energy consumption by 2010. By 2020 this share will be 20 percent. The legislation includes a 6 percent share by 2020 of the total bio fuels that are consumed. Additional, the legislation prescribes a quality label that requires these bio fuels to reduce carbon dioxide emissions by 35 percent with respect to fossil fuels. The Dutch government prescribes a renewable fuel content of 4 percent by 2010. This provision creates a major market for bio-energy, bio fuels, and its conversion technologies.

Another measure in which the government creates and regulates markets is the *Requirement Sustainable Purchase Program (Programma Duurzaam Inkopen).* This program requires the government to purchase 100 percent sustainable products by 2010. Provinces and water boards are required to purchase 50 percent by the same year. The government developed sustainability criterion for a large number of products. Purchases under the program need to meet these specifications.

An influential governmental regulation tool is the recently established package of sustainable biomass production and import criteria. The Dutch Government aims to develop a certification system that allows only certain biomass types that can be used for the production of bio fuels, bio energy, and bio chemical's in the Netherlands.

Market regulations and formation is accomplished by:

- ○ Renewable Portfolio Standard (RPS) Bio energy and bio fuels) (EU)
- ○ Renewable Fuel Standard (RFS) (NL)
- ○ Requirement Sustainable Purchase Program
- ○ Sustainable Biomass Production Criteria (SenterNovem)

Figure 29. Dutch market regulations and formation legislations.

5.8.3 CREATING FINANCIAL RESOURCES

The subsidy program *Fueling Stations Alternative Fuels* provides 1.8 million in grants for the development of fueling stations for natural gas and bio-ethanol. The *Program Carbon Dioxide Reduction Innovative Transportation Bio fuels* (*Subsidieprogramma Innovatieve Biobrandstoffen voor Transport)* foresee around EUR 12 million in grants for innovative development, distribution or use of transportation bio fuels.
Next to federal government grants, local governments also provide grants. One of these is the grant for *Sustainable Energy and Energy Savings* that is provided by the Provence

Noord-Brabant and Overijssel (budget unknown). Companies can apply for grants for research, investment, and education projects that due with energy savings and sustainable energy that reduce carbon dioxide emissions and reduce the use of fossil fuels. (SenterNovem, 2009)
The Energy Research Grant Program (Energie Onderzoek Subsidie (EOS)) aims to increase the quality of research and knowledge and foresees EUR 10 million in grants over 2009. The program stimulates research, development and demonstration (RD&D) projects concerning new technologies in order to improve the domestic sustainable energy supply. The program provides grants to universities, research institutes and the private companies. (SenterNovem, 2009)

The most important financial resources created are:

○ Subsidy Program Fueling Stations Alternative Fuels (TAB)	*Producers*
○ Carbon Dioxide Reduction Innovative Transportation Bio fuels	*Producers*
○ Sustainable Energy and Energy Savings	*Producers*
○ Energy Research Grant (EOS)	*RD&D*

Figure 30. Financial resources in The Netherlands

5.8.4 KNOWLEDGE DEVELOPMENT

The Netherlands has a network of government funded high-quality universities and research centers. Additionally, the Dutch government stimulates knowledge development through various research programs, e.g. SBIR, Energy Transition Program, CatchBio, B-Basic, Sustainable Hydrogen Program, and EOS.
The SBIR program (Small Business Innovation Research) aims stimulate small companies to develop innovative technologies and products based on biomass (SenterNovem, 2009).
In 2005 the interdepartmental government program 'Energy Transition' was established. The program, administered by SenterNovem, aims to encourage and speed-up the shift to new sources of energy. The initiative focuses on six central themes; New Gas and Clean Fossil Fuels, Sustainable Mobility, Green Raw Materials, Chain Efficiency, Sustainable Electricity, Built Environment and the 'Greenhouse as Energy Source' platform. In the program companies, knowledge institutes, government and non-government organizations work together in order to share knowledge and experience to optimize the transition from conventional energy sources to future sustainable energy sources.
The CatchBio partnership between universities and private companies aims to develop clean and efficient processes for biomass conversion into low-cost and sustainable bio fuels, chemicals and pharmaceuticals. CatchBio is part of a EURO 100 million SmartMix program provided by the Netherlands Organization for Scientific Research (NWO), Ministry of Education, Culture and Science, and the Dutch Ministry of Economical Affairs. (NOW, 2008)
The B-Basic program is a research consortium of universities, research centers, and industrial actors. B-Basic focuses on developing bio-based sustainable process concepts for the chemical industry, using renewable resources. ACTS coordinates the program. (B-Basic, 2008; NWO, 2008). The Sustainable Hydrogen Program aims to develop the knowledge and technology concepts to enable the transition from fossil to renewable sources in our current society. The program is funded with EURO 18.2 million provided by industrial partners, the Ministry of Economic Affairs, the Ministry of Housing, Spatial Planning and the Environment, and the Netherlands Organization for Scientific Research. (NOW, 2008). The Energy Research Grant Program (Energie Onderzoek Subsidie (EOS)) aims to increase the quality of research and knowledge. The program stimulates research, development and demonstration (RD&D) projects concerning new technologies in order to improve the domestic sustainable energy supply. The program provides grants to universities, research institutes and the private companies. (SenterNovem, 2009)

The most important initiatives on knowledge development include:

- Small Business Innovation Research Program (SBIR)
- Energy Transition Program
- CatchBio
- B-Basic
- Sustainable Hydrogen Program
- Energie Onderzoek Subsidie (EOS)

Figure 31. Knowledge Development Initiatives

5.9 CONCLUSION

In this chapter the answer to the following research question is provided;

What is the current technological situation in the Netherlands?

5.9.1 TECHNOLOGICAL SITUATION: MAIN ACTORS

The innovational landscape of the Netherlands consists of a large variety of actors, although they are not equally distributed over the different fields. The government, industrial actors, universities and small, medium and large sized companies dominate the landscape. The government is an important player and includes several influencing legislations and executing agencies that, in addition, has an advising role. The Netherlands count several large multinationals, such as Shell, DSM, and Purac, which are involved with research, development and production of bio products, especially bio chemicals and bio fuels. Dutch universities, such as Wageningen University and Research Center (WUR), conduct fundamental research on agriculture, biology, chemistry and conversion methods. However, applied research is less common, due to less collaboration between universities and small, medium and large organizations. Intermediate organizations and Venture Capital (VC) providers only exist in small amount in the Dutch technological landscape. This can probably be explained by the conservative, paternalistic and risk-avoiding policy of the Dutch government.

5.9.2 TECHNOLOGICAL SITUATION: FEEDSTOCK AND CONVERSION TECHNOLOGIES

The Netherlands can be considered as a front runner towards the development of knowledge with respect to the sustainability of biomass. In 2007 the Dutch government presented their vision on the sustainability of biomass in the *'Green Book'*. Early 2009 the criteria in this study where concretized that allows the Dutch Government to introduce a progressive biomass sustainability certification systems on the near term. Consequently, the long-term government policy is focused on the development of sustainable second-generation bio products, especially bio fuels. To date, no second-generation bio fuels are commercially available, primary due to the fact that conversion costs are too high.

Universities as WUR, TU Delft and institutes as the Kluyver Centre for Genomics, conduct research to overtake these and other hurdles. These institutes strongly focus on the development of biocatalysts and microorganisms that will optimize fermentation, enzymatic hydrolysis and other conversion processes. These developments aim to lead to more cost effective large-scale conversion processes for the production of second-generation bio transportation fuels, bio chemical's and bio energy. Algae fulfill a promising but mior role in the Netherlands. Various organizations focus on algae production and the conversion of algae into second generation (aviation) bio fuels. Despite of these research efforts, production (enzymatic hydrolysis is considered as the prime and most efficient technology) of second-generation bio transportation fuels is still in the development stage.

Nevertheless, technologies and market shares of transportation bio fuels and bio energy are in increasing. The Netherlands presents various companies that commercially produce first-generation bio fuels through starch fermentation (mainly ethanol) and transesterification (bio diesel) of fat containing feedstock. The obligated renewable fuel content of gasoline (3,75%) creates a large market for first generation bio ethanol and bio diesel. On the long term first generation bio fuels need to be substituted by more sustainable second-generation fuels.

	The Netherlands
Feedstock Production Technologies	
Resource Availability and Costs	**
Sustainable Production	***
Genetics, Genomics, and Plant Science	**
Algea	**
Processing and Conversion Technologies	
Thermo Chemical methods	
Combustion and Co-firing	*Mature*
Combined Heat and Power	*Mature*
Gasification	*Introduction*
Pyrolysis	*Introduction*
Bio Chemical methods	
Transesterfication	*Growth*
Anaerobic Digestion	*Mature*
Fermentation	*Growth*
Enzymatic Hydrolysis	*Development*
Chemical Hydrolysis	*Development*
Simultaneous Saccharification and Fermentation	*Development*
(Technologies solely concerning the conversion of biomass)	

Figure 32 Technical situation, overview The Netherlands

More developed technologies are biomass pyrolysis and gasification. ECN and Essent currently commercially apply biomass gasification for power generation. Both facilities produce synthetic natural gas (SNG) from lignocellulosic feedstock that substitutes or complements natural gas in power plants. Pyrolysis is not commercially applied in the Netherlands but is expected to be realized on the short term. The Netherlands can be considered as a leading country on these both areas. The Univeristy of Twente can be considered as one of the important research institutes on both gasification and pyrolysis. They conduct ongoing research on both areas. Dutch companies HoST, iRes, BTG (a University of Twente spinoff) are global pyrolysis and gasification experts.

Combustion, biomass co-firing, combined heat and power, and anaerobic digestion systems are commonly applied methods to convert biomass into heat and electricity.

5.9.3 TECHNOLOGICAL SITUATION: SYSTEM FUNCTIONS

In the Netherlands incentives are provided on governmental level in several forms. The most common incentives are grants tax breaks to technology users in order to stimulate the development and spread of new technologies and their products. Incentives are provided that encourage the production of bio energy (SDE), although no incentives are provided that encourage the production of bio fuels.
Grants are provided by the federal government (SDE, EOS, FSAF, as well as by local governments - such as the province of Noord-Brabant and Overijssel - and function as a financial resource. Companies can apply for grants for projects that deal with energy savings and sustainable energy that reduce carbon dioxide emissions and reduce the use of fossil fuels.
The Dutch government prescribes a renewable fuel content of 3.75 percent by 2010. This provision creates a major market for bio-energy, bio fuels, and its conversion technologies. Next to Dutch regulation measures, the European Union also plays a vital role in regulating and creating of markets. A strong market regulation tool is the recently established progressive package of biomass sustainability production criteria by the Dutch government. The fundamental approach of Dutch universities strongly contributes to the knowledge concerning the development of bio-product, feedstock, and conversion technology related knowledge.

6 COMPARISON (U.S. WEST COAST AND THE NETHERLANDS)

In this chapter an overview of several technologies that are in a different stage in both countries is given, as well as an overview of the similarities or differences from the system functions in both countries. In order to distinguish technologies and knowledge that can be relevant for Dutch industries both situation need to be compared. The following question is answered:

How do the current situations in the U.S. and in the Netherlands compare?

The question is answered by providing a comparative analysis of the differences in technological availability, and secondly, by comparing and analyzing the system functions in both countries. Then the final research question is answered:

How could Dutch Government encourage the transfer of these U.S. technologies to Dutch industries (and vice versa) in order to support the development of the bio-based economy?

6.1 AVAILABLE TECHNOLOGIES AND KNOWLEDGE

The results from section 4.7 and 5.7 show that the U.S. West Coast states represent similar *feedstock production* and *processing and conversion technologies* in comparison with The Netherlands. Nevertheless, the sections show that there are differences in the lifecycle stages of the available technologies in both countries.

The analysis results are visualized in the table below.

	U.S. West Coast 	**The Netherlands** 
Feedstock Production Technologies		
Resource Availability and Costs	***	**
Sustainable Production	***	***
Genetics, Genomics, and Plant Science	***	**
Algea	***	**
Processing and Conversion Technologies		
Thermo Chemical methods		
Combustion and Co-firing	*Mature*	*Mature*
Combined Heat and Power	*Mature*	*Mature*
Gasification	*Introduction*	*Introduction*
Pyrolysis	*Growth*	*Introduction*
Bio Chemical methods		
Transesterfication	*Growth*	*Growth*
Anaerobic Digestion	*Mature*	*Mature*
Fermentation	*Mature*	*Growth*
Enzymatic Hydrolysis	*Introduction*	*Development*
Chemical Hydrolysis	*Introduction*	*Development*
Simultaneous Saccharification and Fermentation	*Introduction*	*Development*
(Technologies solely concerning the conversion of biomass)		

For the processing and conversion technologies the largest life cycle stage discrepancy exists for *pyrolysis, fermentation, enzymatic hydrolysis, chemical hydrolysis,* and *simultaneous saccharification and fermentation.* For feedstock production technologies a discrepancy exists for *resource availabilities* and *algea feedstock.*

PROCESSING AND CONVERSION TECHNOLOGIES

In the U.S. West Coast states several pyrolysis-based bio energy plants are operational on a commercial base. Additionally, several pilot plants are in operation. The Netherlands house several pilot plants and has no commercial-scale pyrolysis plants, even though, the Netherlands are a frontrunner on researching pyrolysis technology.

Ethanol facilities (first generation) that primary use biomass fermentation technologies are in large amounts present in the U.S. West Coast states. The Netherlands currently counts one company that produces first generation bio-ethanol through fermentation. One Dutch company improved the fermentation process significantly and claims to be able to ferment cellulosic feedstock directly into second generation bio-ethanol, without hydrolysis step. Half a dozen more plants are expected to be build in the next years.

Enzymatic hydrolysis is the key process in manufacturing second-generation ethanol. The Netherlands and the U.S. West Coast states both have no second-generation ethanol production facilities. Even though, one U.S. firm plans to build an enzymatic hydrolysis-based cellulosic ethanol plant soon. Additionally, the western United States, especially the Silicon Valley region, is frontrunner in developing hydrolysis enzymes. They recently launched the first commercial enzymes ever. With the same reason simultaneous saccharification and fermentation can be considered as more successful in the West Coast states since enzymes fulfill a key role in the SSF process. Most important chemical hydrolysis patents are hold by a single U.S. company. As a consequence, the technology is currently introduced to the U.S. market for transportation bio fuel manufacturing. The Netherlands is still researching the technology for the same applications and has not applied the technology on commercial scale.

FEEDSTOCK PRODUCTION TECHNOLOGIES

Finally, a knowledge gap exists with respect to feedstock production technologies in both countries. *Resource availabilities, genetics genomics & plant science,* and *algae feedstock* face differences in knowledge base. The U.S. offers large amounts of biomass that needs to be accounted on costs, quality and quantity. Hence, knowledge concerning biomass availability and costs is considered as broad. The U.S. government initiated large and comprehensive research projects that study synthetic biology, a combination of genetics, genomics, and biology, which is expected to accelerate the bio fuel economy. Developments on algae feedstock face increasing interest at the U.S. West Coast. Plenty of research, development and demonstration efforts currently take place dealing with specie selection, cost effective cultivation, and low cost harvesting. Last year the first ever commercial–scale effort was announced in which bio fuel will be produced from algae.

6.2 SYSTEM FUNCTIONS

This section compares the most important functions in both countries. Technologies in a specific country are developed under those specific functions. Adopting these technologies to another region with a different set of functions can hinder the development, use and diffusion of that technology. An overview of the system functions is represented in the table on the next page.

The table shows a comparison of available legislative programs for each of the four functions. Both countries fulfill all four functions relatively similar. Most initiatives are focused on the development of final products instead of particular technologies. Relatively similar initiatives exist that benefit the development of technologies and knowledge related to bio energy. Nevertheless, functions related to bio fuel technologies are fulfilled different in both countries. Formation of markets, creation of financial resources, and the development of knowledge are considered as fulfilled similar, although the Netherlands offers no incentives for bio fuel production and use. Hence, most of the more developed technologies and knowledge in the U.S. are use to produce bio fuels.

The previously distinguished technologies pyrolysis, fermentation, enzymatic hydrolysis, chemical hydrolysis, and simultaneous saccharification and fermentation, are mostly applied to generate bio fuels and bio energy. Because of the significantly bio energy and bio fuel markets that are created, the sufficient availability of financial resources, and the strong development of knowledge in the Netherlands, the previous distinguished technologies and knowledge areas are all considered as relevant to transfer to Dutch industries.

United States of America	**The Netherlands**
Creation of Incentives	
Renewable Energy Production incentive	Program Stimulation Sustainable Energy Production (SDE)
Production Incentive for Cullulosic Biofuels	Tax Break for Energy Investments (EIA)
Small Ethanol Producer Credits	Tax Break for Environmental investments (MIA)
Alternative Motor Vehicle Credits	
Cellulosic Biofuel Producer Credits	
Credit for Installation of Alternative Fueling Stations	
Regulations and Formation of Markets	
Renewable Fuel Standard (RFS)	EU: Renewable Portfolio Standard (RPS)
Renewable Portfolio Standard (RPS)	Renewable Fuel Standards (RFS)
Federal Procurement of Biobased Products	Requirment Sustainable Purchase Program
Federal Purchase Requirements	Sustainable Biomass Production Criteria
Federal use of Alternative Fuels by Dual Fueled Vehicles	
Clean School Bus Program	
Alternative Motor Vehicle Credits for Buyers of New Vehicles	
Creation of Financial Resources	
Renewable Fuel Capital Investment Program	Subsidy Program Fueling Stations Alternative Fuels
Grants for Production of Advanced Biofuels	Carbon Dioxide Reduction Innovative Transport
Loans and Loan Guarantees for Renewable Energy Systems	Energy Rsearch Grant
Biorefinery Development Grants	Sustainable Energy and Energy Savings
Grants for Production of Advanced Biofuels	
Express Loans for Renewable Energy and Energy Efficiency	
Grants for Conversion Assistance for Cellulosic Biomass Producers	
Development of Knowledge	
BioEnergy Program	Small Business Innovation Research Program (SBIR)
Catalysis Research Program	Energy Transition
System Biology Program	Energy Research Grant (EOS)
Advanced Biofuel Technologies Program	CatchBIO
Cellulosic Ethanol and Biofuels Research	B-Basic
Bioenergy Research Centers	Energy Transition Program
Algal Biomass	Sustainable Hydrogen Program

Table 4. Overview four system functions in both geographical areas

Pyrolysis can be applied to manufacture bio-oil that can be used for bio energy (heat and power) generation as well as to produce second-generation bio fuels. Fermentation, enzymatic hydrolysis, chemical hydrolysis, and simultaneous saccharification and fermentation are commonly applied to produce first- and second generation bio fuels.

The U.S. West Coast states fulfill many functions that benefit development, use, and diffuse of bio fuel related technologies, especially second-generation cellulosic ethanol technologies.

Both countries execute various knowledge development programs focused on bio products and additionally have excellent research and educational systems. The U.S. government employs programs on the development of bio energy technologies, catalysis research, development of advanced biofuel technologies, and the development of cellulosic ethanol and other bio fuel related technologies. The Netherlands has programs focused on developing knowledge related to conversion technologies for the production of bio energy (Energy Transition and EOS, SBIR e.g.), bio fuels (CatchBio, B-Basic, SBIR, Sustainable Hydrogen Program e.g.), and bio chemicals (CatchBio, B-Basic, SBIR e.g.).

In both countries the function *market creation and regulation* is fulfilled relatively similar. Both entities established comprehensive renewable fuel standards that require every gallon of fuel sold at the pump should contain a certain percentage of renewable fuel. The European Union prescribes a renewable fuel content of 6 percent by 2020, the state of California and the federal government for instance obligate both 30 percent (!) by 2020. Concerning market creation of bio energy; the EU requires that by 2020 it member states should use a minimum of 20 percent bio-energy from their total energy consumption. The state of California for instance, requires 33 percent from the total energy mix should be derived from biomass by 2020.

Financial resources in the U.S. are both provided by the Federal and State government through loans, loan guarantees and grants, as well as by venture capital investors. In the Netherlands the government typically provides innumerable financially resources mainly through grants. Examples are the subsidy program fueling stations alternative fuels, carbon dioxide reduction, and EOS. Venture Capital is less common in the Netherlands.

The U.S. government provides a balanced mix of incentives for bio fuels as well as for bio energy. Knowledge is developed in order to develop various conversion technologies for the production of bio fuels, various programs are offered that provide financial resources to research, development, demonstration and production of bio fuels, and incentives are provided to producers of bio fuels, bio fuel consumers, and to fuel stations. The way these functions are fulfilled result in strongly development bio fuel (ethanol) related technologies at the U.S. West Coast, such as pyrolysis, fermentation, enzymatic and chemical hydrolysis, and simultaneous saccharification and fermentation. The Netherlands on the other hand provides no incentives for the production or use of bio fuels. The lack of these incentives can be considered to slow the use of these technologies since processing costs of bio fuels stay unacceptable high. Hence, the absence of these incentives can be considered as one of the reasons the market position of these technologies in the Netherlands is less mature.
Both the U.S. and the Netherlands foresee in incentives that encourage bio energy production. The Netherlands in example, offers favorable tax credits for organizations that invest in bio energy systems.

Finally, remarkable is the special knowledge development program from the U.S. government on algae biomass. Already during the seventies a large research program was set up by the U.S. government in order to study the production from bio fuels from these micro organisms. To date, the U.S. government focuses again on the development of bio fuel and other bio products from algae through the Algal Biomass program.
The strong developed knowledge concerning algae biomass in the U.S. is considered as relevant to share with Dutch industries. Especially considered the scarcity of biomass in the Netherlands and the fact that large amounts of biomass can be utilized on a relatively small acreage. Further more, algae can be converted into bio energy, bio fuels and bio chemicals. The presences of bio energy production incentives in the Netherlands are favorable for algae applications. Additionally, a large market is present to apply algae for bio energy generation. Hence, algae are considered as attractive biomass resource in the Netherlands. The need for extensive knowledge sharing regarding this topic decreases and can be considered as significantly relevant.

6.3 GOVERNMENTAL ENCOURAGEMENT

In this section the next question is answered:

"How could Dutch Government encourage the transfer of these U.S. technologies to Dutch industries (and vice versa) in order to support the development of the bio-based economy?"

The theory as shown in section 3.5 says that the development, use, and spreading of new technologies is affected by many economic, social, political, organizational, and other determining factors (Edquist, 2001). These external factors can be seen as individual *'functions of the system'* that need to be fulfilled to certain extend. The better these functions are fulfilled, the better technologies are developed, used and spread.

The following technologies are considered as further developed in the U.S. and relevant for Dutch industries:

- Pyrolysis;
- Fermentation;
- Enzymatic Hydrolysis;
- Chemical Hydrolysis;
- Simultaneous Saccharification & Fermentation.

Most of these technologies are applied to manufacture transportation bio fuels. In the previous chapters is demonstrated that the lack of production incentives for bio fuels are considered as reason of the poor market development of these technologies.

The Dutch government can encourage the transfer (and development) of these technologies in the Netherlands by designing the optimal 'landscape' through the adoption of distinct bio fuel incentives, as is done in the U.S. The U.S. government for instance provides $250 million to producers of cellulosic bio fuels in the next ten years to ensure an annual production of one billion gallons of these bio fuels. To small ethanol producers a $10 cents per gallon incentive on the first 15 million gallons of ethanol fuel produced is provided in the first year. A comparable incentive is provided to bio diesel producers. An alternative fuel infrastructure is ensured by providing owners of alternative fueling stations a 30 percent tax credit on investments in new alternative fuel installations. Additionally, consumers can save up to $4,000 on the purchase of a new alternative fueled vehicle in form of a tax credit. In the Netherlands there is a lack of these kinds of stimulating incentives on the production and use of transportation bio fuels.

The previous section showed that it is considered as relevant to share knowledge concerning algae biomass. The U.S. government employs a dedicated research program to algae biomass; the Netherlands has no dedicated algae biomass research program. In order to effectively share and apply algae related knowledge the Dutch government could encourage the transfer of this knowledge by setting up a similar dedicated algal biomass research program. New legislative bio fuel production incentives support and accelerate effective application of algae knowledge for bio fuel manufacturing in the Netherlands.

In April 2009 the Dutch government established the final biomass sustainability criteria. With these criteria a clear view is provided what types of feedstock are allowed to be used for the manufacturing of bio fuels. The combination of algae biomass program, new production incentives and transparent biomass criteria are considered to offer great opportunities for the Dutch industry to apply pyrolysis, fermentation, enzymatic hydrolysis, chemical hydrolysis, and simultaneous saccharification and fermentation on commercial scale for the production of bio fuels.

7 CONCLUSION AND RECOMMENDATION

7.1 CONCLUSION

In this final chapter a conclusion is drawn from the previous chapters. In this section an answer is provided to the central question:

"What available knowledge and technologies in the field of bio-based economy in the West Coast of the United States are relevant for Dutch industries (and vice versa) and how could the Dutch Government encourage the transfer of these U.S. technologies to Dutch industries (and vice versa) in order to support the development of the bio-based economy?"

The extensive analysis that was conducted in this research shows that the Netherlands represents similar *feedstock production* and *processing and conversion technologies* in comparison with West Coast of the United States. The research also shows that there are differences in the lifecycle stages of some of the available technologies in both countries, and according to these differences and differences in system functions some technologies are considered to be relevant for Dutch industries.

This research showed that a market development discrepancy exists for the technologies pyrolysis, fermentation, enzymatic hydrolysis, chemical hydrolysis, and simultaneous saccharification and fermentation. These technologies are considered as more developed in the U.S. Since the current political plans are strongly focused on alternative fuels, these technologies face rapid developments that are expected to continue in the future.
Because of the significant bio energy and bio fuel markets that are created, the sufficient availability of financial resources, and the strong development of knowledge in the Netherlands, these technologies are all considered as relevant to transfer to Dutch industries. Especially the transfer of pyrolysis knowledge to the Netherlands is considered as relevant since this technology, applied to produce bio oil for bio energy generation, faces favorable conditions in the Netherlands, in particular: favorable incentives, available financial resources, the presence of markets for bio energy, and availeble knowledge; benefit the development, use and diffusion of pyrolysis technology in the Netherlands.

The research furthermore showed that with respect to feedstock production technologies, knowledge sharing around *algae feedstock* is considered as relevant since algae offer large opportunities for Dutch industries; algae require little land, algae can be used as feedstock to generate bio energy, the presence of bio energy incentives are favorable for algae, and large markets are created to generate bio energy. Even though the Netherlands offers no dedicated algae RD&D programs, the benefits are compelling.

The lack of bio fuel production incentives in the Netherlands is considered as prime imperfection that hinders the large-scale application of the less-developed technologies in the Netherlands. The Dutch government can encourage the development by adopting distinct bio fuel production incentives and incentives for consumers on alternative fuel vehicles. These incentives stimulate the Dutch bio fuel industry to apply their technologies for bio fuel production on large commercial scale. Especially since the Dutch government established (early 2009) biomass sustainability criteria that are a guideline to what types of feedstock the government allows to be used for bio fuel production. This combination of production incentives and transparent biomass criteria offers great opportunities for the Dutch bio fuel industry to develop their technologies. It can be expected that these measures accelerate the domestic bio fuel production, reduce the current import of bio fuels, boost the domestic economy, and additionally will create many new jobs.

7.2 REFLECTIONS

RESULTS VERSUS OBJECTIVES

This research was started by stating various research objectives. The objectives of this research were formulated as following: Within the field of bio-based economy at the U.S. West Coast,

- to provide an overview of the current actors and their objectives. Attention has to be paid to government policy and –programs as well as companies and private initiatives;
- to provide an overview of the current knowledge and technology base in the U.S. and in the Netherlands;
- to provide an overview of the future expectations of these initiatives;
- to distinguish U.S. knowledge or technologies that can be relevant for Dutch industries, and vice versa;
- to analyze in what way the Dutch government can encourage the transfer of potential technology or knowledge to Dutch industries and vice versa, in order to support the developments of a bio-based economy.

The objectives of this research are considered as achieved. Sections 4.2 until 4.6, and 5.2 until 5.6 provided a detailed overview of the current actors and their objectives in the U.S. and the Netherlands. The most important government policies and programs were elaborated in detail for both countries in sections 4.8 and 5.8. The current knowledge and technology base in the U.S. and in the Netherlands are described in detail in sections 4.7 and 5.7. The second and third objectives are achieved in the chapter six of this report. This chapter distinguishes technologies and knowledge according the Product Life Cycle and the System Function approach that can be relevant for Dutch industries. The chapter also recommends how the Dutch government can encourage the transfer of these technologies and knowledge to Dutch industries on the macro economical level.

These findings and information in this research is considered to be of great value for Dutch industries and government. According to this research two articles were written that are published on the NOST website. Both articles *("Algen: de derde generatie biobrandstoffen?" and "Bio-based economy in de VS")* are also used on the EVD website ("Landensite: kansrijke markten") to provide an overview of the current market developments -among others actors, technologies, future expectations, government initiatives- in the U.S. biomass and renewable sector.

PROCESS

Because of the broad delineation of this research the choice was made to collect mainly qualitative data. It has been considered as difficult to provide all relevant data for all technologies without creating a bulky report. Additionally, it has been difficult due to the same reason to gather specific quantitative data in order to conduct an objective comparison. For instance, it is hard to trace on what specific technologies a financial R&D budgets are spent and what amount of electrical power is produced using one specific technology or resource in a single state.

The broad research subject also led to a long data collection and processing period. Because this research was conducted over a long period it was difficult to keep track of all new innovations. Innovations in the bio fuels sector develop very quickly, which means this research is outdated really quickly. This long period can be explained by the fact that from nature I have a more physical-theoretical centered personality, rather than a theoretical(-physical) person. This results in the fact that the processing period, writing the research proposal and writing the final report were a slow-moving rather than a smooth process. In the future this can be approved by narrowing the research subject in order to improve the length of the research and better this personal skill.

The overall process of the research, data collection through interviews, applying the snowball method, and collecting data at conferences and seminars went well. Data was collected in all product groups by interviewing various persons with professional and/or academically backgrounds in technologies related to bio fuels, bio energy, and bio chemicals. Hence, the results of the research are considered as representative.

THEORIES USED

Along with practical limitations of this research as stated above, the choice of the theoretical framework had its limitations. The innovation system approach is considered as a practical tool for analyzing all the important actors in a sector. In combination with the system function approach the sectoral innovation system approach the model is a complex approach to analyze technological change of various independent technologies. The complexity increases when more functions, more technologies, and more technology-product combinations are analyzed and compared.

Another limitation of the innovation system approach is considered the lacking of Venture Capital as primary actor group in the model. Especially since this research focused on the U.S. In this study we assumed venture capital to have a more prominent role in the actor landscape since the considered strong influences on the development, use, and spread of technological innovations in certain countries (the U.S.A e.g.). Venture capital not only provides financial resources but they also provide expertise on successful knowledge valorization and spread of new technologies to research institutes, start-ups, entrepreneurs, government etc.

Additionally, the innovation system model is not suitable to identify various different technologies within the innovation system.

The Product Life Cycle theory as used in this research is a market driven model and mainly looks at the product development stage -in this research technologies- in the market. It provides a good overview of the current technological situation from a market point of view; nevertheless it lacks to quantify technological superiority or performance. This is the reason that in this research no differences in available technologies are found in both countries. For example: a technology can be applied on large scale in the U.S. and on a small scale in the Netherlands even though the Dutch technology offers better performances.

7.3 RECOMMENDATIONS

The research subject in this study was setup broadly. It is recommended that future studies that apply the theoretical innovation system approach in combination with the system functions approach apply a narrow focus area with respect to technologies and technology-product combinations. This enables gathering more qualitative and quantitative data at the same time analyzing these data in a shorter time period.

It is also recommended to carry out a comparable research that uses another model than the PLC model to analyze technologies. One can consider to use a model that makes the analysis of technological performance possible, in order to compare technological qualities in two geographically areas.

The applied Innovation System model in combination with the System Function model are considered as practical models for researchers to analyze and compare one technology in more geographical locations. In order to analyze various technologies a study can be conducted to what operational criteria can be used best to analyze the effect from each function on the development of the specific technology. By doing so each function can be 'measured' for each technology in order to conduct a comprehensive comparison that is more representative.

A final recommendation is to conduct more academic research to the position of Venture Capital in the Innovation System model. In this study the assumption is made that Venture Capitalists have a more prominent role in the actor landscape since the considerably influence the development, use, and spread of technological innovations in the U.S.

Literature List

(Abengoa, 2009) Abengoa Bio Energy Website [online] (sited January 15th, 2009) Available from <URL: http://www.abengoabio energy.com/>

(ARS, 2007) USDA Agriculture Research Service [online] (sited December 15th, 2007) Available from <URL: http://www.ars.usda.gov>

(BBE, 2007) The European Bio-based Economy Website [online] (Cited November 20th 2007) Available from <URL: http://www.bio-economy.net>

(B-Basic, 2008) B-Basic Website [online] (Cited on November 7, 2008) Available from: <URL:http://www.b-basic.nl>

(BRDA, 2000) United States of America (2002) *Biomass Research and Development Act of 2000*, US DOE, Washington

(BIO, 2007) Biotechnology Industry Organization (BIO) (2007) *Guide to Biotechnology*

(Bio News, 2007) Bio News Online Website [online] (Cited on November 26th 2007) Available from <URL: http://www.bionewsonline.com>

(BioRights, 2009) BioRight News article Published on Duurzame energie thuis.nl [online] (Cited on February 14, 2009) Available from <URL:http://www.duurzameenergiethuis.nl/energie/levendige-%E2%80%98marktdag%E2%80%99-over-tweede-generatie-biobrandstoffen-1106.html>

(Biodiesel Kampen, 2008) Biodiesel kampen Website [online] (Cited on november 23, 2009) Available from <URL:http://www.biodieselkampen.com/>

(Biodiesel Las Vegas, 2007)Biodiesel Las Vegas Website [online] (Cited on November 20th 2007) Available from <URL: http://www.nclasvegas.com/biodiesel/>

(Bio Energy Twente, 2008) Bio Energy Twente Website [online] (Cited on december 12, 2008) Available from <URL:http://www.bioenergietwente.nl/>

(Biomass, 2007) Office of the Biomass Program Energy Efficiency and Renewable Energy U.S. Department of Energy, October 2007. *Biomass Multi-Year* Program Plan [Online] (Cited on February 15th 2008) Available from <URL://http://www1.eere.energy.gov/biomass/>

(BioRights, 2009) 'Presentation SenterNovem November 18th 2008 Bio Rights' [online] (Cited 27 March 29, 2009) Available from <URL://http://www.senternovem.nl>

(BlueFire, 2007) BlueFire Ethnanol Incorporated's Website [online] (Cited on November 30th 2007) Available from <URL:http://bluefireethanol.com>

(Budget of the US, 2008) 'Budget of the United States Government; FY '08' [online] (Cited on February 26th 2008) Available from <URL:http://www.gpoaccess.gov/usbudget/fy08/browse.html>

(CalEPA, 2008) The California Environmental Protection Agency Website [online] (Cited Feb 5, 2008) Available from <URL:http://www.calepa.ca.gov/>

(Carlsson et al, 2004) Carlsson, B and Jacobsson, S (2004) 'Dynamics of Innovation Systems-Policy-Making in a Complex and Non-deterministic World' *University of Utrecht*

(Carlsson et al, 2002) Carlsson, B, Jacobsson, S, Holmen, M and Rickne, A (2002) 'Innovation systems: analytical and methodological issues', *Research Policy 31,* 233-245

(Carlsson et al, 1991) Carlsson, B and Stankiewicz, R (1991) 'On the nature, function and composition of technological systems' J. Evol. Econ. 1 (2) 93 – 118

(CBC, 2008) The California Biomass Collaborative [online] (sited February 15th, 2008) Available from <URL:http://biomass.ucdavis.edu>

(CEC, 2008) California Energy Commission [online] (sited February 15th, 2008) Available from URL:http:// www.energy.ca.gov>

(Cleantech.com, 2008) CleanEdge Website [online] (sited December 10th, 2008) Available from <URL:http://cleantech.com/about/pressreleases/011008.cfm>

(CleanEdge, 2009) CleanEdge Website [online] (sited January 15th, 2009) Available from <URL:http://www.cleanedge.com/>

(Cleantech Holland, 2009) Cleantech Holland Website [online] (Cited on January 15, 2009) Available from <URL:http://www.cleantechholland.nl/>

(Cooperatie Carnola, 2008) Cooperatie Carnola Website [online] (Cited on november 23, 2008) Available from <URL:http://www.carnola.nl/>

(Conklin, 1996) Conklin, E.J. (1996) 'Designing organization memory: preserving intellectual assets in a knowledge economy' *Glebe Creek, MD*

(Codexis, 2007) Codexis Website [online] (Cited on November 20, 2007) Available from <URL:http://www.codexis.com>

(Colmac, 2008) Colmac Enrgy Inc. Website [online] (Cited on February 19, 2008) Available from <URL:http://www.aciinc.net/CEI.html>

(CSM, 2008) CSM Website [online] (Cited on December 10, 2008) Available from <URL:http://www.csm.nl/>

(DARPA, 2008) US Defense Advanced Research Projects Agency [online] (Cited feb 10, 2008) Available from <URL:http://www.darpa.mill>

(Davenport et al, 1998) Davenport, T and Prusak, L (1998) *Working knowledge. How organizations manage what they know*, Cambridge, MA: Harvard Business School Press

(Dynamotive, 2008) Dynamotive Energy Systems Inc. Website [online] (Cited on December 10, 2008) Available from <URL: http://www.dynamotive.com/>

(DFJ, 2008) Draper Fisher Jurvetson Website [online] (Cited on November 20th, 2008) Available from <URL:http://www.kpcb.com/>

(DOE, 2008) The USA Department of Energy Website [online] (Cited Feb 4, 2008) Available from <URL: http://www.energy.gov>

(DOW, 2007) DOW Chemical Company Website [online] (Cited November 20th 2007) Available from <URL:http://www.dow.com>

(Diversified Energy, 2008) Diversified Energy Corporation Website [online] (Cited on January 16, 2008) Available from <URL:http://www.diversified-energy.com>

(DSM, 2008) DSM Website [online] (Cited on February 2008) Available from <URL:http://www.dsm.com>

(Dlvplant, 2009) DLV plant Website [online] (Cited on January 23, 2009) Available from: <URL:http://www.dlvplant.nl/biogas_en_ethanolproductie_nl.html>

(Ecoventures, 2008) Ecoventures Website [online] (Cited on December 14, 2008) Available from <URL: http://www.ecoventures.nl/>

(Edquist, 1997) Edquist, C (1997) 'Systems of innovation approaches –their emerging and characteristics' in C. Edquist (ed.) (1997) *Systems of Innovation: Technologies, institutions and Organizations,* London: Printer/Cassell

(Edquist, 2001) Edquist, C (2001) 'The System of Innovation Approach and Innovation Policy: An account of the state of the art' *Danish Research Unit for Industrial Dynamics* [online] (Cited August 1 2007) Available from <URL: http://www.druid.dk/uploads/tx_picturedb/ds2001-178.pdf>

(Edquist, 2005) Edquist, C (2005) 'Systems of Innovation: Perspectives and Challenges' *in* Fagerberg, J, Nelson, R.R. and Mowery, D.C (eds) 'The Oxford Handbook of Innovation', *Oxford University Press*, 179-208

(EPA, 2008) US Environmental Protection Agency [online] (Cited on nov 15, 2008) Available from <URL: http://www.epa.gov/>

(EPAct, 2005) United States of America (2005) *Energy Policy Act of 2005*, US DOE, Washington

(Essent, 2008) Essent Website [online] (Cited on September 7, 2008) Available from <URL: http://www.essent.nl/content/Images/Bio_energiecentrale_Cuijk_26-32387_tcm301-26763.pdf>

(EPM, 2009) Ethanol Producer Magazine [Online] (Cited on March 31, 2009) Available from <URL:http://www.ethanolproducer.com/article.jsp?article_id=5466>

(van Ex, 1999) van Ex, F (1999) 'Technologische innovatie en diffusie, economische groei en technologisch beleid: een literatuur overzicht' *CESIT Discussion paper No. 99-03,* 1-65

(EERE, 2007) US DOE Energy Efficiency and Renewable Energy Office [online] (Cited on dec 10, 2007) Available from <URL:http://www.eere.energy.gov/news/news_detail. cfm/news_id=116033>

(EERE, 2009) US DOE Energy Efficiency and Renewable Energy Office [online] (Cited on January 21, 2009) Available from <URL:http://www.eere.energy.gov>

(EIA, 2008) Energy Information Administration Website [online] (Cited on May 20, 2008) Available from <URL:http://www.eia.doe.gov>

(Farm Bill, 2002) United States of America (2002) *Farm Security and Rural Investment Act of 2002*, USDA, Washington

(Farrell *et al.*, 2008) Farrell, A and Gopal, A (2008) 'Bio energy Research Needs for Heat, Electricity, and Liquid Fuels' in MRS Bulletin Vol 33, april 2008.

(Genencor, 2007) Genencor Website [online] (Cited on October 23, 2007) Available from <URL:http://www.genencor.com>

(Gillard, 2007) Interview Gillard, K. Principal, BASF Venure Capital America Inc. October 23, 2007. By J.H.H.F.Roeloffzen

(GTC, 2007) Gasification Technologies Council Website [online] (Cited November 26, 2007) Available from <URL:http://www.gasification.org>

(GTL, 2008) DOE's Genome-GTL Program Website [online] (Cited February 29th 2008) Available from <URL:http://genomicsgtl.energy.gov/program/index.shtml>

(Herschbach, 1995) Herschbach, D.R (1995) 'Technology as Knowledge: Implications for Instruction' *Journal of Technology Education, Vol. 7, No.1,* 32-41

(Hekkert *et al.,* 2007) Hekkert, M.P., Suurs, R.A.A., Negro, S.O., Kuhlmann, S and Smits, R.E.H.M. (2007) 'Function of innovation systems: A new approach for analysing technological change', Science direct, Technological Forecasting & Social Change 74, 413-432

(Hardy, 2002) Hardy, R.W.F (2002) 'The Bio-based Economy' Reprintedfrom: Trends in new crops and new uses, J. Janick and A. Whipkey, ASHS Press, Alexandria, VA

(Hildreth et al., 2002) Hildreth, P.M. and Kimble, C (2002) 'The duality of knowledge' *Information Research, Vol. 8 No. 1*

(HoST, 2008) HoST Website [online] (Cited on November 6, 2008) Available from <URL:http://www.host.nl/nl>

(Hedman, 2007) Bruce A. Hedman. Energy and Environmental Analysis, Inc. 2007 [online] (sited april, 1st 2008) Available from <URL:http://www.energetics.com/napavallayCHPworkshop/pdfs/hedman.pdf>

(INL, 2008) Idaho National Laboratory Website [online] (Cited April 21, 2008) Available from: <URL:http://www.inel.gov>

(IEO, 2007) U.S. Department of Energy, Energy Information Administration (DOE/EIA) (2007) *International Energy Outlook 2007,* United States of America (Jacobsson *et al.,* 2000) Jacobsson, S and Johnson, A (2000) 'The diffusion of renewable energy technology: ananalytic framework and key issues for research' *Energy Policy 28*. 625-640

(Imperium, 2007) Imperium Renewables Website [online] (Cited on November 8, 2007) Available from <URL:http://www.imperiumrenewables.com/?

(JBEI, 2008) Joint Bio energy Insitute [online] (Cited on April 22, 2008) Available from <URL:http://jbei.org>

(JGI, 2007) DOE Joint Genome Institute Website [online] (Cited on November 24, 2007) Available from <URL:http://www.jgi.doe.gov>

(Johnson, 2001) Johnson, A (2001) 'Functions in Innovation System Approaches' *Website of the Danish Research Unit for Industrial Dynamics* [online] (Cited July 26 2007) Available from URL:http://www.druid.dk/uploads/tx_picturedb/ds2001-205.pdf

(Kara, 2008) Kara Energy Systems Website [online] (Cited on November 6, 2009) Available from <URL:http://www.kara.nl/>

(Keasling, 2007) Interview Keasling, J. Chief executive officer, JBEI November 8, 2007. By J.H.H.F.Roeloffzen

(KPCB, 2008) Kleiner Perkins Caufield & Byers Website [online] (Cited November 20th, 2008) Available from:<URL:http://www.kpcb.com/>

(Khosla, 2008) Khosla Ventures Website [online] (Cited November 20, 2008) Available from: <URL:http://www.khoslaventures.com/>

(Kluyver, 2008) Kluyver Centre for Genomics of Industrial Fermentation Website [online] (Cited on December 15, 2008) Available from <URL:http://www.kluyvercentre.nl>

(Kiplinger's, 2007) Kiplinger's (2007) Bio fuels market Alert, Complementary Issue, August 2007

(Kuhlmann, 2002) Kuhlmann, S (2002) 'Governance and Intelligence in Research and Innovation Systems' *Universiteit Utrecht, Faculteit Ruimtelijke Wetenschappen*

(Kuhlmann, 2001) Kuhlmann, S and Arnold, S (2001) 'RCN in the Norwegian research and Innovation System' Background report No. 12

(LNV, 2007) Dutch Ministry of Agriculture, Nature and Food Quality (LNV) (2007) 'Bio-Based Economy: Combining agro and chemical', Website Dutch Ministry of Agriculture, Nature and Food Quality [online] (sited July 2, 2007) Available from <URL:http://www.minlnv.nl/cdlpub/servlet/CDLServlet?p_file_id=14937>

(Lundvall, 1992) Lundvall, B.A. (1992) 'National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning' *Printer, London*

(Levitt, 1965) Levitt, T (1965) 'Putting the Product Life Cycle to Work' *Harvard Business Review* (November- December, 1965)

(Levitan, 2000) Levitan, L (2000) 'How Many Times Can We Skin this Cat Called Earth? Risk and Constraints to the Bio-based Economy' *Cornell University, Ithaca, NY*

(LLNL, 2008) Discover LLNL. Tracy Edition [online] (Cited April 2008) Available from <URL:hhtp://www.llnl.gov>

(LS9, 2008) LS9 Inc. Website [online] (Cited on February 18th, 2008) Available from <URL:http://www.ls9.com/>

(LSBC, 2008) LifeSciences British Columbia Website [online] (Cited on February 18th, 2008) Available from <URL:http://www.lifesciencesbc.ca/>

(Mendel, 2008) Mendel Biotechnology Inc. Website [online] (Cited on November 23, 2008) Available from <URL:http://www.mendelbio.com>

(NBB, 2007) Natinoal Biodiesel Board (NBB) [online] (Cited on November 18th, 2007) Available from <URL:http://www.biodiesel.org//

(Nedalco, 2008) Koninklijke Nedalco Website [online] (Cited on December 12, 2008) Available from <URL:http://www.nedalco.nl/>

(NETL, 2008) National Energy Technology Laboratory Website [online] (Cited on April 22, 2008) Available from <URL://www.netl.doe.gov>

(Negro *et al.,* 2004) Negro, S, Hekkert, M.P. and Smits, R (2004) 'On the dynamics of a technology specific innovation system: The case of biomass digestion technology in the Netherlands from 1974 until 2004' *Website University of Utrecht, Innovation Stydies* [online] (Cited on August 1, 2007) Available from

<URL:http://nwi.geog.uu.nl/content/files/negro_1104935853_Paper%20DRUID%20Winter%202005%20Simona%20Negro.doc.pdf>

(NRC, 2000) National Resource Council (NRC) (2000) *Bio-based Industrial Products, Priorities for Research and commercialization,* National Academy Press, Washington, D.C.

(NGI, 2008) Netherlands Genomics Initiative Website [online] (Cited on November 6, 2008) Available from <URL:http://www.genomics.nl/>

(NREL & GRI, 2003) NREL and the Gas Research Institute (2003) 'Gas-fired Distributes Energy Resources Technology Characterizations'

(Novozymes, 2007) Novozymes Website [online] (cites on October 25, 2007) Available from <URL:http://novozymes.com>

(Nussbaumer, 2003) Nussbaumer, Thomas (2003) 'Combustion and Co-combustion of Biomass: Fundamentals, Technologies, and primary Measures or Emission Reduction' in Energy & Fuels 2003, 17, 1510- 1521.

(NWO, 2008) The Netherlands Organization for Scientific Research Website [online] (Cited on November 6, 2008) Available from <URL:http://www.nwo.nl>

(PaperFoam, 2008) PaperFoam Website [online] (Cited on November 25, 2008) Available from <URL:http://www.paperfoam.com/>

(Pinal, 2008) Pinal Energy Processors Website [online] (Cited on may 14, 2008) Available from <URL:http://pinalenergyllc.com>

(PNNL, 2008) Pacific Northwest National Laboratory Website [online] (Cited on April 22, 2008) Available from <URL:http://www.pnl.gov>

(Phoenix, 2007) Phoenix Consulting Group International Website [online] (Cited on November 22, 2007) Available from <URL:http://phoenixcgi.com>

(Purac, 2008) Purac Website [online] (Cited on November 25, 2008) Available from <URL:http://www.purac.nl/>

(PWC, 2007) Price Waterhouse Coopers, 'Cleantech comes of age' [online] (cited on July 18, 2007) Available from <URL: http://www.pwc.com/extweb/pwcpublications.nsf/docid/F5FAF2869E17839E852574340044178D/$file/pwc-cleantech-052008.pdf>

(SenterNovem, 2007) SenterNovem, Energy Transition, Platform Groene Grondstoffen (2007) 'Toetsingskader voor duurzame biomassa' [online] (visited Sept 26 2008) Available from <URL:http:// http://www.senternovem.nl/energietransitiegg/documentatie/downloads_rapporten_en_achtergrondinformatie.asp>

(RealEnergy, 2008) RealEnergy LLC. Website 2007 [online] (sited april 18, 2008) Available from <URL:http://www.realenergy.com/>

(RFA, 2008) Renewable Fuel Association Website [online] (Cited on February 11, 2008) Available from <URL:http://www.ethanolrfa.org>

(Rickne, 2001) Rickne, A. (2001) 'Assessing the Functionality of an Innovation System' Conference paper for the Nelson and Winter Conference arranged by DRUID in Aalborg, Denmark

(Robsnon, 2002) Robson, C (2002) *Real World Research* (2nd edition), Oxford, Blackwell

(Rodenburg, 2008) Rodenurg Polymers Website [online] (Cited on november 7, 2008) Available from <URL:http://www.biopolymers.nl/>

(Rulke *et al.*, 1998) Rulke, D, Zaheer, S, and Anderson, M (1998) 'Transitive knowledge and performance in the retail food industry'*New York, NY*

(Sandia, 2008) Sandia National Laboratories Website [online] (Cited April 21, 2008) Available from <URL:http://www.sandia.gov>

(Saunders *et al.*, 2007) Saunders, M, Lewis, P and Thornhill, A (2007) *Research Methods for Business Students* (4th edn), Pearson Education Limited, Essex

(SenterNovem, 2007) SenterNovem, Energy Transition, Platform Groene Grondstoffen (2007) 'Toetsingskader voor duurzame biomassa' [online] (sited Sept 26 2008) Available from <URL:http:// http://www.senternovem.nl/energietransitiegg/documentatie/downloads_rapporten_en_achtergrondinformatie.asp>

(SenterNovem, 2009) SenterNovem Website [online] (Cited on February 10, 2009) Available from <URL: http://www.senternovem.nl>

(SF Gate, 2006) SF Gate (2006) 'When Kitchen Waste Isn't Wasted' SF Gate, San Francisco, October 25. [online] <URL:http://www.sfgate.com>
(SF Business Times, 2007) San Francisco Business Times (2007) 'UC Berkeley wins race for $500 million bio fuels center' San Francisco Business Times, San Francisco, 1 February. [online] <URL:http://www.bizjournals.com/sanfrancisco/stories/2007/01/29/daily34.html>

(Stanford, 2008) Stanford University Website [online] (Cited April 20, 2008) Available from <URL:http://www.stanford.edu>

(State of California, 2008) State of California Website [online] (Cited April 20, 2008) Available from <URL: http://www.energy.ca.gov/>

(Start Green, 2008) StarGreen Website [online] (Cited on December 14, 2008) Available from <URL: www.startgreen.nl>

(Sun Oil Biodiesel, 2008) Sun Oil Biodiesel Website [online] (Cited on November 23, 2008) Available from <URL:http://www.sunoil-biodiesel.com/>

(De Stentor, 2008) De Stentor Website [online] (Cited on December 17, 2008) Available from <URL:http://www.destentor.nl/regio/kampen/article1348085.ece>

(Shell, 2008) Royal Dutch Shel Website [online] (Cited on December 17, 2008) Available from <URL:http://www.shell.com/>

(Twence, 2008) Twence Website [online] (Cited on September 3, 2008) Available from <URL:http://www.twence.nl>

(TWC, 2009) Twente Water Center Website [online] (Cited on February 9, 2009) Available from <URL:http://www.water.utwente.nl/>

(Bio-based, 2007) The European Bio-based Economy Website [online] (Cited July 2, 2007) Available from <URL:http://www.bio-economy.net>

(BRDi TAC, 2002) USDA and DOE, Biomass Research and Development Technical Advisory Committee (2002) 'Roadmap for Biomass Technologies in the United States' [online] (sited July 10 2007) Available from <URL:http://www.brdisolutions.com/pdfs/FinalBiomassRoadmap.pdf>

(DOE/OBP, 2007) U.S. Department of Energy, Office of the Biomass Program (DOE/OBP), Energy Efficiency and Renewable Energy. (2007) *Biomass Multi-Year Program Plan October 2007,* United States of America

(UCBerkeley, 2007) UC Berkeley Website [online] (Cited April 7, 2008) Available from <URL: http://berkeley.edu/>

(UC Davis, 2008) UC Davis Website [online] (Cited April 5, 2008) Available from <URL:http://www.ucdavis.edu/index.html>

(UCLA, 2007) UC Los Angeles Website [online] (Cited November 6,2008) Available from <URL:http://www.ucla.edu>

(USAGOV, 2007) The USA Government Website [online] (Cited Sept 23,2007) Available from <URL:http://www.usa.gov>

(USDA/RD, 2007) The USA Department of Agriculture, Rural Development Website [online] (Cited on December 11,2007) Available from <URL:http://www.rurdev.usda.gov/rd>

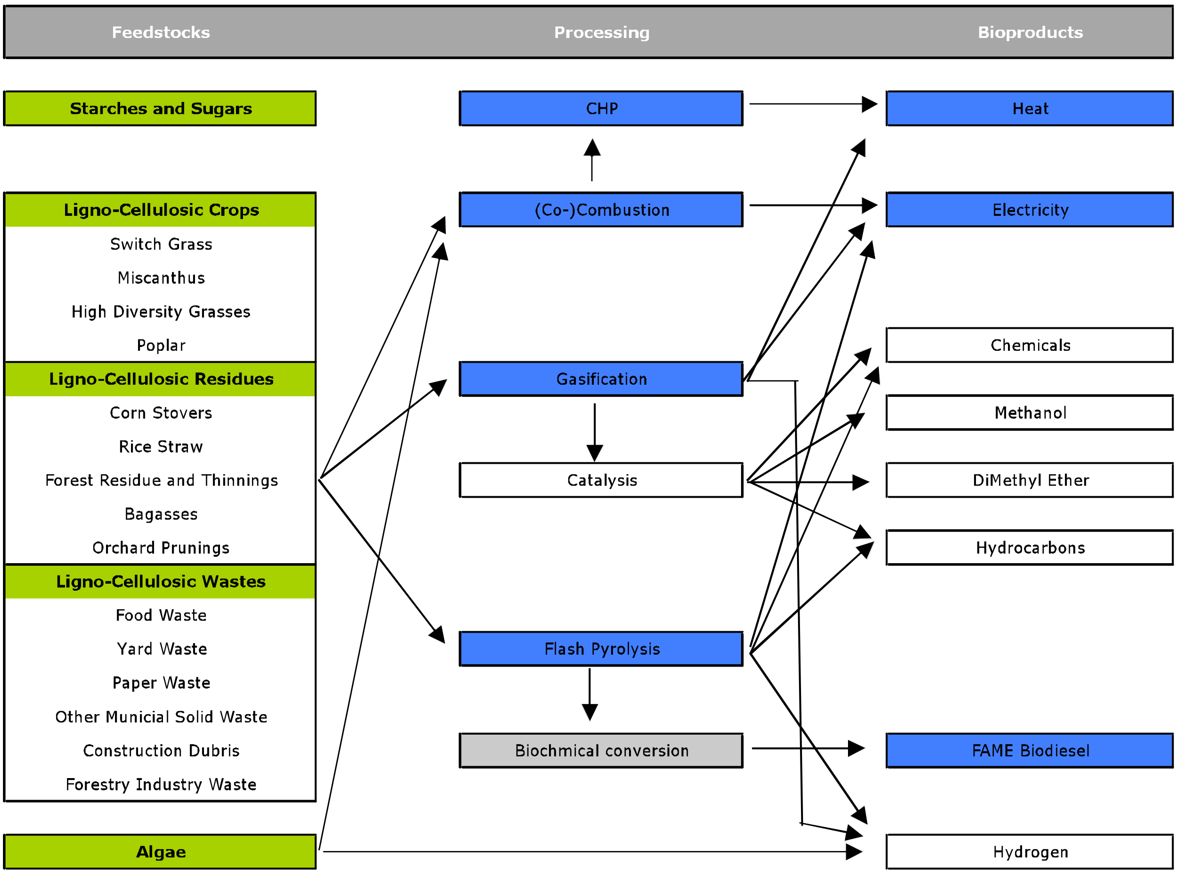
(Verenium, 2007) Verenium Website [online] (Cited on November 29, 2007) Available from URL:http://www.verenium.com

(Wheelabrator, 2008) Wheelabrator Website [online] (Cited on September 2008) Available from <URL:http://www.wheelabratortechnologies.com/>

(Wood, 1996) Wood, L (1996) ' The end of the product life cycle? Education says goodbye to an old friend' *Journal or Marketing Management 6(2). 190: 145-55*

(WUR, 2009) Wageningen University and Research Centre Website [online] (Cited on February 5, 2009) Available from <URL:http://www.wur.nl/NL/>

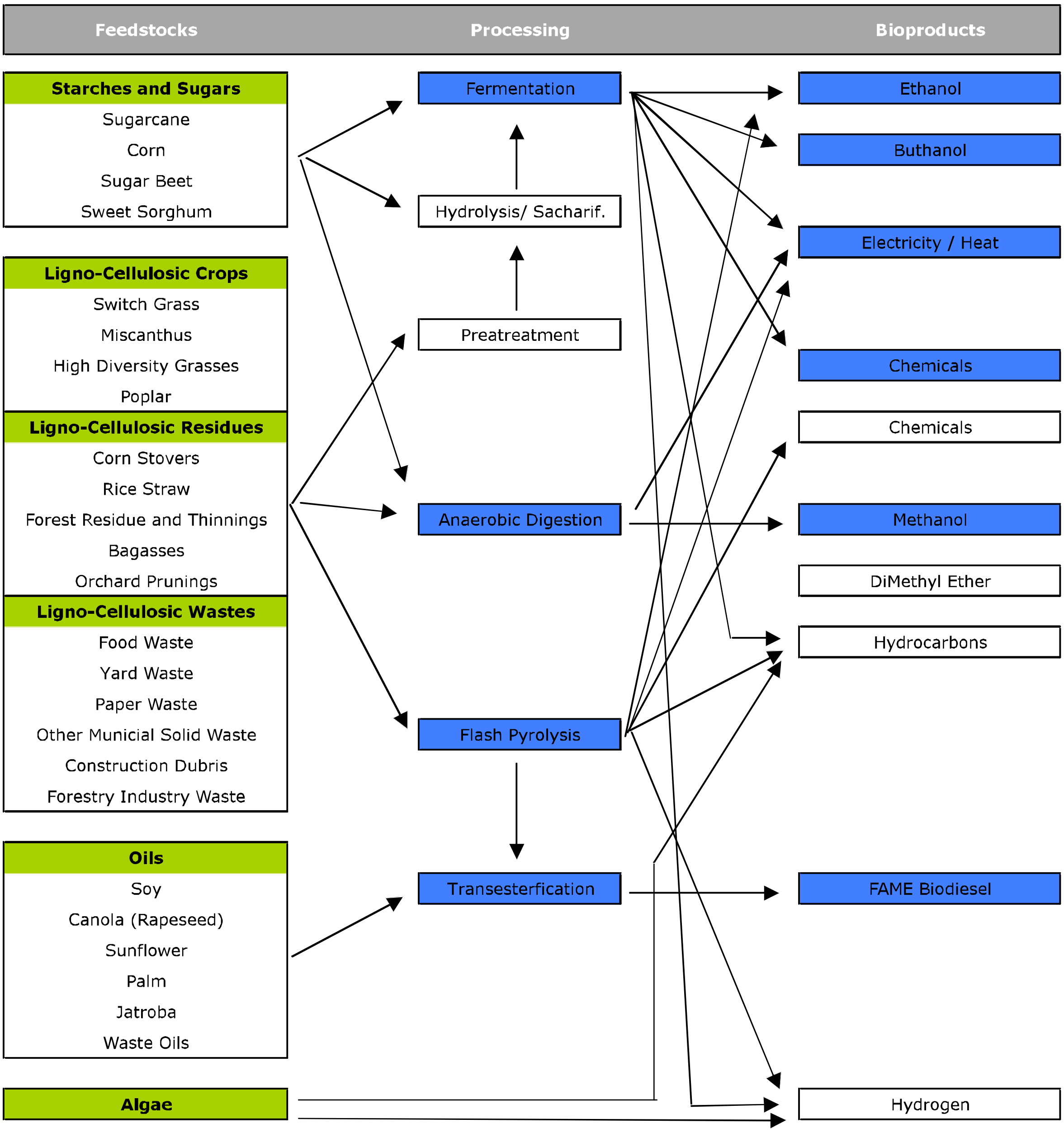
APPENDIX 1. BIO PRODUCT PRODUCTION PATHWAYS; THERMOCHEMICAL CONVERSION



* The blue boxes can be considered as commercial available pathways/ technologies.

(Figure based on a matrix originally prepared by Alexander E. Farrell)

APPENDIX 2. BIO PRODUCT PRODUCTION PATHWAYS; BIO CHEMICAL CONVERSION



* The blue boxes can be considered as commercial available pathways/ technologies.

(Figure based on a matrix originally prepared by Alexander E. Farrell)

APPENDIX 3. CURRENT AND FUTURE EFFORTS IN ETHANOL TRANSPORTATION FUEL PRODUCTION IN THE WESTERN UNITED STATES

Name	Stage	Location	Feedstock	Generation	Annual capacity
Pacific Ethanol inc.	In Operation	Boardman, OR	Corn	First Generation	170 Million liter
Pacific Ethanol inc.	In Operation	Madera, CA	Corn	First Generation	150 Million liter
Pacific Ethanol inc.	In Operation	Stockton, CA	Corn	First Generation	230 Million liter
Pacific Ethanol inc.	In Operation	Burley, ID	Corn	First Generation	230 Million liter
Idaho Ethanol Processing	In Operation	Caldwell, ID	Potato Waste	First Generation	15 Million liter
Pinal Energy LLC	In Operation	Maricaop, AZ	Corn	First Generation	210 Million liter
Altra Biofuels Phoenix Bio Industries LLC	In Operation	Goshen, CA	Corn	First Generation	120 Million liter
Parallel Products	In Operation	Rancho Cucamonga, CA	-	-	- -
Golden Cheese Company of California	In Operation	Corona, CA	Cheese Whey	First Generation	20 Million liter
Northwest Renewable, LLC	Under Construction	Longview, WA	Corn	First Generation	210 Million liter
Cilion Ethanol	Under Construction	Keyes, CA	Corn	First Generation	190 Million liter
Calgren Renewable Fuels LLC	Under Construction	Pixley, CA	Corn	First Generation	210 Million liter
BlueFire Ethanol	Concept	Langcaster, CA	Various	Second Generation	70 Million liter
Colusa Biomass Energy Corporation	Concept	Colusa, CA	Waste Rice Straw	Second Generation	- -

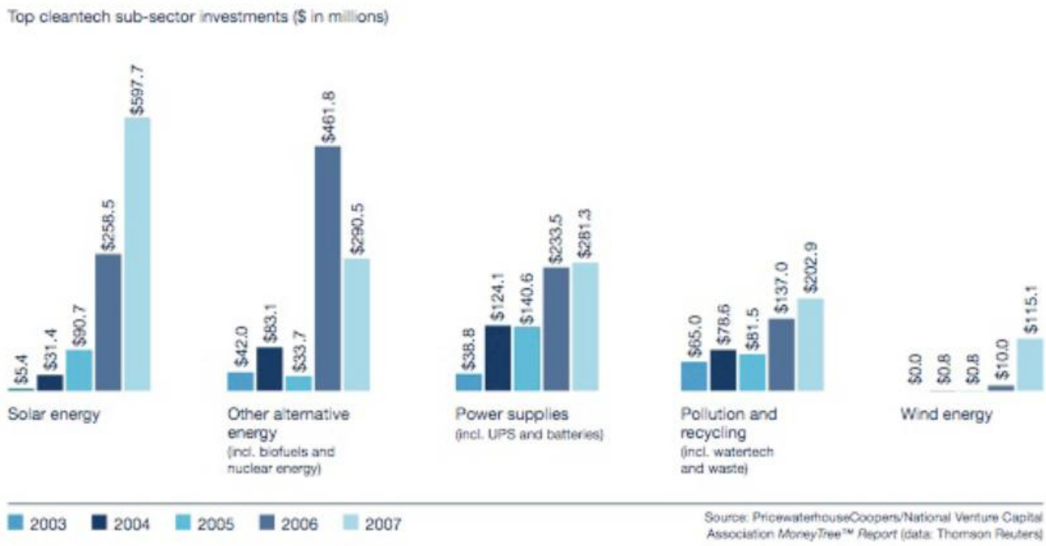
(Source: Ethanol Renewable Fuels Association, 2009)

APPENDIX 4. CURRENT AND FUTURE EFFORTS IN BIO FUEL PRODUCTION IN THE NETHERLANDS

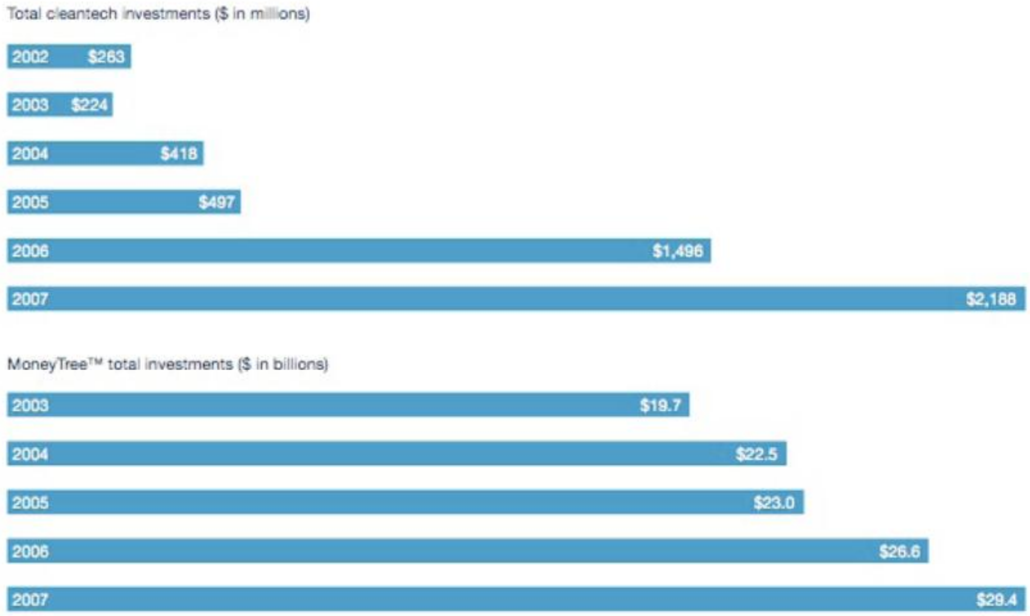
Name	Stage	Fuel	Details	Feedstock	Annual capacity
Biodieselkampen BV	In Operation	Biodiesel	Biodiesel manufacturing	WVO	60 Million liter
Biogast	In Operation	Biogas	Green gas	n.a.	n.a.
Biopetrol AG Industries	In Operation	Biodiesel	Biopetrol Rotterdam B.V.	PPO	451 Million liter
Biovalue B.V.	In Operation	Biodiesel	Biodieselfacility Eemshaven	PPO	255 Million liter
CleanerG B.V.	In Operation	Biodiesel	Biodieselfacility Zwijndrecht	PPO	226 Million liter
Coöperatie Carnola	In Operation	Biodiesel	Production PPO	PPO	2 Million liter
Ecopark Harlingen Holding BV	In Operation	Biodiesel	Oliemolen Harlingen	PPO	30 Million liter
Ecoson/Vion	In Operation	Biodiesel	Biodiesel- and electricityproduction Ecoson	Animal Fats	6 Million liter
LyondellBasell Industries	In Operation	ETBE	Bio- ETBE production Rotterdam	-	4 Million liter
Noord Nederlandse Oliemolen B.V.	In Operation	Biodiesel	Production PPO	PPO	n.a.
OPEK Nederland B.V.	In Operation	Biodiesel	Production PPO	PPO	0,5 Million liter
Roosendaal Energy	In Operation	Biodiesel	Biodieselfacility Sluiskil	PPO/ animal fats	280 Million liter
SABIC	In Operation	ETBE	Bio- ETBE production Geleen	-	175 Million liter
Sunoil Biodiesel B.V.	In Operation	Biodiesel	Biodieselfacility Emmen	WVO/ animal fats	80 Million liter
Maatschap Bosma	In Operation	Bio-ethanol	Production bioethanol from potato starch	Potato	5 Million liter
Abengoa Bioenergy Netherlands BV	Startup	Bio-ethanol	Bio-ethanolfacility Rotterdam	Grain	480 Million liter
B2G/ Neste Oil	Startup	Biodiesel	NExBTL biodiesel Rotterdam	PPO/ animal fats	903 Million liter
BioDsl	Startup	Biodiesel	Biodieselfacility	PPO/ animal fats	11 Million liter
BioMCN BV	Startup	Biomethanol	Methanolfacility Delfzijl	n.a.	903 Million liter
Dutch Biodiesel / Argos oil	Startup	Biodiesel	Biodieselfacility Rotterdam	PPO	282 Million liter
Greenmills Properties BV / Noba Vet	Startup	Biodiesel, Bio-ethanol	Production biodiesel, biogas and bioethanol (biodiesel resp ethanol)	WVO-n.a.	150-5 Million liter
ROVA	Startup	Biogas	Driving on naturalgas	Green waste	3 Million Cubic Meter
Koningklijke Nedalco	Concept	Bio-ethanol	Second-generation ethanol plant Sas van Gent	Lignocellulosic feedstock	200 Million liter
Bio-Ethanol Rotterdam (BER)	Concept	Bio-ethanol	Production Bio-ethanol and SuBERgas	Grain	125 Million liter
Biofueling BV	Concept	Biodiesel	Biodieselfacility Terneuzen	PPO	226 Million liter
Dekro BV (J.H. Adams)	Concept	BioEnergy/ Bio-ethanol	Bio-energy (including ethanol) facility Nieuwe Pekela	Potato, corn, grain	15 Million liter
European Bulk Services (EBS) B.V	Concept	Biodiesel	Biodieselfacility Rotterdam	n.a.	564 Million liter
Futura Petroleum - Harvest Biofuels	Concept	Bio-ethanol	Bio-ethanolfacility Amsterdam	Grain	124 Million liter
Groene Poort	Concept	BioEnergy/ Bio-ethanol	Small scale bio-energy plant including ethanol facility	Grain	n.a.
N2 Energy BV	Concept	Bio-ethanol	Bio-ethanol facility Hardenberg	Biomass Waste	34 Million liter
Nivoba B.V.	Concept	Bio-ethanol	Pentagreen B.V.	Wheat	n.a.
WHEB Biofuels Ltd	Concept	Biodiesel	Biodiesel facility Port of Rotterdam	PPO	n.a.

PPO: Pure Vegerable Oils, WVO: Waste Vegetable Oils, (Source: SenterNovem, 2009) n.a.: Not Available

APPENDIX 5. CLEANTECH INVESTMENTS V.S. BY VENTURE CAPITALISTS



Top cleantech sub-sector investments ($ in million) (PWC, 2007)



Historical Cleantech investments in the U.S. (PWC, 2007)

APPENDIX 6. LIST OF INTERVIEWEES AND VISITED CONFERENCES/SEMINARS

NAME INTERVIEWEE/ CONFERENCE	ORGINiZATION	LOCATION	DATE
Dhr. K. Kwant	Senter Novem	Arnhem, The Netherlands	June 12, 2007
Dhr. Van der Meer	University Twente	Enschede, The Netherlands	June 2007
Dhr. Brem	University Twente	Enschede, The Netherlands	June 14, 2007
Dr. Remco Hoogma	Senter Novem	Arnhem, The Netherlands	June 12, 2007
Ir. Erik van Seventer	Wageningen University and Research Center	Wageningen, The Netherlands	June 12, 2007
Marjan Botman	Dutch Ministry of Foreign Affairs	The Hague, The Netherlands	June 2007
Prof. Chris Somerville	Stanford University, EBI	Palo Alto, CA, U.S.A.	September 18, 2007
Prof. Jay Keasling	UCI Berkeley, JBEI	Telephone	November 8, 2007
Alex Farrel (associate professor)	UC Berekeley	Berkeley, CA, U.S.A.	November 9, 2007
Keith Gillard	BASF Venture Capital	San Francisco, CA, U.S.A.	October 23, 2007
Matthew Gardner	Bay BIO	South San Francisco, CA, U.S.A.	October 25, 2007
Chris Cassidy	USDA Rural Development	Las Vegas, NV, U.S.A./ San Fransicso, CA, U.S.A.	October 10/ november, 2007
Matthew Gregori	Biodiesel of Las Vegas	Las Vegas, NV, U.S.A.	September 20, 2007
Prof. dr. ir. L. van der Wielen	Delf University/ Shell	San Mateo, CA, U.S.A.	October, 2007
AFVi Biofuels Drive Economic Solutions Forum 2007		Las Vegas, NV, U.S.A.	September 20, 2007
BBI Biofuels Biofuels Workshop & Trade Show Series 2007		Portland, OR, U.S.A.	November 28-30 2007
Colloquium Alex Farrel ERG 'Biofuels in the 21st Century'		Berkeley, CA, U.S.A.	October 31, 2007
Astia Clean Tech Breakfast 'Biobased Products'		San Francisco, CA, U.S.A.	July, 2007
Algae Biomass Summit 2007		San Francisco, CA, U.S.A.	November 14-16, 2007
Somerville Lecture, Science at the Theatre Berkeley		Berkeley, CA, U.S.A.	November 12, 2007
California Cleantech Open 2007		San Francisco, CA, U.S.A.	Various meetings. 2007