TNO Quality of Life

TNO Report

Biobased economy – Exploring the opportunities for the Netherlands

Bijlage 1

Overview of high value added applications of biomass and biorefinery

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Summary

The Dutch government has the policy objective to stimulate the biobased economy. The use of materials, chemicals and fuels produced from biological materials can save fossil resources, reduce the emission of carbon dioxide, decrease negative effects on the environment and health, support the agricultural sector and can lead to product innovation (in particular in the chemistry sector). Preferably, the production of materials, chemicals and fuels, in particular high value compounds, should be produced in the Netherlands using local biomass feedstock. However, importing of feedstocks will be unavoidable to reach our targets with respect to quantities.

The Netherlands is in a good position to develop a biobased economy as it has a high qualified knowledge position at universities, institutes and companies, a strong and productive agricultural sector, a strong chemistry sector and large ports to import biomass. In general these are supportive conditions for innovations in this field that could lead to the development and production of biomass-based high value added products. The question that is addressed in this project is what are these potential applications and in which should the Dutch government invest.

In order to support the Dutch government's decision making on which measures should be chosen in order to speed up the realization of a biobased economy and more specific to support the development of potential attractive biomass-based products, TNO was commissioned to do a study on the market chances for the biobased economy in the Netherlands. Food and feed products were excluded as well as traditional construction materials. The study was split up in three parts:

1. Inventory of potential attractive products (combined with a production process) that are available or under development, and a pre-selection of the most promising.
2. Market study of selected products based on potential and chances in the market. The products are categorized in three classes: High chance (sells itself without government stimulation; high impact), Medium chance (introduction is promising buts needs government intervention) and Low chance (not feasible).
3. Proposal of which policy instruments the Dutch government can us in order to stimulate 'Medium Chance'-products.

This report presents the results of the first part. First a pre-selection of 34 products or product categories (materials, chemicals and fuels) was made based on available information from desk research, expert interviews and evaluations made by the TNO expert. Additional information on these preselected products and product combinations was collected, in particular on the following aspects:

- Techno-economical feasibility
- Time-to-market
- Added value
- Sustainability/favourable LCA
    - Reduction energy use (fossil sources)
    - Reduction greenhouse gas emission
    - Other aspects
- Fit in Netherlands agro sector (present volumes, current crops, present industries)

- Fit in Netherlands chemistry sector
- Netherlands knowledge position (presence of unique expertise)

The products were grouped in the following main categories:

- Biopolymers
- Biofuels
- Pharmaceuticals
- Base chemicals
- Plasticisers
- Proteins and peptides
- Paint, inks and adhesives

The assessment of the products on each of these aspects is presented in tables with scores on relevant aspects.

Our main conclusion is that – based on the information collected and our expertise in the field - the best chances are for a number of specific products in the group of biopolymers and in the group of base chemicals.

The four most promising biopolymers in order of decreasing chance are:

1. Polylactic acid
2. Agro fibre composites
3. Thermoplastic starch
4. Modified starch

The six most promising base chemicals in order of decreasing chance are:

5. Succinic acid
6. Ethanol (for polyethylene production)
7. Itaconic acid
8. Isosorbide
9. Tetrahydrofuran
10. 1,4-Butanediol

In addition we also propose to include:

11. Biobased paints are a chance, mainly because the future volumes produced in the Netherlands.
12. HTU diesel is a promising biofuel to replace diesel, which is interesting mainly because of volumes and knowledge position.
13. Enzymes produced by fermentation continues to be interesting, because of the high value.
14. Proteins from plant and animals may be interesting. The business is already well established and innovations are possible.
15. Biopharmaceuticals may be interesting, because of the high value and the novelty (rather than cephalosporins).

Besides these chances, important running developments such as first and second generation fuel bioethanol are important to boost our biobased economy on short term. Care should be taken that these developments not retard the production of the selected products above.

1 Introduction

The Dutch government has the policy objective to stimulate the biobased economy. The use of materials, chemicals and fuels produced from biological materials can save fossil resources, reduce the emission of carbon dioxide, decrease negative effects on the environment and health, support the agricultural sector and can lead to product innovation (in particular in the chemistry sector). Preferably, the production of biobased materials, chemicals and fuels, in particular high value compounds, should be produced in the Netherlands using local feedstock. However, importing of feedstocks will be unavoidable to reach our targets with respect to quantities. The Platform Groene Grondstoffen, the official advisors to the government, has assessed how the Netherlands can get the 900 PJ biomass (about 54 million ton of dry matter) required in 2030. At least 50% should be imported, 33% will be waste organic materials from national sources and maximum 17% will be derived from national energy crop cultivation (Rabou *et al.*, 2006). The Netherlands is in a good position to develop a biobased economy as it has a high qualified knowledge position at universities, institutes and companies, a strong and productive agricultural sector, a strong chemistry sector and large ports to import biomass (Overheidsvisie, 2007).

Nevertheless, the biobased economy does not develop fast enough. Many biobased products are still more expensive than the conventional alternatives and (expensive) R&D is required to make them more attractive for the market. This is one important factor that slows the introduction of these products. Other factors that retard the developments are uncertainties about raw material prices and legislation, problems to organize the complete production chain and approval procedures. Government intends to stimulate a fast development of the biobased economy, e.g. by R&D subsidies, investment funds, taxes and laws. However, the efficacy of these measures is not known beforehand and depends on the specific problems of each product/market combination.

The questions that are addressed in this project is what are the potential attractive biomass-based products that suit best to the Dutch strengths in this field and which products need government support for its development in order to lead to marketable products.

In order to support the Dutch government's decision making on which measures should be chosen in order to speed up the realization of a biobased economy and more specific to support the development of potential attractive biomass-based products, TNO was commissioned to do a study on the market chances for the biobased economy in the Netherlands. Food and feed products were excluded as well as traditional construction materials. The study was split up in three parts:

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3. Proposal of which policy instruments the Dutch government can us in order to stimulate 'Medium Chance'-products.

This report presents the results of Part 1.

In our study biobased is defined as ‘made of biomass’. This biomass can be of plant, animal or microbial origin. The conversion of biomass into a biobased product can be biological, chemical or mechanical. Biobased is not the same as biodegradable: many biobased products are biodegradable but not all.

In the Netherlands it is generally acknowledged that many biobased products can be produced from sugar and starch, but that the use of these raw materials should not interfere too much with food and feed market or, if imported, leads to deforestation and poverty abroad. Therefore, the use of waste wood, grass and straw should get priority in the development of the biobased economy. This policy has a slight effect on the product choices, e.g. plastic composites containing fibres fit in to this policy better than starch as a plastic. However, this effect is not dramatic. Many biobased products can be produced from carbohydrates from various origins (beets, wheat, grass, wood). The price, availability and law determine which raw materials are the most interesting to produce a certain product. However, the chain will only run if the product gets a chance on the market.

In our study we focus on potential attractive products in combination with a specific technology through which they can be produced. This can be part of a biorefinery process. Also biorefineries are a chance as they are tools to efficiently produce biobased products. However, the need for biorefineries depends on the market chances of the products produced. Therefore, this study focuses primarily on products.

In Chapter 2 we explain the methodology used in the inventory.

Chapter 3 on Results provides the available and relevant information on each product and the assessment of each product on seven aspects. The 34 products belong to the following main product categories: biopolymers, biofuels, pharmaceuticals, base chemicals, plasticisers, proteins and peptides and paint, inks and adhesives. The chapter closes with an overview tables holding the scores of each product on seven different aspects.

The report concludes in Chapter 4 with the list of selected products that are recommended for the market study in Part 2.

We thank two reviewers (US based experts in the field) for their valuable comments on the draft version of this report.

2 Methodology

On the basis of a number of studies (of which some are presented in more detail in this chapter) and expertise available at TNO we have estimated that almost 1000 different biobased products can be produced.

First a pre-selection of 34 products or product categories was made based on several documents and other information sources and on experts' opinions. The documents and information sources included key reports on biobased products (Werpy and Petersen, 2004; Patel *et al.*, 2006; Paster *et al.*, 2003; Nowicki *et al.*, 2008; see also Box 1), national and international conferences of the last few years (e.g. the annual World Congresses on Industrial Biotechnology & Bioprocessing, the annual Symposiums on Biotechnology for Fuels and Chemicals, Netherlands Biotechnology Congress, numerous biofuel conferences, TWA Symposium). Interviews have been held with expert, including those from the Wageningen University and Research Center and from TNO. Especially, some other sources proved to be very valuable: companies collaborating with TNO, TNO studies on biobased economy and national research programs in which TNO is collaborating (e.g. B-Basic, Kluyver Centre for Genomics of Industrial Fermentation, the Carbohydrate Competence Center, WISEBIOMAS).

Box 1: Key reports on potential attractive biobased products

According to LEI report 6.08.01 (Nowicki *et al.*, 2008) 780 products within the PRODCOM listing are biobased: 323 are materials derived from biomass, 101 are compounds produced from biomass and 356 are building blocks (to produce other products). In 2005 the market size of the EU25 was 245 billion € for the biobased products and a growth of 210 billion € must be possible, in particular in building blocks. Biofuels, base chemicals, plant extracts, pharma ingredients and paints and inks can be large markets if the biological alternatives are able to substitute the conventional products (Nowicki *et al.*, 2008).

In the USA, the National Renewable Energy Laboratory has carried out a selection process on request of the Department of Energy (Werpy and Petersen, 2004). The authors focused on chemicals that can be produced from sugars and synthesis gas. 300 chemicals were screened on market potential and technological feasibility as assessment criteria. 12 chemicals were selected, which were all building block chemicals: 1,4-diacids (scuccinic, fumaric, malic), 2,5-furan dicarboxylic acid, 3-hydroxy propionic acid, aspartic acid, glucaric acid, glutamic acid, itaconic acid, levulinic acid, 3-hydroxybutyrolactone, glycerol, sorbitol and xylitol/arabinitol. A second category included lactic acid and furfural.

In the Dutch BREW project (Patel *et al.*, 2006) acrylic acid, succinic acid, 1-4-butanediol, tetrahydrofuran, gamma-butyrolactone and levulinic acid were recognized as promising products produced from biomass.

Paster *et al.* (2003) give a list of possible products that can be produced from biomass with the current market price, the current market volume (including non biobased) and the estimated 2020 market volume. From this list candidates with a good combination of high value and a high market volume can be selected. The authors suggest lactic acid, ethyl lactate, 1,3-propanediol, succinic acid, Bionolle 4,4-polyester, propylene glycol, 3-hydroxy propionic acid, itaconic acid, isosorbide and levulinic acid, and other compounds.

In addition, relevant reports of the Platform Groene Grondstoffen were included in the study.

The 34 preselected product (group)s mainly concern bulk chemicals. Only a few fine chemicals are included (biopharmaceuticals, cephalosporins and certain synthetic proteins and functional peptides). The reason for this is that the Netherlands (still) is a strong bulk chemical producer and despite of policies of companies to shift to fine chemicals, such a shift has not yet clearly established. On the basis of what we learned from our visits to biotechnology and bioprocessing conferences we found that this also applies for biochemicals. Biotechnology companies mainly show their developments on bulk biochemical production.

More information on the 34 preselected products or product groups was collected, in particular on the following seven aspects which are used to assess the importance of each product:

- Techno-economical feasibility
- Time-to-market
- Added value
- Sustainability/favourable Life Cycle Analysis (LCA)
    - Reduction energy use (fossil sources)
    - Reduction greenhouse gas emission
    - Other aspects
- Fit with the Netherlands agro sector (present volumes, current crops, present industries)
- Fit with the Netherlands chemistry sector
- Netherlands knowledge position (presence of unique expertise)

Added value generally means the difference between the value of a product and the raw materials or the product from the previous production stage. In this study the value of the whole chain including crop cultivation (from plant seed to biobased product) was considered.

The production of the selected biobased substances should be viable in the Netherlands or at least interesting for the Netherlands, which implies a high economic, environmental or sustainability product value. Also the products should lead to an additional (future) market chance, which implies a degree of novelty.

Only information that was readily available to the authors has been used. The emphasis was on molecules rather than on complete formulations. We experienced gaps in information on LCA data of product and their product chains: for most products these data were lacking, for some other products these data were poorly accessible.

Care should be taken when comparing environmental and energy aspects of biobased products with petrol based equivalents. LCA studies should bear in mind that the production process of a biobased production process is not yet that optimized as a competing petrol-based product.

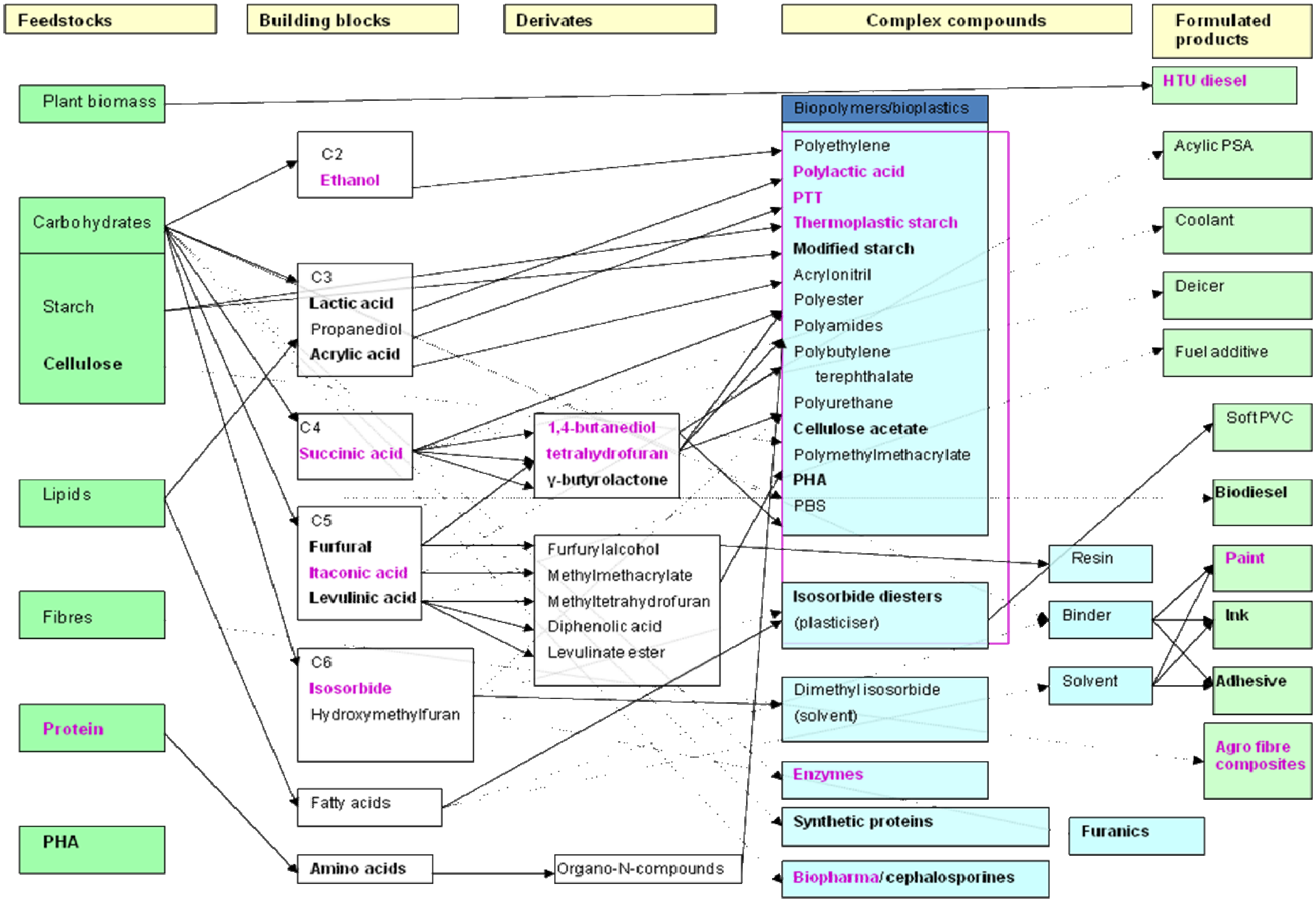
Food and feed and traditional construction materials already have a considerable market in the Netherlands, which will remain and sustain. That is why these applications did not get priority in the selection process. Bioethanol already is conquering market in the

Netherlands rapidly. Although the value per kg of this biofuel is low, a production activity in the Netherlands presently supports the Dutch wheat farmers and fits in our oil industry. Moreover, the activity will stimulate further development of biorefineries, biomass logistics and the biobased economy in general. However, as soon as other biobased products with a higher added value get a substantial market share, local biofuel production may not be able to compete with these new biobased activities for local biomass, unless as import of biomass becomes feasible or as the tail part of a biorefinery (bio-cascading). In our study the focus is on these new biobased activities.

Biodiesel produced from plant oil and waste oil is another product with a considerable present market. However, market growth is not expected because of the lack of low cost feedstocks. Biodiesel from algae may be a far future market chance. However, the Netherlands is a diesel consuming country and Europe consumes more diesel than gasoline. Therefore, there is a need for biobased alternatives for diesel. Furanics, butanol, Fischer Tropsch diesel and HTU diesel may be good alternatives, as well as products refined from pyrolysis oil.

All biobased raw materials were considered: waste biomass such as wood, grass and straw, as well as high value feedstocks such as sugar (sucrose), wheat and corn.

On the basis of the information collected for each of the aspects mentioned above, a selection was made for products to be studied in a detailed market study. See the figure on the next page for an overview of the products.


Feedstocks
Building blocks
Derivates
Complex compounds
Formulated products
Plant biomass
Carbohydrates
Starch
Cellulose
Lipids
Fibres
Protein
PHA
C2
Ethanol
C3
Lactic acid
Propanediol
Acrylic acid
C4
Succinic acid
C5
Furfural
Itaconic acid
Levulinic acid
C6
Isosorbide
Hydroxymethylfuran
Fatty acids
Amino acids
1,4-butanediol
tetrahydrofuran
γ-butyrolactone
Furfurylalcohol
Methylmethacrylate
Methyltetrahydrofuran
Diphenolic acid
Levulinate ester
Organo-N-compounds
Biopolymers/bioplastics
Polyethylene
Polylactic acid
PTT
Thermoplastic starch
Modified starch
Acrylonitril
Polyester
Polyamides
Polybutylene terephthalate
Polyurethane
Cellulose acetate
Polymethylmethacrylate
PHA
PBS
Isosorbide diesters (plasticiser)
Dimethyl isosorbide (solvent)
Enzymes
Synthetic proteins
Biopharma/cephalosporines
Resin
Binder
Solvent
Furanics
HTU diesel
Acylic PSA
Coolant
Deicer
Fuel additive
Soft PVC
Biodiesel
Paint
Ink
Adhesive
Agro fibre composites

3 Results

This chapter presents for each of the 34 products information on the product itself, on the main producers in the Netherlands and worldwide, on the seven aspects and on the product chain as far as information on each aspect is available. The chapter closes with a table that summarises the assessment for all 34 products.

Each product section holds a table with the results of the assessment on each of the seven aspects; the assessment is made on the basis of the data presented. Box 2 presents the scales that have been used for the assessment of the products and products groups for each of the seven aspects.

Box 2: Scales for the assessment

1. Estimated techno-economical feasibility: --, -, +, ++

2. Time-to-market:
   S = Short term (1-2 year)
   M = Mid term (3-5 year)
   L = Long term (more than 5 years)

3. Added value:
   L = Low (< €1/kg)
   M = Medium (€ 1 - € 2/kg)
   H = High (> € 2/kg)

4. Sustainability/favourable LCA
   - Reduction energy use (fossil sources): --, -, +, ++
   - Reduction greenhouse gas emission: --, -, +, ++
   - Other aspects: --, -, +, ++

5. Fit with the Netherlands agrosector (present volumes, current crops, present industries): --, -, +, ++

6. Fit with the Netherlands chemistry sector: --, -, +, ++

7. Netherlands knowledge position: --, -, +, ++

-- means that the property a absent or very poor; - means that the property is relatively poor compared with other products; + means that the property is clearly present and moderate/good, while ++ stands for excellent.

3.1 Biopolymers

Development of biopolymers started with the aim to produce biodegradable alternatives to plastics and resins. Saving fossil resources and reducing carbon dioxide emissions is a recent additional motivation in this field. The trend is that the replacement of volumes of fossil-based polymers by biobased polymers is more important than biodegradability. The result is that mixtures of biobased and fossil-based polymers appear on the market and the conversion of bioethanol into bio-polypropylene is considered. These products are not always biodegradable. Market chances for biopolymers now are seriously studied by the Netherlands chemistry sector.

Product 1: lactic acid and polylactic acid
Method of production: fermentation of carbohydrates

At present, lactic acid is mainly produced by fermentation of carbohydrates from sugar beets, wheat or corn. Lactic acid producers have interest in the use of lignocellulosic biomass, but the techno-economic feasibility, in particular because of the complex down stream processing, is moderate. However, lactic acid can be produced for a growing market because of its application in polylactic acid, a bioplastic. Poly-L-lactic acid is poorly biodegradable, while poly-DL-mixtures can be biodegraded within weeks. PLA can be produced as sheets, bottles, foams, fibres (woven and non-woven) and has a good transparency, a low gas diffusion and is waterproof. Applications can be found in food packaging, clothing and medical (objects in the human body). In 2007 the global production volume was 200,000 – 400,000 ton/year. Purac (the Netherlands), Nature Works LLC (USA), ADM (USA) and Galactic (Belgium) are large producers. A trend has been started to outplace production to countries with low wages and low sugar prices. In addition, the investment climate in the Netherlands is not favourable for such activities, according two experts interviewed.
Tate and Lyle recently (June 2006) bought Hycail, a Dutch university spin-off that was a subsidiary of Dairy Farmers of America (DFA) until March 2006. Hycail was set-up in 1997 to investigate the production of PLA from lactose in whey permeate, a by-product of cheese making. Hycail had a small PLA pilot plant. Uhde Inventa-Fisher - a subsidiary of Uhde, a company of Thyssen Krupp Technologies - is an engineering company that has a PLA pilot plant in Berlin. Boehringer Ingelheim produces high-value/low volume PLA for their Resomer® products used in medical applications (Reiss *et al.*, 2007).
The market price for PLA was estimated in 2003 at € 2.20 - 3.40 /kg, to decrease to € 1.35 /kg in 2010 (Cargill Dow, 2003 in Crank *et al.*, 2005). In 2006, the market price for lactic acid was € 1.70/kg. It can be expected that one or more large (150,000 ton/year) PLA factories will be constructed in Europe the coming 2 to 4 year (Bolck, 2008).

The properties of PLA can be changed by mixing it with other compounds. In this way it can be made heat resistant, heat conducting and can get a shape memory and flame retardancy. In Japan consumers products (mobile telephone) are being developed with 90% biobased construction material based on PLA (Masatoshi, 2008).

Total fossil energy requirements of PLA production are lower than that of conventional plastics. Depending on the plastics replaced (PET, HDPE, Nylon-6), fossil energy use is reduced by 20-50 % (Crank *et al.*, 2005; OECD, 2001; Gruber, 2001). However, the process energy requirements of the first commercial PLA plant were much higher than its petrochemical equivalents (Bioplastics 2003). PLA has 67 % less CO_2 emissions compared to nylon and 50 % less than polyester (Gruber, 2001). Other environmental properties of PLA are that it is compostable and recyclable. However, comparable with the controversies on carbon dioxide reduction potential of bioethanol from starch crops, the reduction of greenhouse gas emissions may also be nil, depending on the crops and soil types used. A future use of lignocellulosic biomass may give a better greenhouse gas emission reduction potential.

Crops that are currently grown in the Netherlands (sugar beet, wheat, corn) can be used for this purpose. The production of polylactic acid fits in the Netherlands plastic industry, e.g. Dow Benelux, while lactic acid production is carried out by Purac. With Purac, the Netherlands has a certain knowledge position in lactic acid production.

The product chain consists of the following parts:
- Raw materials: sugar beets, wheat, corn; future: wood, grass, straw
- Sugar production (in case of sugar beets)
- Lactic acid production
- Polylactic acid (granules) production
- Manufacturing of plastic products: bottles, beakers, foil, boxes

Assessment table:

1. Techno-economical feasibility	++
2. Time to market	S
3. Value	M
4. Sustainability, favourable LCA	
* Reduction energy consumption	+
* Reduction greenhouse gas emission	++
* Other aspects	++
5. Fit in Netherlands agro sector	++
6. Fit in Netherlands chemistry sector	++
7. Netherlands Knowledge position	+

Product 2: PHA (polyhydroxyalkanoate)
Method of production: biorefining of activated sludge from wastewater treatment plants

In the Netherlands most wastewater is treated using a (biological) activated sludge process in which pollutants are taken up and converted by bacteria. The bacterial mass, the sludge, increases in the process and has to be removed frequently. Presently, this sludge is dried and, since it is considered as a waste material, incinerated against high costs. However, sometimes the sludge contains large amounts of polyhydroxyalkanoates (PHA), a bioplastic, poly-β-hydroxybutyrate being the most important. In the running EU project NEPTUNE research is carried out to maximize the amount of PHA in sludge and recover it from sludge in a biorefinery approach. The sludge residue is converted into biogas. According to Werker (2007) the process combines well with industrial wastewater treatment. The project is carried a.o. at NanoxKaldnes in Lund (Sweden) but may yield interesting results for the Netherlands, e.g. for agro-industry wastewater and for the plastic processing industry.

By changing the composition of PHA various properties can be created. The material can be flexible, rubber like or rigid. The low water vapor diffusion is a strong point. Many applications must be possible, but because of the high production costs, PHA is rarely applied at the moment. PHA 's prices were estimated in 2003 at € 20.00/kg and expected to decrease to € 3-5/kg in 2010 (Biomer, 2003 in Crank *et al.*, 2005).

Since the raw material is an organic waste (a renewable source) a reduction of carbon dioxide emission can be expected (from raw material via plastic and gray bin to incinerator) compared to fossil based plastics.

However, large quantities of wastewater will be required to produce substantial amounts of PHA. In the Netherlands about 1 billion m^3 wastewater is produced annually containing about 1 billion kg of organic matter. Suppose 10% of the organic matter is transferred to PHA then 100,000 ton PHA can be produced from that source, which is about 5% of the quantity of plastic products sold in the Netherlands.

The product chain consists of the following parts:

- Raw materials: wastewater
- Wastewater treatment
- Extraction of PHA from the sludge (making granules)
- Manufacturing of plastic products: bags, bottles, beakers, foil, boxes

Assessment table:

1. Techno-economical feasibility	-
2. Time to market	L
3. Value	H
4. Sustainability, favourable LCA	
* Reduction energy consumption	
* Reduction greenhouse gas emission	++
* Other aspects	+
5. Fit in Netherlands agro sector	+
6. Fit in Netherlands chemistry sector	+
7. Netherlands Knowledge position	-

Product 3: PHA
Method of production: fermentation of carbohydrates by bacteria

Carbohydrates from biomass can be converted into PHA by bacteria in fermenters, poly-β-butyrate and poly-β-valerate being the most important examples. However, the current production costs are still too high for an economic feasibility. Research laboratories are working on improvement of the production process. Genetic modification of the strains used is an important tool in this optimization. The current production costs of PHAs is estimated at € 10 - 16/kg, but will ultimately, after up-scaling of production facilities end up under € 2 /kg (Reiss *et al.*, 2007). Opinions differ amongst the experts: prices never may be decreased to levels lower than € 4/kg.

It can be expected that the production of PHA in aerated fermenters needs a considerable amount of energy. Therefore, it is not sure if this production technology leads to a reduction in green house gas and fossil energy use. Nevertheless, the better biodegradability of PHA compared to fossil based plastics gives PHA a higher rank on sustainability. Life cycle analysis of CO_2 emissions of PHA production differ widely between values larger and smaller than those for petrochemical-based polymers. As no large scale facilities are already in operation, simulation studies have to provide the figures which implies that outcomes depend very much on the systems boundaries that are chosen. Comparative LCA with PE production shows an increase of $CO_{2\ eq}$ production of more than 200 %, mainly due to the use of energy (Van Ast *et al.*, 2004). Another LCA study concludes that CO_2 emission savings of 27-48 % can be made (Akiyama *et al.*, 2003). PE performs better on all ecological indicators (due to the fact that the PE production process has been highly optimized).

Since hydrocarbons are the raw material, a good fit in the Netherlands agro-sector can be expected. The downstream processing of crude bacterial PHA fits in the Netherlands plastic industry. The bacterial production of PHA is studied at the WUR.

The product chain consists of the following parts:

- Raw materials: sugar beets, wheat, corn; future: wood, grass, straw
- Sugar production (in case of sugar beets)
- Fermentation and PHA recovery
- PHA (granules) production
- Manufacturing of plastic products: bags, bottles, beakers, foil, boxes

Assessment table:

1. Techno-economical feasibility	-
2. Time to market	L
3. Value	H
4. Sustainability, favourable LCA	
* Reduction energy consumption	-
* Reduction greenhouse gas emission	
* Other aspects	+
5. Fit in Netherlands agro sector	++
6. Fit in Netherlands chemistry sector	+
7. Netherlands Knowledge position	+

Product 4: PHA
Method of production: extraction from plants

Metabolix is heading a research project – co-funded by the US Department of Energy - for the development of a genetically modified plant (switchgrass) that produces PHA, which can be extracted from the plant material directly (Reiss *et al.*, 2007). PHAs produced directly in plants could cost under € 1.00/kg (Bioplastics, 2003).

There is a pressing need for product development in the field of PHA. Note that the state of the art in product development for PHA is now at the level product development for PLA was 5 years ago (Petersen, personal communication). Such need is true for many other biobased products.

The product chain consists of the following parts:

- Raw materials: switch grass
- PHA extraction
- PHA (granules) production
- Manufacturing of plastic products: bags, bottles, beakers, foil, boxes

Assessment table:

1. Techno-economical feasibility	-
2. Time to market	L
3. Value	L
4. Sustainability, favourable LCA	
* Reduction energy consumption	
* Reduction greenhouse gas emission	
* Other aspects	
5. Fit in Netherlands agro sector	
6. Fit in Netherlands chemistry sector	
7. Netherlands Knowledge position	-

Product 5: thermoplastic starch
Method of production: corn, wheat or potato fractionation followed by extrusion

Corn, wheat, rice and potato can be fractionated to yield starch, which is a mixture of amylose and amylopectin. By extrusion, a thermoplastic polymer can be obtained. Water sensitivity and other properties can be introduced by addition of plasticisers and mixing it with other polymers. Granules have a value of € 1.50 - € 4.00/kg. The low migration of gases such as oxygen, carbon dioxide and water vapour through starch makes the polymer interesting for food packing (better conservation). Its limited transparency is a negative property. Half of the thermoplastic starch market is occupied by loose-fill foam packing, followed by other packing applications. This biobased plastic already has an established market (Bolck, 2006).

Since starch can replace fossil plastics, a reduction of carbon dioxide emission can be expected in the chain crop – starch – gray container – incinerator. However, similar as bioethanol from starch, the effect is not overwhelming, and opinions exists that the effect is nil or even negative. The good biodegradability of starch is positive with respect to sustainability.

Starch is produced from crops grown in the Netherlands such as potatoes and wheat, while agro companies such as Avebe and Gargill are processing starch in the Netherlands. However, the margins are low. The production slightly fits in the Dutch plastic process industry (mixing it with other polymers, addition of plasticisers). With Avebe, Gargill and research groups on carbohydrates (WUR, TNO) and the planned Carbohydrate Competence Centre, a good knowledge base is present in the Netherlands.

The product chain consists of the following parts:

- Raw materials: corn, wheat, potatoes
- Starch extraction
- Extrusion (granules production)
- Manufacturing of plastic products: bags, bottles, beakers, foil, filling foam

Assessment table:

1. Techno-economical feasibility	++
2. Time to market	S

3. Value	M
4. Sustainability, favourable LCA	
* Reduction energy consumption	+
* Reduction greenhouse gas emission	+
* Other aspects	+
5. Fit in Netherlands agro sector	++
6. Fit in Netherlands chemistry sector	+
7. Netherlands Knowledge position	+

Product 6: cellulose
Method of production: sulphite or kraft pulping of wood

The lignocellulose complex of wood can be broken by the addition of sulphite. This way cellulose can be separated from the other polymers. In such wood biorefineries, the other products can be recovered and validated as well: lignosulphonates (application as binder, fill, glue), vanillin, bioethanol, yeast(extract) (www.borregaard.com). The method of sulphite pulping is considered as environmentally unfriendly. However, improvements are in progress in this field, e.g. the use of wastewater to produce ethanol.

The natural cellulose fiber can be applied in paper and card board, regenerated cellulose (cellophane) on which a second polymer is coated (for sealing) can be used as packing material, and modified cellulose can be used as a thermoplastic polymer (granulate € 3/kg) (Bolck, 2006). Alternative ways to produce cellulose are kraft pulping and fermentative production from glucose by bacteria. The latter cellulose is highly crystalline and rigid and can be used for specific products such as nano composites. In kraft pulping sodium hydroxide and sodium sulphide are used and recovered after the pulping process. A reliable wastewater treatment process is required to deal with the toxic effluent as well as measures to limit odour emissions (e.g. mercaptanes).

The product chain consists of the following parts:

- Raw materials: wood
- Pulping and recovery
- Option: modification and granulating
- Manufacturing of paper, card board, foil, various plastic products

Assessment table:

1. Techno-economical feasibility	++
2. Time to market	S
3. Value	H
4. Sustainability, favourable LCA	
* Reduction energy consumption	-
* Reduction greenhouse gas emission	-
* Other aspects	--
5. Fit in Netherlands agro sector	+
6. Fit in Netherlands chemistry sector	-
7. Netherlands Knowledge position	-

Product 7: PTT (polytrimethylene terephthalate)
Method of production: 1,3 propanediol production by fermentation of carbohydrates; reaction with terephthalic acid

Bio-PDO, the biotech-based 1,3 propanediol, is together with purified terephthalic acid used for the production of polytrimethylene terephthalate (PTT), a polymer with a strongly growing market that currently is produced chemically. In the bioprocess dextrose derived from wet-milled corn is metabolised by genetically engineered *E.coli* bacteria and converted within the organism directly to PDO via an aerobic respiration pathway (Reiss *et al.*, 2007). An alternative is to produce PDO from glycerol from biodiesel plants. Tate and Lyle (headquarter based in the UK) through its joint venture with DuPont produces Bio-PDO for the production of Sorona®. The price of Bio-PDO is expected to be € 1.30-1.60/kg depending on location and market conditions at the time of marketing (Crank *et al.*, 2005). A representative of DuPont states that the bioroute to PDO is more cost-effective than the petro-route (Heschmeyer, 2004). Metabolix is constructing a 50.000 tonnes/a production plant for Bio-PDO to use corn sugar as a primary feedstock, that should be completed by mid 2008 (Reiss *et al.*, 2007). Fossil CO_2 emissions for the production of PTT based on biotech-based PDO are practically the same as for PET. Total energy requirements for the production of PTT based on biotech-based PDO are 16 % lower than for PET, but this is on the basis of glycerol and not of glucose. The environmental impact of BioPDO based on glucose may be lower. This is under investigation (Crank *et al.* 2005).

In case of a Bio-PDO production in the Netherlands, carbohydrate rich crops produced or potentially produced in the Netherlands can be used as a raw material. E.g. starch from corn or wheat, or sugar from beets, but also waste glycerol from biodiesel production. The production process fits in the Netherlands chemistry sector in which polymers are produced (but less and less) and Dupont has a factory in the Netherlands. The Netherlands has no important knowledge base of this product.

The product chain consists of the following parts:

- Raw materials: sugar beets, wheat, corn; future: wood, grass, straw
- Sugar production (in case of sugar beets)
- 1,3-propanediol production
- Production of PPT by reaction with terephthalic acid
- Granulation
- Manufacturing of plastic products: e.g. bottles

Assessment table:

1. Techno-economical feasibility	+
2. Time to market	S
3. Value	M
4. Sustainability, favourable LCA	
* Reduction energy consumption	+
* Reduction greenhouse gas emission	-
* Other aspects	
5. Fit in Netherlands agro sector	++
6. Fit in Netherlands chemistry sector	++

7. Netherlands Knowledge position	-

Product 8: Solanyl
Method of production: fermentation of potato peels, drying and extrusion

Solanyl is a potato waste-based product produced through a fermentation step converting a part of the starch in the potato peelings to lactic acid (via glucose) by means of lactic acid bacteria that are naturally present in the feedstock, and making the starch molecules smaller. The product is then dried and extruded to obtain thermoplastic properties (Reiss *et al.*, 2007). The cost prices of Solanyl is € 1.13/kg (www.polymer.nl); it is the most competitive biotech-based polymer. Solanyl production uses 40 % less energy than bulk plastics such as PE (www.biopolymer.nl). However, the production by Rodenburg has stopped.
The product chain consists of the following parts:

- Raw materials: potatoes
- Fermentation, drying
- Extrusion (granules production)
- Manufacturing of plastic products: bags, bottles, beakers, foil, filling foam

Assessment table:

1. Techno-economical feasibility	+
2. Time to market	S
3. Value	M
4. Sustainability, favourable LCA	
* Reduction energy consumption	+
* Reduction greenhouse gas emission	+
* Other aspects	
5. Fit in Netherlands agro sector	++
6. Fit in Netherlands chemistry sector	+
7. Netherlands Knowledge position	+

Product 9: cellulose acetate
Method of production: plant cellulose reacts chemically with acetic anhydride

Cellulose acetate is produced from plant cellulose and a chemical reaction with acetic anhydride. It is used as thermoplastic, acetate rayon, filter tow, lacquers and photographic films. Lyocell is a new cellulose acetate product with other properties than rayon. The world production is estimated at 750,000 tons annually (Jong *et al.*, 2004). The material is biodegradable.

The product chain consists of the following parts:

- Raw materials: cellulose (see cellulose)
- Conversion into cellulose acetate
- Manufacturing of textile fibres, various plastic products, lacquers and photographic films

Assessment table:

1. Techno-economical feasibility	++
2. Time to market	S
3. Value	M
4. Sustainability, favourable LCA	
* Reduction energy consumption	
* Reduction greenhouse gas emission	
* Other aspects	
5. Fit in Netherlands agro sector	
6. Fit in Netherlands chemistry sector	
7. Netherlands Knowledge position	

Product 10: composites with natural fibers
Method of production: mixing fibers with plastics

Agro fiber composites are produced by mixing fibers (e.g. from hemp and flax) and plastics such as polypropylene and polyethylene in the granulation process. Agro fiber composites have similar properties as glass fiber/polypropylene. Combinations of agro fiber and PLA are possible as well (Bolck and Harmsen, 2007). Application can be expected in the car manufacturing sector, packaging sector (pallets, boxes) and consumer electrical equipment (frames of TV, PC and refrigerator). Advantages are the softer break surfaces, shape stability at high temperatures, thermal and acoustic insulation, flame retarding properties, biodegradability (fibre/PLA). Moreover, the low weight saves energy and misses the carcinogenicy of glassfibre/PP. According to Carus and Müssig (2008) The EU25 annually produce 350,000 tons of biomaterials of which 140,000 tons bioplastics and 210,000 tons wood/plastic composites and natural fibre reinforced plastics. Already hemp fibre reinforced plastics are used in cars. GreenGran (the Netherlands) is setting up a production line under license of Wageningen University and Research Center (Bolck and Harmsen, 2007). The activity fits in the Netherlands agro sector and can be adopted by the plastic processing sector.

The product chain consists of the following parts:
- Raw materials: wood, grass and straw
- Mixing with fossil or biobased plastics
- Manufacturing of pallets, boxes, frames for electrical equipment, automobile components

Assessment table:

1. Techno-economical feasibility	++
2. Time to market	S
3. Value	M
4. Sustainability, favourable LCA	
* Reduction energy consumption	
* Reduction greenhouse gas emission	+
* Other aspects	+
5. Fit in Netherlands agro sector	++

6. Fit in Netherlands chemistry sector	+
7. Netherlands Knowledge position	+

Product 11: modified starch
Method of production: extraction from wheat, potato and corn, followed by chemical modification

Starch is a traditional plant product with applications in food and feed, as feedstock in fermentation processes and as material for industrial products. In this study the use in industrial products is considered. Examples are the use in paper making (strengthening recycle paper) and as bioplastics. The market for bioplastics based on starch, mainly as plastic bags, is increasing. Problems with strength and water resistance have been solved now, but the price is still high. It is expected that the production costs can be decreased after R&D efforts. In addition, some properties known from the food market, such as crispiness, may be used in non-food applications in future. By modification of starch new properties can be introduced. Acetylated and oxidized starch are examples that result from such modifications. At present, modified starch represents a small economic activity, but growth is expected. Such new activities can be best picked up by starch industry rather than chemistry companies. In future starch will be produced as a part of a biorefining process. Technology push is a strong driving force in this field (Mulder, 2008). Values between € 2 and 5 per kg modified starch are expected. Starch production fits very well in the Netherlands agro sector in which production of potatoes, wheat and corn are dominating crops. As a result, starch has got priority in R&D, which has resulted in a number one position (worldwide) on starch modification science (Slaghek, 2008).

The product chain consists of the following parts:

- Raw materials: potatoes, wheat, corn
- Extraction and chemical modification
- Use in paper making, manufacturing of various plastic products (e.g. bags)

Assessment table:

1. Techno-economical feasibility	-
2. Time to market	M
3. Value	H
4. Sustainability, favourable LCA	
* Reduction energy consumption	
* Reduction greenhouse gas emission	
* Other aspects	
5. Fit in Netherlands agro sector	++
6. Fit in Netherlands chemistry sector	-
7. Netherlands Knowledge position	++

3.2 Biofuels

Product 12: Furanics (furan derivatives)

Method of production: chemical catalytic conversion of sugars derived from biomass

Furanics can be produced from the carbohydrate fraction of biomass, via hydroxymethylfurfural. Such derivatives are expected to be a superior biofuel compared to bioethanol and biodiesel, because of the high energy density and a good blending with diesel as well as gasoline (www.avantium.com). The value of furanics will be, as most bulk fuels, lower than € 1 per kg. One of the motivations for the production of furanics from biomass is the well-to-wheel reduction in carbon dioxide emission. In addition, the use of furanics has other environmental benefits. Short tests have been carried out with mixtures of furanics and diesel in cars in which was proven that the new fuel had favorable environmental characteristics (low sulfur, low fine particles) (www.avantium.com). In the Netherlands Avantium is working on a catalyst that converts sugars into furanics. A better catalyst has to be found yet, but a large scale production of this biofuel is planned in 2008 or 2009 (Baal, 2008). When lignocellulosic biomass is used, this process should be coupled to biomass pretreatment processes, which are still under development as well. This activity has the potential to fit to the Netherlands agro-sector if crops or parts of crops (e.g. waste material) are used for the production of furanics. It also fits in the Netherlands petrochemical industry. With Avantium the Netherlands has a knowledge position in this field.

The product chain consists of the following parts:

- Raw materials: wood, grass, straw
- Chemical conversion of carbohydrates into furan derivatives
- Blending with gasoline or diesel
- Use as an automotive biofuel

Assessment table:

1. Techno-economical feasibility	-
2. Time to market	S
3. Value	L
4. Sustainability, favourable LCA	
* Reduction energy consumption	++
* Reduction greenhouse gas emission	++
* Other aspects	++
5. Fit in Netherlands agro sector	+
6. Fit in Netherlands chemistry sector	++
7. Netherlands Knowledge position	+

Product 13: Diesel from HTU biocrude

Method of production: hydrothermal upgrading of biomass followed by hydrogenation

Wet biomass when heated under pressure reacts with water and releases carbon dioxide. The result is a biocrude with organic compounds with a higher degree of chemical reduction. This biocrude has to be hydrogenated with hydrogen gas to further increase the degree of reduction and produce a liquid with the properties of diesel. The process has been proven for a wide variety of biomass types in a 100 kg biomass/h pilot plant by TNO in collaboration with the French Total and the Dutch Biofuel BV. The estimated production costs are now approaching the current fossil diesel production costs. The energy need in the process is less than 10% of the energy converted, therefore, the environmental impact and effect on fossil resources saving is large. A demo plant should convince investors, but somehow the developments are running very slow. The ability to use wet biomass is favourable to process certain waste fraction from Netherlands agriculture (Zeevalkink, 2008).

The product chain consists of the following parts:

- Raw materials: grass, straw, organic waste
- Hydrothermal upgrading to produce a biocrude
- Hydrogenation to produce a biodiesel
- Blending with diesel
- Use as an automotive biofuel

Assessment table:

1. Techno-economical feasibility	+
2. Time to market	M
3. Value	L
4. Sustainability, favourable LCA	
* Reduction energy consumption	++
* Reduction greenhouse gas emission	++
* Other aspects	++
5. Fit in Netherlands agro sector	+
6. Fit in Netherlands chemistry sector	+
7. Netherlands Knowledge position	++

Product 14: Biodiesel from algae
Method of production: cultivation of algae, extraction of lipids

If the biobased economy develops well, a shortage of biomass will grow, including lignocellulosic biomass (wood, grass, straw). Many experts believe that this shortage can be solved by using algae as a feedstock. Algae produce ten times more biomass per hectare per year compared to terrestrial crops (Thomsen, 2008). At present, algae are used to produce food compounds, but research groups are working on the production of bulk chemicals and biofuels from algae. Certain algae can accumulate lipids, which can be used to produce biodiesel. These algae can be cultivated in bioreactors which are supplied with carbon dioxide or flue gases (Thomsen 2008, Wijffels 2008, Hazewinkel, 2008, Blaauw, 2008). High-rate reactors mostly contain transparent tubes or plastic bags: these are relatively expensive. Open ponds are more cost-effective, but suffer from contamination (replacing the desired algae species by wild types). The state-of-the-art is far away from a competing method to produce biodiesel. The costs of cultivation and harvesting should be decreased one order of magnitude, which can take 10 years. However, the cultivation of algae can be interesting for the Netherlands, because our country will soon suffer from biomass shortage, while we can use our lakes or create shallow ponds from polders and we can use the sea. In addition, the Netherlands has a knowledge position in this field. One of the solutions to make algae utilization cost-effective may be a biorefinery approach: combine the recovery of high value products with the production of low value products such as biodiesel.

The product chain consists of the following parts:

- Raw materials: carbon dioxide, fertilizers/manure
- Production of algae in ponds
- Harvesting algae and extraction of lipids
- Conversion of lipids into biodiesel
- Use as an automotive biofuel

Assessment table:

1. Techno-economical feasibility	__
2. Time to market	L
3. Value	L
4. Sustainability, favourable LCA	
* Reduction energy consumption	++
* Reduction greenhouse gas emission	++
* Other aspects	++
5. Fit in Netherlands agro sector	-
6. Fit in Netherlands chemistry sector	-
7. Netherlands Knowledge position	+

3.3 Pharmaceuticals

Product 15: Biopharmaceuticals
Method of production: conversion of sugars by biological cells in bioreactors

Biopharmaceuticals are high-molecular-weight medicines, mostly proteins, produced by micro-organisms, animal cells and plant cells in bioreactors. Examples are insulin, interferon and glucoserebrosidase. Antibiotics and low-molecular-weight medicines are not part of this product category. The raw material for the production mostly is derived from crops, for example glucose. Although the raw material volumes are small, the products have a high value (knowledge and price). The world market for biopharmaceuticals amounts 59 billion € (2005), which is more than the present biofuel market. The market in the EU25 amounts to 11 billion € and increases 23% every year, which is faster than the growth of the total pharmaceutics market. In 2006, 91 biopharmaceutical active compounds were on the EU25 market, which is 5-6% of all pharmaceutical active compounds (Reiss *et al.*, 2007). The production of these compounds already is technologically feasible, but efforts are made continuously to make new products and production processes. In the Netherlands this is done by Crucell (www.crucell.com), which uses fermentations with yeast to produce bio-active proteins. This activity fits very well in the Dutch fermentation tradition. Because the low volumes of agricultural products required, biopharmaceuticals don't fit very well in the Netherlands agro-industry. Nevertheless, with Crucell and other planned initiatives (Groningen) the Netherlands have some knowledge position in this area.

The product chain consists of the following parts:

- Raw materials: sugar beets, wheat, corn

- Sugar production (in case of sugar beets)
- Fermentation and recovery and purification of the biopharmaceuticals
- Formulation into consumer products
- Use as vaccine or curative medicine

Assessment table:

1. Techno-economical feasibility	+
2. Time to market	S
3. Value	H
4. Sustainability, favourable LCA	
* Reduction energy consumption	-
* Reduction greenhouse gas emission	-
* Other aspects	-
5. Fit in Netherlands agro sector	--
6. Fit in Netherlands chemistry sector	+
7. Netherlands Knowledge position	+

Product 16: cephalosporins
Method of production: fermentation of carbohydrates

The industrial production of β-lactam antibiotics by fermentation over the past 50 years is one of the outstanding examples of biotechnology. Cephalosporins together with penicillins (as end products) are the main antibiotics: 60 % of all antibiotics are semi-synthesised β-lactam antibiotics. Antibiotics are the dominant share of all anti-infectives revenues (57 %). Global anti-infectives revenues in 2004 were 60 billion US$, representing 11 % of the total global pharmaceuticals market (IMS Health 2004).

The cephalosporin nucleus, 7-aminocephalosporic acid (7-ACA), is derived from Cephalosporin C. Some cephalosporins (cephalexin, cephadroxil, cephradine) are made on the basis of the building block 7-ADCA (7-aminodeacetoxy cephalosporinic acid) which is derived from Penicillum G. Both have a structure that is analogous to the penicillin nucleus, 6-aminopenicillanic acid (6-APA). Modification of the 7-ACA or 7-ADCA side-chains resulted in the development of generations of cephalosporins (Reiss *et al.*, 2007).

Since a large part of the organic matter is produced from carbohydrates (e.g. dextrose) in fermentation processes, cephalosporins are high value biobased products.

In Europe the main producers of cephalosporins as active pharmaceutical ingredient and of its building blocks (7-ACA and 7-ADCA) are Sandoz (Switzerland), Antibiotics (Italy) and DSM (The Netherlands). Other smaller producers are ACS Dobfar (Italy) and Bioferma (Spain). European manufacturers tend to shift their production to world areas with a low labour, energy and raw material cost. This is also true for the Netherlands, although we have a good knowledge position, production almost has shifted completely to other countries.

Annual production of cephalosporins is approx. 30,000 tonnes per year; that of penicillins 45,000 tonnes (Dechema, 2004). The market value of 7-ADCA and its related by-products is approx. 200 million US$. Europe contributes approx. 50 %. The market value of 7-ACA in 2006 was estimated at 300 million US$ (Reiss *et al.*, 2007).

The production of cephalosporine is a polluting activity. Complex wastewater treatment facilities are required.

The product chain consists of the following parts:
- Raw materials: sugar beets, wheat, corn
- Sugar production (in case of sugar beets)
- Fermentation and recovery and purification of the required building blocks
- Chemical modification
- Formulation into consumer products
- Use as antibiotics

Assessment table:

1. Techno-economical feasibility	++
2. Time to market	S
3. Value	H
4. Sustainability, favourable LCA	
* Reduction energy consumption	-
* Reduction greenhouse gas emission	-
* Other aspects	-
5. Fit in Netherlands agro sector	-
6. Fit in Netherlands chemistry sector	+
7. Netherlands Knowledge position	+

3.4 Base chemicals

Product 17: furfural
Method of production: acid thermal pretreatment of lignocellulosic biomass (dehydration of xylose)

According to Jong *et al.* (2004) furfural is a flexible chemical raw material, which can be used as a solvent itself in several applications or can be used to prepare furfuryl alcohol used in resin materials and tetrahydrofuran, a common organic solvent. A large number of other chemical transformations are possible; however their present commercial status remains unclear. Nevertheless, the authors of this study think that furfural can be interesting for the Netherlands.

The product chain consists of the following parts:
- Raw materials: wood, grass, straw
- Chemical conversion of xylose into furfural
- Recovery of furfural
- Chemical modification
- Use as solvent and other applications

The information on furfural is too poor to make assessment on the seven aspects.

Product 18: isosorbide
Method of production: chemical modification of glucose via sorbitol

A French R&D programme is running to develop biobased base chemicals. This programme is financed with 90 million € is led by Roquette and has industrial participants such as DSM and Solvay. Isosorbide is one of the favorite platforms. Starting with isosorbide, many other chemicals can be produced. For example isosorbide diesters, isosobide derivatives obtained by esterification with fatty acids, can be used as PVC plasticisers and lubricants. Dimethyl isosobide is a sustainable solvent obtained by methylation of isosorbide. In addition, polymers can be created by reaction with diacids or other compounds. This way, polyesters, polyurethanes and polycarbonates can be produced. Large scale industrial investments are expected after 2010 (www.biohub.fr).

The product chain consists of the following parts:
- Raw materials: sugar beets, potatoes, wheat, corn; future: wood, grass, straw
- Conversion into glucose
- Chemical conversion of glucose into isosorbide
- Further modification of isosorbide into several products
- Use of these products as plasticiser, lubricant, solvent and biopolymer

Assessment table:

1. Techno-economical feasibility	-
2. Time to market	M
3. Value	
4. Sustainability, favourable LCA	
* Reduction energy consumption	
* Reduction greenhouse gas emission	
* Other aspects	
5. Fit in Netherlands agro sector	+
6. Fit in Netherlands chemistry sector	+
7. Netherlands Knowledge position	+

Product 19: acrylic acid
Method of production: fermentation using carbohydrates

Esters of acrylic acid are the base for the production of polymers. The current world production of acrylic acid is more than 4 million ton annually. However, no fermentative production method has been developed yet. Ideas exists how to produce it biologically using genetically engineered micro-organisms (Straathof *et al.*, 2005). Nevertheless, such production can be attractive for the Netherlands since considerable amounts of local crops can be used, it fits in the Netherlands polymer industry and there is a knowledge position.

The product chain consists of the following parts:

- Raw materials: sugar beets, potatoes, wheat, corn; future: wood, grass, straw
- Conversion into mono-saccharides
- Fermentation and recovery of acrylic acid
- Production of biopolymers
- Manufacturing of products like Perspex and textile fibres

1. Techno-economical feasibility	--
2. Time to market	L
3. Value	
4. Sustainability, favourable LCA	
* Reduction energy consumption	
* Reduction greenhouse gas emission	
* Other aspects	
5. Fit in Netherlands agro sector	+
6. Fit in Netherlands chemistry sector	+
7. Netherlands Knowledge position	+

Product 20: itaconic acid
Method of production: fermentation using carbohydrates

Itaconic acid can be produced by fermentation using fungi. The bottle neck is the low yield, which should be at least 2 times higher to make production economically attractive in Europe. Research is carried out to improve the production process. Nevertheless, China already has started fermentative production (using the current suboptimal process) and because of this action the price of the base chemical is decreasing. If fermentative production of itaconic acid gets economically feasible, the market can be large. Itaconic acid can be used as one of the monomers in the production of acylic fibre (polymethylmethacrylate; current market 700 ktonnes annually, value about € 0.80/kg) and acrylic PSA (pressure sensitive adhesive; current market 150 ktonnes annually, value about € 6.00/kg) (Zwart, 2006). A knowledge position is available in the Netherlands.

The product chain consists of the following parts:

- Raw materials: sugar beets, potatoes, wheat, corn; future: wood, grass, straw
- Conversion into monosaccharides
- Fermentation and recovery of itaconic acid
- Chemical modification and/or production of biopolymers
- Manufacturing of products like Perspex and adhesives

Assessment table:

1. Techno-economical feasibility	-
2. Time to market	M
3. Value	L
4. Sustainability, favourable LCA	
* Reduction energy consumption	
* Reduction greenhouse gas emission	
* Other aspects	

5. Fit in Netherlands agro sector	+
6. Fit in Netherlands chemistry sector	+
7. Netherlands Knowledge position	-

Product 21: succinic acid
Method of production: fermentation using carbohydrates

The conversion of carbohydrates into succinic acid is technically feasible and economical feasibility will be reached soon. This base chemical now is produced chemically at a volume of about 16 ktonnes annually and is applied as sweeteners in food and beverages (Patel *et al.*, 2006). However, succinic acid has a great potential as a green C4 platform if the production costs can be lowered to € 0.40/kg. In 2003 these costs were € 0.80/kg, but steadily decreasing every year (Patel *et al.*, 2006). Since DSM and Roquette already have started its fermentative production in a pilot plant, production costs may already be acceptable. The bottle necks in techno-economic feasibility are in the derivatisation reactions: the production of polymers and solvents. Succinic acid can be used to produce polyesters with diols, low molecular esters can be used as green solvents, succinate salts can be used as coolants and deicing compounds and polyamides can be produced by polymerization with diamines. The most important expansion of the succinic acid market is expected as a new polymer intermediate, in the manufacture of 1,4-butanediol and tetrahydrofuran, and as an analogous replacement for maleic anhydride. According to DSM 30 % to 40 % energy use can be reached of succinic acid is produced via fermentation instead of conversion of fossil materials. (DSM press release January 18, 2008). A promising biobased polymer is Bionolle, a polybutylene succinate (PBS) which can be produced from succinic acid and 1,4-butanediol. In China a 20,000 ton/year PBS factory is in operation (Tan, 2008).

Production of succinic acid from carbohydrates fits in the Netherlands agro-sector since carbohydrates can be derived from various local crops. The production of polymers fits in the Netherlands chemistry sector, e.g. DSM is active in replacement of chemical intermediates by bio-succinate. A knowledge position is available at Netherlands companies and research organizations.

The product chain consists of the following parts:

- Raw materials: sugar beets, potatoes, wheat, corn; future: wood, grass, straw
- Conversion into monosaccharides
- Fermentation and recovery of succinic acid
- Chemical modification and/or production of biopolymers
- Manufacturing of products like plastics, textile fibres, solvents, de-icing agents

Assessment table:

1. Techno-economical feasibility	-
2. Time to market	S
3. Value	L
4. Sustainability, favourable LCA	
* Reduction energy consumption	+
* Reduction greenhouse gas emission	+
* Other aspects	

5. Fit in Netherlands agro sector	+
6. Fit in Netherlands chemistry sector	+
7. Netherlands Knowledge position	+

Product 22: 1,4-butanediol
Method of production: chemical catalytic conversion of bio-succinate

The current production of fossil based 1,4-butanediol is 300 ktonnes/year and its value is between € 1.00 and € 1.50 per kg (Zwart, 2006). The most important application of 1,4-butanediol is the production of the polymer polybutylene terephthalate. Production of 1,4-butanediol from succinic acid is technically feasible, but improvements still are required in catalyst selectivity and tolerance to fermentation derived contaminants (Patel *et al.*, 2006).

The product chain consists of the following parts:

- Raw materials: bio-succinate
- Chemical conversion into 1,4-butanediol
- Chemical modification and/or production of biopolymers
- Manufacturing of products like polyesters (strong plates and hard and hollow objects) and insulators in electrical equipment

Assessment table:

1. Techno-economical feasibility	-
2. Time to market	M
3. Value	M
4. Sustainability, favourable LCA	
* Reduction energy consumption	
* Reduction greenhouse gas emission	
* Other aspects	
5. Fit in Netherlands agro sector	+
6. Fit in Netherlands chemistry sector	+
7. Netherlands Knowledge position	-

Product 23: tetrahydrofuran
Method of production: chemical catalytic conversion of bio-succinate

The current production of fossil based tetrahydrofuran is 120 ktonnes/year and its value is about € 2.40 per kg (Zwart, 2006). Tetrahydrofuran can be applied as a solvent and as an intermediate in the production of thermoplastic polyurethanes, elastic fibers, molded elastomers and copolyesters or copolyamides. Production of tetrahydrofuran from succinic acid is technically feasible, but similar to 1,4-butanediol production, improvements are required in catalyst selectivity and tolerance to fermentation derived contaminants (Patel *et al.*, 2006).

The product chain consists of the following parts:

- Raw materials: bio-succinate

- Chemical conversion into tetrahydrofuran
- Chemical modification and production of biopolymers
- Manufacturing of various plastic and polyester products (textile fibres, bedding and upholstery foam, hard objects)

Assessment table:

1. Techno-economical feasibility	-
2. Time to market	M
3. Value	H
4. Sustainability, favourable LCA	
* Reduction energy consumption	
* Reduction greenhouse gas emission	
* Other aspects	
5. Fit in Netherlands agro sector	+
6. Fit in Netherlands chemistry sector	+
7. Netherlands Knowledge position	-

Product 24: γ-butyrolactone (GBL)
Method of production: chemical catalytic conversion of bio-succinate

The current production of fossil based GBL is 50 ktonnes/year (Zwart, 2006). The compound is an intermediate in the manufacture of pyrrolidone derivatives and a solvent for polymers and agrochemicals. Production of GBL from succinic acid is technically feasible, but again improvements are required in catalyst selectivity and tolerance to fermentation derived contaminants (Patel *et al.*, 2006).

The product chain consists of the following parts:

- Raw materials: bio-succinate
- Chemical conversion into GBL
- Use as solvent
- Chemical modification and production of biopolymers
- Manufacturing of biopolymer products and agrochemicals

Assessment table:

1. Techno-economical feasibility	-
2. Time to market	M
3. Value	
4. Sustainability, favourable LCA	
* Reduction energy consumption	
* Reduction greenhouse gas emission	
* Other aspects	
5. Fit in Netherlands agro sector	+
6. Fit in Netherlands chemistry sector	+
7. Netherlands Knowledge position	-

Product 25: ethanol
Method of production: fermentation from carbohydrates (from lignocellulosic biomass)

Apart from the use of bioethanol as a fuel, the compound can be used as a base chemical, e.g. in the production of ethylene (by chemical conversion) and subsequently polyethylene. In Brazil and China small factories are already running that convert sugar/starch based bioethanol into bio-polyethylene (Tan, 2008). It can be expected that this ethanol is produced in the same biorefineries as biofuel bioethanol. Because of environmental and food market considerations, the desired development is the production of bioethanol from lignocellulosic biomass, e.g. waste wood, grass and straw or energy crops. Techno-economical feasibility will be expected within a few years. Current production costs are about € 0.55/kg. In Europe about one million tons per year is produced, world wide 40 million tons, and the volume is increasing rapidly.

Like second generation bioethanol production and utilization, polyethylene production from bioethanol and utilization is expected to save fossil resources and reduce carbon dioxide emissions. However, polyethylene is poorly biodegradable.

The activity fits in the Netherlands agro-sector, since it can use wheat straw and grass as raw materials, while the use of energy corps like willow and switch grass seems feasible in the Netherlands (www.switchgrass.nl). In addition, a good connection can be made to the polymer chemistry sector. The Netherlands has a strong knowledge position in bioethanol production from lignocellulosic biomass.

The product chain consists of the following parts:

- Raw materials: wood, grass and straw
- Conversion into fermentable sugars
- Fermentation into bioethanol and recovery by distillation
- Chemical conversion into polyethylene
- Manufacturing of polyethylene products (plastic bags, buckets, toys)

Assessment table:

1. Techno-economical feasibility	-
2. Time to market	M
3. Value	L
4. Sustainability, favourable LCA	
* Reduction energy consumption	+
* Reduction greenhouse gas emission	+
* Other aspects	+
5. Fit in Netherlands agro sector	+
6. Fit in Netherlands chemistry sector	+
7. Netherlands Knowledge position	+

Product 26: levulinic acid
Method of production: chemical reduction of hexoses

At present levulinic acid is a speciality with a price of € 6 – 9 per kg and an annual production of 450 tonnes per year (Patel *et al.*, 2006). Levulinic acid has a potential as a base for the production of methyl tetrahydrofuran (a solvent with similar properties and outlook as tetrahydrofuran), diphenolic acid (Bisphenol A alternative), levulinate esters (fuel oxygenates) and 5-methyl-2-pyrrolidone (solvent). The present market for methyl tetrahydrofuran is large: 25,000 kton per year and its price is € 0.20 – 0.30/kg. The market for diphenolic acid is 4000 kton per year and its price is € 1.50/kg (Zwart, 2006). Technically it is possible to convert hexoses into levulinic acid, but economically a great effort is required with respect to production yield and selectivity of catalysts. The US company Biofine is underway to produce levulinic acid as part of a biorefinery concept for production prices lower than € 3/kg (Hayes *et al.,* 2006) and a target of € 0.35/kg.

Since hexoses can be derived from a wide range of biomass types it fits into the Netherlands agro-sector, most probably as part of a biorefinery in which the pentoses, proteins and lignin are processed as well.

The product chain consists of the following parts:

- Raw materials: wheat, corn, sugar beets, potatoes; Future: wood, grass, straw
- Conversion into hexoses
- Chemical conversion into levulinic acid
- Further chemical modification into various products
- Use as solvent and other applications.

Assessment table:

1. Techno-economical feasibility	--
2. Time to market	L
3. Value	L
4. Sustainability, favourable LCA	
* Reduction energy consumption	
* Reduction greenhouse gas emission	
* Other aspects	
5. Fit in Netherlands agro sector	+
6. Fit in Netherlands chemistry sector	+
7. Netherlands Knowledge position	-

Product 27: amino acids
Method of production: biomass biorefining, separation of amino acids

Petrochemistry is strong in the production of various types of hydrocarbons, but weak in the production of organo-nitrogen compounds, for which considerable effort in form of chemical modification has to be spent. According to Sanders (2008) amino acids can be used as a basis for the production of (biobased) organic nitrogen compounds. Such compounds can then be the base for certain polymers and other products. Amino acids can be produced in biorefineries and require a substantial effort in down stream processing (separation of many compounds). The technology is in an early stage of development, but fits in the Netherlands agro sector. The nitrogen in the amino acids will end up in the final products, which may be polymers. After use, the polymer may be composted: the N will be in the compost and the wastewater from the compost off-gas treatment. In case the polymer is incinerated, the N will end up in the N-fertiliser produced by an off-gas denox system.

The product chain consists of the following parts:
- Raw materials: biomass
- Biorefining, recovery and purification of amino acids
- Conversion of amino acids into various other products (e.g. mono ethanol amine)
- Manufacturing of various consumer products (nylon, bedding and upholstery foam)

Assessment table:

1. Techno-economical feasibility	-
2. Time to market	M
3. Value	L
4. Sustainability, favourable LCA	
* Reduction energy consumption	
* Reduction greenhouse gas emission	
* Other aspects	
5. Fit in Netherlands agro sector	+
6. Fit in Netherlands chemistry sector	-
7. Netherlands Knowledge position	+

3.5 Plasticisers

Product 28: bio-plasticisers
Method of production: chemically from castor oil or isosorbide (see isosorbide section)

Plasticisers are use to make plastics soft, e.g. PVC can be plasticised to manufacture products like vinyl carpets and shower curtains. The compounds are added to the polymers. The annual world production of plasticisers amounts 4.6 million tonnes, of which 84% phthalates. In the Netherlands, annually 0.3 million tonnes phthalate plasticisers are produced. More than 90% of the plasticisers are used to add to PVC. In addition, plasticisers are added to inks, paints, adhesives and cosmetics, to which 5 to 15 volume percents are added. Bulk plasticisers costs € 1.15/kg and niche phthalates € 1.50 to € 2.00 per kg. Plastics generally slowly release their plasticisers in time. There is a growing pressure to reduce the use of current types of plasticisers as they are persistent in environment, accumulate in human and animal fat tissues and are endocrine disruptors and suspect carcinogenic. In particular, the use of phthalates in child toys gets a lot of criticism because of the direct intake of these compounds by oral contact (Molenveld, 2006; Molenveld, 2008).

Drivers to replace fossil based plasticisers by (biobased) alternatives are (1) developing environmental/toxicity legislation and (2) save fossil recources. Not all alternatives are biobased. Among the biobased alternatives are diesters of isosorbide (a diol) and a fatty acid, as studied by Wageningen University and Research Centre, and Grindsted's Soft-N-safe, a castor oil based product from Danisco.

The introduction of biobased plasticisers is hampered by the higher prices compared to bulk plasticisers (1.5 to 2 times) and the fact that it takes time and budget to test them toxicologically and environmentally. Biobased plasticisers already can compete with specialty phthalates. In addition, the biobased alternatives have to compete with fossil based alternatives such as Hexamoll DINCH from BASF and Eastman 168 (Molenveld, 2006; Molenveld, 2008).

Production of bio-plasticisers may be carried out by the Netherlands chemistry sector rather than the sugar and plant oil sector. Already the Netherlands is active in plasticiser production. The raw materials for the production of bio-plasticisers are already produced by the Netherlands agro sector or can easily adopted, and a knowledge base is available within Wageningen University and Research Centre.

The product chain consists of the following parts:
- Raw materials: bio-isosobide, castor oil
- Chemical conversion into plasticisers
- Adding to hard polymers such as PVC
- Manufacturing of soft plastic products (shower curtains, toys, carpets)

Assessment table:

1. Techno-economical feasibility	-
2. Time to market	M
3. Value	M
4. Sustainability, favourable LCA	
* Reduction energy consumption	
* Reduction greenhouse gas emission	
* Other aspects	+
5. Fit in Netherlands agro sector	+
6. Fit in Netherlands chemistry sector	+
7. Netherlands Knowledge position	+

3.6 Proteins and peptides

Product 29: enzymes
Method of production: fermentation of carbohydrates

The total world production of enzymes in 2001 was 53,000 tonnes per year (Reiss *et al.*, 2007). The report also provides data on production by country. Denmark (read Novozymes) is by far the top producer, generating 47 % of the total production volume, followed by The Netherlands (19 %) and the USA (12 %, with Genencor still in US hands, now Danisco). Japan is on a fourth place with 8 %. Other main producing countries are Germany (6 %), France (3 %), UK and Switzerland (each 2 %). The other countries (which also might include European countries, such as Italy and Spain) account for the rest (1 %). The total market values of industrial enzymes and food and feed enzymes was in 2004/2005 1,635 million € (source: DSM expert); the Dechema report (2004) gives a higher figure: 1,830 million €. A Novozymes data source (www.novozymes) states that Novozymes is responsible for 44 % of the market size of industrial enzymes, Genencor 18 %, DSM 5 %, BASF 5 % and other companies for the other 28 %. It is expected that cellulases for second generation biofuel production may be the next blockbuster in this sector. Considerable effort is made to make its production more cost-efficient, which may take years. Although the production of enzymes consume energy and produce pollutants, enzymes play a role in the replacement of polluting and energy consuming chemical reactions by milder biological reactions.

The product chain consists of the following parts:

- Raw materials: sugar beets, wheat, corn
- Sugar production (in case of sugar beets)
- Fermentation and recovery and purification of the enzymes
- Use in bioethanol, food, feed, detergent industry

Assessment table:

1. Techno-economical feasibility	++
2. Time to market	S
3. Value	H
4. Sustainability, favourable LCA	
* Reduction energy consumption	+
* Reduction greenhouse gas emission	+
* Other aspects	+
5. Fit in Netherlands agro sector	+
6. Fit in Netherlands chemistry sector	+
7. Netherlands Knowledge position	+

Product 30: plant and animal proteins
Method of production: extraction from plants and animal products

Proteins from plants and animal products already have many industrial non-food/feed applications. The main application can be found in surfactants, adhesives, coatings and thermoplastic material. Casein (from milk) can be used as glue and is despite of its high prices (€ 4/kg) accepted on the market because of its unique rheological properties. Soy proteins are used in paper coatings (€ 2/kg). Gelatin (from bones) in cosmetics and photographic emulsions (€ 1 to € 20/kg), keratin (from chicken feather) in shampoo and collagen (from hides) in biomedical applications. Proteins have unique properties, and therefore in principle numerous possible applications. However, new developments have been stagnated, but as a result of the rise of the biobased economy, new protein sources have become available and more R&D has been started. Among these new sources are proteins from energy crops such as jatropha (WUR project) and rape seed. Research is carried out on the effect of glucosylation of rape seed proteins on properties. The residues from bioethanol production from corn and wheat (DDGS; dried distillers grain and solubles) are another protein source (wheat gluten and yeast protein). The challenge here is what to do with denatured proteins. In far future, amino acids may be recovered, separated and used as base chemicals (Mulder, 2008). R&D is focussed on new sources and new applications. In the past the high production costs were hampering further market penetration, but the trend predicts that these problems will be solved. New products may be ready for the market in 5 years.

The product chain consists of the following parts:

- Raw materials: plant and animal products
- Extraction of proteins
- Formulation into consumer products
- Use in cosmetics, photography, shampoo, paper and biomedical applications

Assessment table:

1. Techno-economical feasibility	++
2. Time to market	S
3. Value	H
4. Sustainability, favourable LCA	
* Reduction energy consumption	
* Reduction greenhouse gas emission	
* Other aspects	
5. Fit in Netherlands agro sector	+
6. Fit in Netherlands chemistry sector	-
7. Netherlands Knowledge position	+

Product 31: synthetic proteins and functional peptides
Method of production: fermentation of carbohydrates

New proteins can be synthesized with aid of modified genes. Production can take place with genetically modified organisms. Such proteins may contain natural amino acids or even amino acids that are not found in nature. Since proteins have an enormous range of different properties, many applications can be possible. At present, medical applications have priority. New proteins are used as support material and have a role in controlled release of medicines. New proteins can be more resistant against protease. Industrial applications are still in an early exploratory stage. E.g. proteins can be used in the assembly of chips and can produce nano-structures. The same development takes place in the field of functional peptides (protein fragments): many combinations of amino acids can be made and the properties of the resulting peptides should be explored. The value of synthetic proteins and peptides will range between € 10 and 100 per kg. The developments are in an early stage and the time to market is long. In the USA PPI (Protein Polymer Industries) is trying to enter the market, however, the approval procedures of new products consume time. Scientists have the feeling that synthetic proteins can be a large market, but first R&D is required to explore what can be made and how it can be applied. At Wageningen University and Research Centre R&D is carried out on this subject. However, only R&D will not be the solution here, the development of new applications is equally important. The use of carbohydrates as raw material fits in the Netherlands agro sector, and the use of fermentation to produce compounds fits in a national tradition. The chemistry sector is reserved and considers this development as far future (Wolf, 2008).

The product chain consists of the following parts:

- Raw materials: sugar beets, wheat, corn

- Sugar production (in case of sugar beets)
- Fermentation and recovery and purification of the proteins
- Various applications

Assessment table:

1. Techno-economical feasibility	--
2. Time to market	L
3. Value	H
4. Sustainability, favourable LCA	
* Reduction energy consumption	
* Reduction greenhouse gas emission	
* Other aspects	
5. Fit in Netherlands agro sector	+
6. Fit in Netherlands chemistry sector	-
7. Netherlands Knowledge position	+

3.7 Paints, inks and adhesives

Product 32: biobased paints
Method of production: biobased solvents and binders

Paint is composed of a solvent, a binder, a pigment and additives. The driving force to replace organic solvents is toxicity and saving fossil resources. The biobased alternative is plant oil (e.g. soy oil and sunflower oil). The driving force to replace binders is to save fossil resources. Such binders are mostly based on a chemical combination of sugars and fatty acids. An important prerequisite for paint is that the compounds are not biodegradable. Wageningen University and Research Centre has developed reactive solvents: these solvent don't evaporate but react with the binder when in contact with air. Pigments cannot be replaced by biobased alternatives easily as they are not stable. That is why biobased paint solvents and binders have the largest market chances (Haveren ,2008). According to Nowicki *et al.* (2008) the market for paint in the EU25 amounts about 18 billion €. The authors estimate the potential biobased value at 15 billion €, which is very optimistic, since pigments, which can hardly be replaced by biobased alternatives take ¾ of the value of paint. Therefore, the biobased paint compounds may take maximum 4 billion €. The market will be smaller than that for biopolymers. Bio-binders have a value of € 1.50 - 2.30/kg.

Important markets within the paint market are:

- Home improvement paint. Already 40%- 50% biobased (the binder resins). The organic solvents are now being replaced by water, but the binders still can be petrochemicals. A step in the right direction is the use of alkyd emulsions that are partly biobased (a DSM development). The solvent still is water. Another alternative is the use of plant oil as a solvent.
- Car repair coatings. A bio-polyurethane can be used in water, but the principle is in an early development stage.
- Powder coatings as used in electrostatic spraying of metal surfaces (cars, refrigerators). No solvent is used, but the binders and additives can be biobased

(Wageningen University and Research Centre and Technical University Eindhoven).

Worldwide, the Netherlands is an important producer of coatings and our country is on forefront of the developments in biobased paints, therefore, we are in a good position to start production in this field. Although large companies have worked on biobased paints and now have the intellectual property rights, introduction in the market is slow. The reason is that the production costs are slightly higher than conventional paints, while the properties are the same (not better). For large companies there is no reason to introduce biobased paints. SME's are more interested to sell biobased paints but don't have the rights (Haveren, 2008).

The product chain consists of the following parts:
- Raw materials: plant oil, sugars
- Chemical modification to produce binders and solvents
- Addition to paint

Assessment table:

1. Techno-economical feasibility	+
2. Time to market	S
3. Value	M
4. Sustainability, favourable LCA	
* Reduction energy consumption	
* Reduction greenhouse gas emission	
* Other aspects	+
5. Fit in Netherlands agro sector	+
6. Fit in Netherlands chemistry sector	++
7. Netherlands Knowledge position	++

Product 33: biobased inks
Method of production: biobased solvents and binders

In the formulation of biobased inks, more or less the same compounds are used as in biobased paints. The worldwide ink market is 5 times smaller than the paint market and in the Netherlands this factor is even larger (Haveren, 2008).

The product chain consists of the following parts:
- Raw materials: plant oil, sugars
- Chemical modification to produce binders and solvents
- Addition to inks

Assessment table:

1. Techno-economical feasibility	+
2. Time to market	S
3. Value	M
4. Sustainability, favourable LCA	
* Reduction energy consumption	

* Reduction greenhouse gas emission	
* Other aspects	+
5. Fit in Netherlands agro sector	-
6. Fit in Netherlands chemistry sector	+
7. Netherlands Knowledge position	++

Product 34: biobased adhesives
Method of production: biobased solvents and polymers

Adhesives contain solvents, polymers and additives. Biobased adhesives based on starch already are on the market.
Two other chances are:

- Polyurethane adhesives. The biobased alternative can be based on reactive drying (polymerising biobased compounds instead of evaporation) and the use of biopolymers.
- Adhesives containing MS polymers (modified silyl). Since these are expensive, cheaper or better biobased alternatives may have a chance. However, they are not found yet.

Market volumes of adhesives are smaller than paint. Development and introduction in the Netherlands are hindered by the fact that the Netherlands does not have large producers, while small producers don't have the budget for such innovation. If budgets are available within 3 year new biobased adhesives can be introduced on the market (Israel, 2008).

The product chain consists of the following parts:

- Raw materials: potatoes, wheat, corn
- Extraction of starch or production of biopolymers
- Use in formulation of adhesives

Assessment table:

1. Techno-economical feasibility	-
2. Time to market	M
3. Value	M
4. Sustainability, favourable LCA	
* Reduction energy consumption	-
* Reduction greenhouse gas emission	-
* Other aspects	+
5. Fit in Netherlands agro sector	-
6. Fit in Netherlands chemistry sector	-
7. Netherlands Knowledge position	+

3.8 Miscellaneous

Next to products based on carbohydrates and proteins as the raw materials, lignin and plant oils can used to produce a whole family of products. Opportunities that arise from utilizing lignin fit into three categories:
• power, fuel and syngas (generally near-term opportunities)
• macromolecules (generally medium-term opportunities)
• aromatics and miscellaneous monomers (long-term opportunities).

The use of lignin as a macromolecule is not new. Lignin is currently used as dispersant, emulsifier and binder, however, future opportunities comprise the use of lignin in polymer modifiers, adhesives and resins. On a long term lignin can replace oil in the production of benzene, toluene, xylene and phenol (Bozell *et al.*, 2007). Glycerol, which is now available against low prices as a by-product of biodiesel production, can be used as a raw material to produce various products as well.

3.9 Overview

The table on the next three pages provides the overview of the assessment of all 34 products

Product and process	1. Techno-economical feasibility	2. Time to market	3. Value	4. Sustainability, favorable LCA			5. Fit in NL agro sector	6. Fit in NL chemistry sector	7. Dutch knowledge position
				Reduction energy consump-tion	**Reduction Greenhouse gas emission**	**Other aspects**			
BIOPOLYMERS									
1. Polylactic acid (fermentation from carbohydrates)	++	S	M	+	++	++	++	++	+
2. PHA (from activated sludge)	-	L	H		++	+	+	+	-
3. PHA (from carbohydrates by bacterial fermentation	-	L	H	-		+	++	+	+
4. PHA (from plants)	-	L	L						-
5. Thermoplastic starch (plant fractionation)	++	S	M	+	+	+	++	+	+
6. Cellulose (sulphite or kraft pulping)	++	S	H	-	-	--	+	-	-
7. PTT (from propanediol via fermentation)	+	S	M	+	-		++	++	-
8. Solanyl (fermentation potato peelings)	+	S	M	+	+		++	+	+
9. Cellulose acetate	++	S							
10. Agro fiber composites (mix natural fibers with plastics)	++	S	M		+	+	++	+	+
11. Modified starch (extraction from crops and chemical conversion)	-	M	H				++	-	++

BIOFUELS									
12. Furanics (chem catalytic from sugars)	-	S	L	++	++	++	+	++	+
13. HTU diesel (hydrothermal upgrading)	+	M	L	++	++	++	+	+	++
14. Biodiesel from algae (cultiva-tion algae, extraction of lipids)	--	L	L	++	++	++	-	-	+
PHARMACEUTICALS									
15. Biopharmaceuticals (bioconversion of sugars)	+	S	H	-	-	-	--	+	+
16. Cephalosporins (bioconversion of sugars)	++	S	H	-	-	-	-	+	+
BASE CHEMICALS									
17. Furfural (chemical conversion lignocellulose)									
18. Isosorbide (Chemical conversion glucose)	-	M					+	+	+
19. Acrylic acid (fermentation carbohydrates)	--	L					+	+	+
20. Itaconic acid (fermentation carbohydrates)	-	M	L				+	+	+
21. Succinic acid (fermentation carbohydrates)	-	S	L	+	+		+	+	+
22. 1,4-butanediol (chemical conversion of biosuccinate)	-	M	M				+	+	-
23. Tetrahydrofuran (chemical	-	M	H				+	+	-

conversion of biosuccinate)									
24. γ-butyrolactone (chemical conversion of biosuccinate)	-	M					+	+	-
25. Ethanol (fermentation of carbohydrolates; lignocellulosic)	-	M	L	+	+	+	+	+	+
26. Levulinic acid (chemical conversion of sugars)	_	L	L				+	+	-
27. Amino acids (biorefining and separation)	-	M	L				+	-	+
PROTEINS AND PEPTIDES									
28. Enzymes (fermentation of carbohydrates)	++	S	H	+	+	+	+	+	+
29. Proteins from plants and animals (extraction)	++	S	H				+	-	+
30. Synthetic proteins and functional peptides (fermentation of carbohydrates)	--	L	H				+	-	+
PLASTICISERS									
31. Bio-plasticisers (chemical conversion isosorbide / castor oil)	-	M	M			+	+	+	+
PAINT, INK AND ADHESIVES									
32. Biobased paints (biobased solvents and binders)	+	S	M			+	+	++	++
33. Biobased inks (biobased solvents and binders)	+	S	M			+	-	+	++
34. Adhesives (biobased solvents and polymers)	-	M	M	-	-	+	-	-	+

4 Selection of products recommended for market study

The selection of products that are recommended to be included in the market was based on the information presented in the previous chapter and in particularly on the assessment. Our first selection step was focused on the group level: groups (categories) with a higher ratio + to – got a higher priority. Within that group a second ranking took place. In the biopolymer group, the top four had a high or medium value and at least 8 + in total, or a ++ in the category Dutch knowledge position. In the base chemical group products with at least 3 + were selected, followed by high and medium valued products. The large future volumes and high turn over played an additional role in the selection. The other products should at least have a medium value and at least 7 + or a high value and at least 3 + under the condition that the products don't score too much –. Novelty and turn over played additional roles in the selection. Time-to-market has not played a heavy role in the final selection process as the Netherlands needs developments of various time horizons.

Based on the information above we conclude that the best chances are for products in the biopolymer group and in the base chemicals groups. Volumes played an important additional role in selecting biopolymers and volume and versatility in selecting base chemicals. The products suggested only have a chance, but not a guarantee to make it on the market. In part 2 and 3 of this study the situation with respect to market introduction will be worked out further.

The four most promising biopolymers in order of decreasing chance:
1. polylactic acid
2. agro fibre composites
3. thermoplastic starch
4. modified starch

The six most promising base chemicals in order of decreasing chance:
5. succinic acid
6. ethanol
7. itaconic acid
8. isosorbide
9. tetrahydrofuran
10. 1,4-butanediol

In addition we also propose:

11. Biobased paints are a chance, mainly because the future volumes produced in the Netherlands.
12. HTU diesel is a promising biofuel to replace diesel, which is interesting mainly because of volumes and knowledge position.
13. Enzymes produced by fermentation continues to be interesting, because of the high value.
14. Proteins from plant and animals may be interesting. The business is already well established and innovations are possible.
15. Biopharmaceuticals may be interesting, because of the high value and the novelty (rather than cephalosporins).

Besides these chances, important running developments such as first and second generation fuel bioethanol are important to boost our biobased economy on short term. Care should be taken that these developments not retard the production of the selected products above.

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