Netherlands Enterprise Agency

Sustain-
able
Bio-
mass

Setting up international biobased commodity trade chains

>> *Sustainable. Agricultural. Innovative. International.*

Colophon

Date	May 2014.
Status	

This study was carried out in the framework of the Netherlands Programmes Sustainable Biomass by

Name organisation	Wageningen UR, Food and Biobased Research
Contact person	Jan E.G. van Dam, Wolter Elbersen, René van Ree

Contact

Netherlands Programmes Sustainable Biomass

Kees Kwant
NL Enterprise Agency
Croeselaan 15, 3521 BJ Utrecht
P.O. Box 8242, 3503 RE Utrecht
The Netherlands
Email: Kees.Kwant@rvo.nl
Phone: +31 - 88 - 602 2458
www.rvo.nl/biomass

Organisation 1

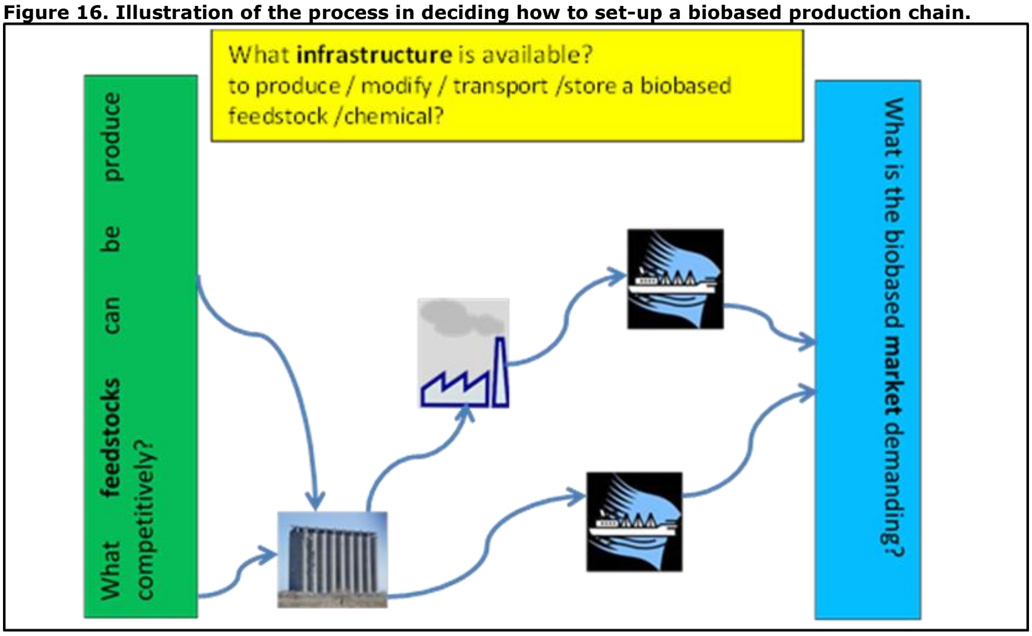
Wageningen UR, Food and Biobased Research
Biobased Research
Bornse Weilanden 9,
6708 WG Wageningen
Tel: 0317 480 084
E-mail: info.fbr@wur.nl

Index

Executive summary

Setting up biobased production chains, from biomass feedstock to final biobased product (energy, chemicals, materials) is a complicated process in which a whole range of decisions have to be made. Choices include what feedstocks to use, arranging logistics and, most important of all, the locating of facilities to compact, dewater and convert the biomass into tradable intermediates and final products. Choices depend on the local conditions and factors such as the economy-of-scale of intermediate steps. These are complicated by the fact that biomass is produced dispersed (a low density per area) and is almost by definition bulky, low in energy density and generally contains considerable amounts of water. Also other aspects such as (local and international) market demands, regulations and competing applications for biomass feedstocks are relevant aspects.

Figure 16. Illustration of the process in deciding how to set-up a biobased production chain.



The objective of this study was to develop an overview of possibilities, choices and trade-offs for production and trading of biobased commodities (e.g. raw materials and biobased chemical "building blocks" and fuels that may guide project developers and decision makers in the development of business cases.

Approach

The potential of biobased feedstocks and commodities for production of materials, chemicals and fuels from renewable sources replacing fossil based products are reviewed and classified together with their market perspectives (chapter 2). Next, the importance of dealing with commodities (or not) and economy-of-scale issues were elaborated (chapter 3), which play a crucial role in biobased chains. A set of steps and tools that may guide business developers or entrepreneurs in making decisions when setting up (international) biobased production chains is described.

The method is then applied (chapter 4) to Ukraine and used to select and assess 5 promising biobased commodity trade chains.

A classification of primary crops and products is presented together with a simple SWOT assessment method to judge if local feedstocks may be a good starting point for a biobased export chains. This includes:

1. Availability of the feedstock (crop or a co-product). Here the amount but also the density and contractibility of the feedstock is relevant.
2. Local experience with the crop.
3. Competing or alternative uses (now and in the future) for the feedstock.
4. Stability of supply. This is especially relevant when dealing with co-products that depend on demand and production of a main product.
5. Sustainability of the feedstock. Can the feedstock be produced in accordance with standards developed for biofuels?
6. Infrastructure to produce and process the crop/co-product of interest.
7. The cost.
8. Co-product value.
9. The Outlook. How are the factors expected to develop?

Based on input from industry business developers a logical set of criteria was identified that guide the choice of siting conversion. The factors include:

1. Feedstock cost.
2. Security of supply and quality of the feedstock.
3. Infrastructure: What part of the production chain is already available?
4. Skilled labour and technical expertise.
5. Cost of operation.
6. Logistics (reliable / low cost).
7. Investment cost and return on investments.
8. Tariffs (import/export) and taxes.
9. By-product value.
10. Regulation environment.
11. Rule of law.

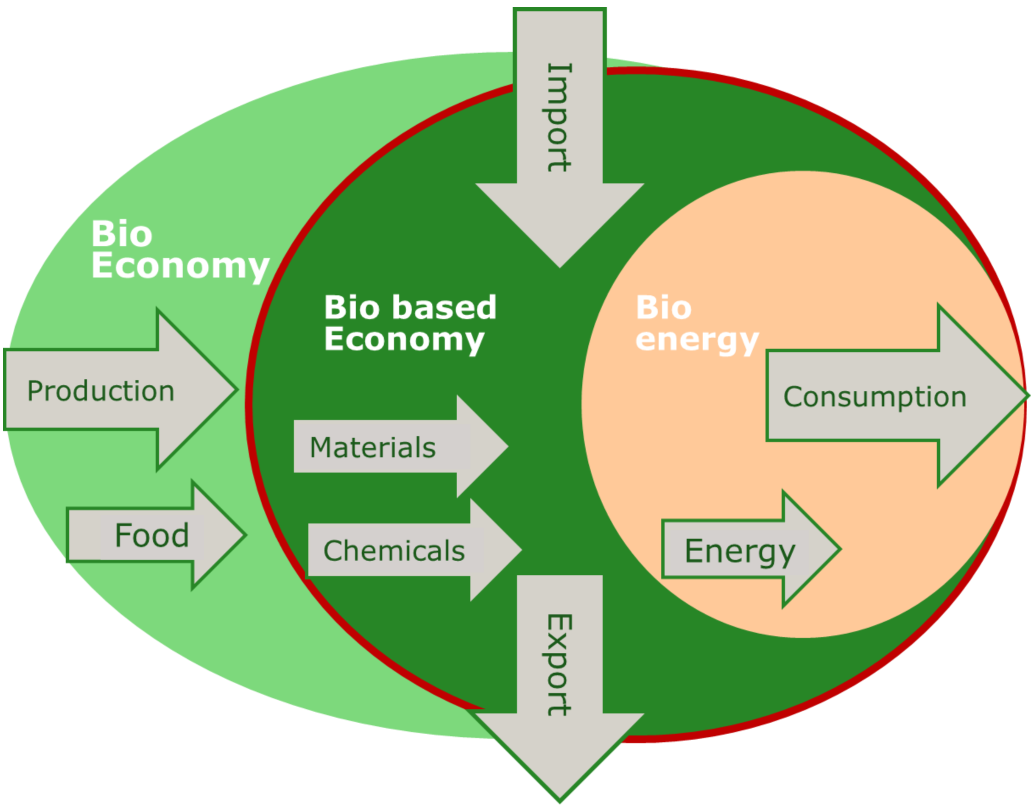
5 potential biobased export trade chains from Ukraine to the EU/The Netherlands were assessed using the tools described above (see chapter 4). Based on previous studies and expert judgement the production of (basic) feedstocks was judged favourably in Ukraine for established crops. Sugar beet and lignocellulose (straw, energy crops) was assessed to still be unattractive but having a large potential if productivity and associated infrastructure and policies could be improved. Siting of the main (costly) conversion step was compared between Ukraine and the Netherlands. Factors associated with cost (though not financing) were judged to be advantageous for Ukraine. Siting in the Netherlands was judged to score better on security of supply, infrastructure, logistics, tariffs, by-product value and regulation environment and rule of law.

Definitions

Bioeconomy
Economic activities based on microbial, vegetable or animal resources, e.g. recently fixed biotic /organic carbon. It includes all food, feed and non-food applications of biomass.

Biobased economy
The part of the economy that uses biomass, crops and residues of agriculture and food industry for the manufacturing of materials, chemicals, transportation fuels and energy is defined as biobased economy. The biobased economy as part of the bioeconomy consists of all options to produce non-food products and energy services from biomass, as illustrated by Fig. 1.

Figure 1. Embedding of the biobased economy in the bioeconomy
(Meesters et al., 2014, according to K. Kwant, AgNL)



Bioenergy
Energy services and products made out of biomass.

Renewable resources
Renewable resources are natural resources that are harvested through cultivation or natural growth / deposition.

Commodities
Commodities are raw materials, products or intermediate products that are fungible and being traded in bulk volumes world-wide. Biobased commodities can either consist of selected parts of a crop or extracted and derived components. The composition is well known and defined. Commodities should be easily tradable and storable meaning that they should contain little amounts of water and have a low volume to weight ratio. Examples are: wheat/flower, soy beans/soy oil, wood/pellets, bioethanol/lactic acid. For a more extensive discussion on biobased commodities see Chapter 3.

Composite goods
Composite goods are mostly consumer goods. They are often composed of fossil as well as mineral or biobased components.

Commodification
Assignment of an economic value to goods that previously were not considered as such, and can be traded as a commodity. (For example: lignin, biochar, aquatic biomass, straw, etc.). See also chapter 3.4.

Biobased polymers are man-made polymers derived from renewable biomass sources.

Biobased chemicals[1] are substitutes for petrochemicals or novel products derived from renewable biomass sources (recent fixed CO_2).

Green chemicals[2] are products that reduce or eliminate generation of hazardous substances (not necessarily of renewable origin).

Platform chemicals are chemicals on which a group of products can be produced.

Basic chemicals[3] include bulk petrochemicals and derived chemicals as well as inorganic chemicals and fertilizers.

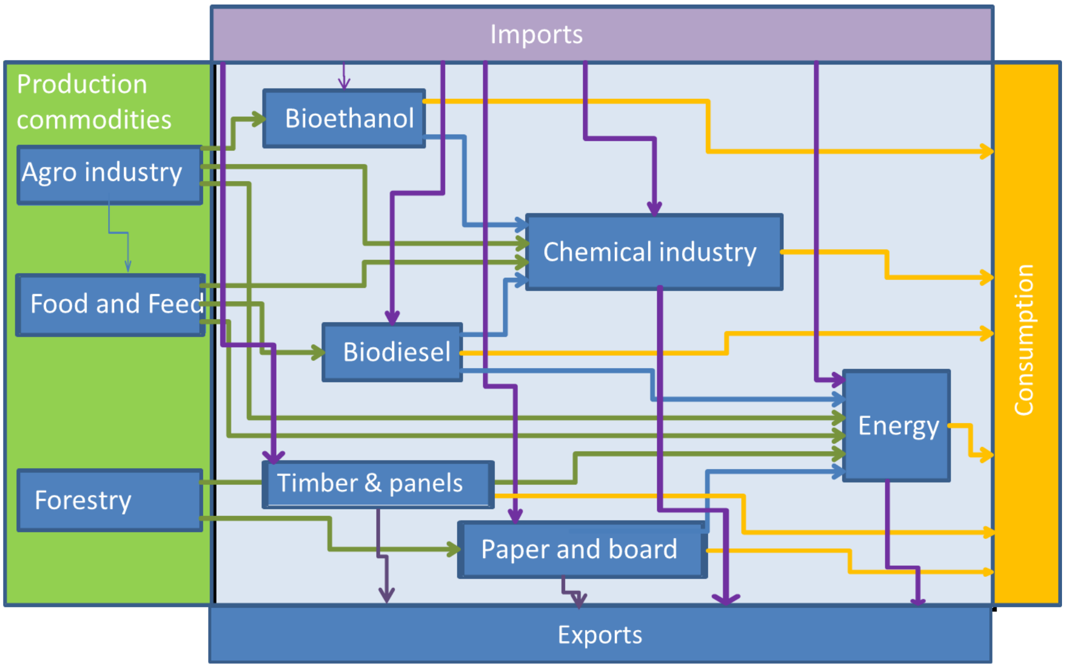
Specialty or 'fine' chemicals are high valued products with diverse markets, such as: paints, adhesives, pigments and inks (can be categorized according their functional properties).

1 http://www.wageningenur.nl/en/Expertise-Services/Research-Institutes/food-biobased-research/Expertise-areas/Biobased-chemicals.htm
2 http://www2.epa.gov/green-chemistry
3 US Environmental Protection Agency (EPA) 2010– TSCA – New Chemicals program (NCP) Chemical categories,

1 Introduction

To reduce greenhouse gas emissions the substitution of fossil resources by renewable biological and CO_2 neutral resources is a logical development of political concern with global impact.

Figure 2. Most influential industrial sectors involved in the biobased economy (Meesters et al., 2014)**.**



The forestry industry traditionally has been producing timber and panels for building and construction industries, as well as supplying to the paper and pulp industry. Besides the use of fuel wood, the production of fuels (bioethanol, biodiesel) and energy based upon renewable resources (carbohydrates and vegetable oils) has taken off worldwide (Fig.2). The production of chemicals and products from bio-based raw materials, as substitute for fossil based products, is also receiving serious attention from industrial R&D, and is expected to have an increasing impact on the markets of bio-plastics and bio-resins (Philp et al., 2013).

Setting up a business to produce biobased products from biomass to final products is a complicated development in which a whole range of decisions have to be made. It is complicated to choose what feedstocks can best be used and how the logistics can be planned and where intermediates can be produced best. These choices depend on the local perspective and the economy-of-scale of the subsequent steps in the total production chain from crop to final consumer. Also market demands and competing applications for biomass feedstocks are very relevant aspects.

Farmer cooperatives have the choice to supply their product on local demand or export (surplus) to higher demanding, potentially more profitable but risky foreign markets. Organisation of such a market chain requires believe in the outcome and investment in product quality, knowledge of the customer demands, motivation and willingness to perform. Existence of all intermediate chain elements (processing, logistics, financial contracts, etc.) is essential for success.
Supply of competing volumes of biomass feedstock is the basis for the selection of the most suitable (intermediate) biobased commodity products for local conversion and export trading markets. On the other side offers for guaranteed supplies of high quality feedstock have positive effects on the selection by the end-product manufacturers of the most competing raw material on the global market.

The objective of this study is to develop an overview of possibilities, choices and trade-offs for production and trading of biobased commodities (e.g. raw materials and biobased chemical "building blocks") that will guide project developers and decision makers in the development of business cases. With special focus on chains for manufacturing of biobased chemicals.

Approach
The potential biobased feedstocks and commodities for production of materials and chemical ingredients from renewable sources instead of fossil based products are reviewed.

As a first step the biomass raw materials can be classified according the composition of the main economic products of the crops. Cash crops are classified (Table 1) as: carbohydrate rich crops, including: sugar crops (A1), starch crops (A2); lignocellulosic fibre crops (B); oil crops (C); protein rich crops (D) or crops that are produced for harvest of other ingredients (e.g. rubber, dyes, fragrances and spices, E).
The second step is to describe the current and emerging processes for manufacturing biobased materials and the key chemical building blocks that are produced therefrom. One of the key elements to this is for example the production of fermentable sugars or monosaccharides (e.g. hexoses, C6 and pentoses, C5) from the various biomass feedstocks containing carbohydrates and lignocellulose.
Next the aspects that need to be considered when setting up international production chains are reviewed, which include the importance of commodities and economy-of-scale, followed by a set of steps and tools that guide business developers or entrepreneurs in setting up (international) biobased production chains. The method is then applied to Ukraine and used to select and assess 5 promising biobased chains.

2 Biobased feedstocks, chemicals and fuel production chains

2.1 Biobased Market demand

2.1.1 Biobased market development

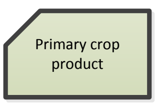
The EU has ambitious plans for the Biobased Economy (BBE). The use of sustainable biomass resources and reuse of scarce resources fits in the policy targets for a circular economy. Policy is made to reduce CO_2 emissions and stimulate the use of biofuels and biomass for fossil energy saving. In contrast to policies for stimulation of renewable energy (Renewable Energy Directive 2009) only limited measures are taken for promotion of bioplastics and biobased materials (Carrez et al., 2013). The most direct policy support from EU is the Common Agricultural policy (CAP) that aims to support increased supply of energy crops. New proposals are made also to include biobased materials in the new CAP (2014-2020)[4]. The use of biomass in materials is, however, poorly documented in economic statistics and therefore it is difficult to determine the growth targets for the biobased economy. Monitoring of biobased economy is elaborated in the *Bioeconomy Observatory* by Joint Research Centre for the European Commission (Meesters et al 2014).

2.1.2 Biobased trade

The main production chains of biobased commodities are involving products based on agricultural and forestry crops. In Table 1 the most important industrial crops are categorised and listed. Biobased commodities can consist of the whole crop or more often selected and processed parts and extracted components. Commodities are classified in international trade, for example in the Harmonized System Code[5]. No such codes for biobased commodity products are available yet, other than the category of residues from food industries, animal feed (HS code 23) or miscellaneous chemical products (HS code 38). For the development of the biobased economy it is relevant that the commodity use in non-food markets is better highlighted and distinguishable from other classes of commodities (Vellema et al. 2009).

Under auspices of the World Customs Organization (WCO)[6] the EU DG Enterprise and Industry is elaborating the harmonizing of customs codes for biobased products.

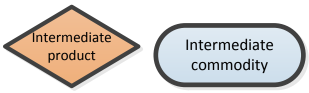
Along the production chain from crop to final product we can distinguish categories of products:



Primary crop products (can be a commodity) are grown and harvested for the economic valuable parts that are stored and traded, e.g. grains, pulses, wood, oil seeds, fibres (Chapt. 2.1).

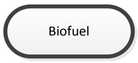
4 http://ec.europa.eu/enterprise/policies/innovation/policy/lead-market-initiative/files/bio-based-priority-recommendations_en.pdf
5 http://www.foreign-trade.com/reference/hscode.htm
6 http://www.wcoomd.org/en.aspx

Secondary crop products (some of which are commodities) are derived from the by-products of commodity crop production. Examples are: grain straw, soy protein, wheat bran, bagasse, etc.

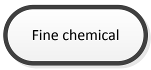


Intermediate products (some of which are commodities) are the derived main products from the commodity crops that can be used as raw material for industrial converters. Examples of these are: sugar, flour, starch, pellets, vegetable oil, protein or pyrolysis oil.

Biobased platform chemicals (De Jong et al., 2012) are another category of (potential) commodities that can be used as feedstock in different chemical or biochemical industrial processes to manufacture a range of consumer products. These basic products such as glucose, lignin, and ethanol could be referred to as platform chemicals (Chapt. 2.2).



Biofuel refers to all fluid or gaseous fuels derived from biomass, such as: bioethanol, biodiesel, bioETBE, bioMTBE, bioCNG, bioLNG, pyrolysis oil, etc. In some cases solid fuels (such as fuel wood) are also referred to as biofuels, though most definitions of biofuels exclude them.



Biobased or 'green' fine chemicals are the products of biorefining and biotechnological conversion of the platform commodities. For example: itaconic acid, lactic acid, isopropanol, BTX, etc.

Biobased polymers: Examples are: biopolypropylene, biopolyethylene, polylactic acid, etc. (Chapt. 2.3).

2.2 Primary crop products

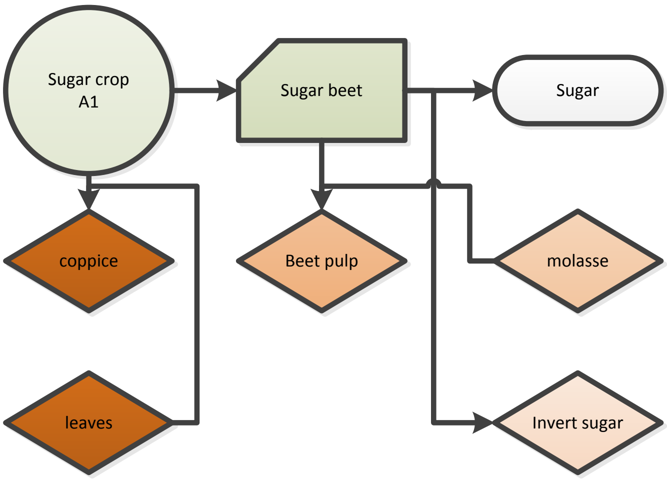
Production of agricultural commodity crops (categories A, and C to E, Table 1) is primarily to supply the food and feed markets. At various stages in the production process chains of food and feed products, residues and by-products are liberated that may find useful outlets in the biobased economy. Lignocellulose biomass (category B) is used mainly for non-food products and derived from forestry products, fibre crops and agricultural residues (secondary products of A, C to E such as straws and hulls).

Table 1. Primary crops and products

Carbohydrates			
A1	Sugar crops	Sugar beet	
		Sugar cane	
A2	Starch crops	Grains	Rice, **corn**, **wheat**, oat, **barley**, rye
			Sorghum, millet
		Tubers	**Potato**, cassava, sweet potato, arrowroot, yam
		Pulses	Bean, pea, lentil
		Sago	
Lignocellulose			
B1	Wood	Softwood	**Pine, spruce, fir**
		(non-tropical) Hardwood	Oak, **beech, birch, poplar, willow**, eucalypt
B2	Fibre crops		Cotton
		Soft fibres	Flax, hemp, kenaf
		Hard Fibres	Sisal, coir
B3	Herbaceous crops		Bamboo and rattan
			Reed, typha,
		Grasses	Miscanthus, switch grass
Oils and Fats			
C	Oil crops		**Sunflower**, rape, **soy**, olive
			Castor, linseed, sesame
Proteins			
D	Fodder crops		**Soy**, grasses, lucerne (alfalfa), clover, turnip, canola (rape)
Other			
E1	Rubber		Hevea, (dandelion)
E2	Fruits and vegetables		**Apple**, pear, plums, grape, lemon, orange Tomato, eggplant, sweet pepper, Artichoke, spinach, carrot, cardoon
E3	Beverages		cocoa, coffee and tea
E4	Spices and fragrances		Hop, mustard, lavender
E5	Nuts		Walnut, almond, hazelnut, pistachio, chestnut

The production of refined sugar (saccharose, category A1) from sugar beet (Fig. 3) yields at harvest the coppice and leaves. In the sugar factory a major side product is the beet pulp. Currently, these residues are mainly used in fodder. Lower grades of purified sugar (molasses, invert sugar syrups) still find wide application in food and beverage industries. The use of sugar in non-food industries is limited to for example retardant of cement setting and as ingredient of sizing agents in textile processing. Also in some pharmaceutical products sugar can be found. Most of non-food sugar use is found in the fermentation (of lower grade syrups, molasses and invert sugar) to ethanol (biofuel) or other (chemical) products that are produced by biotechnological processes applying selective enzymatic conversion by microorganisms.

Figure 3. Scheme of sugar crop processing chain (A1)



Starch can be obtained from a variety of crops (A2), including grains (e.g. wheat, corn, barley, oats, rye, and rice, Fig.4) and tubers (Fig.5). Potato is the most important tuber crop for starch production in the temperate climate zones. Starch and starch derivatives frequently find application in non-food uses or are hydrolysed into its monomeric glucose building blocks (C6) as fermentation feedstock.

Figure 4. Scheme of starch production chain from grains (A2)

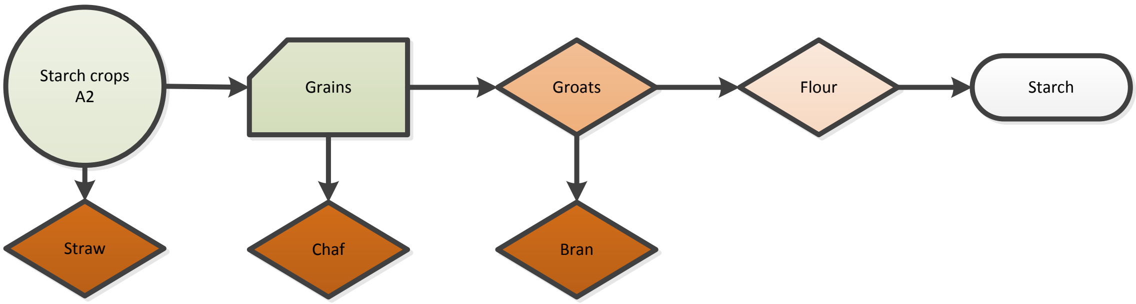
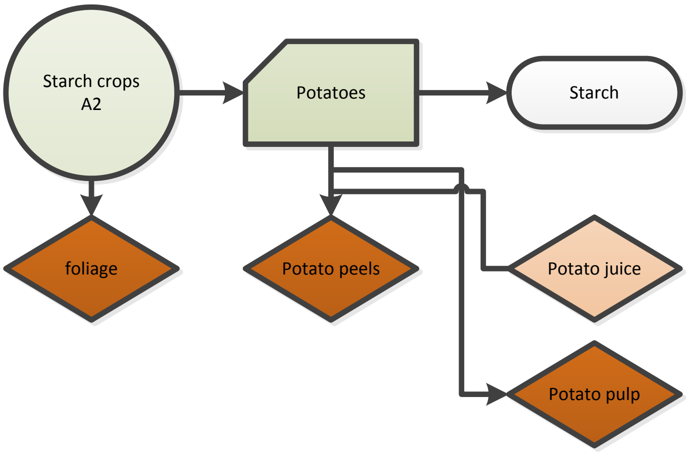
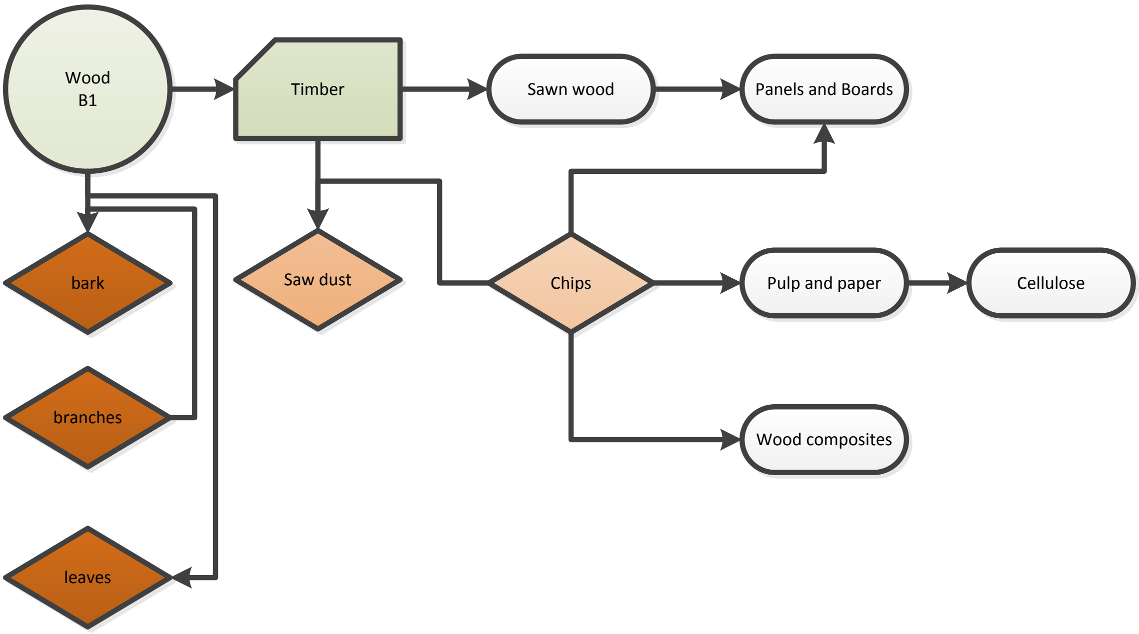


Figure 5. Scheme of starch production from potatoes (A2)



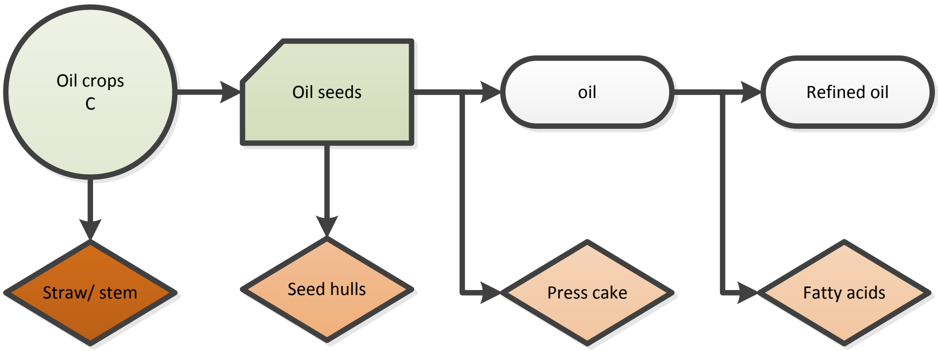
The lignocellulose (category B, Fig.6) is traditionally linked to the non-food markets of fuel wood, as well as to materials and products for building and construction, textiles, and furniture manufacturing. Chipped wood is used for paper and pulp production or wood particle composites. The use of lignocellulose feedstock for 2nd generation biofuel production is receiving currently world-wide attention from industrial R&D. The aim is to efficiently produce glucose (C6) from the cellulose by chemical and enzymatic conversion steps.

Figure 6. Scheme of lignocellulose processing (B)



Vegetable oils (category C) are obtained from various oilseeds. In Fig.7 the simplified scheme of oil production is represented. In non-food and non-feed industrial applications various vegetable oils and fatty acids are applied in soaps and surfactants, coatings and paints, linoleum flooring, or biodiesel production. Bio-polyesters and urethane foams may be (partly) derived from oil seed crops.

Figure 7. Scheme of vegetable oil production (C)



D, E – The crops of categories D and E, e.g. fodder crops that are rich in proteins and other crops, that are diverse in their production scale and uses and of less relevance here for describing the new bulk commodity markets. The use of (vegetable) proteins in non-food industries is limited to adhesives and glues or coatings. Soybean protein and gluten were shown to be suitable for manufacturing thermoplastics, and foams. Plant proteins can be suitably used as surfactants, for example in the production of foamed lightweight concrete.

2.3 Biorefinery and biotechnological conversion to platform or 'fine' chemicals

With the emergence of the biobased economy the search has intensified for suitable feedstock for biotechnological conversion by fermentation or biorefinery and (hydro)thermal processes (Fig.8) for production of biobased chemicals, fuels, plastics, and resins. Sugar and starch are the most easy digestible carbohydrates and therefore these are the most suitable feedstock for biotechnological conversion, with the assistance of microorganisms and enzymes into a variety of chemical components from ethanol and acetic acid to hydrogen and lactic acid.

Concerns about the competition of food and feed applications of crops versus uses for biofuel and bioplastics production, have led to the development of so called second generation – or advanced – biofuels. These are mainly based upon the biorefinery conversion of lignocellulose feedstock (both crops and residues). Lignocellulosic materials are woody parts of plants that all contain cellulose, non-cellulose polysaccharides – often referred to as hemicellulose or pentosans – and lignin in different proportions.

Hydrolysis of cellulose and hemicellulose will yield sugar (glucose C6 and pentose C5), that can be used in the same way as carbohydrate feedstock for fermentation or chemical conversion.

The production of biopolymers based on vegetable or animal derived feedstock still has a relatively modest market share (Sanz Mirabal et al. 2013), but trends are observed that 'green' products are receiving strong attention from industrial R&D. Substantial growth is expected, especially for bioplastics (OECD 2013). Polylactic acid (PLA) and biopolyethylene (bio-PET) are entering the market for bulk plastic products. Many other specialty products can be produced from biobased chemical ingredients or are yet partially biobased. For example, in the production of polyurethanes (PUR) biobased polyols can substitute for petrochemicals, but the reactive isocyanate still is petro-chemistry based.

Biopolymers can be categorized according the type of polymer (e.g. carbohydrate derivatives, bio-olefins, bio-polyesters, bio-polyamides, rubbers and resins) (Table 2).

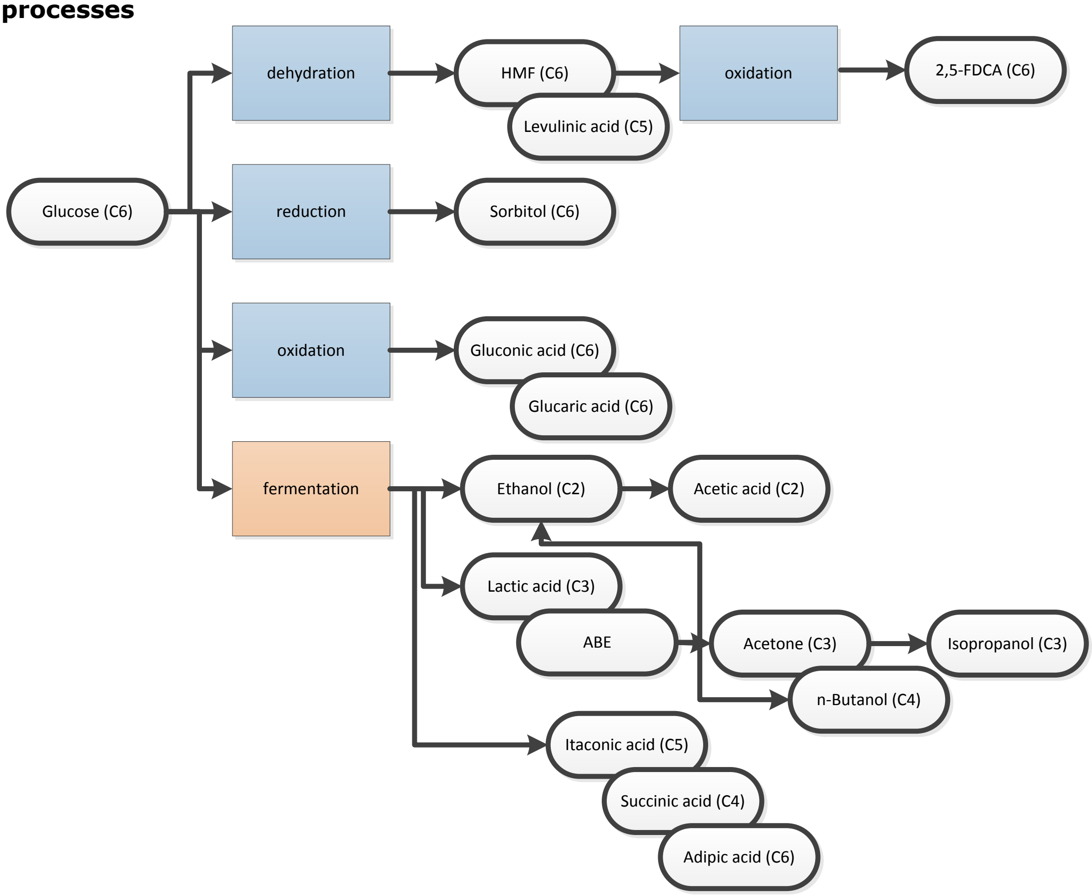
Table 2. Biopolymers classified according the constituents e.g. biobased chemical building blocks (acc. Harmsen & Hackmann, 2012)

	Class biopolymers	Products	Chemical building block	Process type
1	Starch derivatives	Thermoplastic starch Starch esters Starch ethers Oxidized starch	Starch	Chemical modification
2	Cellulose derivatives	Celluloid, Viscose / rayon,	Cellulose	Chemical modification
	Cellulose esters	Cellulose acetate (CDA) cellulose propionate (CPA)	Cellulose	Chemical modification
	Cellulose ethers	Methyl cellulose Ethyl cellulose Hydroxypropyl cellulose (HPC) Carboxymethyl cellulose (CMC)	Cellulose	Chemical modification
3	Bio-polyesters	PLA	Lactic acid	Fermentation*
		PHA (PHB/PHV)	Hydroxyalkanoate	Fermentation
		PCL	Caprolacton	Fermentation*
		PBS	Succinic acid	Fermentation*
		PET	Terephtalic acid	Chemical conversion
		PEF	Furandicarboxylate	Chemical conversion
		Alkyd	Polyunsaturated fatty acids	Chemical cross-linking
4	Bio-polyolefins	Bio-PE	Ethene	Fermentation*, Chemical modification
		Bio-PP	Propene	Fermentation*,

				Chemical modification
5	Bio PUR		Castor oil Oxidized soy oil	Chemical modification
6	Bio-polyamides	PA6	Lysine	Fermentation*
		PA11	Castor oil	Thermo-chemical modification
		PA4.10 – PA10.10	Castor oil	Thermo-chemical modification
7	Bio-rubbers	Polyisoprene	Latex	Vulcanisation
		Isobutyl rubber Butadiene rubber	Isobutene Butadiene	Fermentation*
8	Bioresins	Furan resin	Furfural	Chemical extraction
		Lignin resin	Lignin	Chemical extraction

* fermentation of (C6) sugars

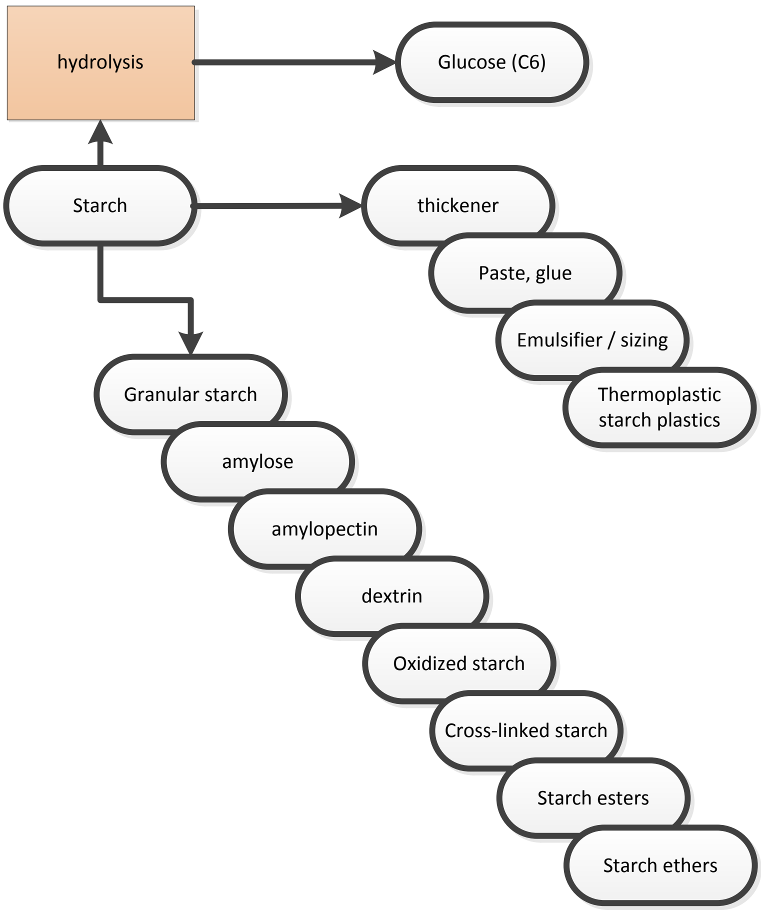
Figure 8. Sugar (hexose, C6) as platform commodity as feedstock for conversion processes to key 'green' chemicals by chemical and enzymatic processes



2.3.1 *Starch based chemicals and polymers*

Starch finds wide application – as such or in a modified form – also in many non-food applications, for example as thickener in paints and inks, as sizing agent in textile processing and paper production, in glues and biodegradable plastics (Fig.9). Starch can be efficiently hydrolysed by enzymes (amylase) or chemically by acid treatment to its monomeric constituent glucose (C6). The glucose can be further converted to green chemicals, as presented in Fig.8.

Figure 9. Starch based products and industrial use

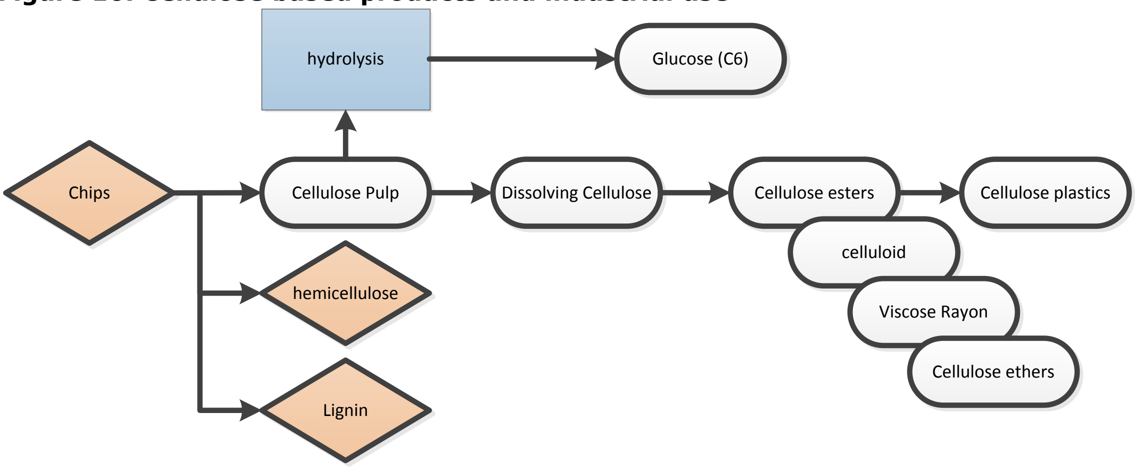


2.3.2 *Cellulose based chemicals and polymers*

Lignocellulosic resources (mostly wood) are used for refining to different qualities of cellulosic fibres (Fig.10) that find commercial outlets in panels and boards, paper grade pulps and chemical grade pulps.

Besides this, highly purified dissolving cellulose is converted by chemical processes to viscose rayon or cellulose derivatives. Alternatively, the cellulose (and hemicellulose) can be hydrolysed by the various 2nd generation biorefinery procedures to yield glucose, which is the platform C6 chemical, suitable for fermentation and conversion to 'green' chemicals (Fig. 8).

Figure 10. Cellulose based products and industrial use



2.4 Fermentation to biogas (Methane C1)

Heterogeneous biomass can be decomposed and digested under anaerobic conditions by bacteria to form biogas that is mainly composed of methane (C1). Biogas can be compressed and used like natural gas as vehicle fuel.

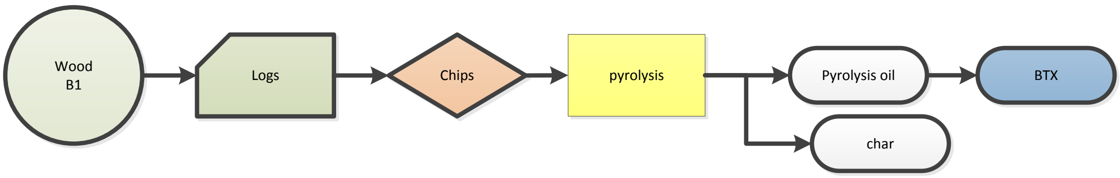
2.5 Thermal conversion of biomass

Hydrothermal processes have been designed to convert biomass into crude oil or tars and to obtain biogenic chemicals, liquid fuels and energy carriers with higher heating value that can be stored, transported and converted in the existing infrastructure for petrochemical production.

2.5.1 Pyrolysis

The thermochemical decomposition of biomass at approximately 500 ^{o}C in the absence of oxygen yields pyrolysis oil and char (Fig. 11).

Figure 11. Pyrolysis of lignocellulosic biomass to BTX



2.5.2 *Liquefaction*

Hydrothermal liquefaction converts biomass into crude oil (thermochemical conversion at lower temperatures in the presence of water). Hydrothermal upgrading process (HTU®) is a liquefaction process for solid biomass under high pressure and catalytic hydrogenation conditions (hydrodeoxygenation) yielding bio-crude oil suitable as transportation fuel.

2.5.3 *Torrefaction*

Torrefaction of biomass is used for upgrading the calorific value of lower qualities lignocellulosics. By heating the biomass at relatively mild conditions (250-350 ^oC) and low oxygen carbonization occurs, yielding a biomass product with higher calorific value that can be pelletized easily and stored longer without degradation.

2.5.4 *Gasification to syngas (synthesis gas)*

Syngas is a mixture of gasses (H_2, CO and some CO_2), that is formed by gasification of diverse biomass sources similar to coal gasification. Syngas can be used for the Fischer-Tropsch process to produce methane and methanol (C1).

2.6 Bio-polymers and biobased plastics

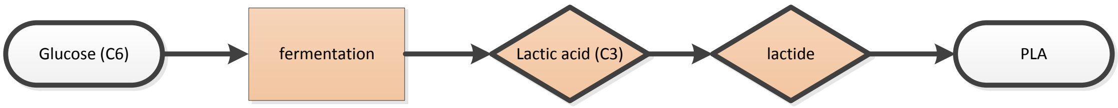
Different synthetic polymers, that currently commonly are produced by the petrochemical industries, can be produced from biobased chemical building blocks. Some examples of biobased polyesters, bio-olefins and bio-polyamides are given in the following paragraphs.

2.6.1 *Biobased polyesters*

<u>PLA Polylactic acid (and blends)</u>

Polylactic acid (PLA) is currently the most important biobased polyester that is produced on commercial scales. It is produced by fermentation from sugar to lactic acid and is polymerized to PLA via its dimer form lactid (Fig.12).

Figure 12. Polylactic acid production from glucose fermentation



PHA/PHB Polyhydroxyalkanoates (polyhydroxybutyrate)
PHAs are bioplastics that are produced by bacterial fermentation of glucose or lipids (e.g. *Alcaligenes eutrophus; Bacilus subtilis*). These organisms are capable of biosynthesis of natural polyesters from hydroxyacids (PHA) of different chain length (most commonly polyhydroxybutyrate PHB and polyhydroxyvalerate PHV) and many different co-polymers may be formed (PHB/PHV)/(PHB/PHH), depending on the organism or conditions of biosynthesis.

Polybutyleen succinate (Biobased succinic acid) (PBS)
Polymerisation of succinic acid with 1,4-butane diol yields PBS, a polymer that currently is produced largely form petrochemical raw materials. Both building blocks can be produced from biomass by combined sequences of fermentation routes (Fig. 8) and chemical conversion steps.

In a similar way other polymers can be synthesised from biobased monomers, such as: Polycaprolacton (PCL), Polybutyleen succinate adipate (PBSA), Polytrimethylene terephtalate (PTT), Polybutyleen adipaat tereftalate (PBAT).

The monomers for production of biobased Polyethylene terephtalate (PET) can be derived through various routes. Ethylene glycol can be obtained by chemical conversion of ethanol via ethylene or hydrogenolysis of glycerol, xylitol or sorbitol. The biobased terephtalic acid production is more complex and currently in development from biobased para-xylene.

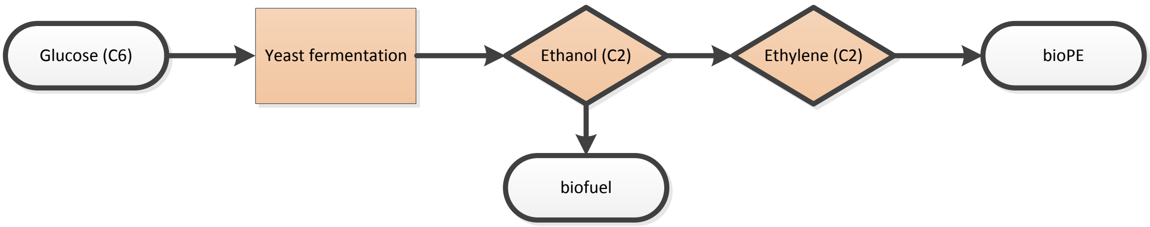
Another development of biobased polymers concerns the production of Polyethylene furan dicarboxylate (PEF). The selective chemical oxidation of C6 sugars (fructose) to 2,5 furan dicarboxylic acid (2,5-FDCA) yields the building block for a new biobased polymer PEF.

Other biobased polyesters that have a firm position in the chemical industries are the Alkyd resins, polyesters based upon polyunsaturated fatty acids (derived from tung oil, linseed oil, soybean oil, corn oil), used in coatings, paints. These 'drying' oils are well known in the production of oleochemicals (e.g. epoxidized oils).

2.6.2 *Biobased polyolefins and vinyl polymers*

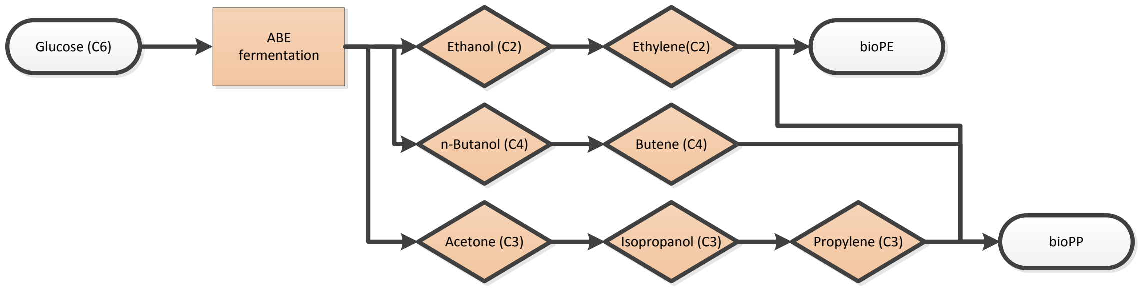
Polyethylene is the most common plastic on the market. The biobased alternative for polyethylene (BioPE) can be produced from ethylene that is derived from ethanol fermentation (Fig.13).

Figure 13. – Bio-PE production from ethanol fermentation



The route to biobased alternatives for other polyolefins such as Bio-polypropylene (BioPP) and also polyvinyl chloride (PVC), polystyrene (PS), polyvinyl acetate (PVA) polymethylmetacrylate (PMMA), or polyacrylic acid (PAA) is more complex but may be derived from the ABE fermentation route (Fig.14).

Figure 14. – Glucose conversion by ABE fermentation for polyolefin production



2.6.3 Biobased polyurethanes

Polyurethanes (PUR) are polymers that are composed of two components: a polyol and isocyanate. As polyols various biobased products are used. Polyols based on fatty acids find the most commercial application currently (soy oil, Castor oil). Besides, polyetherpolyols can be produced on basis of sugar or sugar alcohols.

Castor oil → polyols → bio-PUR (soft- and hard foam)

2.6.4 Biobased polyamides

Polyamides or nylons are a group of important engineering plastics that also can be produced from biobased ingredients. The production process is based upon the polymerisation reaction of bifunctional components containing an amide group and a carboxylic acid. Different polyamides can be produced via different routes using biobased starting chemicals such as sugar to lysine or castor oil to sebacic acid.

Starch → Glucose → lysine → Caprolactam → PA6

Castor oil → ricinoleic acid → undecanic acid → Amino-undecanic acid → PA 11

→ sebacic acid → (TMDA) → PA 4.10

→ (PMDA) → PA 5.10

→ (HMDA) → PA 6.10

→ DMDA → PA 10.10

2.6.5 Biobased rubber (semi-synthetic rubber)

Natural rubber latex (Polyisopreen) is an important industrial commodity that is derived from the tapping of the rubber tree (*Hevea braziliensis*). Alternative crop sources of isoprenic latex have been identified such as Guayule (*Parthenium* *argentatum*) and Russian dandelion (*Taraxacum koksaghyz*). Synthetic rubbers produced from isobutene or butadiene may also be derived from bioresources through fermentation and chemical dehydration steps.

2.6.6 *Biobased resins (thermosetting resins)*

Thermosetting resins are used for glues, paints and coatings as well as for production of moulded parts. These resins can be based on renewable chemical building blocks. Bio-derived epoxy resin systems for example are commercialized. Glycerol can be chemically converted to epichlorhydrin, acrylic acid or propylene glycol, that are important components in, respectively epoxy, acrylic or polyester resins. The commercial use of biobased phenolics (tannins, ferulic acid) is still limited as compared to the petrochemical production.

Furan resins are produced from lignocellulosic biomass that is pentosan (C5) rich by strong acid treatment that releases furfural. The resins produced traditionally are used for iron casting moulds. Furan based resins are also suitable for wood glue production and wood impregnation.

Lignin is the by-product released from paper pulp production, but also from the 2^{nd} generation lignocellulose biorefineries. Currently this black liquor stream is largely used for generation of process energy in the pulping mills. Lignin has been successfully used in resin formulations. Soluble lignins (e.g. lignosulfonates) are commercially applied as additive in cements. Much industrial R&D is focussed on the conversion of lignin to monomeric aromatic chemicals BTX (Benzene, Toluene, Xylene).

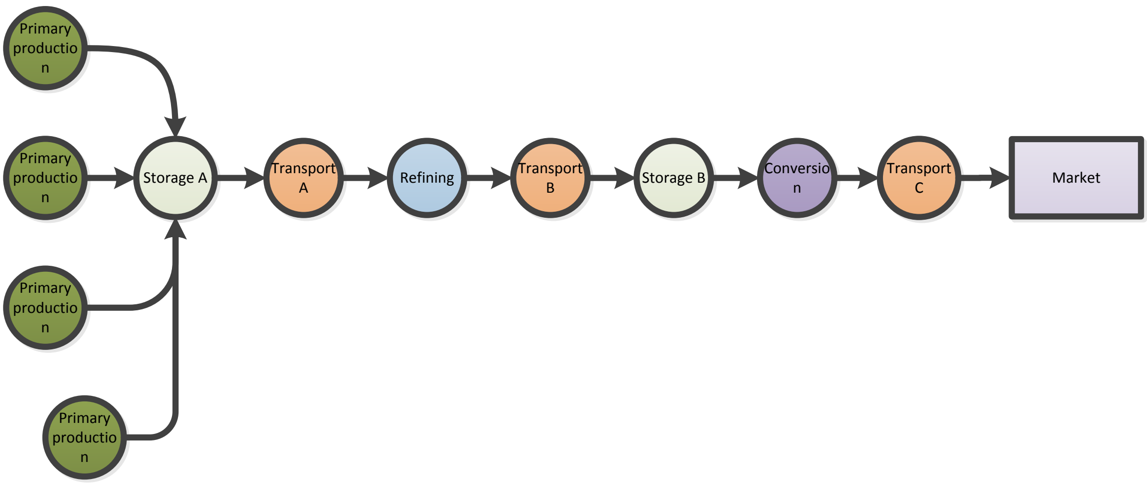
Cashew nutshell liquid (CNSL) containing cardanol is an example of a strongly reactive biobased resin component that has been used as curing agent in wood glues and polyurethane.

3 Setting up Biobased (Commodity) Chains

This chapter reviews the aspects that have to be taken into account when setting up biobased trade chains. The perspective is that of potential entrepreneurs or investors who are considering setting up a production chain from a country where a biomass feedstock can be produced competitively to an overseas market with focus on the EU and The Netherlands. The focus is the production of biobased chemicals and fuels.

In Fig. 15 a scheme of the production chain from crop or agro-feedstock through intermediate product/commodity platform chemical to chemical building block to final product (in this case a biopolymer) is shown. In chapter 2 a range of production chains from crop (or residue) to final products or fuels are presented which show what steps, processes, feedstocks and intermediate products are involved.

Figure15. – Schematic of a production and delivery chain from biomass feedstock through transport, refinery and conversion steps up to the final market.



Three types of viewpoints in setting up a chain can be identified:
Feedstock producer: Can this feedstock be a start of a biobased production chain? Can the feedstock be competitive?
Final producer serving the market: How can I produce a biobased product for the market? What feedstock should I use? What is the biobased market demanding?
Intermediate party: Can this piece of infrastructure (transport/storage) or specific technology be part of the production and delivery chain from feedstock to final user?

The selection process is illustrated in Fig. 16 where the production chain connecting the feedstock to a biomass market (final product) by production chains is illustrated.

The initiative to set-up a production chain can start at the feedstock side:

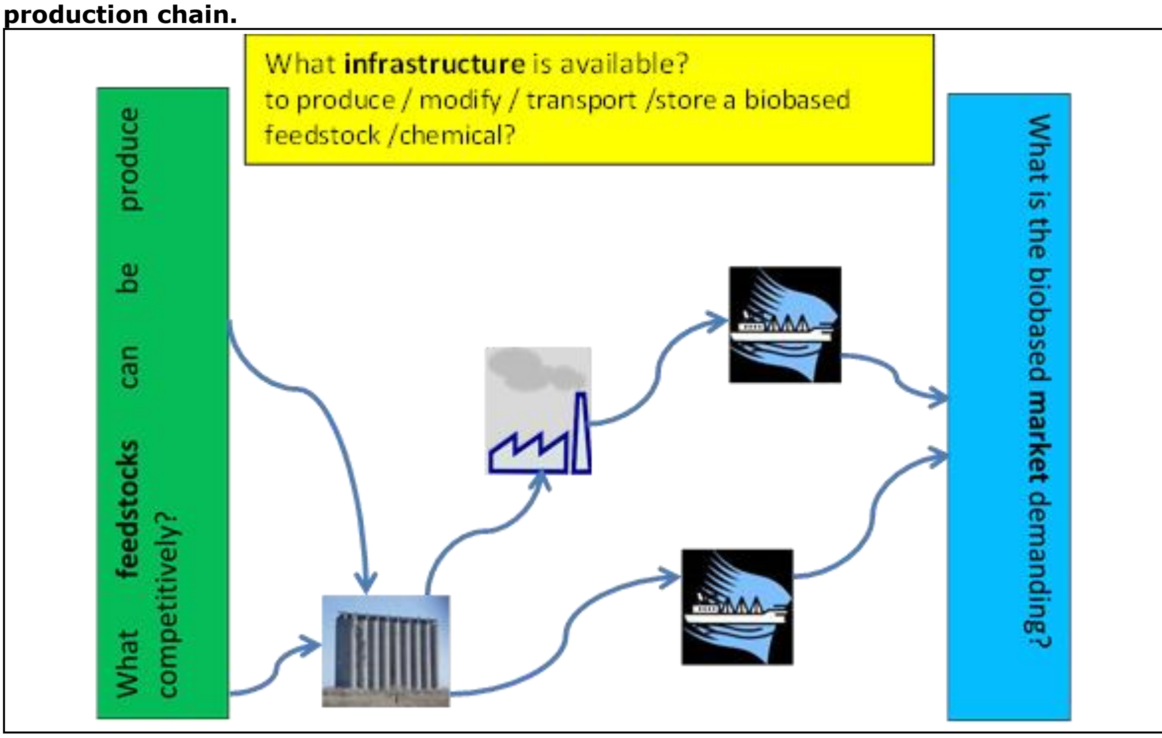
- What biobased product or market could be supplied with this feedstock?

Or from the infrastructure side:

- Can my processing facility, harbour facility, transport facility be a part of a biobased production chain?

Or from the final product producer (overseas) looking for feedstock for producing or using a biobased fuel or chemical.

Figure 16. Illustration of the process in deciding how to set-up a biobased production chain.



When setting up biobased chains a large number of factors need to be considered. First we review two aspects that have a large impact on biobased chains and that have to be considered carefully when taking initiatives, viz.: 1) the role of biobased commodities and 2) the economy-of-scale of the different steps in the total production chain from field to consumer.

3.1 Biobased trade and biobased commodities

In recent years a number of reviews have been made to assess biomass and bio-commodities trade and how they will develop (Van Dam et al., 2005; Sanders et al., 2009; Junginger et al., 2011). The studies show what aspects are important in setting up biobased or biomass feedstock trade chains. The studies all identify the need for biobased commodities to be developed.

Sanders et al. (2009) explains in detail the logic and technical requirements set for a tradable commodity.

The importance of international standardisation and "commodification[7]" of the biobased resources becomes obvious when considering the economic advantages that commodities have compared to non-commodity feedstocks (Vellema et al., 2009).

When a product is a full commodity (see table 3 for an overview) there are mainly advantages for its use as industrial feedstock. In the biobased production chains described in chapter 2 real commodities are (still) scarce. In table 3 an overview of the characteristics of a real commodity and the associated advantages is given and compared to a product that is not a real commodity.

For a biobased product to be a commodity it is very important that it is easily transportable and storable, meaning that it has low moisture and a high energy content (GJ/ton). It is also necessary that quality is standardized, such that the product is completely interchangeable (fungible). This allows the development of many other standards for handling, transport and further processing. It also allows for standard contracting and trade to be developed. This is essential for financial instruments and a markets to develop. Standards for sustainability are now compulsory for biobased transport fuels in the EU. Also for other biobased applications these type of sustainability standards are likely to be demanded and implemented in the coming years.

If a product is a real commodity it can be traded as such (for example wheat or wood pellets). If a product is not a real commodity, such as sugar beets, then a more complex relationship between producer and buyer is necessary and the distance will generally be small and the trust between the chain partners has to be high.
The security of supply is generally lower because alternative feedstock sourcing is difficult or impossible. This explains why, perishable and voluminous feedstocks, such as sugar beet and sugar cane, are processed locally and there is a very close relationship between agro-producer and the processor. Generally the processing plants are owned by cooperatives ensuring supply.

A recent project focusing on producing pellets from straw, reed and switchgrass (Elbersen et al 2013) helped to highlight the factors that are important for setting up biomass trade chains specifically in financial terms. The project identified the fact that pellets made from non-wood biomass are not a commodity

7 Assignment of an economic value to goods that previously were not considered as such and can be traded as a commodity

Table 3. Description of a real commodity versus products that are not a real commodity

A full commodity	Not a commodity
Easily transportable and storable → high energy content, low moisture, low volume **Quality standardized** **Fungible** (= "exchangeable") Standard transport, contracting, insurance, safety, etc. Standard processing, etc. **Functioning market** Trade system → Price formation Financial instruments (futures, etc.) High "tradability" **Sustainability** Standard certification systems exist	**Not easily transportable or storable** **No standards** (quality, sustainability, safety, etc.) **No exchange markets** No market price No financial instruments (futures) **No sustainability standards** **Transaction costs higher** **Security of supply becomes very important/difficult** **Long term relationships needed** One on One and Case by Case relations **Vertical chain integration**

Trading products that are not full commodities is more difficult as all relevant technical, financial, legal and sustainability issues have to be defined and agreed on separately and there is a strong dependence between supplier and producer. Examples of full commodities and products that are not (full) commodities (yet) are given in Table 4. In the right column sugar beet and straw are presented as non-commodities because of high moisture contents. Straw pellets and torrefied pellets could become commodities because they are easily stored and transported, but proper standards and trade financial instruments have not been developed and implemented yet.

Table 4. Examples of real commodities and products that do not qualify as a commodity.

Commodity	Not a commodity
Sugar	Sugar beet
Rape seed	Straw
Wheat	
Corn	
Plant oils	*Not a commodity (yet)*
Ethanol	Straw pellets
	Torrefied pellets
Mostly a commodity	Pyrolysis oil
Wood pellets	Wood chips
Timber, logs	
Roundwood	
Pulp	

3.2 Economy-of-scale

"Economies-of-scale are the cost advantages that enterprises obtain due to size, output, or scale of operation, with cost per unit of output generally decreasing with increasing scale as fixed costs are spread out over more units of output.

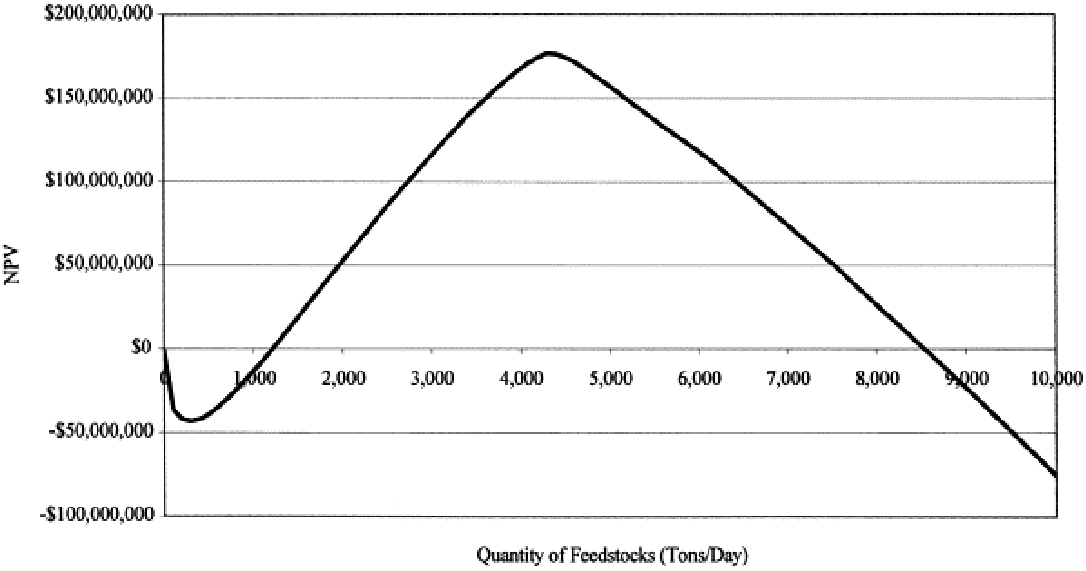
Often operational efficiency is also greater with increasing scale, leading to lower variable cost as well”[8].

Biomass is generally a very bulky product, containing water and unwanted components, such as nutrients. It is also dispersed over large areas at a low density. For example straw is bulky and only produced at 2 to 6 tons (DM) per hectare with a moisture content of 15%; wood residues from clearing will be available at approximately 20 tons per ha with a moisture content of 50%; sugar beet will have a yield of 40 to 80 tons per ha with a moisture content of 80%. Bulky crops and crops with high water content (e.g. sugarcane, sugar beet, cassava, industrial potato), need to be processed (de-watering, increased energy concentration, etc.). As pointed out by Sanders et al. (2009) this will have to be executed close to the field, in order to prevent high transportation costs, losses of minerals and crop degradation. The optimum scale of collection is relatively small.

In general conversion systems require large scale to be economic. This goes especially for conversion steps that include high temperature steps. At the same time the cost of supplying the biomass will then increase as the area from where the biomass has to be sourced is increased. A good example is ethanol and sugar production from sugar cane. Here the economy-of-scale of the ethanol plant is limited by the increasing cost of transportation. While the size of the conversion system has to be large, especially due to the distillation step. For other conversion systems the optimum economy-of-scale is even larger.
Factories that convert biomass into products are generally limited in operational scale by the cost of biomass transport. Especially, if the biomass is bulky and or has a high water content. This is illustrated by figure 17. Here the net present value of the investment in a lignocellulose (straw and similar biomass) to ethanol plant is negative if the plant has a capacity of less than 1.200 tons per day of feedstock, and optimal at 4.360 tons per day. Beyond 4.360 tons per day the cost of biomass transport does not compensate the additional revenue of more ethanol production.

8 Wikipedia (April 2014)

Fig.17. Estimated net present value of a lignocellulose-to-ethanol (second generation) plant versus size of the plant (feedstock use) for a case in the USA (Ref. Kaylen et al., 2007)**.**



So the "economy-of-scale" can be calculated for a whole production system, as illustrated in figure 17, where economy-of-scale of logistics limits the size of the total system. Intermediate steps are often added to be able to operate conversion steps at a larger economy-of-scale. For example baling of straw to be able to increase the economy-of-scale of logistics.
Pre-treatment technologies to reduce volume, remove water, increase energy density, recycle nutrients and make storage possible, are also generally necessary when supplying customers overseas. Often these pre-treatment options also have to be implemented for local use to make storage possible and deliver a standardised feedstock.

Economy-of-scale is also relevant for other aspects, The relative cost of other issues, such as contracting, financing, insurance and certification, also are less costly at larger scales. If a product is a commodity the cost of these issues will also be lower. So the economy-of-scale can also be reduced if the product is a commodity.

3.3 What feedstocks can be produced competitively?

A biobased trade chain either starts from a feedstock base or from a market demand. Relevant potential feedstocks include primary crops, from which some intermediate products such as starch, sugar and so called secondary products or by-products (straw) are produced at the farm level. Other feedstocks include secondary or processing residues and by-products such as wheat bran and bagasse that are released at the agro-industry levels. In Chapter 2 an overview is given of the crops, secondary crop products or intermediate products that can be used as feedstocks for chemicals or fuels.
When assessing if a certain feedstock may be soured competitively, a range of often self-evident factors may be considered. Here we review some relevant ones that have come up in the assessment in Chapter 4.

Availability of the feedstock: How much feedstock is available and at what density (ton/ha)? Does this fit the economy-of-scale of the foreseen downstream processing?
Experience and knowledge base: Experience in growing a crop decreases lag-time for implementation, and will reduce overall risks associated with introducing and developing a new crop locally.
Competing or alternative uses: Alternative uses are very important and may also include the need to maintain soil quality in the case of residues (straw) or bedding for animals.
Stability of supply: This factor is always important in farming as production may vary according to the weather. For residues and by-products it is even more important because the main application determines availability of a residue (i.e. wheat straw). Wood processing residues are a function of wood product demand, the collapse of wood processing industries may reduce availability of residues to nil.
Infrastructure: Many crops or residues are or can only become available at competitive costs if infrastructure to store and bring it to market is available.
Cost: Self-evident
Sustainability: For biobased products sustainability is very relevant certainly when export to EU markets is anticipated. For transportation biofuels specific sustainability demands are in place. See the Renewable Energy Directive (EC, 2009) and the issues surrounding the choice of certification systems (NL Agency, 2011; Van Dam et al., 2012). Though not yet in place, similar demands may be expected for biobased chemicals and products. In general efficient high productivity will contribute to sustainability. Avoiding food competition will make residues more attractive.
Co-product value: The local value of co-products is very relevant for the total economic performance. The sustainability of the main product can improve by allocating part of the impact to the co-product.
Outlook: How are the factors above expected to develop?

These factors can be assessed combined in a SWOT analysis (Table 5), which can be used to identify what need to be changed in order to improve the case.

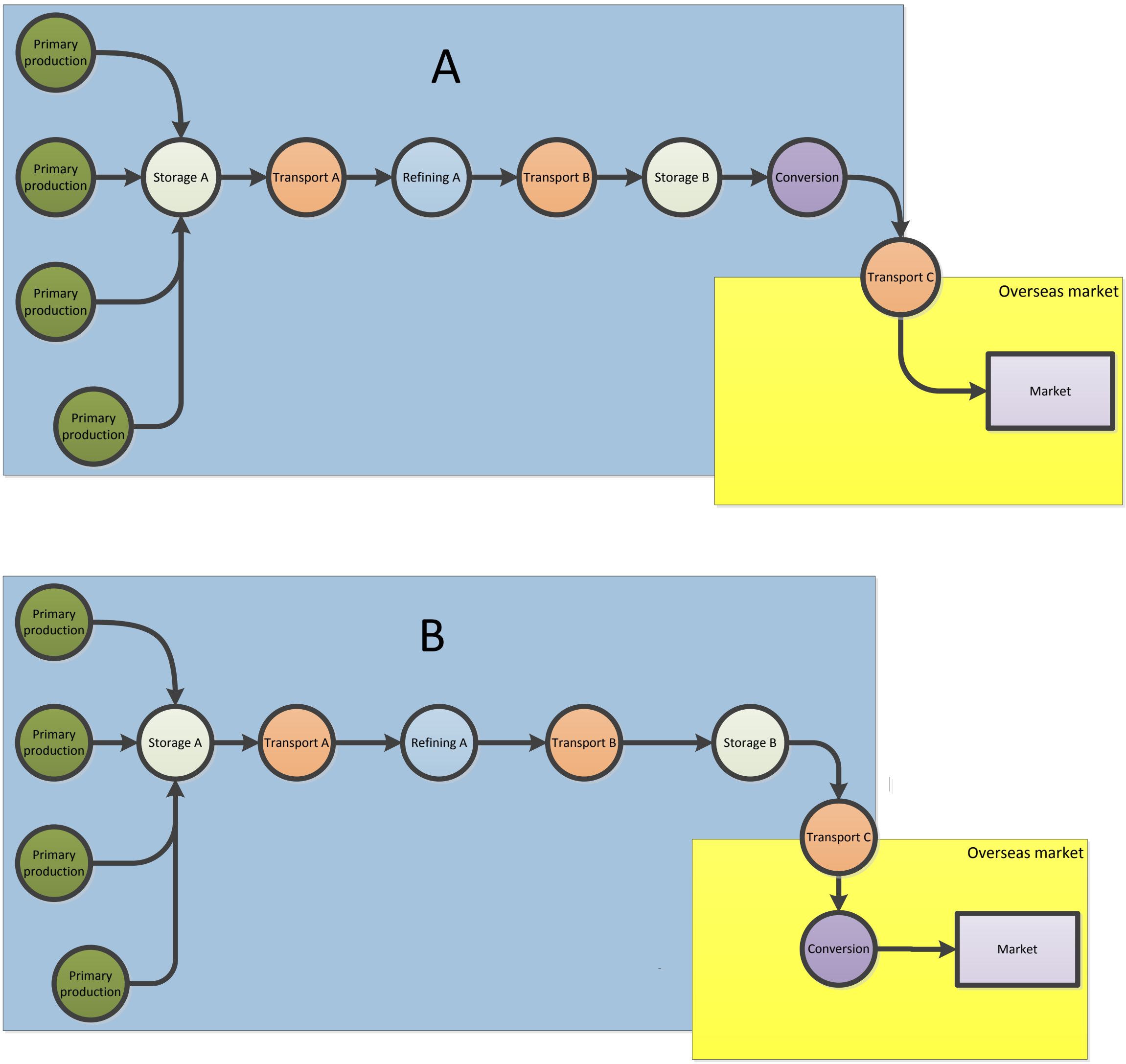
Table 5. SWOT analysis to assess the relative attractiveness of a feedstock for a certain application and market. The SWOT can also be used to define actions for improvement.

STRENGTH ■ How can I build on this strength?	**WEAKNESS** ■ How can I compensate for this weakness?
OPPORTUNITY ■ How to make best use of this opportunity?	**THREAT** ■ How can I minimize this threat?

3.4 Setting up and assessing a biobased production chain

As a starting point we assume that a production chain from feedstock to a final (foreign) market can be defined. Therefore, an attractive feedstock has been identified and both the product and market are defined. Connecting both ends requires a processing and logistical chain, as shown in Fig.15.
In general, the chain will be built around the main conversion facility. For example, the biodiesel plant or the second generation ethanol plant. This determines what is transported: oil seeds? vegetable oil? or biodiesel? The two options are illustrated in Fig.18.

Figure 18. Setup of two alternative biobased production and delivery chains from feedstock to final market. Feedstock can be converted locally after which the product (or intermediate) is transported (A) or the feedstock can be exported and converted overseas (B) where the market is served.



The choice what to transport (feedstock, intermediate or the product) and therefore, where to site the main processing step, is complex but many factors can be defined that guide this choice. To define the relevant factors we interviewed a number of business developers involved in setting up transnational biobased production chains. The main factors that guide this choice are summed up below. In all cases the local price of the feedstock was the most important factor mentioned at first. At closer review, many other factors can be almost of equal importance or concern.

Factors to consider in assessing the attractiveness of investing in conversion infrastructure at a certain location:

1. Feedstock cost: This is a very important factor especially for simpler conversion steps.
2. Security of supply and quality of the feedstock: Here seasonality and variations between years is considered. If the feedstock is a commodity security of supply is easier to guarantee,
3. Infrastructure: What part of the production chain is available? Aspects such as the availability of cost effective transport, energy supply and storage facilities are considered.
4. Skilled labour and technical expertise:
5. Cost of operation: Here we consider the cost of labour, energy cost, etc.
6. Logistics (reliable / low cost): Consider the availability of cost of effective transport, up-scaling possibilities, etc.
7. Investment cost and return on investments: Consider total investment but also local incentives and interest rate or availability of low cost loans, etc.
8. Tariffs (import/export) and taxes: Here one should consider import tariffs which can differ between feedstocks (raw materials) and finished products (for example gains vs ethanol). Also tax incentives and subsidies can be very relevant.
9. By-product value: Generally by-products will be produced. The local value of these products can be very relevant. Consider for example the value of residues as fodder or for renewable energy production.
10. Regulation environment: Here we consider renewable energy regulations, environmental regulations, sustainability demands and incentives. The predictability of changes to regulations is also very relevant here; frequent changes in regulations may make long term investments more hazardous.
11. Rule of law: Under rule of law we consider in how far contracts can be enforced and property is protected. Other relevant aspects may be intellectual property protection.

The factors can be explained in much more detail but should be more or less self-evident. Commonly, most important factors for success of chain development include the existence of reliable bonds between chain partners unless a commodity can be traded. The factors above can be used in a multi-criteria evaluation and combined with the SWOT analysis when comparing two siting options. In Chapter 4 the factors are used in assessing siting options for conversion plants. The factors can be used in a multi-criteria analysis to show the relative attractiveness of siting a conversion plant at location A or (overseas) at location B, as illustrated in Table 6.
Keep in mind that the purpose of the table is to gain insight and that in practice some factors are much more relevant and may overrule all others.

Table 6. Multi-criteria analysis table to assess the relative attractiveness siting a conversion plant at location A or vs. location B. (Based on suggestion by E. Wubben).

Factor	Location A	Location B	Explanation
Feedstock cost	Score 1 to 5*		
Security of supply of the feedstock			
Infrastructure			
Cost of operation			
Labour and expertise			
Logistics			
Investment cost			
Tariffs			
By-product value			
Regulation environment			
Rule of law			
Sum			

*Score: 1 is most negative, 5 is most positive.

3.5 A short guide for setting up a biobased production chain.

The process of setting up a biobased production chain from feedstock to a biobased market is complicated and can hardly be put into fixed rules. At the same time there is a certain logic that can be applied in a decision tree.

A short guide for setting up a biobased production chain:

A. Can you envision a biobased production chain defined by a specific feedstock and a specific final product and market?
    a. Yes? → go to B
    b. No? → See chapter 2 for possible feedstock - final product/market applications
B. Assess the relative attractiveness of the feedstock for the envisioned application and production chain. Use a SWOT analysis to assess the attractiveness of the feedstock (Chapter 3.3). Is the feedstock sufficiently attractive?
    a. Yes? → go to C
    b. No? → adapt the envisioned chain and go to A.
C. Describe the envisioned chain in more detail and compare options for siting the main conversion system(s). A multi-criteria analysis, as described in chapter 3.4 can be used to compare siting options. Is it possible to reach a decision on the main options for setting up the chain?

   a. No? -→ Adapt the options and go to C again or go to A again
   b. Yes? → Go to D

D. Start implementation steps. This may include a wide range of actions including in depth financial analysis, getting commitment from financiers and potential partners in the chain, etc.

This short guide is used in chapter 4. for the development and assessment of some specific biobased commodity chains Ukraine – EU or The Netherlands.

4 Selection and assessment of (potential) biobased commodity chains in Ukraine

4.1 Introduction

In order to select the most feasible biobased commodity chains in Ukraine an assessment of the current situation for business opportunities was recently made (Kalniskaya, 2013).

4.1.1 Summary of The ProMarketing report

J. Kalniskaya (2013) describes the current situation in Ukraine in both the agricultural sector and the chemical sector. The Ukrainian position is characterized in the abundance of fertile arable land and substantial exports of surplus of agro-products (wheat grain, corn, soy, and oil seeds) to the world market. Almost half (ca. 45%) of the agricultural biomass waste produced (estimated over 100 Mt/y) is not used and may find added value for primary energy production or alternatively in biorefineries. The major crops are wheat, barley, corn, sunflower, sugar beet, soy bean, rapeseed and potatoes (Table 7). From year to year production areas and yields may vary.

The Current production of crop residues in Ukraine, e.g. straws and stems amounts to 86 million tons (wet) per year. Cereal straws and stems currently have few uses. Only a fraction is used for animal bedding. Most is left in the field and serves as soil amendment if not burned in the field. Sunflower husk is partially used for making pellets and briquettes (70%) and used as solid biofuel. Animal waste (28 Mt) is used as fertilizer and there is some conversion to biogas. Wood based biomass residues are largely lost or burnt. Approximately 2.1-2.5 million m^3 of wood biomass is unused.

<u>Food processing waste</u> (sugar mills, distilleries & breweries, juice production, oil extraction, cheese production plants and slaughterhouse effluents) may be used for energy generation (steam, biogas). Surplus of some solid fuel is exported (sunflower husk); other residues do not find added value.

The chemical industry in Ukraine is a major industrial sector. It is complex with many branches largely based on minerals, and fossil based carbon (petro-chemistry) including the manufacturing of polymers, resins and organic chemicals from crude oil, natural gas or coal.

The biomass processing industries include bio-ethanol, biodiesel, biogas and solid biofuel production. The biobased chemicals sector includes a lactic acid production plant (1000 to 12000 t/y; Kyiv Lactic Acid Plant). The lactic acid appears to be mainly used in the food industry and competition on the world market with synthetic lactic acid from China is difficult. Further options and advantages for biorefineries in Ukraine are presented. Five selected crops and biomass residues were worked out in some detail: corn, sunflower, rapeseed, animal waste (manure) and sugar beet. In the report barriers and bottlenecks for the biobased approach in Ukraine are analysed in a SWOT, and conclusions and recommendations are given (Kalniskaya, 2013).

4.1.2 *Agricultural production and forestry in Ukraine*

To arrive at the most suitable choice of commodity production chains in Ukraine the overall picture of biomass use and availability in Ukraine is assessed. Therefore information is needed on the current production systems and practice of use of residues with the (potentially) available raw materials. Ukraine has large areas of fertile soils that is (not extensively) used for primary production of commodity crops.

Based upon the published statistics on Ukraine of FAO (Tables 7 and 8) the most common agricultural and forestry based commodities produced can be derived.

Table 7. Major agricultural crops produced in Ukraine (FAO 2011)

	Area harvested ha	Production ton	t/ha	Residues	commodity
	A1 Sugar crops				
Sugar beet	515.800	18.740.000	36.4	leaves, coppice	sugar (C6)
	A2 grains				
Barley	3.684.200	9.097.700	2.4	Straw, chaff	
Maize	3.543.700	22.837.900	6.4	Stems, cobs	starch
Millet	156.400	278.800	1.7	Stems	
Oats	279.900	505.600	1.8	Straw, chaff	
Rye	279.100	578.900	2.1	Straw, chaff	
(Sorghum	66.700	175.900)	2.6	Stem	
Wheat	6.657.300	22.323.600	3.3	straw, chaff	starch
Buckweed	285.700	281.600	1.0	straw, hulls,	
	A2 Tubers				
Potatoes	1.443.000	24.248.000	16.8	Foliage	starch
	A3 pulses				
Peas	244.900	364.300	1.5	Straw, hulls	
	C Oil crops				
Soybeans	1.110.300	2.264.400	2.0	straw, hulls	oil
(Linseed	58.700	51.100)		Straw, hulls	oil
Rapeseed	832.700	1.437.500	1.7	Straw, hulls	oil
Sunflower seed	4.716.600	8.670.500	1.8	stems, seed hulls, flower heads	oil
	E fruits				
Apples	105.200	954.100	9.0	pruning, lop, branches, wood	

In Table 7 the most prominent agricultural crops in Ukraine are listed. The areas harvested are dominated by grains (wheat, barley and corn) followed by the production of sunflowers, potatoes and soy bean. It was mentioned (Kalniskaya, interview, 2013) that large part of the potatoes harvested are not consumed, due to poor management and lack of storage facilities.

Table 8. List of lignocellulosic products produced in and exported from Ukraine (t/yr).

Lignocellulose product	Production	Exports	Commodity
Round wood (c)	313.826	2.217.278	Round wood
Round wood (nc)	257.847	790.802	Round wood
Saw logs(c)	4.544.700		
Saw logs (nc)	1.755.300		
Sawn wood (c)	1.408.000	1.171.382	Sawn wood
Sawn wood (nc)	490.000	339.636	Sawn wood
Veneer sheets	103.000	54.897	Boards & panels
Particle board	1.642.000	427.266	Boards & panels
Plywood	169.000	111.077	Boards & panels
Chips and particle	442.000	18.544	chips
Wood residues	719.800	486.721	
Pulpwood (c)	682.100		Cellulose pulp
Pulpwood (nc)	435.600		Cellulose pulp
Recovered paper	339.000		Cellulose pulp
Wood fuel (c)	6.492.162	1.143.785	Fuel wood
Wood fuel (nc)	3.028.738		Fuel wood
Wood charcoal	125.000	83.164	Charcoal

c = coniferous or softwoods e.g. spruce, pine ;
nc = non-coniferous or hardwood e.g. birch, (beech), poplar, (eucalypt)

In Table 8 the volumes of forestry products in Ukraine are listed. It can be observed that:

- Paper pulp is imported for a large part (no significant kraft pulping / sulphite pulping)
- Paper and board products are net imported
- The largest part of the wood harvest is consumed as local fuel.

It can be anticipated that competing claims for resources may occur when wood production is used on large commercial scales for other trade than the current practice of local wood fuel consumption.

Wood (and other lignocellulosic residues) based potential products or traded commodities can be identified: chips, pellets, charcoal, pyrolysis oil, 2nd generation biofuels and syngas.

From these data the amounts of biomass from verge grasses are not available. Ukrainian reed may also be a relevant lignocellulosic feedstock. The area of reed in the Danube delta only is estimated at 105.000 ha, yielding on average 5 t/dm/ha. This is partly (ca. 10%) harvested (ca. 50.000 t/y) (Köbbing et al., 2013; van der Sluis et al, 2013).

4.1.3 *Assessing potential biobased (export) chains for Ukraine*

Based on the assessment of agricultural and forestry production in Ukraine above, we have selected 5 biobased production chains from feedstock to a final market product that has a growth potential and could be attractive for involvement of production or conversion in Ukraine. The 5 production chains are described in short and assessed using the short guide for setting up biobased production chains (incl. SWOT analysis and multi-criteria analysis) as introduced in Chapter 3.

The large scale agricultural production of crops in Ukraine (Table 8) and the competitive exports of carbohydrate rich commodities (A2) like maize (corn), wheat, and the oil crops (C) sunflower, and soybean, make the selection of these crops for the chain evaluation the obvious choice. Also the large potential in Ukraine of the forestry based production of lignocellulosic biomass (B) or exploration of unused straw and natural reed stands and grasses[9] as feedstock deserves consideration. Sugar beet and potato are examples of prominent Ukrainian crops that have more difficulty to compete on the global commodity markets in the current situation (Kalniskaya, 2013). Probably due to quality management in the chain (storage, transport, processing).

The selection of suitable production chains involves evaluation of the existing market and scope for potential new biobased markets. Projected increased industrial demand for bioethanol, and chemical building blocks for production of biobased polymers (Sanz Mirabal et al., 2013), is the driving motive for selection of target commodity products. The proven biobased chains from sugar (A1) and starch (A2) to bioethanol or to polylactic acid need to be compared for the feasibility in the Ukrainian setting of infrastructure and production efficiency or sustainability.

Selection of five value chains
Five promising or relevant biobased production chains have been identified, based on a long list of biomass crops and known residues (Table 9). They have an economic potential (bulk volume/high added value) or may illustrate the potential for local production and processing or export to EU markets. The process described in Chapter 3 to guide setting up of biobased production and delivery chains was executed resulting in different promising biobased production chains for Ukraine and export to the EU. Each of these chains are described in chapters 4.2 to 4.7

9 Here we focus on perennial biomass grasses such as Miscanthus, switchgrass and Reed Canary Grass.

Table 9. Long list of potential biomass supply in Ukraine based on the crops that currently are produced economically and competitively.

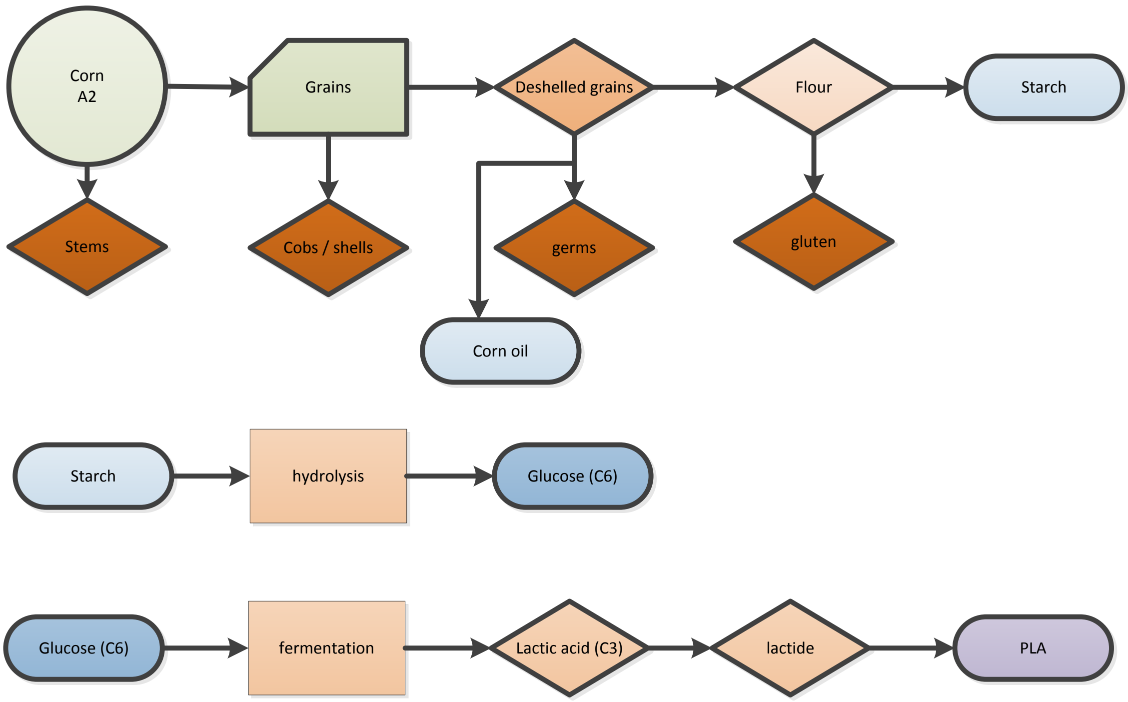
	Crop	Infrastructure	Economic	Sustainable	Logistics	Remarks
A1	Sugar beet	±	±	0	Campaign crop requires local processing	Potential high productivity
A2	Wheat	++	++	0	Existing	Competitive production
	Barley	+	++	0	Existing	Competitive production
	Maize	++	++	0	Existing	Competitive production
	Potatoes	±	-	0	Lack of storage. Relatively expensive	For local consumption
B	Coniferous wood (soft wood) residue	+	-	++	Potentially scattered	Residue availability uncertain
	Non-coniferous wood (hard wood) residue	+	-	++	Potentially scattered	Residue availability uncertain
	Straw	-	-	+/0	Low productivity leads to costly logistics	Residue availability uncertain
	Reed	-	-	++	Harvest cost uncertain	Sustainability high if executed well
	Grasses	-	-	+	Large potential needs to be developed	Large sustainable potential especially on marginal lands
C/D	Soybean	+	+	0	Existing	Competitive production
	Sunflower	++	++	0	Existing	Competitive production
	Rapeseed	+	+	0	Existing	Competitive production

4.2 Chain 1: Corn (Maize) to poly-lactic acid

Polylactic acid (PLA) is one of the largest biobased polymers currently on the market with a production volume of around 250 kton/year (Harmsen and Hackmann, 2012; Sanz Mirabal, 2013). It is produced by polymerisation of lactic acid, which is generally produced by fermentation from sugars directly or starch indirectly (see Fig. 19). Feedstocks for lactic acid production are sugar-rich and starch-rich biomass, such as: sugar cane, maize and tapioca (cassava). Lactic acid has a market volume of around 300-400 kton/year, with a market price of 1000-1200 €/ton (lactic acid factsheet cited by Harmsen and Hackmann, 2012). The raw material costs are the dominant economic factor in a PLA production plant (OECD 2013).
Lactic acid has the potential to grow considerably in terms of market volume (European Bioplastics, 2013). A significant increase in volume is projected for the years to come to 800 kton in 2020 (Sanz Mirabel 2013). Currently the main producers are based in the USA (Nature Works), Thailand (Purac/Corbion, The Netherlands) and China.

One attractive feature of lactic acid (PLA) is the high yield of fermentation from glucose and favourable LCA (Patel et al. 2003). Two molecules of lactic acid are formed from one molecule of glucose via glycolysis. In contrast to ethanol fermentation where two molecules of ethanol produce two molecules of CO_2, reducing the theoretical yield to 51%.

Figure 19. Chain 1. Illustrating the processing steps from maize/corn to polylactic acid (PLA).



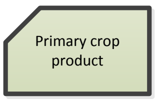
Maize (corn) is one of the most cost effective sources for production of starch, and is also used commercially (in the USA) for lactic acid production. Ukraine is a large and competitive producer of corn, a known glucose source for lactic acid production.

Table 10. SWOT analysis for corn from Ukraine for PLA production.

STRENGTH	**WEAKNESS**
■ Crop is productive and established in Ukraine, expansion is possible ■ Infrastructure and knowledge base available (corn industry) ■ Corn has high productivity ■ High yields may compensate ILUC	■ Cost is high compared to imports ■ Food competition and ILUC ■ Short harvest campaign makes processing relatively expensive ■ No established PLA fermentation plants
OPPORTUNITY	**THREAT**
■ Co-products (may add to income and reduce impact): stover and stems ■ Potential as a feedstock for fermentation industry and feedstock for chemical industry is huge! ■ Not just PLA ■ Multi-purpose is possible: food and fuel made in one plant.	■ Market access to EU may be limited ■ Second generation (lignocellulose based) lactic acid should have a better sustainability impact, especially if food competition and ILUC is considered ■ Local stimulation of biofuels may lead to competition for maize and higher prices

The use of biobased chemicals for production of biopolymers has the advantage of reduction of CO_2 emissions (Essel and Carus 2012). The main issues of the sustainability of the biopolymer production from food grade sources are related to land use and competition with food production. Compared to biofuels production, bioplastics show higher land use efficiency (Endres and Siebert-Rath, 2011). The current situation in Ukraine concerning land use efficiency shows that the potential for higher productivity and expansion of production is feasible. Corn is one of the top agricultural crops in Ukraine, and one of the most promising biomass feedstocks (Kalniskaya, 2013).

Corn production and processing is well established in Ukraine. Various options for corn production chains can be considered for Ukraine and The Netherlands:

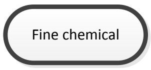


A – Exports from Ukraine of corn grains (shelled dent corn) for conversion in The Netherlands to PLA.

B – Wet milled and refined corn flour production in Ukraine and exports to The Netherlands.

C – Refined corn starch production in Ukraine and shipping to The Netherlands for hydrolysis and fermentation to lactic acid.

D – Hydrolysed corn starch production in Ukraine and shipment to The Netherlands for fermentation.



E – Production of lactic acid / lactide in Ukraine from corn sugar and export of lactide to the The Netherlands.

F – Production of polylactic acid (PLA) from corn based lactide in Ukraine, and shipment of PLA granules to the Netherlands for bioplastic polymer end-product manufacturing.

The current corn industries in Ukraine include the whole chain from grain to starch (C) and hydrolysis to glucose (D). The fermenting industries in Ukraine produce lactic acid on small scale, but so far do not produce lactic acid (E, F) for PLA production.

The use of field (stalks, corn cobs), and processing (seed shells, gluten) by-products from production appears to have only a low value currently in Ukraine. The field residues may be considered for 2^{nd} generation (lignocellulosic) uses. We compare chain A (exports from Ukraine of corn grains (shelled dent corn) for conversion in The Netherlands to PLA (polylactic acid) to option F (production of PLA from corn based lactide in Ukraine, and shipment of PLA granules to the Netherlands).

Table 11. Multi-criteria factor analysis of local (in Ukraine) conversion of corn to PLA (F) vs export of grain for conversion in the Netherlands (A). Note that this assessment is made based on a short review and expert judgement.

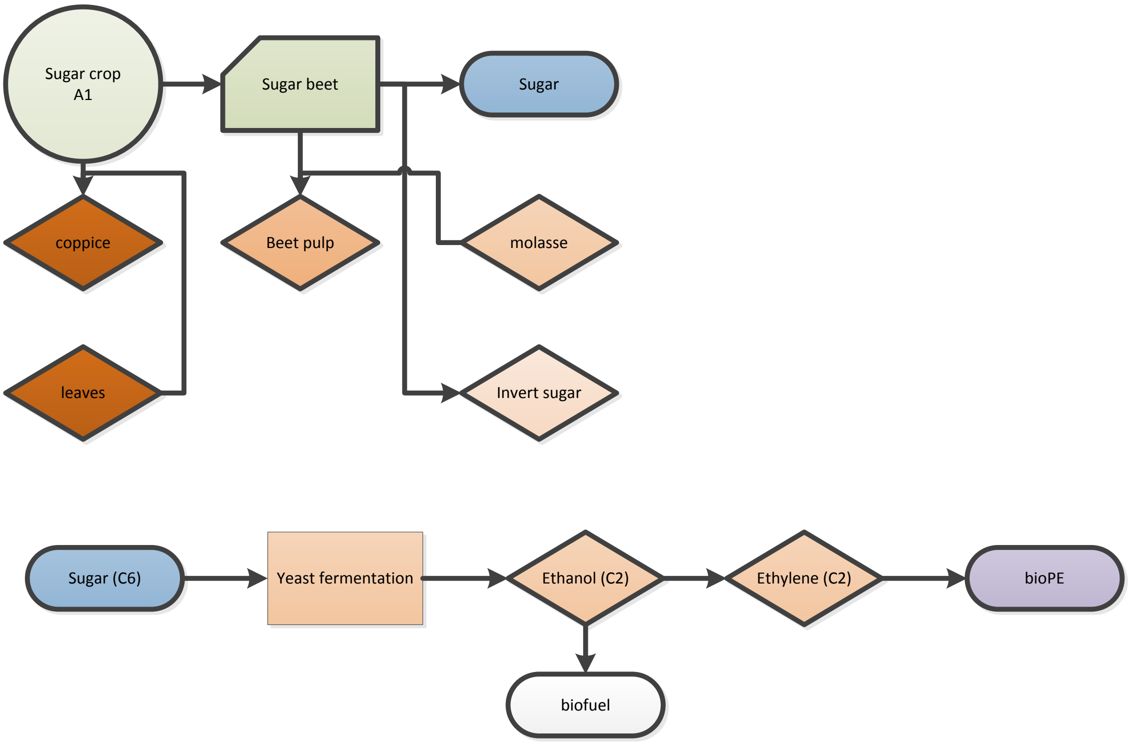
Factor	Ukraine	Netherlands/ Rotterdam	Explanation
Feedstock cost	5	2	Feedstock cost probably lower in Ukraine.
Security of supply of the feedstock	4	5	Security of supply is larger at the port due to possibility of sourcing from multiple locations
Infrastructure	4	5	Ukraine infrastructure is available for corn products but less for PLA production
Cost of operation	3	3	Taxes and labour may be lower in Ukraine. Energy may be more expensive.
Labour and expertise	4	3	Labour is cheaper in Ukraine but obtaining the right expertise is more likely in Rotterdam
Logistics	4	5	Infrastructure in Rotterdam is more developed and reliable.
Investment cost	3	4	Investment cost in new technology is large and the higher interest rate in Ukraine will be an issue. It seems likely that investment incentives /tax breaks are more available in The Netherlands
Tariffs	2	3	Tariffs on importing raw materials are generally lower than on finished materials.
By-product value	2	5	The value of by-products (seed shells, gluten) is likely to be better in The Netherlands due to well-developed fodder market
Regulation environment	2	5	Regulations and stimulation of these biobased activities are judged to be weak in Ukraine
Rule of law	1	5	Enforcing contracts and protection of intellectual property (in this area) is judged to be weak in Ukraine.
Sum	34	45	

Score: 1 is most negative, 5 is most positive.

From tables 10 and 11 it can be concluded that overall the siting of the PLA production plant in the corn supply and conversion chain seems to be more attractive in Rotterdam. Export of corn grains is for now the best option if Ukrainian suppliers are competitive. Production of PLA in Ukraine requires local investment in the technology, which could be extended from the existing corn production and processing infrastructure. Supplying a local market may be an option to kick-start such an industry. Ukrainian exports of PLA pellets for supplying EU bioplastics industries could become competitive.

4.3 Chain 2: Sugar beet to sugar to ethanol to polyethylene

Figure 20. Sugar beet chain to sugar production, ethanol and biopolyethylene



Sugar is the major feedstock for biobased plastics by fermentation processes. The EU sugar production and imports have been regulated in the past decades under the CAP (Common Agricultural Policy). Imports of industrial sugar into the EU is still under high imports duty, but this is proposed to be abandoned in 2015. Competition with sugar cane will be strong.

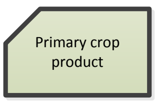
Sugar beet is not a commodity and transport of the unprocessed crop is not viable so conversion is needed into an intermediate product: sugar - ethanol and then to poly-ethylene.

Table 12. SWOT analysis for using sugar beet as a crop for ethanol and biobased products in Ukraine.

STRENGTH ■ Crop is potentially very productive ■ Knowledge base available (sugar beet) ■ Sugar beet has a good water use efficiency and salt / heat tolerance ■ High yields may compensate ILUC	**WEAKNESS** ■ Current production cost is high compared to other countries (Brazil?) ■ Food competition and ILUC may be an issue ■ Short harvest campaign makes processing relatively expensive and less flexible compared to starch crops
OPPORTUNITY ■ Co-products (may add to income and reduce impact): tops and fibre pulp ■ Potential as a feedstock for fermentation industry and feedstock for chemical industry is huge! ■ Not just ethanol but also other 'green chemicals'! ■ Double purpose is possible food and fuel made in one plant	**THREAT** ■ Market access to EU may (for now) be limited ■ Second generation (lignocellulose based) has better sustainability impact, especially if ILUC is considered ■ Starch crops are also an alternative for most applications (energy and chemicals) and often cheaper

Currently the sugar beet productivity in Ukraine is less competitive on the global sugar market. Alternatively the whole sugar beet (including the leaves?) can be converted as sugar rich feedstock for fermentation to ethanol. A logistical negative aspect is that the sugar beets are not produced and available for processing the whole year round, so annual campaigns with peaks of production in the last part of the year. (Frost storage effects?)

Sugar beet is a well-established crop in Ukraine, although the current processing capacity does not compete to produce sugar for the exports markets. The production of bio-PE from sugar is not existing in Ukraine. The options for sugar beet production and valorisation chains will be considered here for Ukraine and The Netherlands are:



A – No exports of sugar beets is feasible from Ukraine for conversion in The Netherlands to PLA.

B – Crude sugar beet molasse production in Ukraine and exports to The Netherlands for further refining and fermentation.

Intermediate commodity

C – Refined sugar production in Ukraine and shipping to The Netherlands for fermentation to ethanol.

Platform chemical

D – Ethanol production in Ukraine and shipment to The Netherlands for chemical conversion to ethylene / bio-polyethylene (BioPE).

Fine chemical

E – Production of ethylene in Ukraine from sugar and exports to the The Netherlands.

Biopolymer

F – Production of bio-polyethylene (Bio-PE) from sugar beet based ethylene in Ukraine and shipment of bio-PE granules to the Netherlands for bioplastic polymer end-product manufacturing.

As the transportation and exports of sugar beet (option A) is not economic feasible the potential of trade in its derived products (molasses, B or sugar, C) need evaluation. As current sugar commodity prices does not allow competitive imports in EU of sugar from Ukraine the remaining options to be considered are the production of bioethanol (D) or even ethylene (E)and bio-polyethylene (F). Currently, the Ukrainian infrastructure for PE production is fully petrochemical based.

The price for production of bio-PE from sugar beet in Europe is estimated at €2000/t (Sanz Mirabel 2013), which is double the price for bio-PE from sugar cane in Brazil.

Favourable for sugar crops are the efficiency of land use per ton as well as the avoided non-renewable energy use (NREU) (Bos et al. 2012). Sugar yield is highest in EU of more than 10 t / ha per year for sugar beet.

Figure 21. Land use ha/ton for biobased polymer production (Bos et al. 2012)

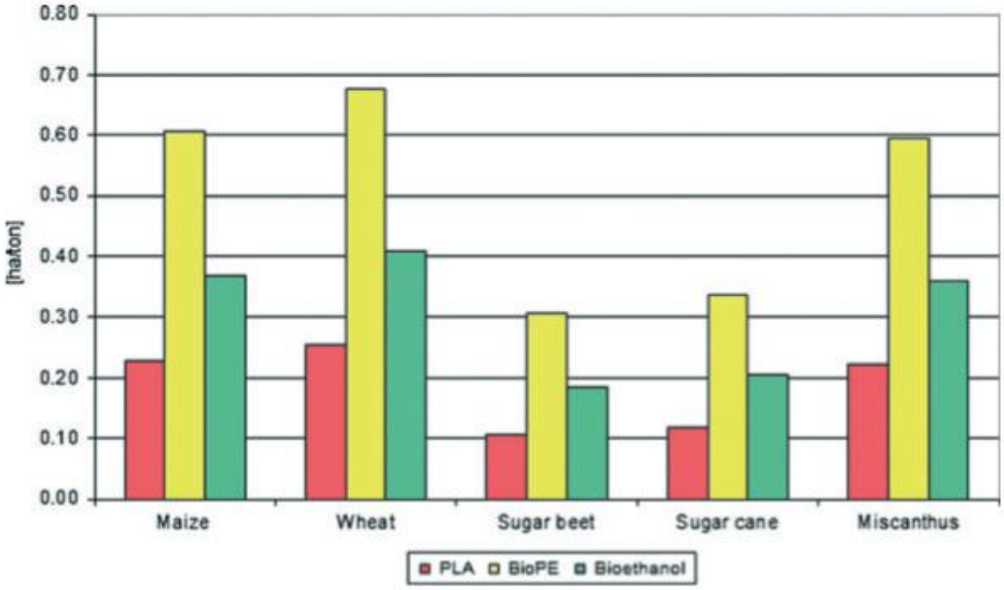


Table 13. Multi-criteria factor analysis of local (in Ukraine) conversion of sugar beet to ethanol and Bio-PE (F) vs export of ethanol and production of ethanol to Bio-PE overseas (the Netherlands) (D).

Factor	Ukraine	Netherlands/ Rotterdam	Explanation
Feedstock cost	3	2	Feedstock cost (sugar beet ethanol) is expected to be slightly lower in Ukraine
Security of supply of the feedstock	2	5	Security of supply is larger at the port due to possibility of sourcing (ethanol) from other locations
Infrastructure	3	4	In Ukraine part of the infrastructure is available although not efficiently linked
Cost of operation	3	2	Overall the cost of operation may be lower in Ukraine though energy cost is uncertain.
Labour and expertise	3	3	Labour is cheaper in Ukraine but obtaining the right expertise is more likely in The Netherlands
Logistics	2	4	Infrastructure in Ukraine less developed
Investment cost	4	3	Investment cost in new technology is large. It seems likely that investment incentives /tax breaks are more available in The Netherlands
Tariffs	2	2	Tariffs on ethanol in EU are

			relevant have favourable conditions?.
By-product value	2	4	Residues are released in Ukraine and of low value
Regulation environment	2	5	Regulations and stimulation of these biobased activities are judged to be weak in Ukraine
Rule of law	2	5	Enforcing contracts and protection of intellectual property (in this area) is judged to be weak in Ukraine.
Sum	28	39	

Score: 1 is most negative, 5 is most positive.

Conclusion: beet ethanol is not the most competitive option but may become interesting due to high productivity potential, as shown in NW Europe, and local conversion options into intermediary feedstocks (ethanol). A thorough analysis of yield potential in Ukraine and actions to reach this potential is needed. Further analysis is needed to make choices.

Currently the bioethanol production (for biofuel) is insignificant in Ukraine and mainly based on sugar beet and a little corn feedstock. In Ukraine the construction of a bioethanol (99% pure) facility for 30 kt /yr started in January 2014 that will be based on grain fermentation (corn, wheat, rye, barley and sorghum) (by Zarya-Bio LLC Development Company) at a projected cost of 41 M€ (Biofuels International news).

4.4 Chain 3&4: Lignocellulose to 2nd generation bio-ethanol or biofuel for renewable energy

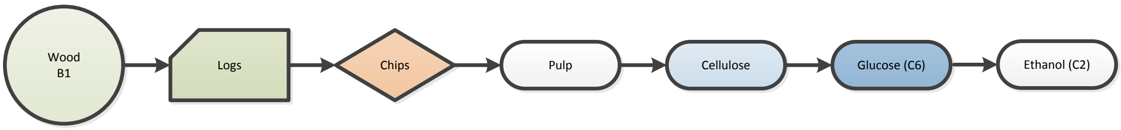
Ukraine has a large underutilised potential to produce or mobilise lignocellulosic biomass. As discussed by Kalnitskaya, (2013) up to 100 Mtons of crop residues is produced which have few other uses than use as soil amendment or are sometimes also burned in the field (de Jamblinne, 2013). On top of this, natural reed stands can be harvested and perennial biomass crops can be grown to supply low cost lignocellulosic material (Pellets for Power project, 2013). Wood residues are also available through in much smaller quantities than herbaceous lignocellulosic biomass. Approximately, 2.1 to 2.5 million m^3 of wood biomass (approximately 1000 kton dry matter) is unused (Kalnitskaya, 2013) while the potential availability of straw or reed is more than 10 fold higher.
Intermediate lignocellulosic products or commodities are traded such as logs, chips and wood pellets. Moreover, lignocellulosic derived products can become real commodities such as herbaceous pellets, pyrolysis oil, briquettes and torrefied pellets. These can be converted into platform chemicals or fuels such as 2nd generation biofuels and syngas. Production of second generation fuels/and chemicals from lignocellulose is currently being developed and first large scale plants are being established (Fig 22).

Figure 22. Demoplants for bioenergy in Europe *(ref. IEA Task 39: http://demoplants.bioenergy2020.eu/projects/mapindex)*.

4.4.1 *2nd generation biofuels*

Production of second generation bio-fuels from waste and crop residues as non-food lignocellulosic feedstock is receiving much attention world-wide. The use of these fuels can be counted double towards fulfilling the renewable transport fuel target in many EU countries. This should give these fuels potentially a relatively attractive market price.

Figure 23. Lignocellulose chain for 2nd generation bioethanol production



Lignocellulose resources in Ukraine are diverse and may be produced competitively. Wood products such as round wood, timber and fuel wood are exported (Table 9). Agricultural residues such as wheat straw, corn stems and cobs, sunflower husks etc. (Table 8) are rich in lignocellulose and potentially suitable as feedstock for biorefinery processes. Similarly, energy crops like perennial biomass grasses (Miscanthus, reed canary grass, switchgrass, sorghum, or reed and typha) could be sources of lignocellulosic feedstock. Low cost lignocellulose may also be produced from short rotation willow coppice, which has been introduced to Ukraine in recent years.
These feedstocks could be produced on the large areas of land that are available at low cost or on currently non-productive and unused land.
Overall, Ukraine appears to have excellent conditions for production of low cost lignocellulosic feedstocks.

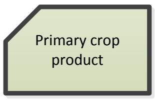
Table 14. SWOT of lignocellulosic (herbaceous) biomass production and delivery for export in Ukraine

STRENGTH	**WEAKNESS**
■ Large amounts of (crop) residues available ■ Large amounts of land available at low cost ■ Pelletizing plants do exist ■ Agricultural knowledge base is available ■ Vast areas of underutilized reed lands	■ Low productivity makes using crop residues less attractive (less available per ha leading to higher cost per ton) ■ Transport infrastructure is often lacking and relatively costly ■ Contracting is difficult in Ukraine ■ Lignocellulosic (not wood) pellets are not a commodity ■ Financing facilities is relatively costly and often unavailable
OPPORTUNITY	**THREAT**
■ New biomass crops have been introduced and tested (willow coppice and switchgrass) ■ Herbaceous pellets can become a commodity making trade much more attractive	■ Local demand for biomass pellets may be more competitive than the price paid for export ■ Herbaceous pellets are not a commodity (yet)

Design of the supply chain and siting of conversion facilities to make second generation ethanol from lignocellulosic biomass requires comparison of siting a

plant in Ukraine near the biomass production location vs converting the biomass into pellets which are exported for conversion into ethanol in a EU harbour (e.g. Rotterdam). We use the list of factors determining the attractiveness of investing in conversion infrastructure from chapter 3. The score is made based a short review and expert judgement. A commercial lignocellulose to ethanol plant is expected to require at least 1.000 kton DM biomass input per year to produce approximately 150.000 m^3 ethanol.
When such a bioethanol plant in Rotterdam is established the feedstock choices for imports are summarized below and include logs (A), wood chips or pellets (B), refined pulp (C) or hydrolysed biomass (D).

Options for 2nd generation lignocellulose biofuel production chains for Ukraine and The Netherlands:

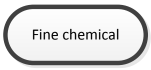


A – Exports from Ukraine of logs for biorefining in The Netherlands to biofuel

B – Wood chips or straw pellets production in Ukraine and exports to The Netherlands for further refining and fermentation (to ethanol).

C – Refined pulp or cellulose production in Ukraine and shipping to The Netherlands for fermentation to ethanol.

D – Hydrolysed cellulose production (glucose, C6) in Ukraine and shipment to The Netherlands for fermentative conversion to ethanol.



E – Production of ethanol in Ukraine by 2nd generation lignocellulose biorefinery and exports to The Netherlands.

The transportation costs for bulky biomass is restricting the transportation distances of for example straw bales and wood logs (option A). Therefore, products with higher energy density are preferred for export trade. Wood chips or pellets (option B) require relatively low technological investments compared to biorefineries for cellulose pulp (C) or glucose production (D). Pulping facilities to produce cellulose pulps are available in Ukraine, although they do not compete on the global pulp markets. Currently there is no such biorefinery facility operational in Ukraine to produce hydrolysed lignocellulose (D). Transportation and storage of these sugar syrups may require significant concentration to avoid transportation of water and preliminary fermentation. Based on these observations it can be concluded that the most feasible choice is option B as long as the local infrastructure in Ukraine is not established for large scale 2nd generation bioethanol production.

Table 15. Multi-criteria factor analysis of local (in Ukraine) conversion of lignocellulosic biomass to ethanol in Ukraine (E) vs export of biomass pellets and production of (second generation) ethanol overseas (the Netherlands) (B).

Factor	Ukraine	Netherlands/ Rotterdam	Explanation
Feedstock cost	4	2	Feedstock cost should clearly be lower in Ukraine
Security of supply of the feedstock	3	5	Security of supply should be larger at the port due to possibility of sourcing from other locations
Infrastructure	3	4	In Ukraine it may be possible to find part of the infrastructure but this is more extensive in Rotterdam
Cost of operation	3	2	The price of feedstock lignocellulose should be lower in Ukraine. Energy and cost of expertise are uncertain in Ukraine
Labour and expertise	3	3	Labour is cheaper in Ukraine but obtaining the right expertise is more likely in Rotterdam
Logistics	2	4	Infrastructure in Ukraine is less developed
Investment cost	4	3	Investment cost in new technology is large and the higher interest rate in Ukraine is a negative factor. It seems likely that investment incentives /tax breaks are more available in The Netherlands
Tariffs	2	4	Tariffs on importing raw materials are generally lower than on finished materials (ethanol).
By-product value	2	5	The value of by-products (lignin, CO_2) is likely to be better in Rotterdam
Regulation environment	2	5	Regulations and stimulation of these biobased activities are not in place (yet) in Ukraine.
Rule of law	2	5	Enforcing contracts and protection of intellectual property (in this area) is judged to be weak in Ukraine.
Sum	30	42	

Score: 1 is most negative, 5 is most positive.

From table 15 it can be concluded that overall the siting of the lignocellulose to ethanol conversion plant in the biomass supply and conversion chain seems to be most attractive in Rotterdam, when wood chips or pellets can be purchased competitively from Ukrainian suppliers.

4.4.2 *Lignocellulose pyrolysis*

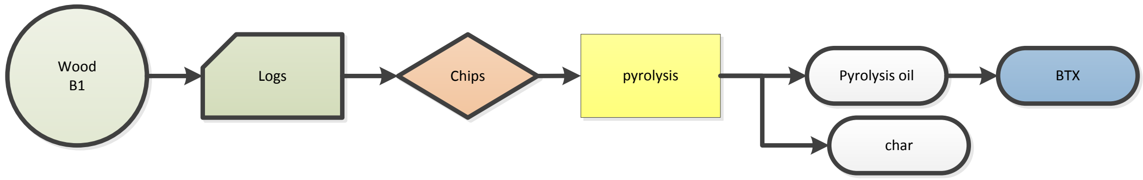


Fig .24 Lignocellulose chain for pyrolysis oil and BTX production

Lignocellulosic biomass of different origin may be used for the thermochemical production of pyrolysis oil or bio-oil (2.5.1) and char (Fig.24). The char commonly is used for process heat. The pyrolysis oil or biocrude is a heterogeneous mixture of biomass decomposition products composed of many organic compounds including organic acids, oxygenated hydrocarbons (alcohols, ketones), and aromatic compounds. It is suitable as a substitute for low grade industrial diesel oil. Further refining with suitable catalysts is yielding monomeric phenols (BTX benzene, toluene and xylene).

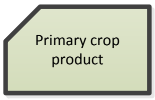
The SWOT analysis of the lignocellulose feedstock supply is similar to the SWOT for 2nd generation biofuels production (Table 14). The availability of pyrolysis technology in Ukraine is to our knowledge not operational. In the Netherlands patented technology for bio-oil production has been developed and a full plant is under construction (BTL-BTG, Enschede, 2014).

Table 16. SWOT of lignocellulosic (herbaceous) biomass production in Ukraine for pyrolysis and export

STRENGTH	**WEAKNESS**
▪ Large amounts of forestry products and (crop) residues available ▪ Large amounts of land available at low cost ▪ Agricultural knowledge base is available ▪ Vast areas of underutilized reed lands	▪ Low productivity makes using crop residues less attractive (less available per ha leading to higher cost per ton) ▪ No pyrolysis plants are operational ▪ Transport infrastructure is often lacking and relatively costly ▪ Contracting is difficult in Ukraine ▪ Financing facilities is relatively costly and often unavailable

OPPORTUNITY	THREAT
■ Pyrolysis oil can become a commodity making trade much more attractive ■ Transfer of know-how for instalment of local pyrolysis technology	■ Local demand for pyrolysis oil may be more competitive than the price paid for export ■ Pyrolysis oil is not a commodity (yet)

Evaluation of the options for lignocellulose bio-oil production chains for Ukraine and The Netherlands include:



A – Exports from Ukraine of logs for pyrolysis in The Netherlands to bio-oil and BTX.

B – Wood chips or straw pellets production in Ukraine and exports to The Netherlands for further thermochemical conversion.

C – Pyrolysis in Ukraine and shipping of bio-oil to The Netherlands for use as fuel or chemical refining to BTX.

D – Production of refined pyrolysis oil (BTX) in Ukraine and shipment to The Netherlands for use as platform chemical.

The major advantage of pyrolysis process is that the bulky biomass with low energy density is not transported, but a crude liquid oil with higher energy density (~20 GJ/m^3). So obviously the most advantageous option would be the instalment of a pyrolysis plant near the biomass production site (option C). The bio-oil could be used locally as liquid energy carrier or exported for further refining of the crude bio-oil into phenolic chemicals (BTX). The bio-oil refining can be performed in a centralized chemical plant, analogous to petrochemical refineries.

Table 17. Multi-criteria factor analysis of production of refined pyrolysis oil (BTX) in Ukraine and shipment to The Netherlands for use as platform chemical (D) vs Pyrolysis oil production in Ukraine and shipping of bio-oil to The Netherlands for use as fuel or refining to BTX (C).

Factor	Ukraine	Netherlands / Rotterdam	Explanation
Feedstock cost	4	2	Feedstock cost should clearly be lower in Ukraine
Security of supply of the feedstock	3	4	Security of supply should be larger at the port due to possibility of sourcing from other locations
Infrastructure	3	3	In Ukraine it may be possible to find part of the infrastructure (unused refineries) but adapting it to the specific demand may be difficult
Cost of operation	3	3	Uncertain though energy cost and efficiency may be problematic in Ukraine
Labour and expertise	3	3	Labour is cheaper in Ukraine but obtaining the right expertise is more likely in Rotterdam
Logistics	2	4	Logistical infrastructure in Ukraine less developed and seems relatively costly
Investment cost	4	3	Investment cost in new technology is large and the higher interest rate will be. It seems likely that investment incentives /tax breaks are more available in The Netherlands
Tariffs	2	4	Tariffs on importing raw materials are generally lower than on finished materials.
By-product value	3	4	May not be very relevant in this case but should be better in Rotterdam
Regulation environment	2	4	Production of biobased chemicals is not a policy issue in Ukraine (yet) and unlikely to receive incentives as is the case in the EU/The Netherlands
Rule of law	2	5	Enforcing contracts and protection of intellectual property (in this area) is judged to be weak in Ukraine.
Sum	31	39	

Score: 1 is most negative, 5 is most positive.

The production of pyrolysis oil is one of the main options for converting lignocellulosic materials into a form that is easily stored and transported over long distances. Pyrolysis oil has many potential uses, both as a fuel and as a starting point for production of chemicals. The production of chemicals (BTX) is still judged to be more favourable in the Netherlands mainly due to more stable and secure conditions (regulations, rule of law, security of supply, etc.)

4.5 Chain 5: Oil crop to oleo-chemicals

4.5.1 Sunflower

Sunflower oil production in Ukraine is most prominently established. Ukraine is the world leader in sunflower seed production. Sunflower oil refining yields several by-products besides the high valued food grade oil with high polyunsaturated fatty acids. Most prominent are phosphatides, sterols, lecitin, tocopherol (vitamin E), carotenoids. Currently the seed hulls or husks are used for burning (process heat) or converted to pellets and briquettes. The press cake finds its major outlet in animal feed. The sunflower heads and stems are commonly wasted.

Figure 25. Sunflower seeds to vegetable oil and biodiesel and oleo chemicals.

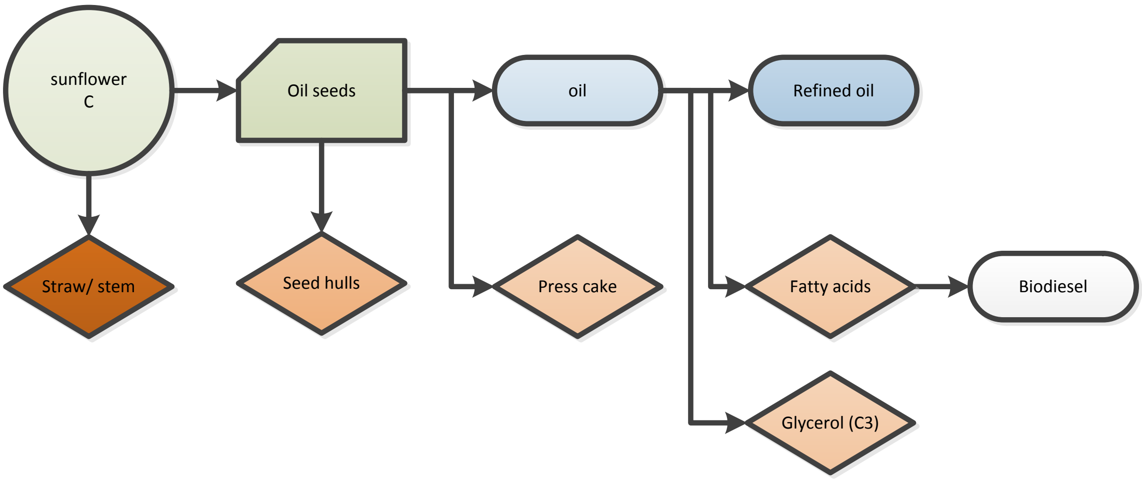
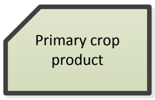


Table 18. SWOT analysis of sunflower as a biobased feedstock.

STRENGTH ■ Established crop in Ukraine ■ Land for additional oil crop is available ■ Conversion processing infrastructure available	**WEAKNESS** ■ Contracting difficult in Ukraine ■ Food competition and iLUC is relevant
OPPORTUNITY ■ Demand for oleo chemicals increasing world wide	**THREAT** ■ ILUC and food security issues

The various options for sunflower production chains for Ukraine and The Netherlands are:

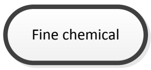


A – Exports from Ukraine of sunflower seeds (dehusked) for refining in The Netherlands to oleochemicals.

B – Sunflower oil expelling in Ukraine and exports of crude oil to The Netherlands for refining.

C – Refined sunflower oil production in Ukraine and shipping to The Netherlands for biodiesel or oleochemical production.

D – Sunflower based oleochemicals, (glycerol, and fatty acid) production in Ukraine and shipment to The Netherlands for conversion.



E – Production of biodiesel in Ukraine from sunflower oil and exports of the biofuel to The Netherlands.

F – Production from sunflower in Ukraine of glycerol derived chemical products (epichlorhydrin, acrylic acid or propylene glycol) and oleochemicals (e.g. epoxidized oil, ozonized) to components of bio-polyesters or polyurethanes and shipment of biochemicals or biopolymers to the Netherlands for bioplastic polymer end-product manufacturing.

The infrastructure for sunflower oil production is well established in Ukraine. Vegetable oil is a commodity that is traded worldwide and sunflower oil is a major export product from Ukraine. The production of non-food products (bio-diesel and oleochemicals) from food-grade vegetable oils is often criticised (increasing food prices and sustainability issues) and the biodiesel industry is facing severe competition from other renewable fuels and lower costs feedstocks (non-edible plant oils, recycled oil). The current global biodiesel production is below 28.500 million litres and is expected to grow to 40.000 million litres in 2022 (OECD-FAO Agricultural outlook 2013-2022)[10]. EU imports of biodiesel amounts currently 2.400 million litres, which is 17% of the consumption, while forecasts for imports 2022 are expected to increase only slightly.

Ukraine is currently producing ca 200 million litres of biodiesel for own consumption, and no exports are reported. The infrastructure to produce biodiesel

10 http://stats.oecd.org/viewhtml.aspx?QueryId=48169&vh=0000&vf=0&l&il=&lang=en

in Ukraine is available (option E), although competitive exports to EU is not realized.

Table 19. Multi-criteria factor analysis of local (in Ukraine) conversion of sunflower oil to biodiesel vs export of sunflower oil and production of biodiesel in the Netherlands.

Factor	Ukraine	Netherlands/ Rotterdam	Explanation
Feedstock cost	4	2	Feedstock is clearly be lower in Ukraine
Security of supply of the feedstock	3	4	Security of supply should be larger at the port due to possibility of sourcing from other locations
Infrastructure	4	4	In Ukraine the infrastructure is available
Cost of operation	3	2	The price of feedstock should be lower in Ukraine close to the production location
Labour and expertise	4	3	Labour is cheaper in Ukraine
Logistics	3	4	Logistics of biodiesel from Ukraine not yet available but expected to be rel. easy implemented.
Investment cost	3	4	large conversion plants are available in the Netherlands. It seems likely that investment incentives /tax breaks are more available in The Netherlands
Tariffs	4	4	Depends on trade agreements. Tariffs for importing vegetable oil are generally lower than for finished products (biodiesel).
By-product value	3	5	The value of by-products (glycerol, e.a) is likely to be better in Rotterdam
Regulation environment	2	4	The biofuel market is uncertain everywhere. The likelihood of receiving incentives is better in EU than in Ukraine.
Rule of law	2	5	Enforcing contracts and protection of intellectual property (in this area) is judged to be weak in Ukraine.
Sum	35	41	

Score: 1 is most negative, 5 is most positive.

Overall it is now more attractive to import oils and convert them to biodiesel in the EU (Rotterdam). A positive change in policies and tariffs and especially investment security can change this.

4.6 Conclusions

5 potential biobased trade chains from Ukraine to the EU/The Netherlands were assessed using the tools described above (see chapter 4). Based on previous studies and expert judgement the production of (basic) feedstocks was judged favourably in Ukraine for established crops. Sugar beet and lignocellulose (straw, energy crops) was assessed still to be unattractive, but having a large potential if productivity and associated infrastructure and necessary policies could be improved. Siting of the main (generally costly) conversion step in a production chain from biomass to final product was compared between Ukraine and the Netherlands. Factors associated with cost were judged to be generally advantageous for Ukraine. At the same time the cost and availability of financing was judged to be less favourable. Siting in the Netherlands was judged to score better on security of supply, infrastructure, logistics, tariffs, by-product value and regulation environment and rule of law.

References

- Bos, H.L., Meesters. K.P.H., Conijn, S.G., Corré. W.J. and Patel, M.K.: "Accounting for the constrained availability of land: a comparison of bio-based ethanol, polyethylene, and PLA with regard to non-renewable energy use and land use". In: Biofuels, Bioprod. Bioref. 6:146–158 (2012).
- Carrez, D., L. Dammer and M. Carus – Policies impacting bioplastics market development. Ch 5 in: Market study on biobased polymers in the World. Capacities, production and applications: Status Quo and Trends towards 2020. Nova Institute 2013
- Darlington, T., D. Kahlbaum, D. O'Connor. S. Mueller, 2013 - Land Use Change Greenhouse Gas Emissions of European Biofuel Policies Utilizing the Global Trade Analysis Project (GTAP) Model. EBB report. http://www.ebb-eu.org/studiesreports/GTAP%20Report%20ILUC%20Aug%2030%202013%20Final.pdf
- EC. 2009. DIRECTIVE 2009/28/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC.
- Elbersen. W and M. Kulyk. 2013. Switchgrass Ukraine. Overview of switchgrass research and guidelines. FBR report for the Pellets for Power project. Sustainable Biomass Import Program – NL Agency – Netherlands.
- Endres, H-J. and A. Siebert-Raths (2011) State of knowledge. In Engineering Biopolymers Markets, Manufacturing, Properties and Applications, Carl Hanser, pp. 27–28. http://edepot.wur.nl/7725
- Essel, R. & M. Carus (2012): Meta-analysis of life cycle assessments for bio-based polymers in the production of Proganic®. nova-Institut, Hürth.
- European Bioplastics
- http://en.european-bioplastics.org/market/market-development/productioncapacity/
- Harmsen Paulien en Martijn Hackmann. 2012. Green building blocks for biobased plastics. Biobased processes and market development. Published in the series "Green raw materials". Wageningen, The Netherlands.
- IEA Bioenergy – Task 42 Biorefinery. 2013. Biofuel-driven Biorefineries. Aselection of the most promising Biorefinery concepts to produce large volumes of road transport biofuels by 2025. February 2013.
- IFPRI 2011 – D. Laborde - Assessing the land use change consequences of European biofuel policies.(http://www.ifpri.org/sites/default/files/publications/biofuelsreportec2011.pdf)
- Jamblinne de P. 2013. Market potential of Ukrainian herbaceous biomass. Analyzing market obstacles and promoting business strategies. Pellets for Power project. Tuzetka S.A.
- Kalnitskaya, Julia. 2013. Business Opportunities in the Biobased Economy in Ukraine. ssessment of opportunities for collaboration on Biobased Economy in Ukraine and the Netherlands. Study by ProMarketing Ukraine

for the Biorenewables Business Platform (BBP), supported by the Dutch Ministry of Economic Affairs (EZ).
- Michael Kaylen, M., D. L. Van Dyne, Y-S. Choi, M. Blase. Economic feasibility of producing ethanol from lignocellulosic feedstocks. Bioresource Technology 72 (2000) 19-32
- Köbbing et al., Mires and Peat 13 (2013) 1-14
- Meesters, Koen P.H., Jan E.G. van Dam, Harriëtte L. Bos - Protocol monitoring materiaalstromen biobased economie (ISBN 978094-6173-702-1) 2014, http://www.rvo.nl/sites/default/files/2014/03/Protocol%20monitoring%20BBE.pdf
- NL Agency. 2011. How to select a biomass certification scheme? By Partners for Innovation.OECD (2013), "Policies for Bioplastics in the Context of a Bioeconomy", OECD Science, Technology and Industry Policy Papers, No. 10, OECD Publishing. http://dx.doi.org/10.1787/5k3xpf9rrw6d-en
- Patel, M., Bastioli, C., Marini, L. & E. Würdinger: Life-cycle assessment of bio-based polymers and natural fibres. In: Biopolymers (2003) Vol. 10: 409-452
- Pellets for Power project, 2013. http://www.switchgrass.nl/en/show/Pellets-for-Power.htm.
- Philp, J.C., R.J. Ritchie, and J.E.M. Allan (2013) Biobased chemicals: the convergence of green chemistry with industrial biotechnology. Trends in Biotechnology 31 (4), 219-222.
- Sanders, J.P.M., E. Annevelink & D. van der Hoeven, 2009. The development of biocommodities and the role of North West European ports in biomassa chains. Biofpr, May/June isssue, 395-409.
- Sanz Mirabal, Adriana, Lena Scholz and Michael Carus eds – Market study on biobased polymers in the World. Capacities, production and applications: Status Quo and Trends towards 2020. Nova Institute 2013
- Sluis van der, T., R. Poppens, P. Kraisvitnii, O. J.P. Lesschen, M. Galytska and H.W. Elbersen. 2013. Reed Harvesting from wetlands for bioenergy. Technical aspects, sustainability and economic viability of reed harvesting in Ukraine. Pellets for Power project. Alterra report 2460.
- Van Dam, J.E.G., B. de Klerk-Engels, P.C. Struik, R. Rabbinge – "Securing renewable resources supplies for changing market demands in a biobased economy"- Ind. Crops and Prod 21 (2005) 129-144.
- Van Dam, Jinke, Sergio Ugarte, Sjors van Iersel. 2012. Selecting a biomass certification system – a benchmark on level of assurance, costs and benefits. March 2012. A study carried out in the framework of the Netherlands Programmes Sustainable Biomass for NL Agency.
- Van Gelder, J.W., K. Kammeraat, H. Kroes. 2008 Soy consumption for feed and fuel in the European Union. Profundo, The Netherlands [Friends of the Earth]
- Van Muiswinkel. 1979. 'Handel, markt en beurs'. Elsevier Nederland. B.V.
- Vellema, Sietze, Harriette Bos, and Jan E.G. van Dam – Perspective for bio-based industrialisation in developing countries. Chapter 15 In: The Biobased Economy, biofuels, materials and chemicals in the post-oil era [Langeveld, Sander and Meeusen eds. Earth scan 2009, ISBN 9781844077700]

Appendix 1. List of biomass buyers, and technology and knowledge providers in The Netherlands

Name	Website	Activities
Abengoa	http://www.abengoabioenergy.com	Biofuel production first and second generation for Eu markets
Akzo Nobel	www.akzonobel.com	Chemical company using biobased feedstocks
Argos Energies	www.argosenergies.com	Biofuels and storage
Avantium	www.avantium.com	Development and commercialisation of new biobased plastics and chemicals
BGP engineers –	www.bgengineers.nl	Engineering,
BiomassBrokers	http://www.biomassbrokers.eu/	Brokerage seriveces for biomass, pellets, chips, biodiesel feedstocks, etc
Biomassresearch	www.biomassresearch.eu	Biobased research and consulting
BioMCN	http://www.biomcn.eu/	Production of biomethanol from glycerin and other feedstocks using second generation technology
BTG	http://www.btgworld.com/en/	Consultancy services, RTD, engineering, project development, Pyrolysis, gasification, combustion, biorefinery
CE-Delft	http://www.ce.nl/	Environmental consultancy,
Cirmac International	http://www.cirmac.com/	Biogas upgrading technology
Corbion Purac	www.purac.com	Biobased chemicals, biobased building blocks
DSM	www.dsm.com	Chemical company, second generation technology procider,
Ecofys	http://www.ecofys.com/	Energy and sustainability consultancy
Eneco	www.eneco.nl	energy producer from biomass
Energon	www.energon.nl	Biomass trade, biomass pellets, pellet production,
EON	www.eon.nl	Biomass co-firing and bioenergy production

Europees Massagoed-Overslagbedrijf (EMO) B.V. –	www.emo.nl	transhipment terminal
FMO	https://www.fmo.nl/	Development bank, financing, private equity,
GDF Suez Nederland	http://www.gdfsuez.nl/	Biomass co-firing and bioenergy production
Geveke	www.geveke-klimaattechniek.nl	Engineering,
GF Verdo	http://www.gfverdo.eu	Biomass trade, biomass pellets, pellet production,
Groningen Seaports	www.groningen-seaports.com	Logistics
Grontmij Energie		consulting,
Host	http://www.host.nl/en/	Supplier of bioenergy systems, complete systems, anaerobic digesters, wood-fired boilers, combined heat and power plants, fluidised-bed gasifiers.
Kara energy systems -	www.kara.nl	Engineering,
Koole	www.koole.com	Storage and transport
Ludan Renewable Energy	http://www.ludan-group.com/LudanGroup.php	Engineering
NatureWorks	www.natureworksllc.com	Bioplastics, biobased chemicals,
Neste oil	http://www.nesteoil.com/	Biodiesel production and technology provider
Newfoss	http://www.newfoss.com/	Biomass biorefinery
Nidera	www.nidera.com	International producer, trader, marketer, bioenergy products and services
Paques	www.en.paques.nl	Anaerobic digestion technologies, water treatment technology,
Partners for innovation	http://www.partnersforinnovation.com/	Innovation consultants
PBE. The Netherlands Bio-Energy Association, NL-BEA	http://www.platformbioenergie.nl/nl/	Dutch association that promotes the interests of Dutch companies involved in the biomass for energy chain.
Port of Amsterdam -	www.amsterdamports.nl	Logistics
Port of Rotterdam -	www.portofrotterdam.com	Logistics
Procede	http://www.procede.nl	Engineering, thermal conversion, combustion, consultancy, project development,
Rabobank	http://www.rabobank.nl	banking, financing, agri and biobased expertise

RWE/Essent	https://www.rwe.com/web/cms/nl/1754916/rwe-generation-se/innovatie/biomassa/	Energy production, buyer of biomass
Sabic	www.sabic.nl	Chemicals
SEnS Capital	http://www.senscapital.nl/	Developer, financier of renewable energy projects.
Sparkling Projects		
Sunoil Biodiesel -	www.sunoil-biodiesel.com	Biodiesel production
Sustec	www.sustec.nl	Biomass and waste conversionm technologies, anaerobic digestion,
Synbra -	www.synbra.com	Plastics, Bioplastics
Teijin -	www.teijinaramid.com	Biobased plastics and chemicals
Topell	www.topellenergy.com	Torrefaction technology provider,
Torrcoal	www.torrcoal.com	Torrefaction technology provider,
Total -	Total - www.totalrefiningchemicals.com	Biobased plastics and chemicals
VOPAK	www.vopak.nl	Tank storage provider
Wellinkceasar	www.wellinkcaesar.nl	Engineering,
Zeeland Seaports (Vlissingen and Terneuzen)	www.zeelandseaports.com	Logistics