IfBB
Institute for Bioplastics
and Biocomposites

Biopolymers
facts and statistics

2016

**HOCHSCHULE
HANNOVER**
UNIVERSITY OF
APPLIED SCIENCES
AND ARTS
–
*Fakultät II
Maschinenbau und
Bioverfahrenstechnik*

1 Introduction and background

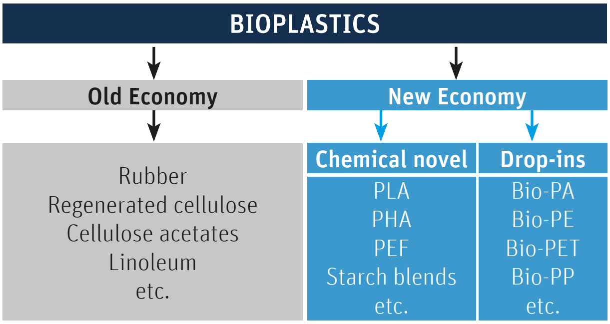
The IfBB – Institute for Bioplastics and Biocomposites is a research institute within the Hochschule Hannover, University of Applied Sciences and Arts, which was established in 2011 to respond to the growing need for expert knowledge in the area of bioplastics. With its practice-oriented research and its collaboration with industrial partners, the IfBB is able to shore up the market for bioplastics and, in addition, foster unbiased public awareness and understanding of the topic.

As an independent research-led expert institution for bioplastics, the IfBB is willing to share its expertise, research findings and data with any interested party via the Internet, online and offline publications or at fairs and conferences. In carrying on these efforts, substantial information regarding market trends, processes and resource needs for bioplastics is being presented here in a concise format, in addition to the more detailed and comprehensive publication "Engineering Biopolymers"[1].

One of our main concerns is to furnish a more rational basis for discussing bioplastics and use fact-based arguments in the public discourse. Furthermore, "Biopolymers – facts and statistics" aims to provide specific, qualified answers easily and quickly for decisionmakers in particular from public administration and the industrial sector. Therefore, this publication is made up like a set of rules and standards and largely foregoes textual detail. It offers extensive market-relevant and technical facts presented in graphs and charts, which means that the information is much easier to grasp. The reader can expect comparative market figures for various materials, regions, applications, process routes, agricultural land use or resource consumption, production capacities, geographic distribution, etc.

In recent years, many new types of bioplastics have emerged and innovative polymer materials are pushing on the plastics market. All the same, bioplastics by no means constitute a completely new class of materials but rather one that has been rediscovered from among the large group of plastic materials.

[1] Endres, Hans-Josef; Siebert-Raths, Andrea: Engineering Biopolymers. Markets, Manufacturing, Properties and Applications. München 2011



The first polymer materials fashioned by human hands were all based on modified natural materials (e.g., casein, gelatine, shellac, celluloid, cellophane, linoleum, rubber, etc.). That means they were bio-based since petrochemical materials were not yet available at that time. Ever since the middle of the 20th century, these early bio-based plastics, with a few exceptions (cellulose and rubber-based materials), have almost been fully replaced by petrochemical materials.

By now, due to ecological concerns, limited petrochemical resources and sometimes new property profiles, bioplastics have undergone a remarkable revival and are taken more and more into focus by the general public, politics, the industrial sector and in particular the research community.

Of particular interest today are new types of bioplastics, which were developed in the past 30 years. The publication presented here refers to the socalled "New Economy" bioplastics as opposed to "Old Economy" bioplastics which indicate earlier materials developed before petrochemical bioplastics emerged, yet still exist on the market today (e.g., rubber, cellophane, viscose, celluloid, cellulose acetate, linoleum).

"New Economy" bioplastics divide up into two main groups. On the one hand, there are those biopolymers which have a new chemical structure virtually unknown in connection with plastics until a few years ago (e.g. new bio-based polyesters such as PLA), on the other hand socalled "drop-ins", with the same chemical structure yet bio-based. The most prominent drop-ins at this point are bio-based PET (Bio-PET) and bio-based polyethylene (Bio-PE).

2

Process routes

Process routes depict the manufacturing steps from the raw material to the finished product, specifying the individual process steps, intermediate products, and input-output streams. So they serve as a guide for all considerations and calculations around the production of bioplastics, in particular also with regard to their resource consumption.

The following methodical approach was chosen to establish the process routes:

The mass flows were first calculated using a molar method based on the chemical process, with the introduction of known rates and conversion factors. The routes so established were confirmed with polymer manufacturers and the industry. In so far as no loss rates due to the chemical processes or the process stages were included, the calculations were made basically assuming no losses. The mass flows show feedstock and resulting land requirements in ha for the production of one metric ton of bioplastics. Feedstock requirements were calculated for the use of different crops. Yields of the most important crops and renewable raw materials used for feedstock are shown in the chart below.

Please note that the yields in this context refer to the crop itself, which contains the raw material for processing, and not to the harvested whole plant.

For calculating water use data, information on water use for different raw materials originally collected by the 'Water Footprint Network' has been used. It is based on FAOSTAT crop definitions (Food and Agriculture Organization of UN) which are also used for land use calculations. This means, water use is only available from "seed to market place". Only water, such as rainwater, irrigation and to somewhat extent process water to clean agricultural products, e.g., used/needed to grow the whole plant is included here. On the other side the water use for the processing like polymerization is neglected. This is part of an ongoing research, but this first simplified approach gives a good indication and delivers first data to the issue of water use of bioplastics.

Feedstock	Crop	Raw material	Global mean yield (Crop)	Average content of raw material	Resulting amount (raw material)
Calculations			->	x ->	=
Sugar cane	Sugar cane (without cane tops)	fermt. Sugar	70 t/ha	13 %	9.1 t sugar/ha
Sugar beet	Beet (without leaves)	fermt. Sugar	52 t/ha	16 %	8.32 t sugar/ha
Corn	Maize kernel	Starch	6.5 t/ha	70 %	4.55 t starch/ha
Potatoes	Potato tuber	Starch	21 t/ha	18 %	3.78 t starch/ha
Wheat	Wheat grains	Starch	3.5 t/ha	46 %	1.60 t starch/ha
Wood	Standing timber, residual wood	Cellulose	1.64 t atro/ha	40 %	0.66 t cellulose/ ha
Castor oil plant	Castor bean	Castor oil	1 t seeds/ha (given one harvest per year)	40 %	0.4 t oil/ha (given one harvest per year)

Glossary

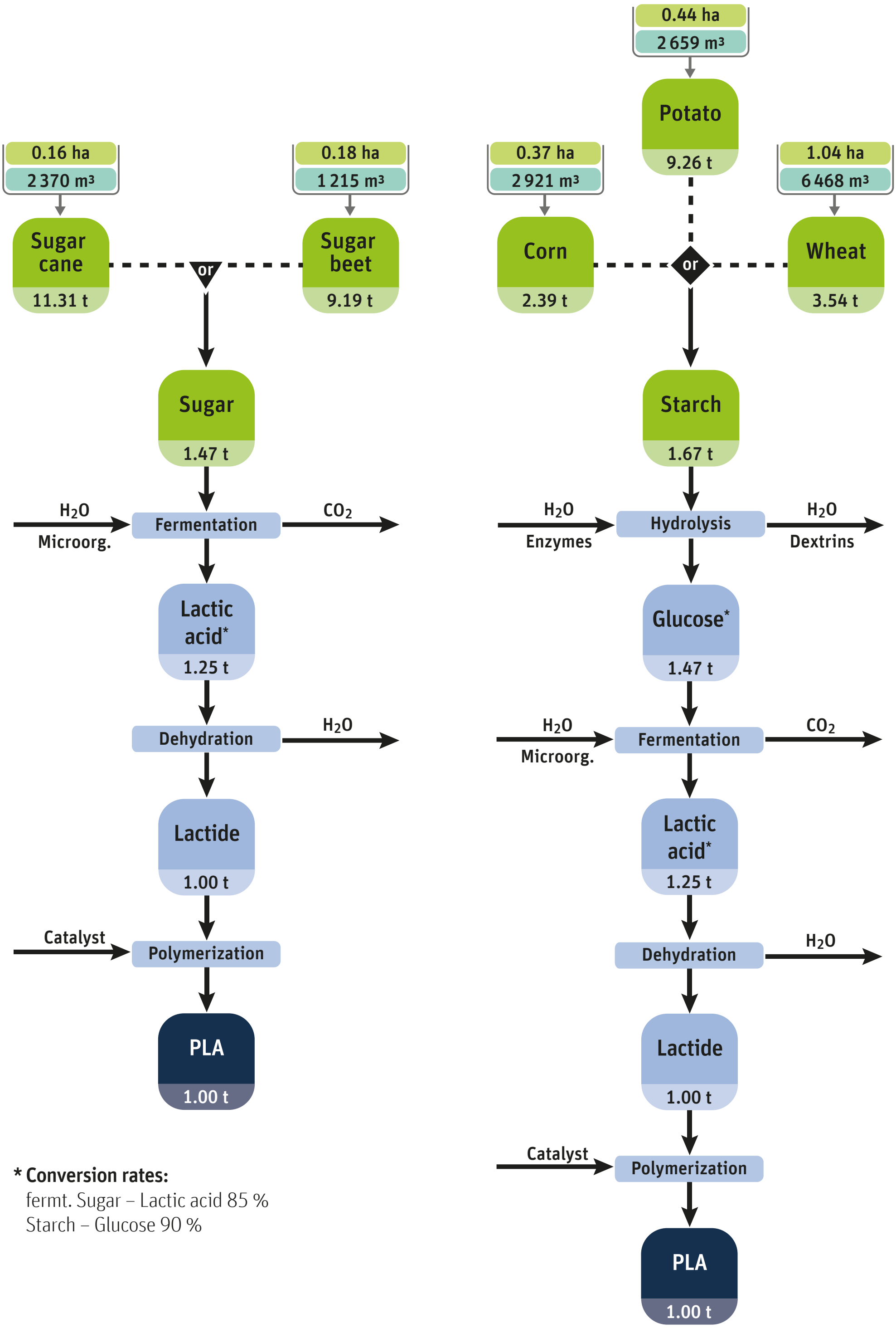
Abbreviations used:

atro = bone dry
bb = bio-based
fermt. = fermentable
SCA = Succinic acid
BDO = Butanediol
PDO = Propanediol
PTA = Purified terephthalic acid
MEG = Monoethylene glycol
PMDA = Pentamethylene diamine
TMDA = Tetramethylene diamine
HMDA = Hexamethylene diamine
DMDA = Decamethylene diamine
red coloured ressources have a petro-based origin

A large amount of additional information is also available at: **www.ifbb-hannover.de**.

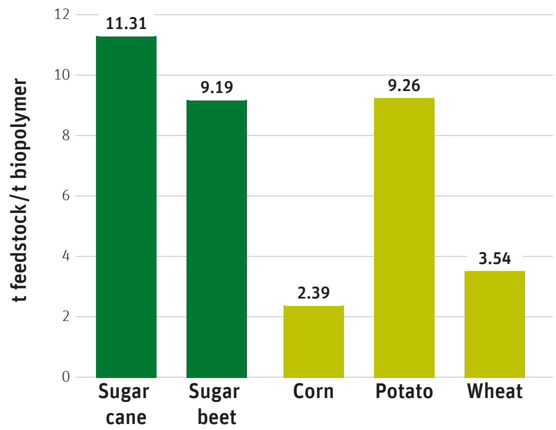
2.1 Bio-based polyesters

2.1.1 Polylactic acid (PLA)

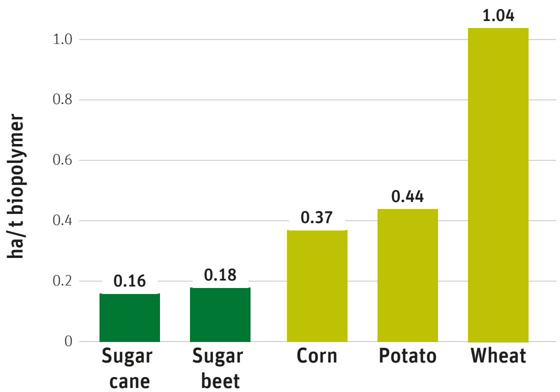


*** Conversion rates:**
fermt. Sugar – Lactic acid 85 %
Starch – Glucose 90 %

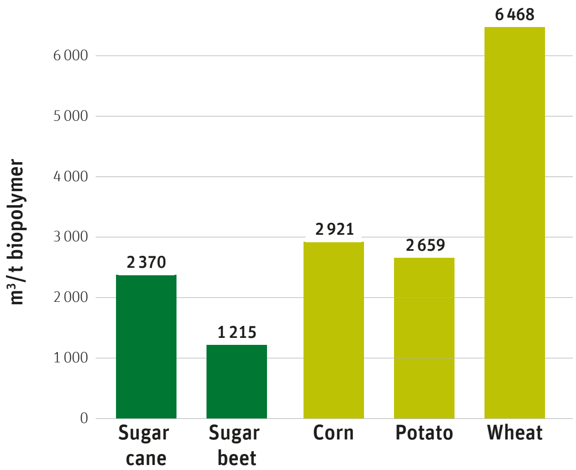
PLA – Feedstock requirements in t (different feedstocks)



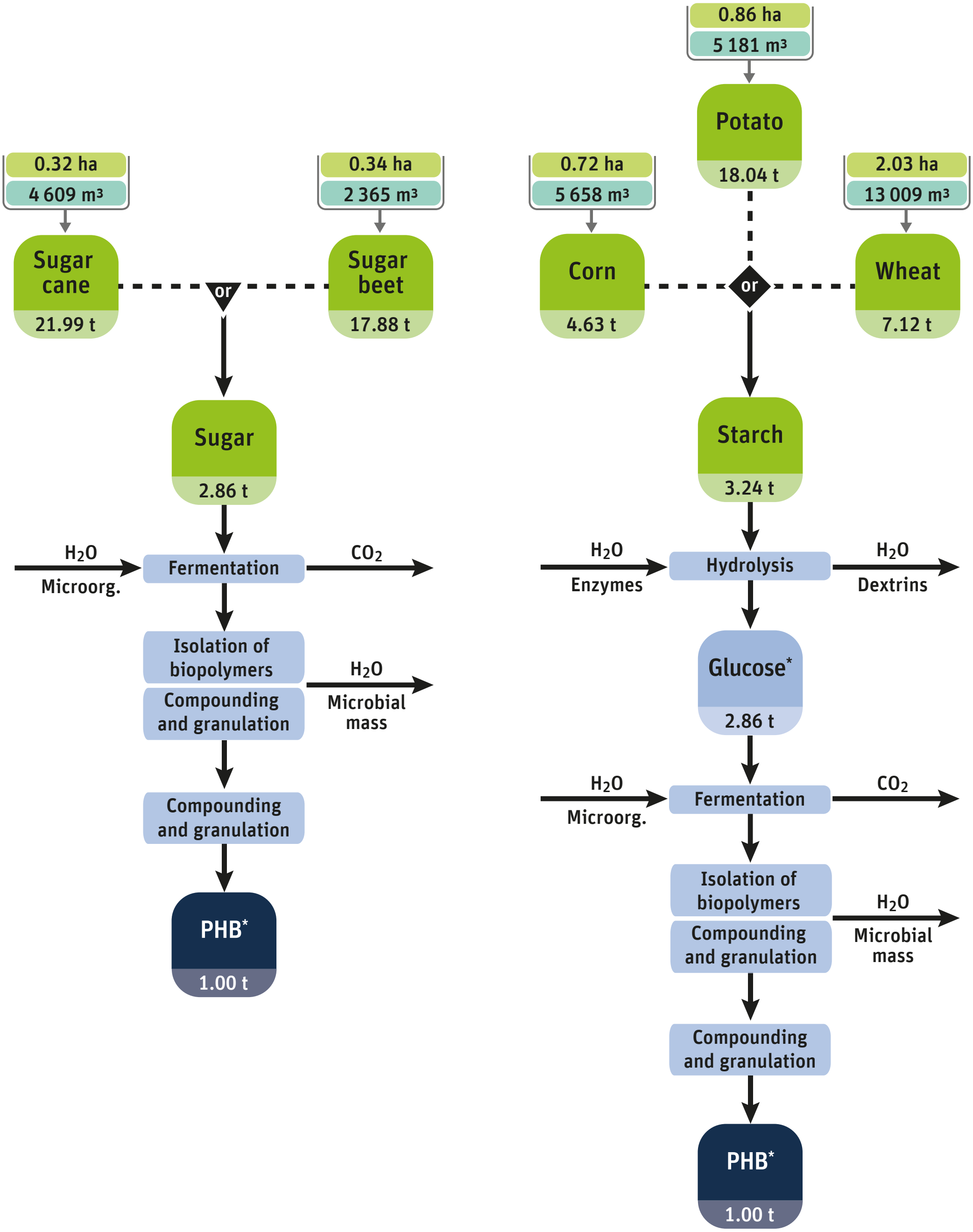
PLA – Land use in ha (different feedstocks)



PLA – Water use in m^3 (different feedstocks)

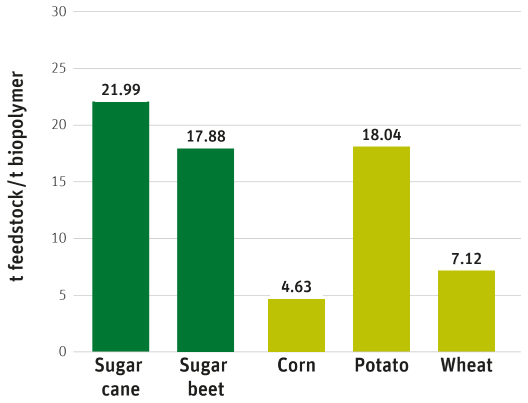


2.1.2 Polyhydroxybutyrat (PHB)

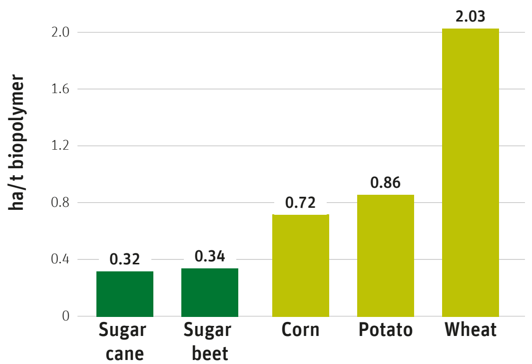


*** Conversion rates:**
Starch – Glucose 90 %
fermt. Sugar – PHB 35 %

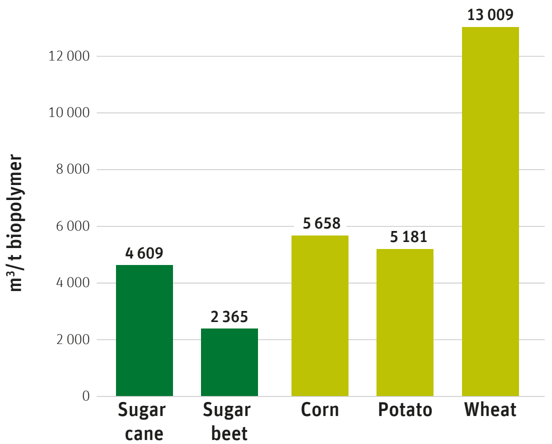
PHB – Feedstock requirements in t (different feedstocks)



PHB – Land use in ha (different feedstocks)

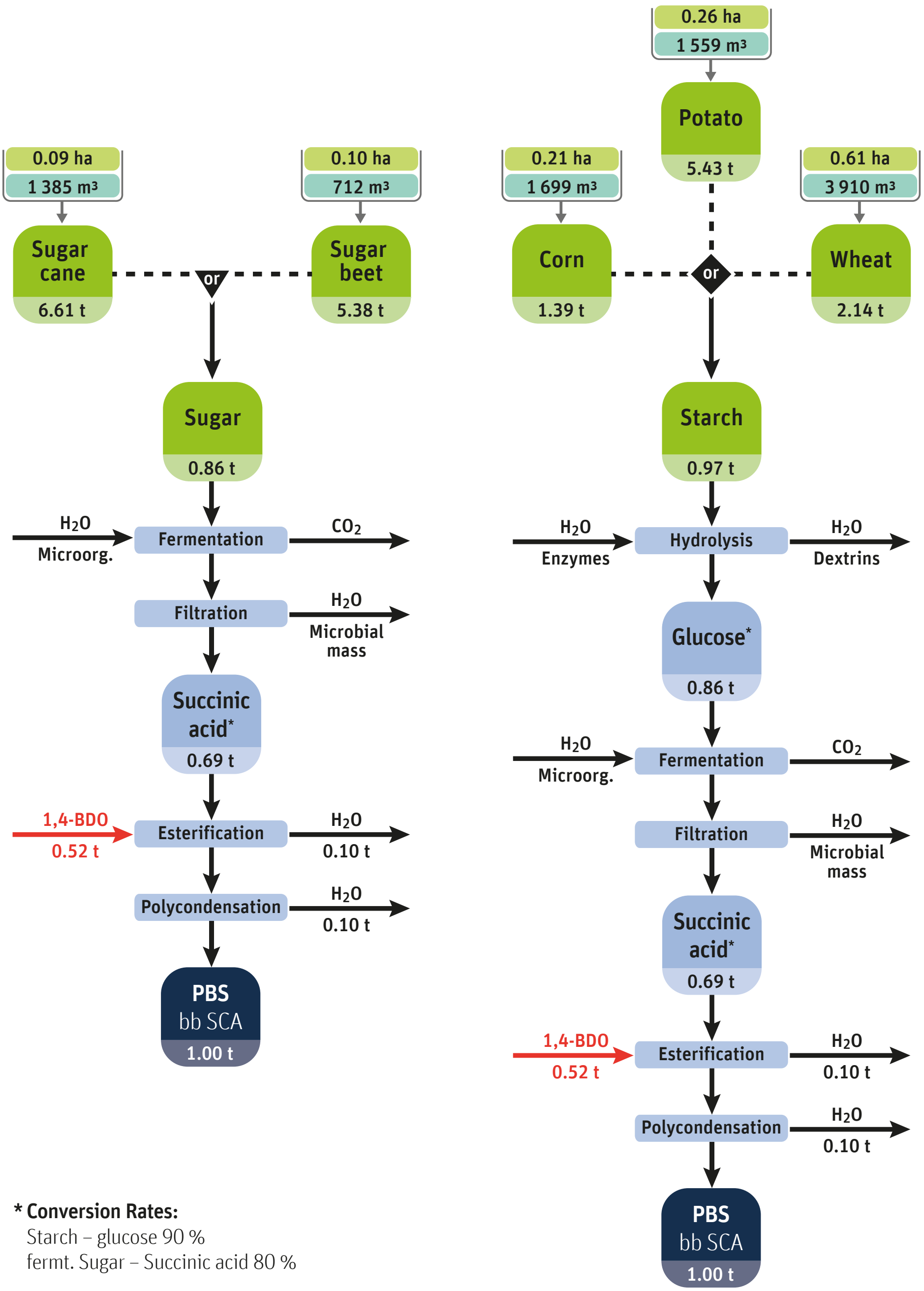


PHB – Water use in m^3 (different feedstocks)



2.1.3 Polybutylene succinate (PBS)

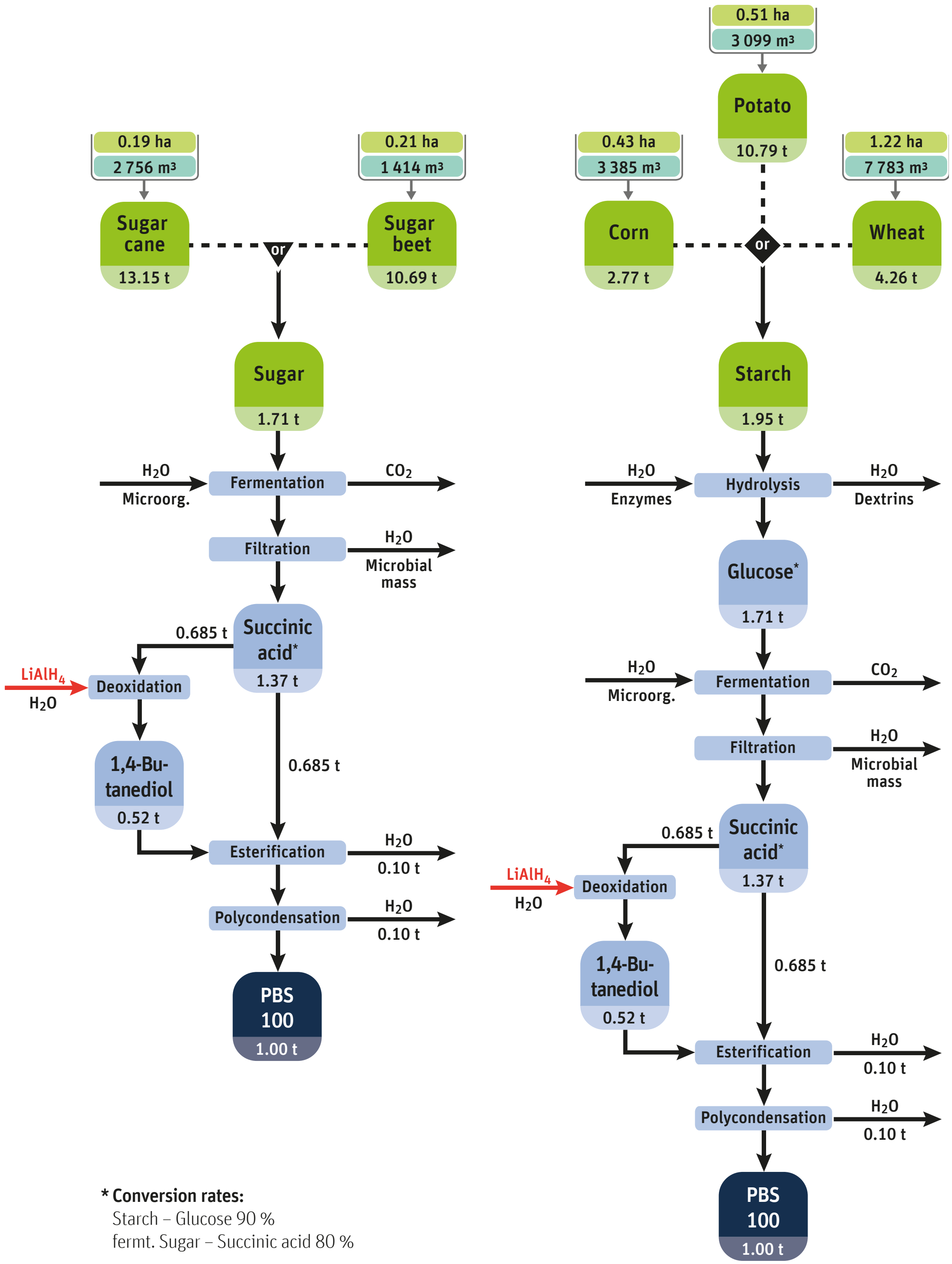
with bio-based succinic acid (PBS bb SCA)



*** Conversion Rates:**
Starch – glucose 90 %
fermt. Sugar – Succinic acid 80 %

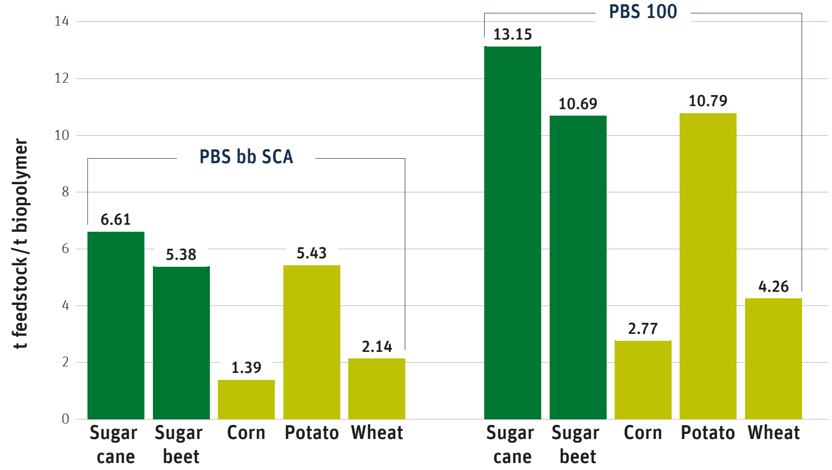
2.1.3 Polybutylene succinate (PBS)

100 % bio-based (PBS 100)

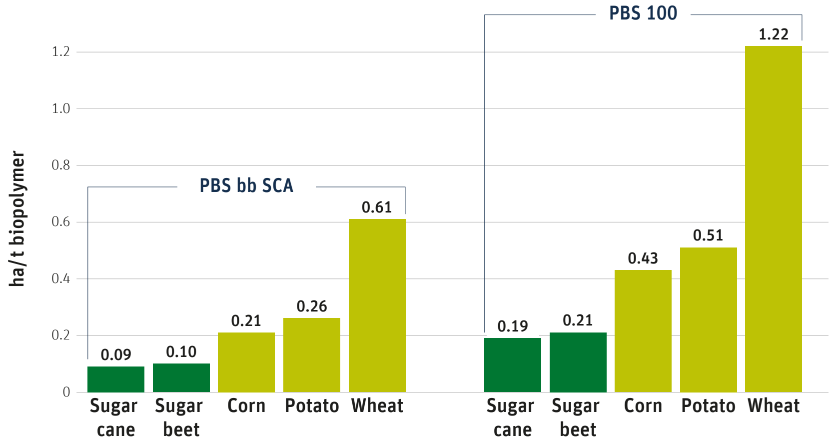


*** Conversion rates:**
Starch – Glucose 90 %
fermt. Sugar – Succinic acid 80 %

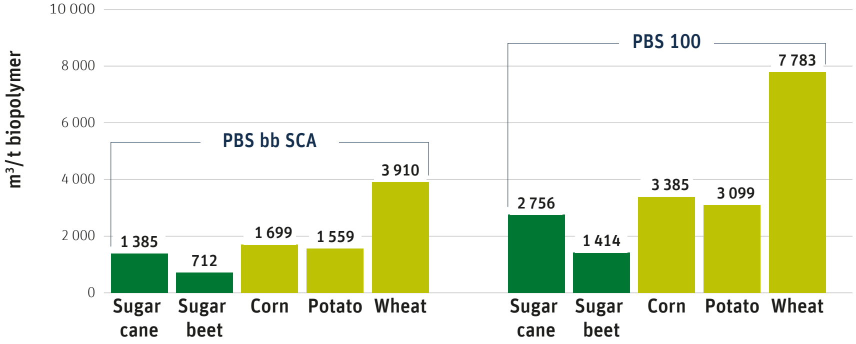
PBS variations – Feedstock requirements in t (different feedstocks)



PBS variations – Land use in ha (different feedstocks)

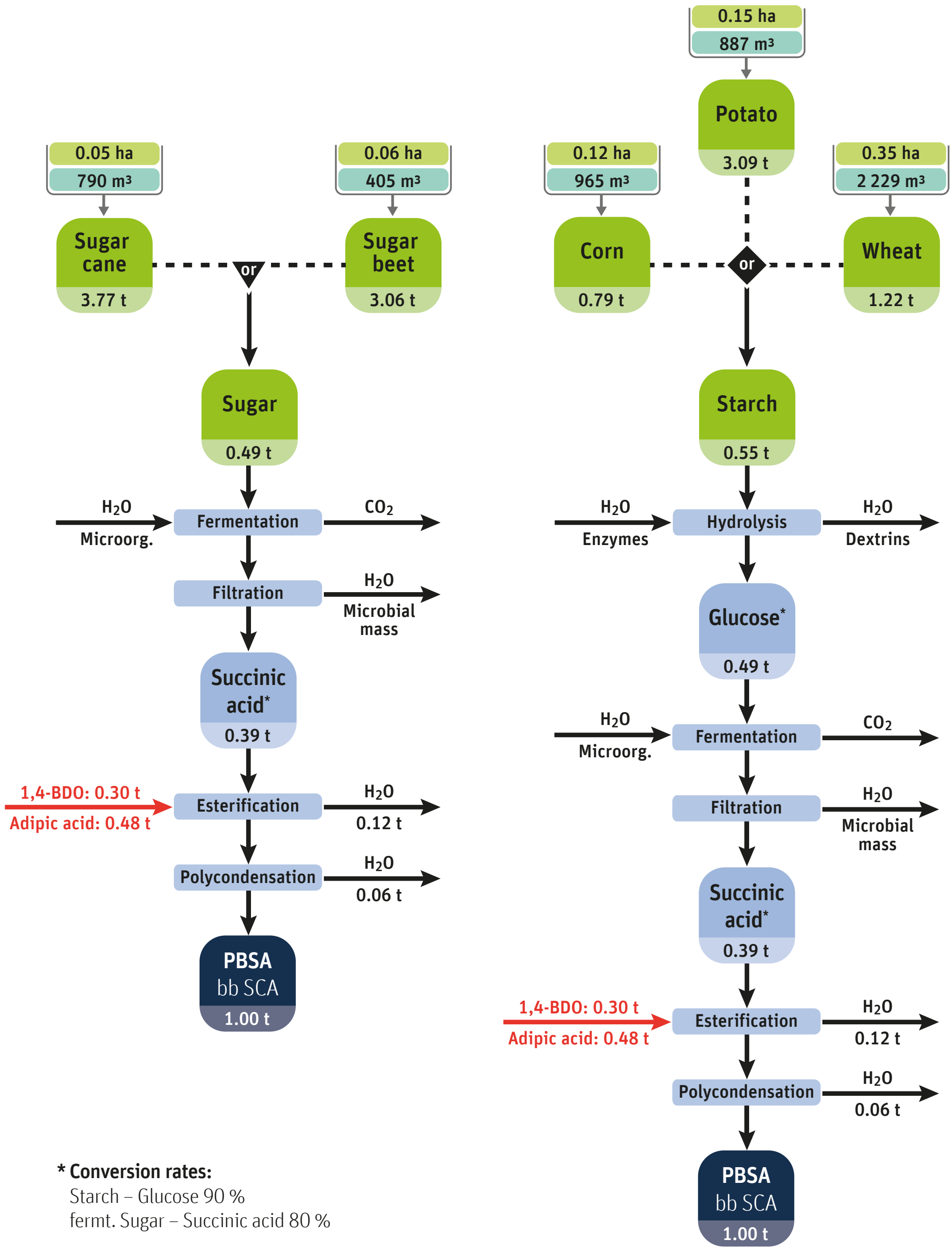


PBS variations – Water use in m^3 (different feedstocks)



2.1.4 Polybutylene succinate adipate (PBSA)

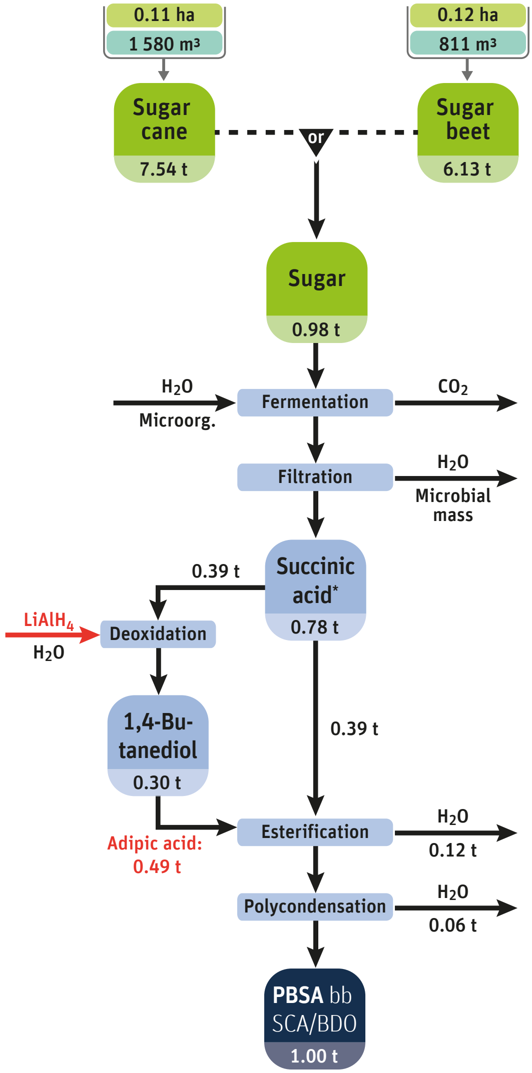
with bio-based succinic acid (PBSA bb SCA)

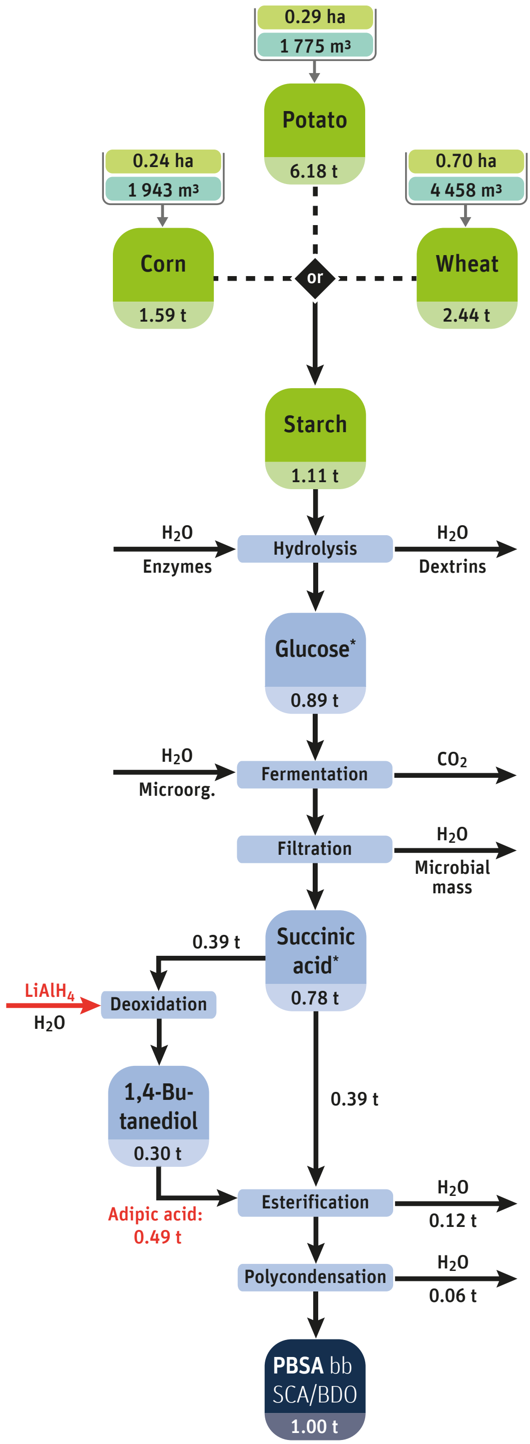


*** Conversion rates:**
Starch – Glucose 90 %
fermt. Sugar – Succinic acid 80 %

2.1.4 Polybutylene succinate adipate (PBSA)

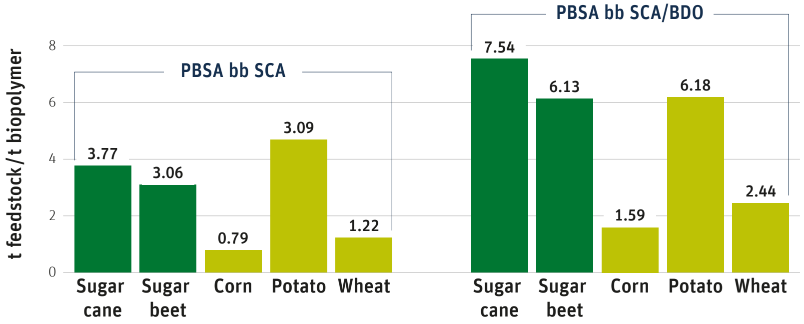
with bio-based succinic acid and 1,4-butanediol (PBSA bb SCA/BDO)



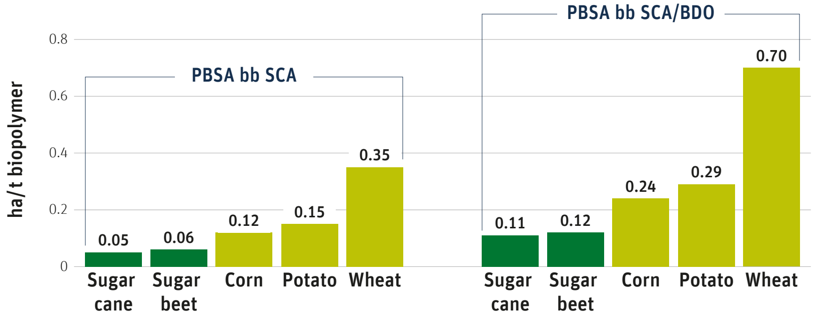


*** Conversion rates:**
Starch – Glucose 90 %
fermt. Sugar – Succinic acid 80 %

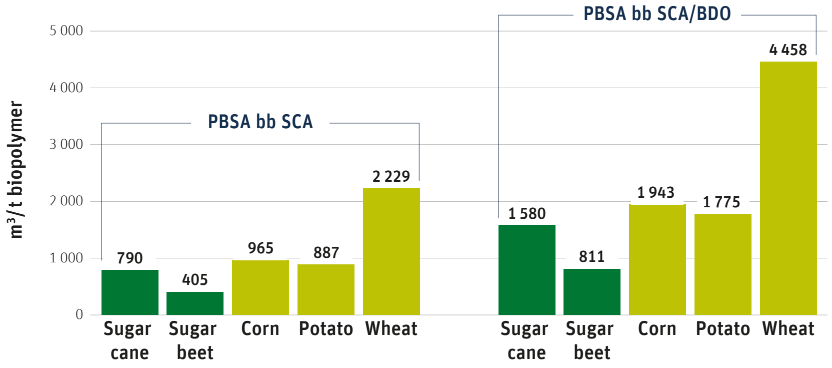
PBSA variations – Feedstock requirements in t (different feedstocks)



PBSA variations – Land use in ha (different feedstocks)

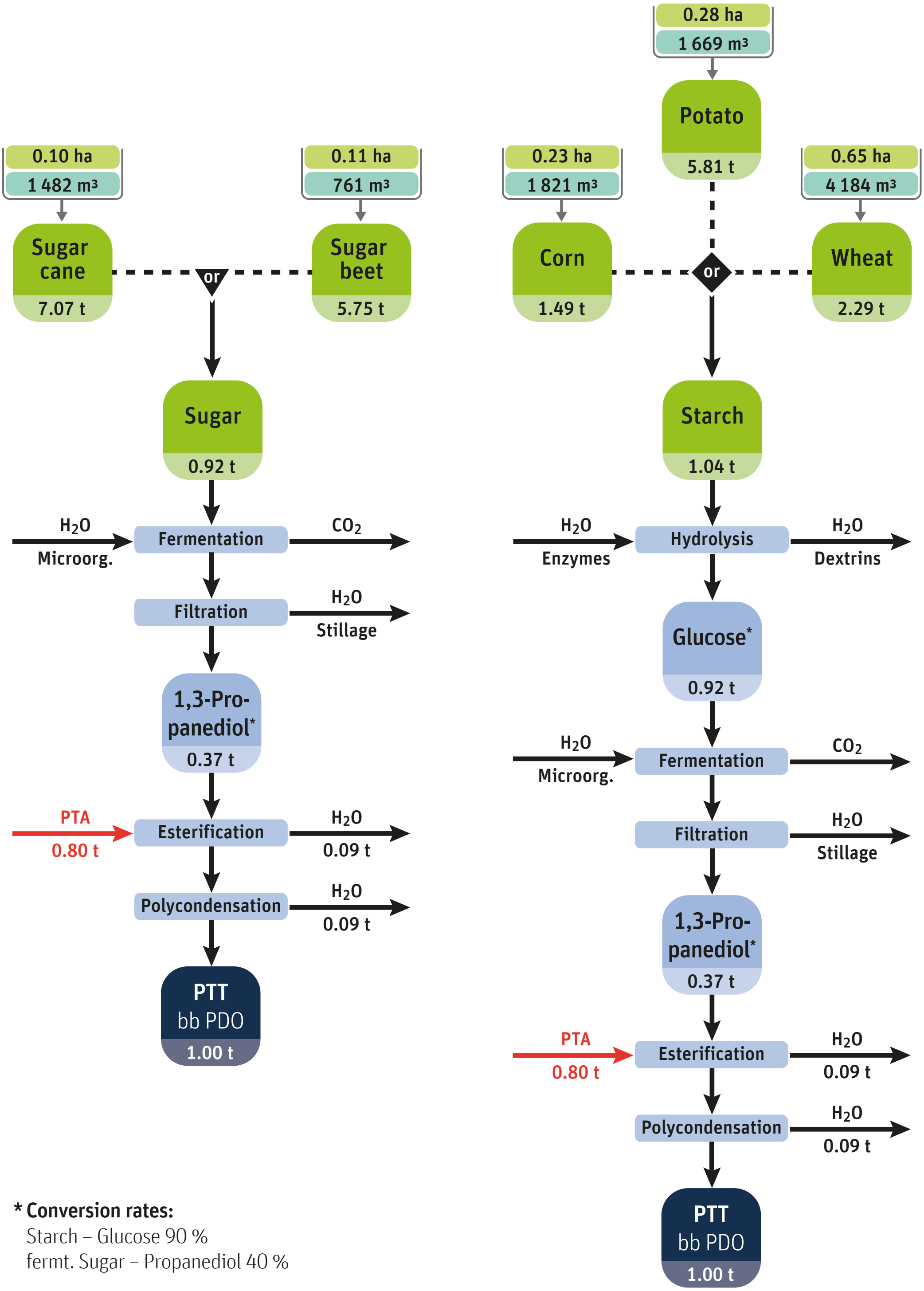


PBSA variations – Water use in m^3 (different feedstocks)



2.1.5 Polytrimethylene terephthalate (PTT)

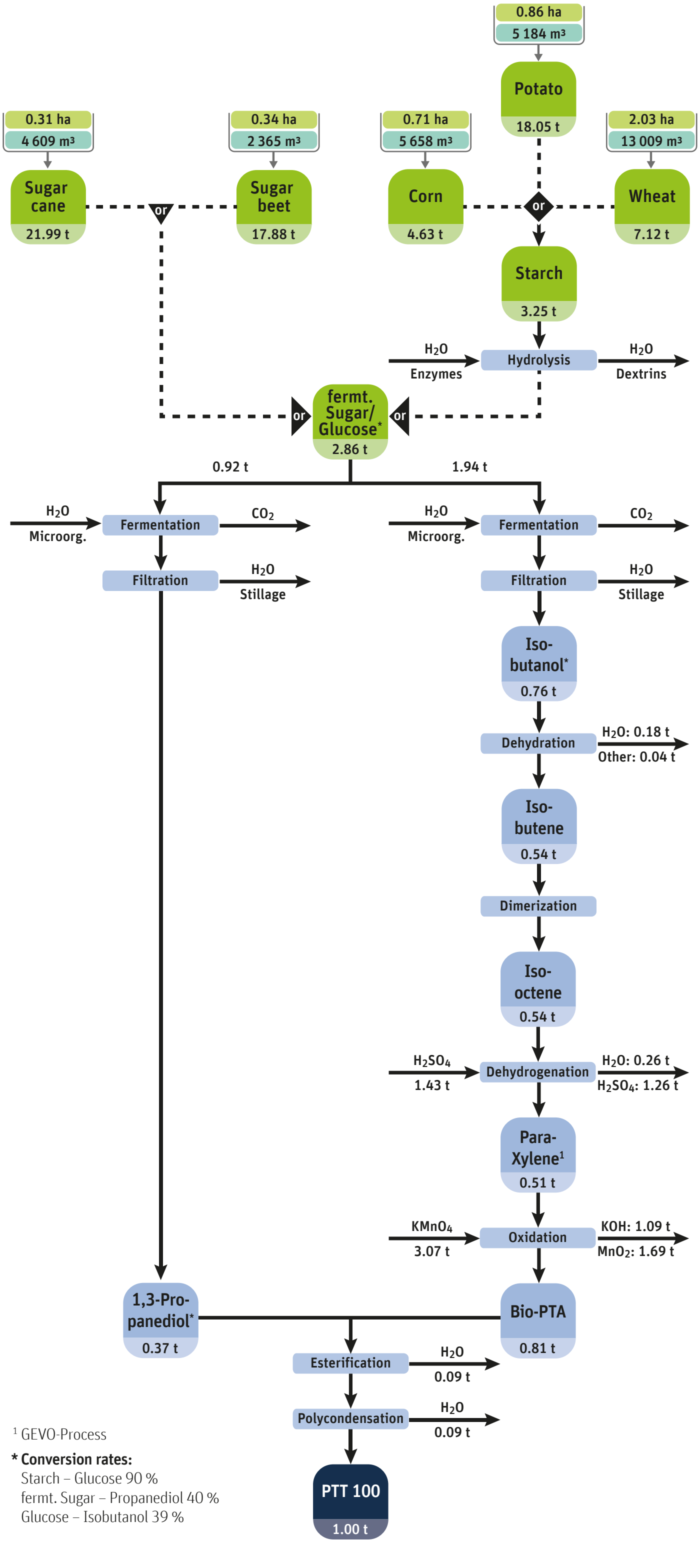
with bio-based 1,3-propanediol (PTT bb PDO)



*** Conversion rates:**
Starch – Glucose 90 %
fermt. Sugar – Propanediol 40 %

2.1.5 Polytrimethylene terephthalate (PTT)

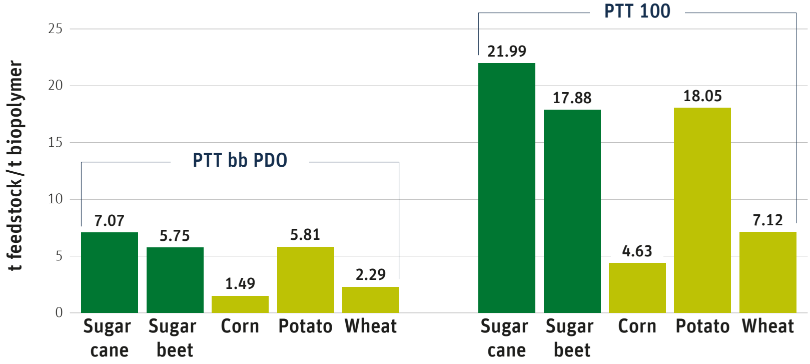
100 % bio-based (PTT 100)



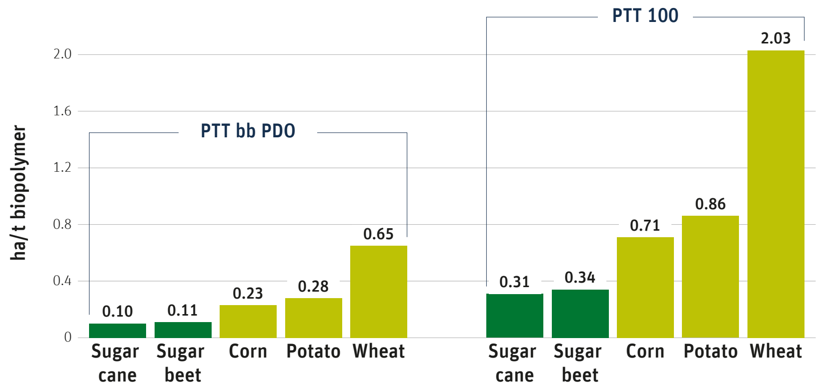
[1] GEVO-Process

*** Conversion rates:**
Starch – Glucose 90 %
fermt. Sugar – Propanediol 40 %
Glucose – Isobutanol 39 %

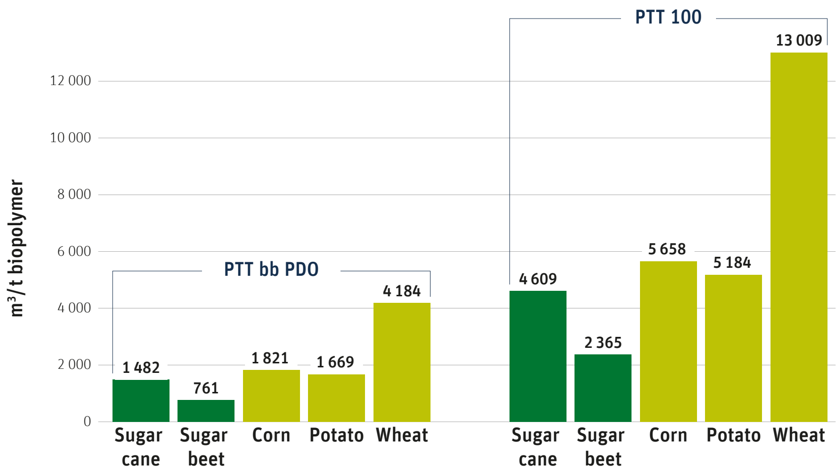
PTT variations – Feedstock requirements in t (different feedstocks)



PTT variations – Land use in ha (different feedstocks)

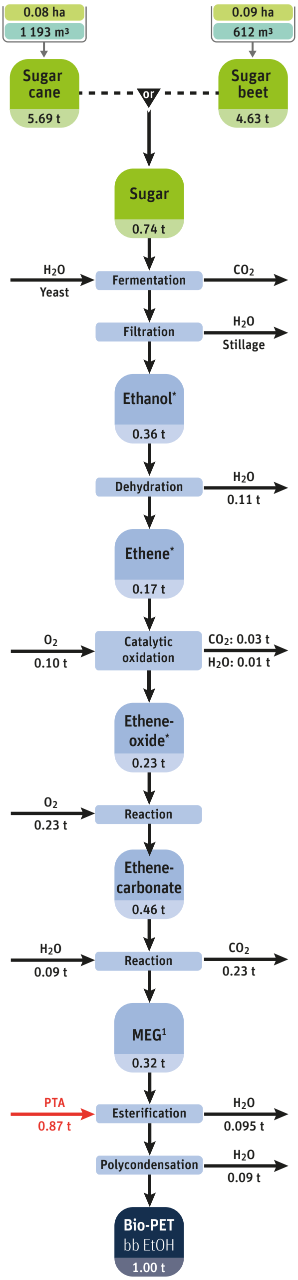


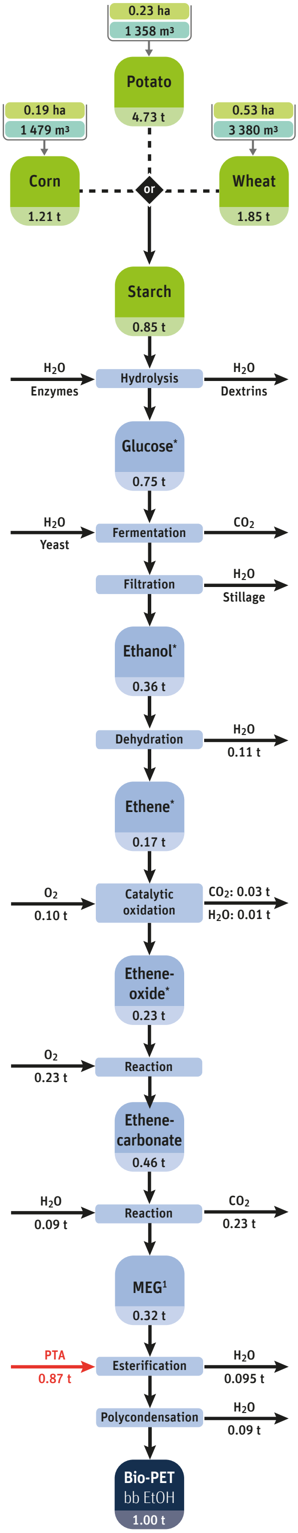
PTT variations – Water use in m^3 (different feedstocks)



2.1.6 Polyethylene terephthalate (Bio-PET)

with bio-based ethanol (Bio-PET bb EtOH)



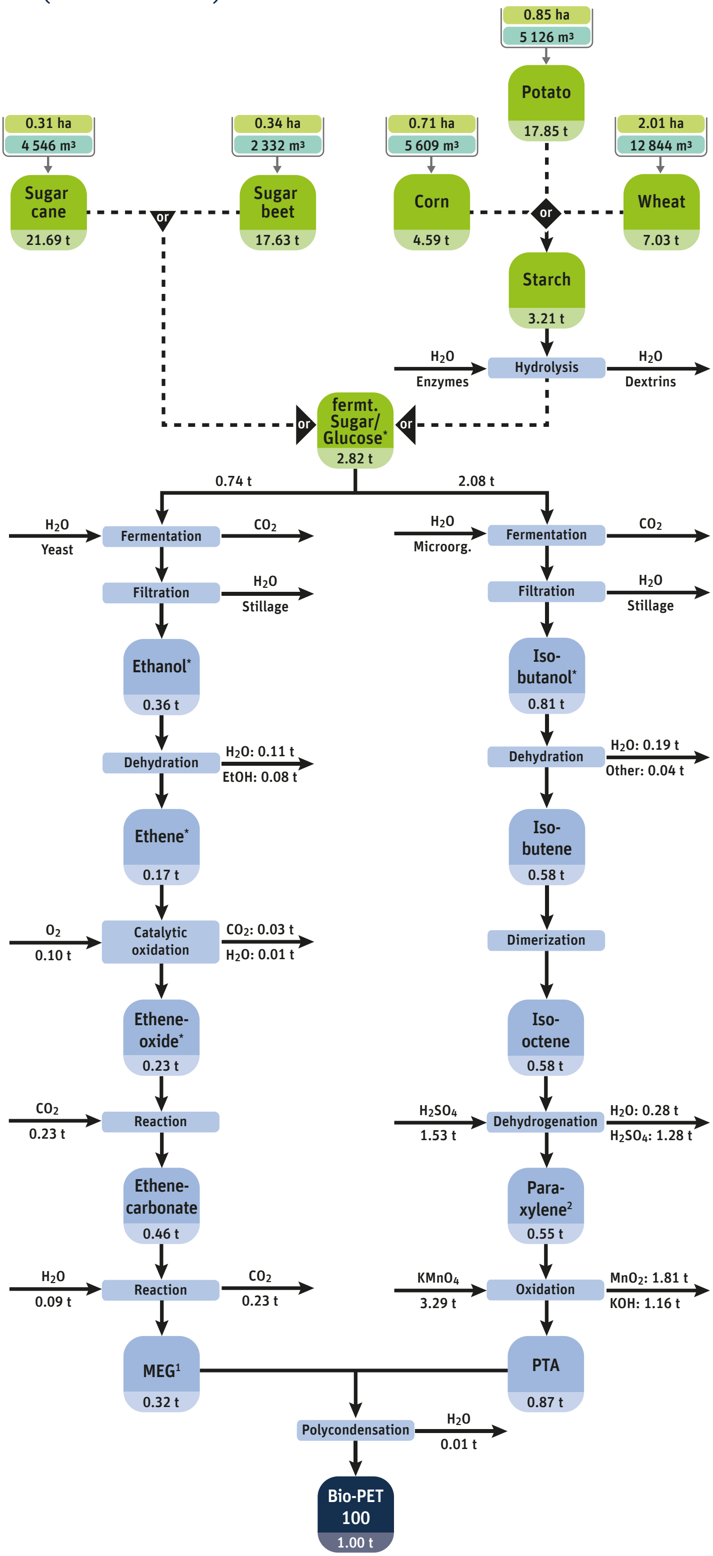


[1] Omega-Process (Shell)

*** Conversion rates:**
Starch – Glucose 90 %
Glucose – Ethanol 48 %
Ethanol – Ethene 48 %
Ethene – Etheneoxide 85 %

2.1.6 Polyethylene terephthalate (Bio-PET)

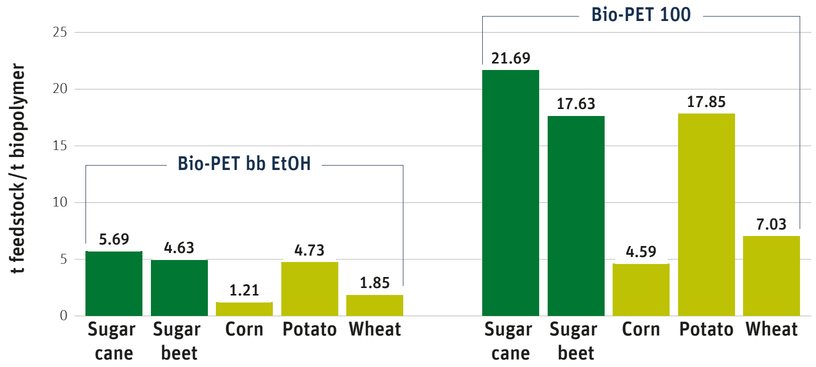
100 % bio-based (Bio-PET 100)



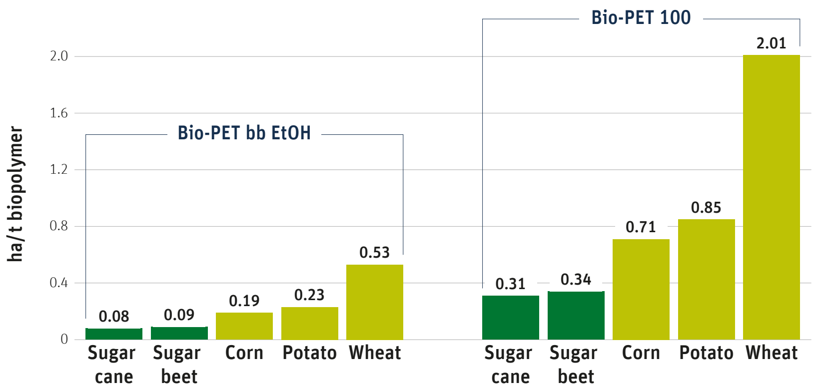
[1] Omega-Process (Shell)
[2] GEVO-Process

*** Conversion rates:**
Starch – Glucose 90 %
Glucose – Ethanol 48 %
Glucose – Isobutanol 39 %
Ethanol – Ethene 48 %
Ethene – Etheneoxide 85 %

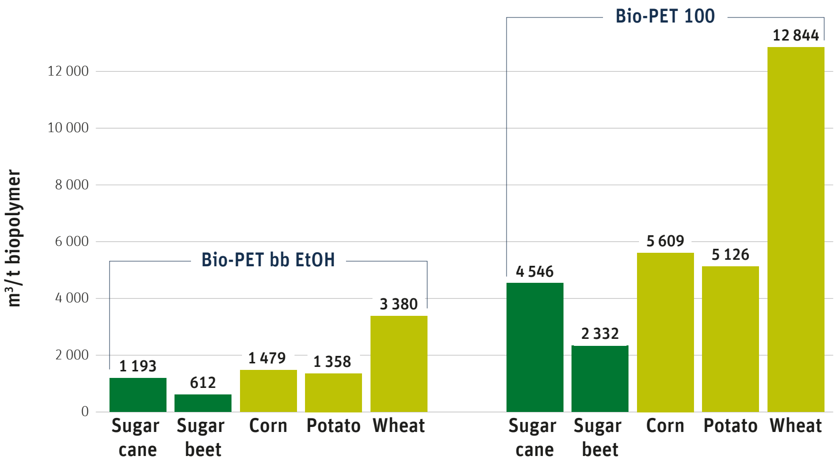
Bio-PET variations – Feedstock requirements in t (different feedstocks)



Bio-PET variations – Land use in ha (different feedstocks)

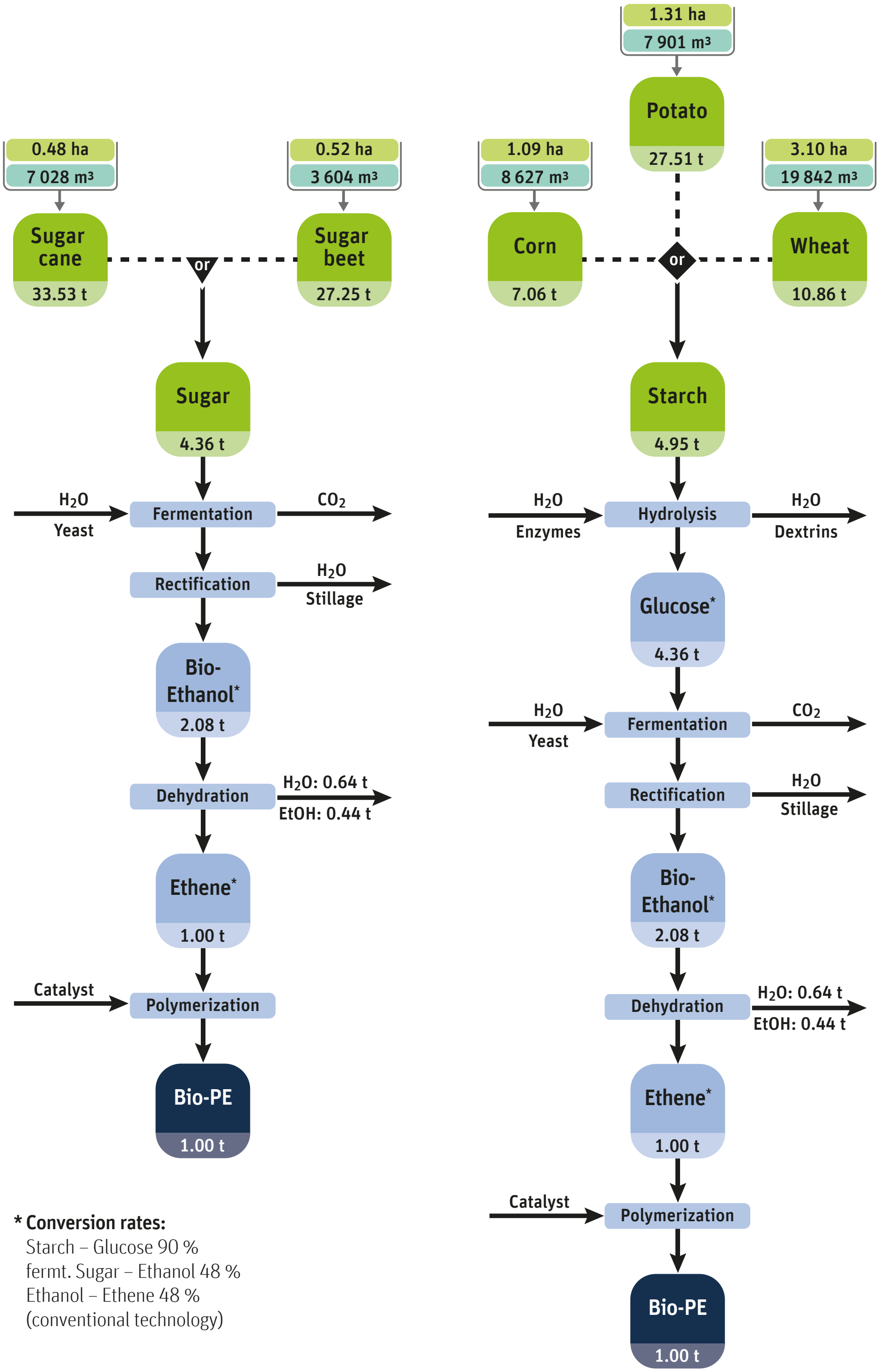


Bio-PET variations – Water use in m³ (different feedstocks)



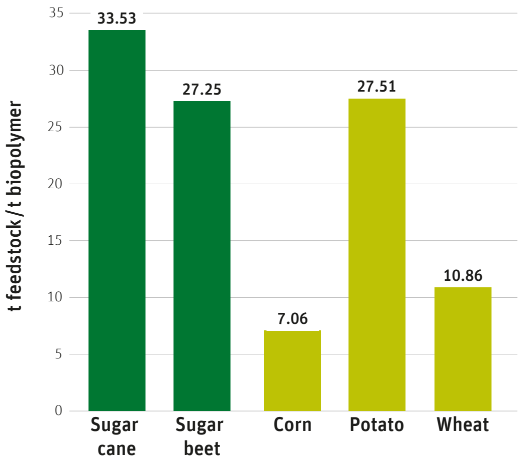
2.2 Bio-based polyolefins

2.2.1 Polyethylene (Bio-PE)

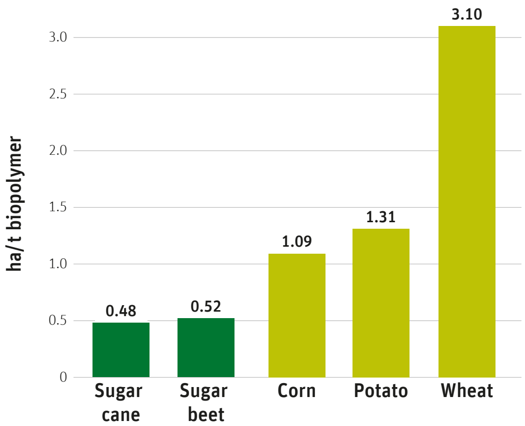


*** Conversion rates:**
Starch – Glucose 90 %
fermt. Sugar – Ethanol 48 %
Ethanol – Ethene 48 %
(conventional technology)

Bio-PE – Feedstock requirements in t (different feedstocks)

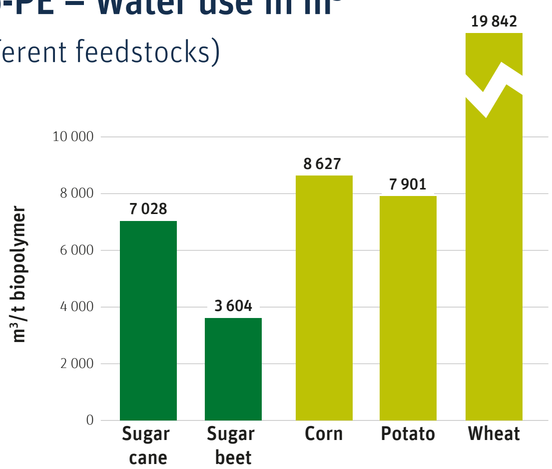


Bio-PE – Land use in ha (different feedstocks)



Bio-PE – Water use in m^3

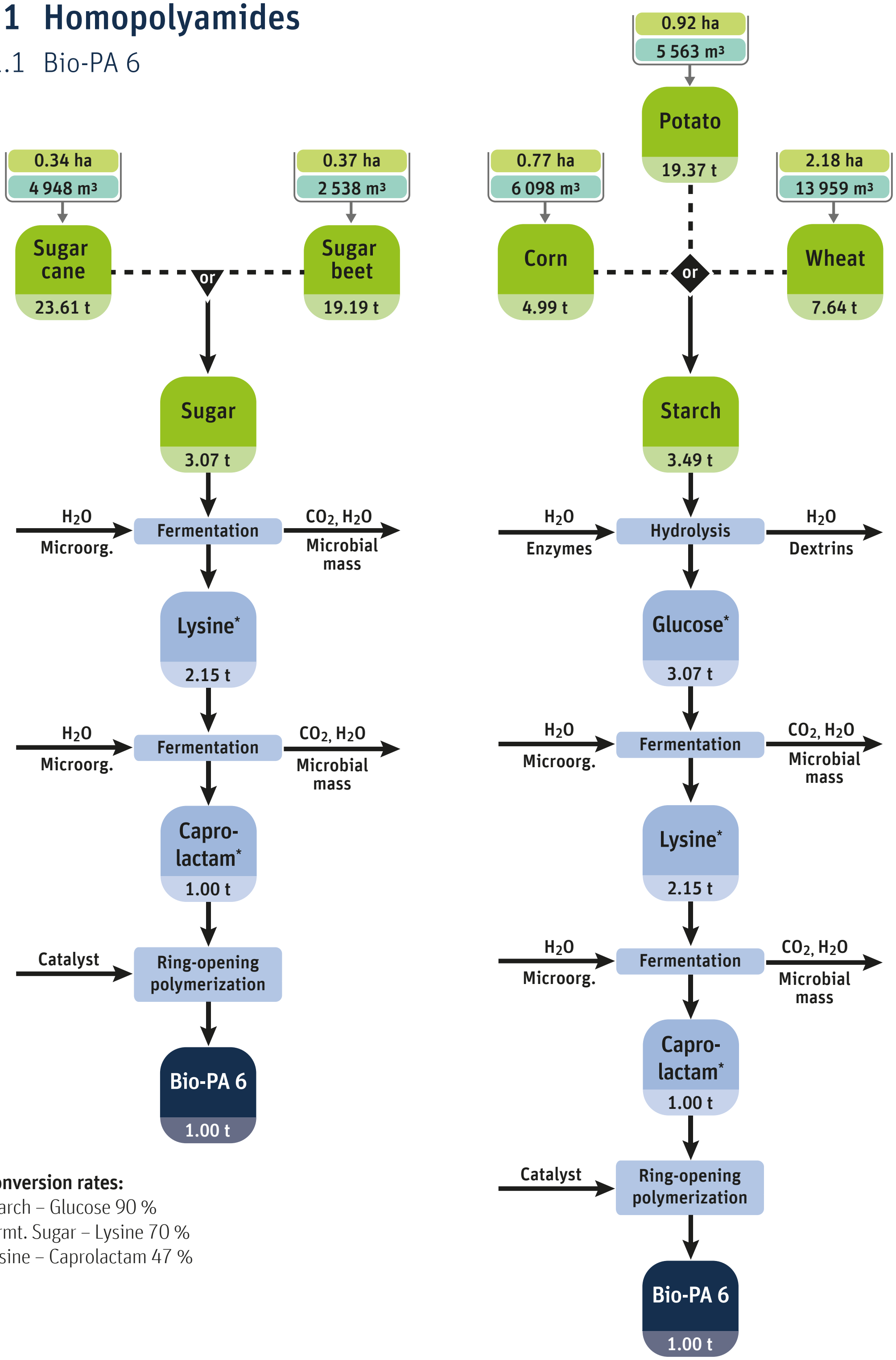
(different feedstocks)



2.3 Bio-based polyamides (Bio-PA)

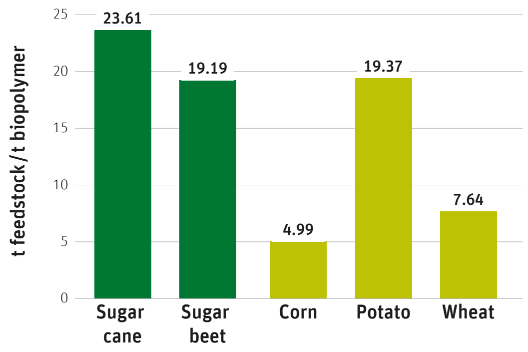
2.3.1 Homopolyamides

2.3.1.1 Bio-PA 6

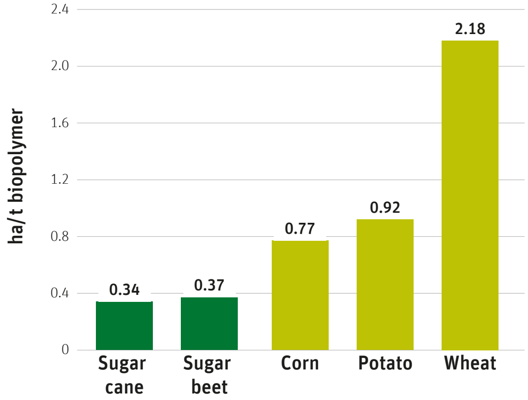


*** Conversion rates:**
Starch – Glucose 90 %
fermt. Sugar – Lysine 70 %
Lysine – Caprolactam 47 %

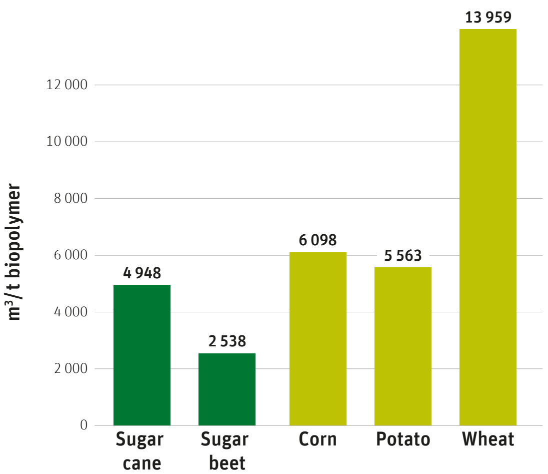
Bio-PA 6 – Feedstock requirements in t (different feedstocks)



Bio-PA 6 – Land use in ha (different feedstocks)

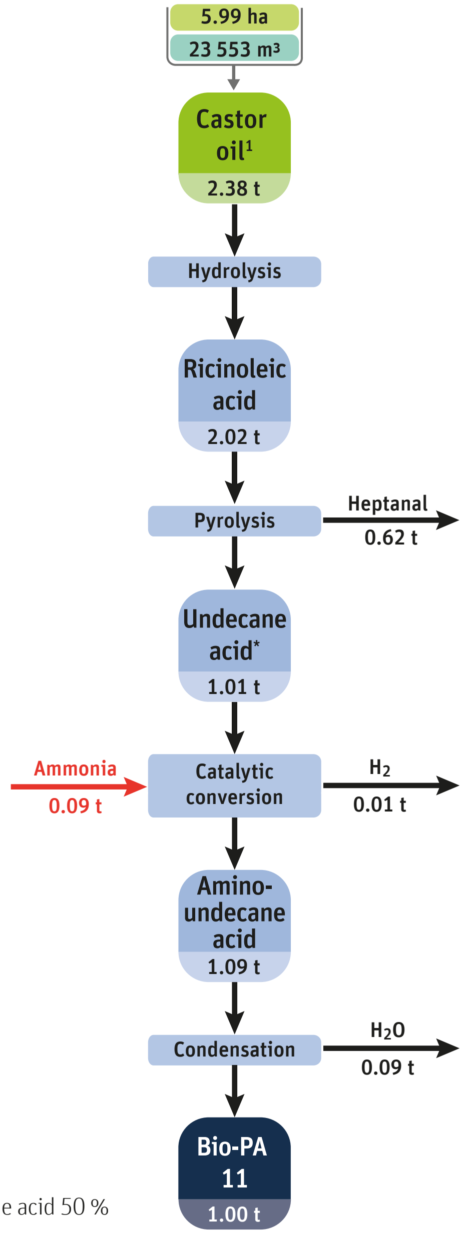


Bio-PA 6 – Water use in m³ (different feedstocks)



2.3.1 Homopolyamides

2.3.1.2 Bio-PA 11

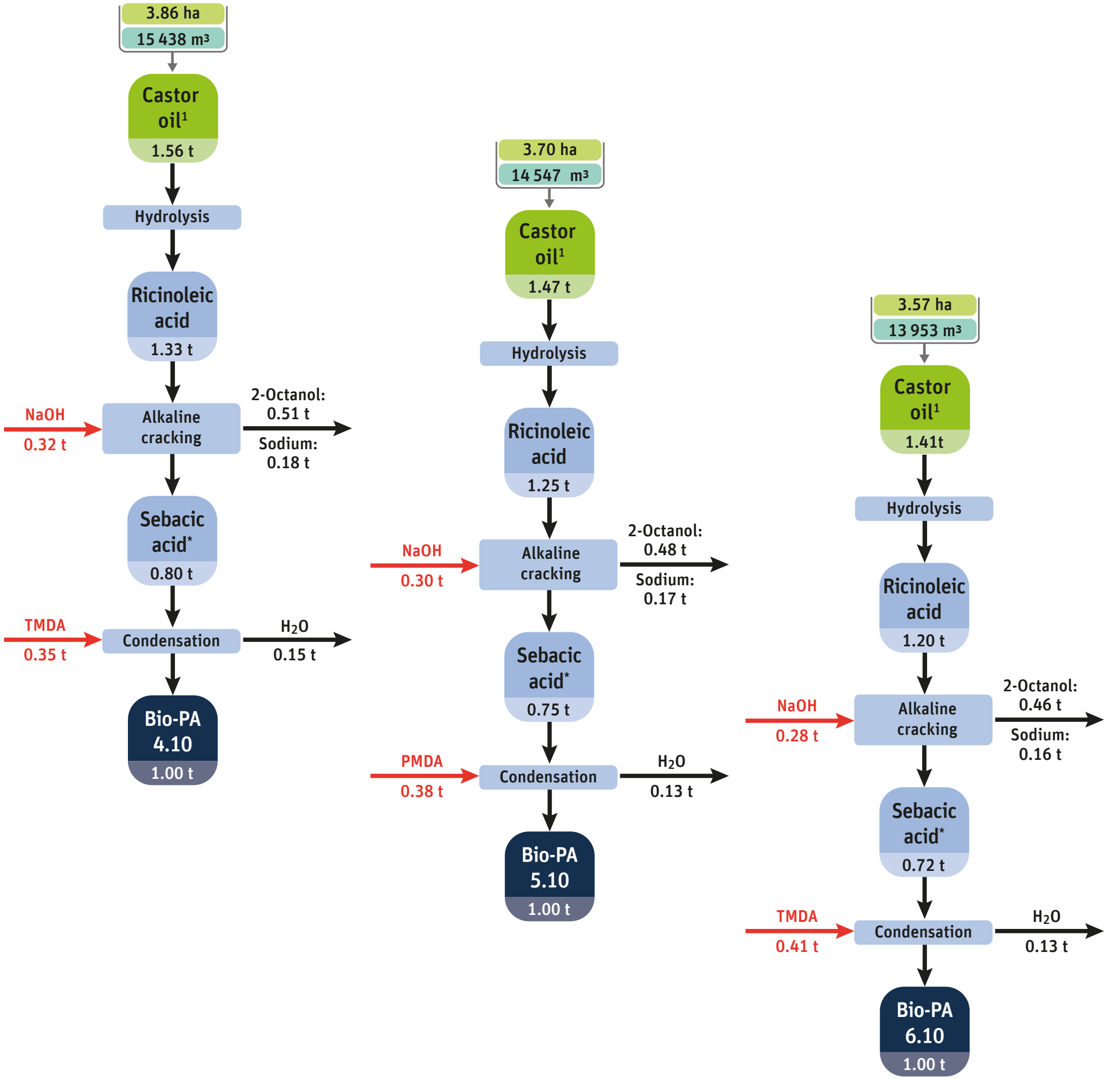


[1] one harvest per year

*** Conversion rates:**
Ricinoleic acid – Undecane acid 50 %

2.3.2 Copolyamides

2.3.2.1 Bio-PA 4.10 – Bio-PA 5.10 – Bio-PA 6.10

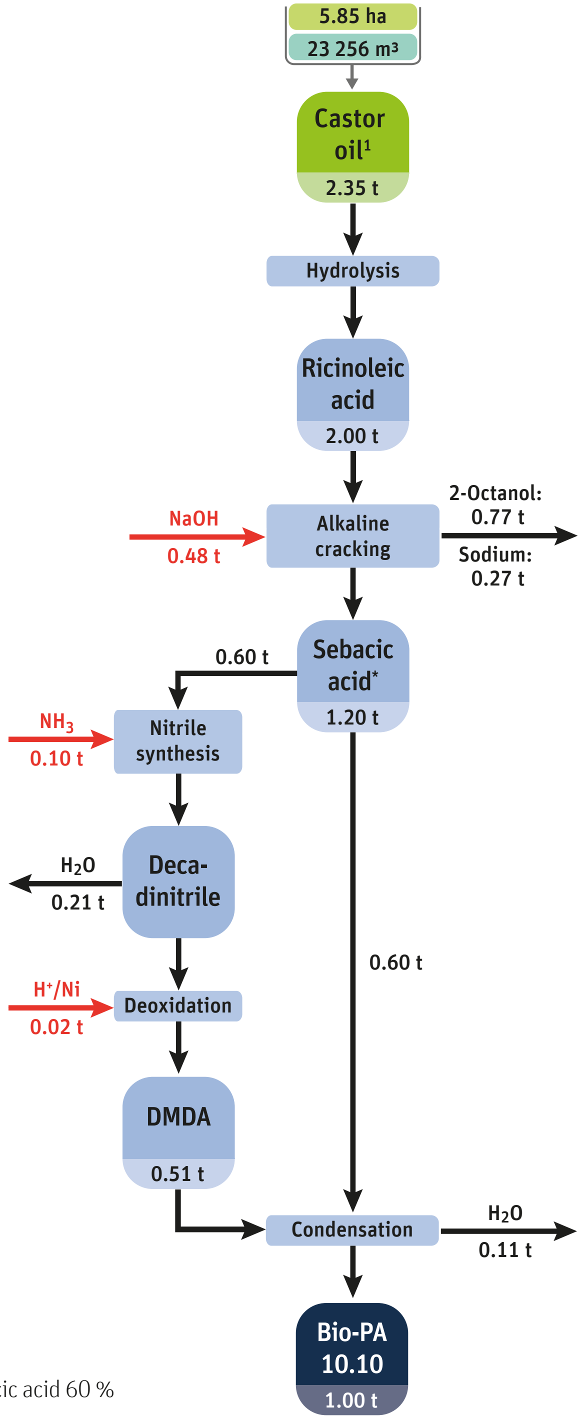


[1] one harvest per year

*** Conversion rates:**
Ricinoleic acid – Sebacic acid 60 %

2.3.2 Copolyamids

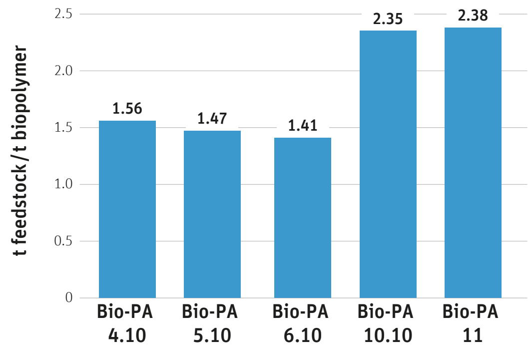
2.3.2.2 Bio-PA 10.10



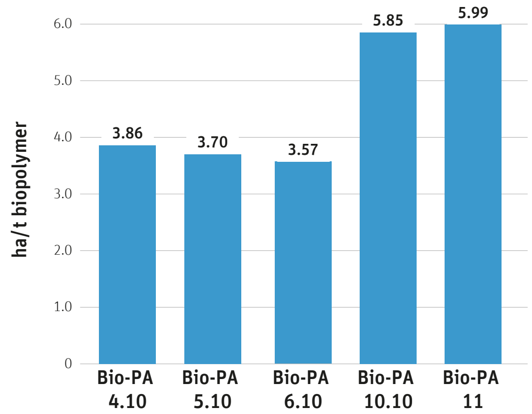
[1] one harvest per year

*** Conversion rates:**
Ricinoleic acid – Sebacic acid 60 %

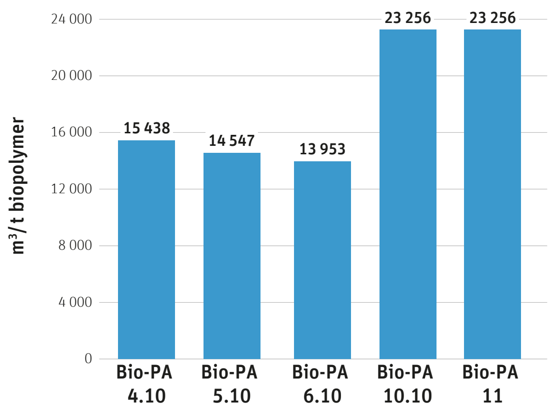
Bio-PA – Feedstock requirements in t (feedstock castor oil)



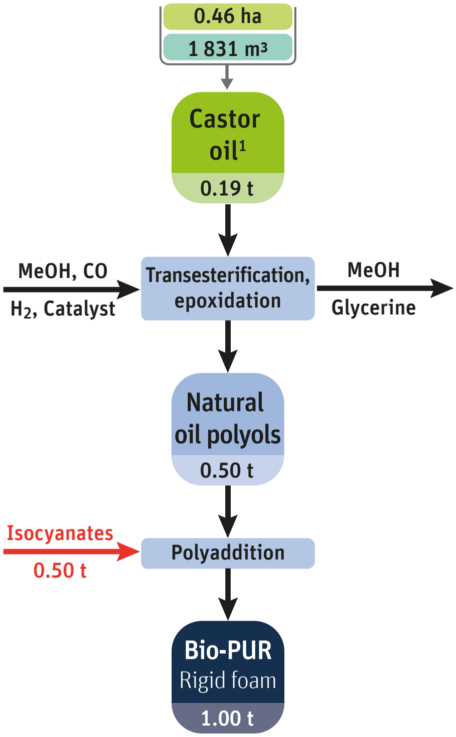
Bio-PA – Land use in ha (feedstock castor oil)

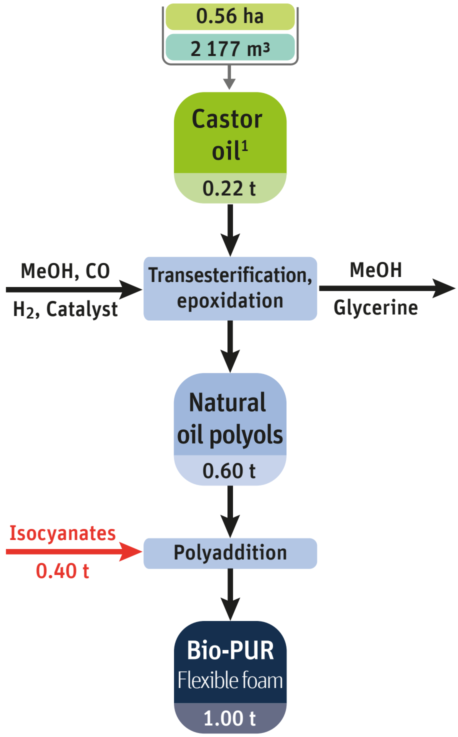


Bio-PA – Water use in m^3 (feedstock castor oil)



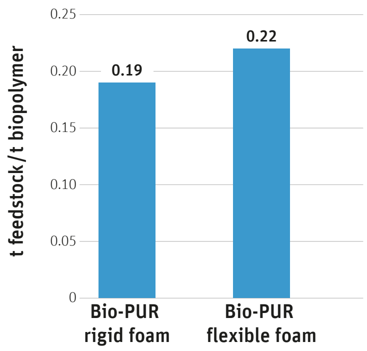
2.4 Polyurethanes



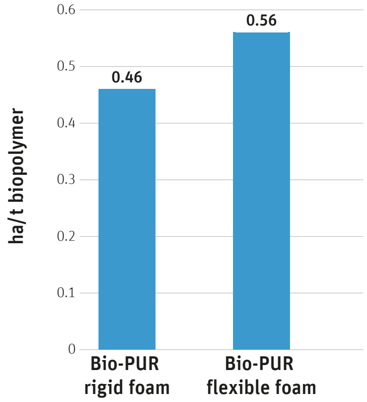


[1] one harvest per year

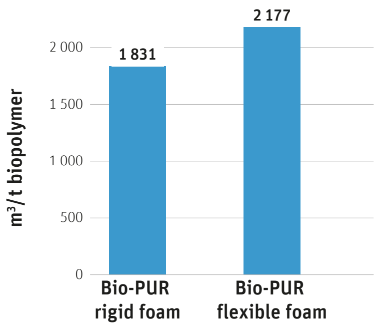
Bio-PUR – Feedstock requirements in t (feedstock castor oil)



Bio-PUR – Land use in ha (feedstock castor oil)



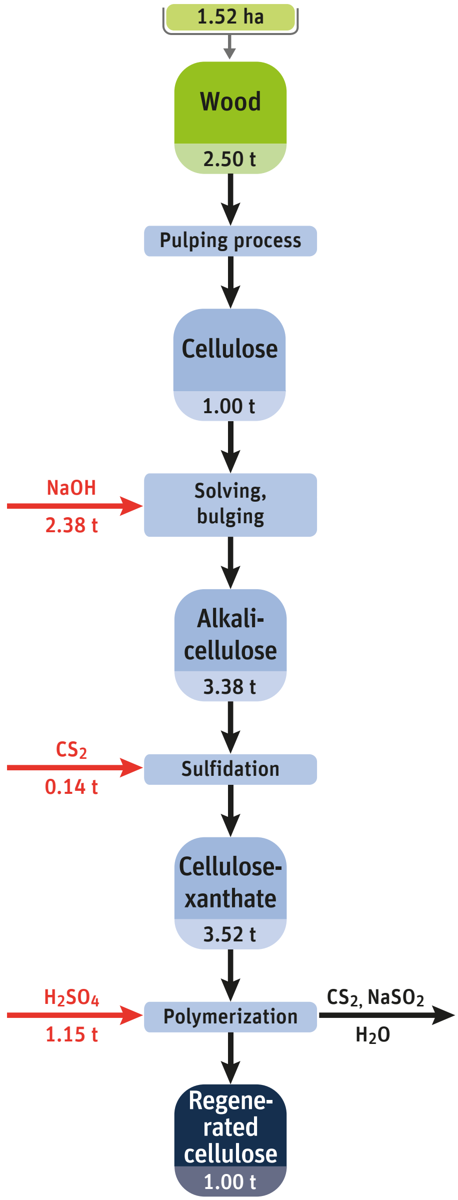
Bio-PUR – Water use in m^3 (feedstock castor oil)



2.5 Polysaccharid polymers

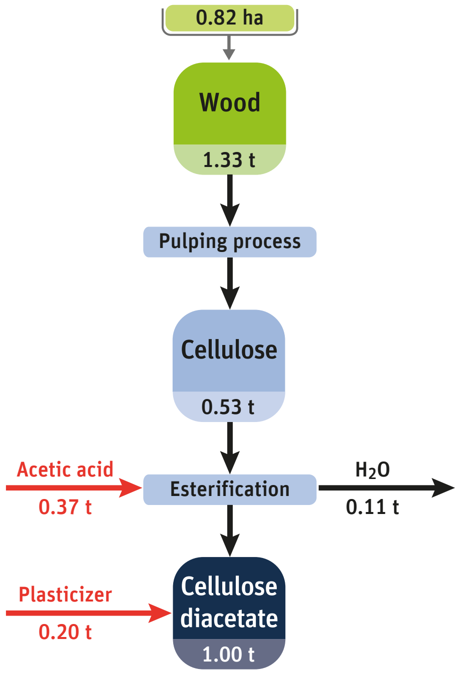
2.5.1 Cellulose-based polymers (Cellulosics)

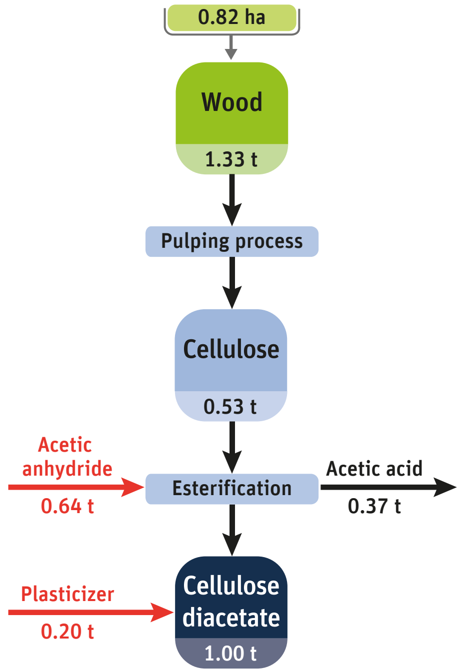
2.5.1.1 Regenerated cellulose



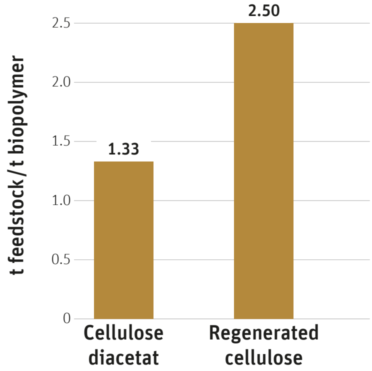
2.5.1 Cellulose-based polymers (Cellulosics)

2.5.1.2 Cellulose diacetate

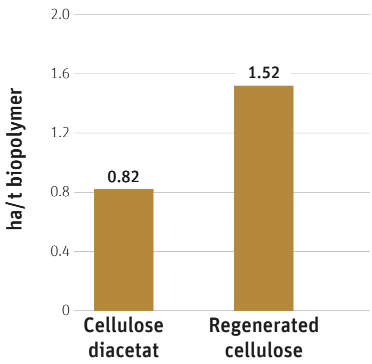




Cellulosics – Feedstock requirements in t (feedstock wood)

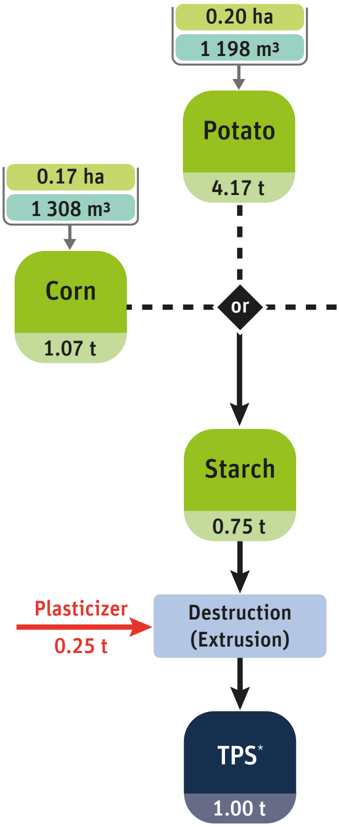


Cellulosics – Land use in ha (feedstock wood)



2.5.2 Starch-based polymers

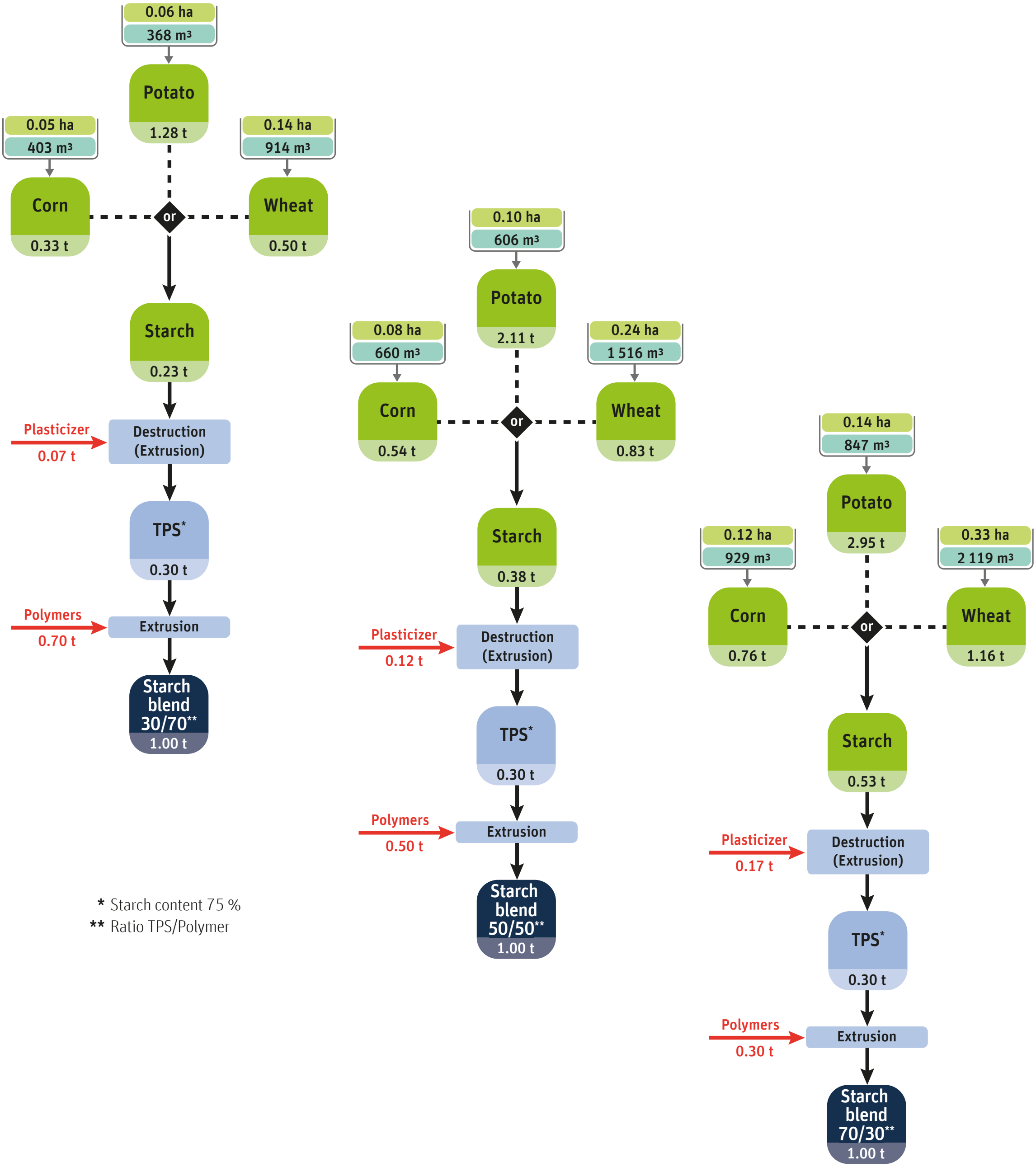
2.5.2.1 Thermoplastic starch (TPS)



* Starch content 75 %

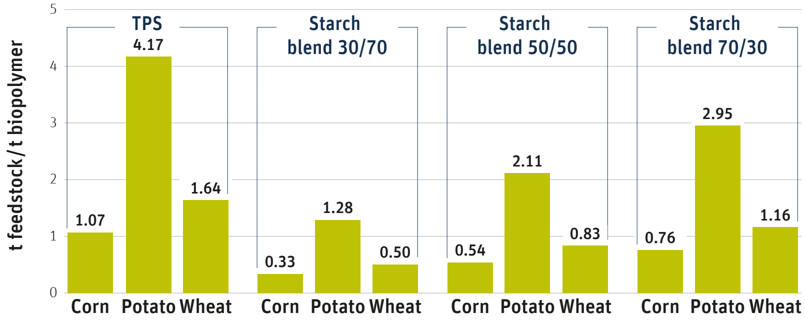
2.5.2 Starch-based polymers

2.5.2.2 Starch blends

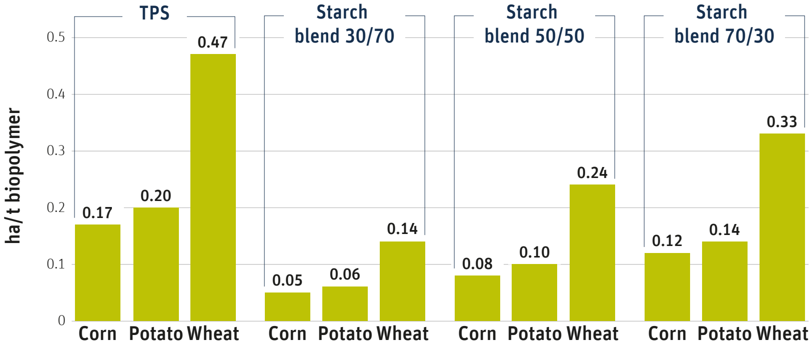


* Starch content 75 %
** Ratio TPS/Polymer

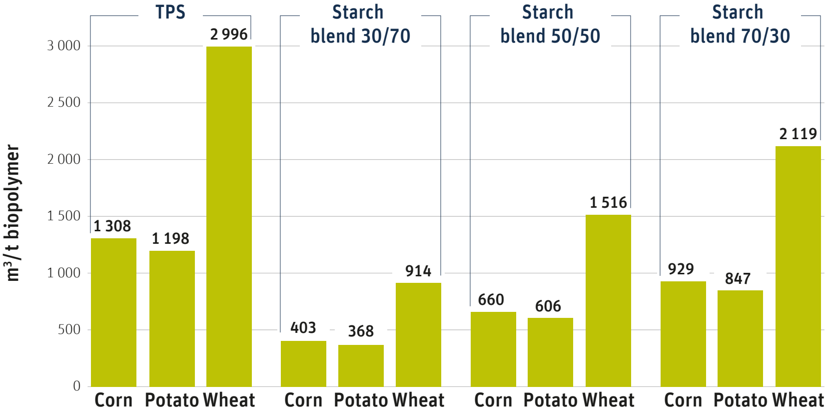
Starch-based polymers – Feedstock requirements in t
(different feedstocks)



Starch-based polymers – Land use in ha (different feedstocks)



Starch-based polymers – Water use in m³ (different feedstocks)



3

Market data and land use facts

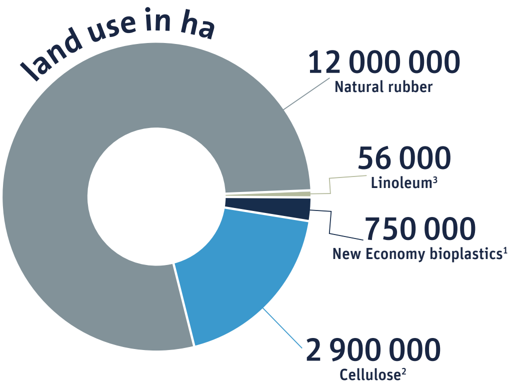
As already mentioned in the introduction, the focus of attention is on "New Economy" bioplastics, including their position at the market. To give the reader an impression of the market share of these innovative and novel bioplastics:

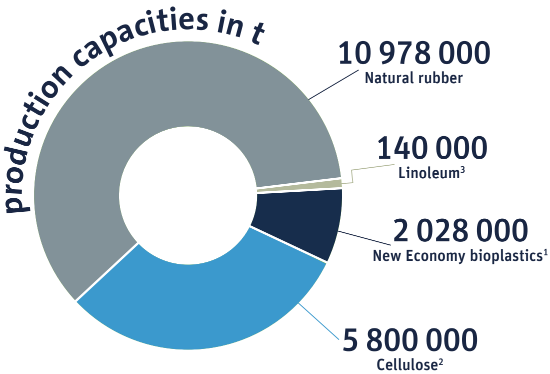
When considering the most important Old Economy bioplastics with their global production capacity of 17 million tonnes annually, it turns out that the share of New Economy bioplastics is almost 10 times lower, i.e. 12 % of the market volume of all bio-based plastics (including the Old Economy bioplastics), with rising tendency.

By and large, Old and New Economy bioplastics (about 18.9 million tonnes) have a combined share of presently about 6 % of the global plastics market. Given the anticipated market growth, especially of New Economy bioplastics, over a 5-year period, the market share of Old and New Economy bioplastics is expected to reach a maximum of 10 % of the global market for plastics within the next 5 years. The corresponding land use of Old and New Economy bioplastics is currently at approximately 15.7 million hectares, which is equivalent to only 0.3 % of the global agricultural area or approximately 1 % of the arable land. Comparing these figures reveals that New Economy bioplastics, which tend to be the only focus of interest in land use discussions, use up only 5 % of the area required for all bio-based plastics combined.

Even though global forecasts predict a rapidly growing market for these novel bioplastics in the next few years, the need for agricultural areas will be kept at a very low level. While the market for new bioplastics has been growing by around 15 % annually during the last three years and a sustained growth is anticipated in the future, it can be assumed that land use for New Economy bioplastics by 2020 (9.4 million tonnes), for example, will be as low as 0.04 % of the global agricultural area or about 0.1 % of the arable land. Regardless of the significant growth rates, it should be mentioned that the market share of these New Economy bioplastics is still hovering at less than 1 % of the global plastics market and is likely not to exceed 2-3 % in the near future. To make things even more compelling, it is a fact that bio-based plastics, even after multiple material usage, can still serve as an energy carrier. This means that additional crop lands, which are currently used for direct energy production, could be set aside for the production of bioplastics. Prior material usage of biomass, as in the case of bioplastics, still permits subsequent trouble-free energy recovery, whereas direct incineration of biomass (and also crude oil-based products!) precludes an immediate subsequent material usage. In this case, more arable land for plant cultivation is needed and consequently another photosynthesis process, in order to gain new resources once again as feedstock for material usage.

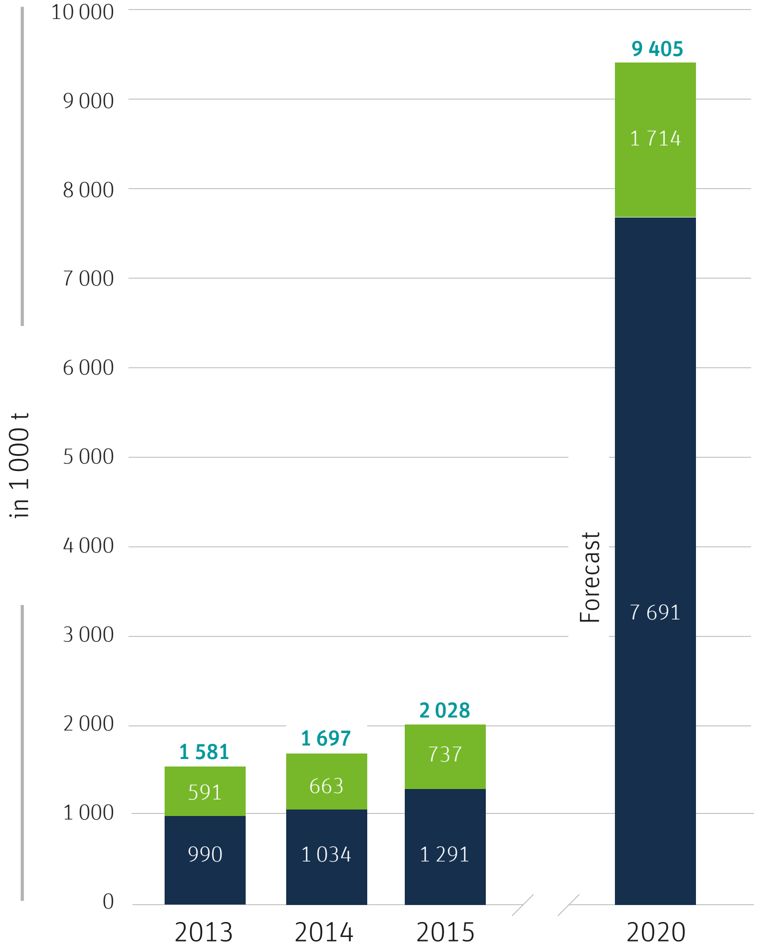
Production capacities and land use Old and New Economy bioplastics





[1] PLA, PHA, PTT, PBAT, Starch blends, Drop-Ins (Bio-PE, Bio-PET, Bio-PA) and other
[2] Material use excl. paperindustry
[3] Calculations include linseed oil only

3.1 New Economy bioplastics global production capacities

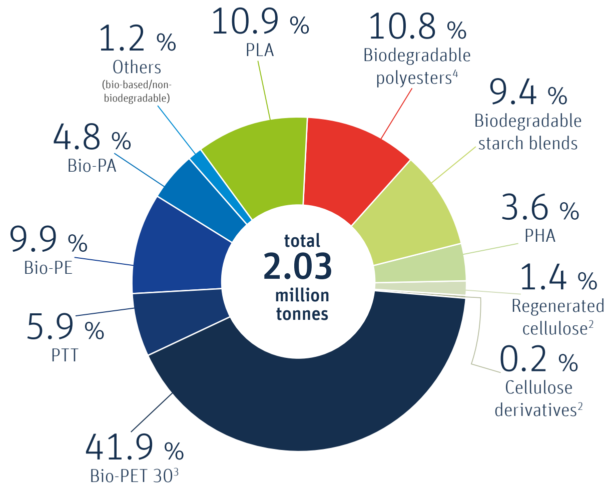


3.2 New Economy bioplastics production capacities by material type

2015

63.7 %
bio-based/non-biodegradable

36.3 %
biodegradable

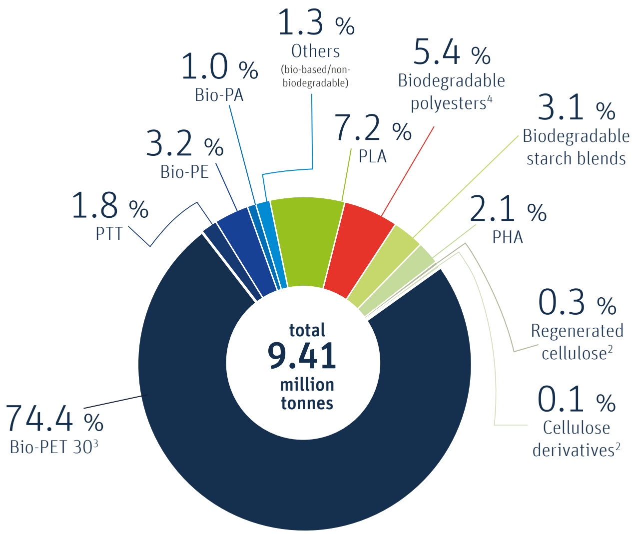


[1] Biodegradable cellulose esters
[2] Compostable hydrated cellulose foils
[3] Bio-based content amounts 30%
[4] Contains PBAT, PBS, PCL

2020

81.8 %
bio-based/non-biodegradable

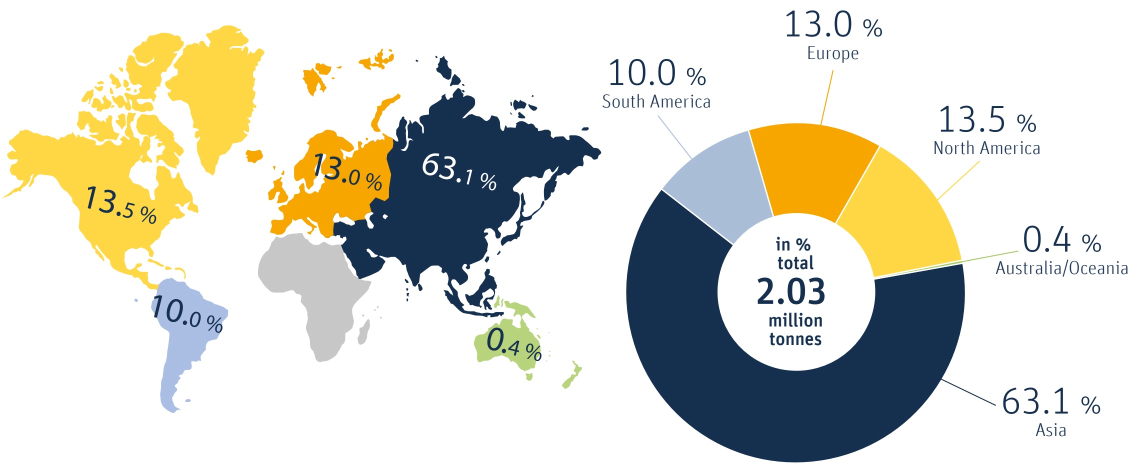
18.2 %
biodegradable



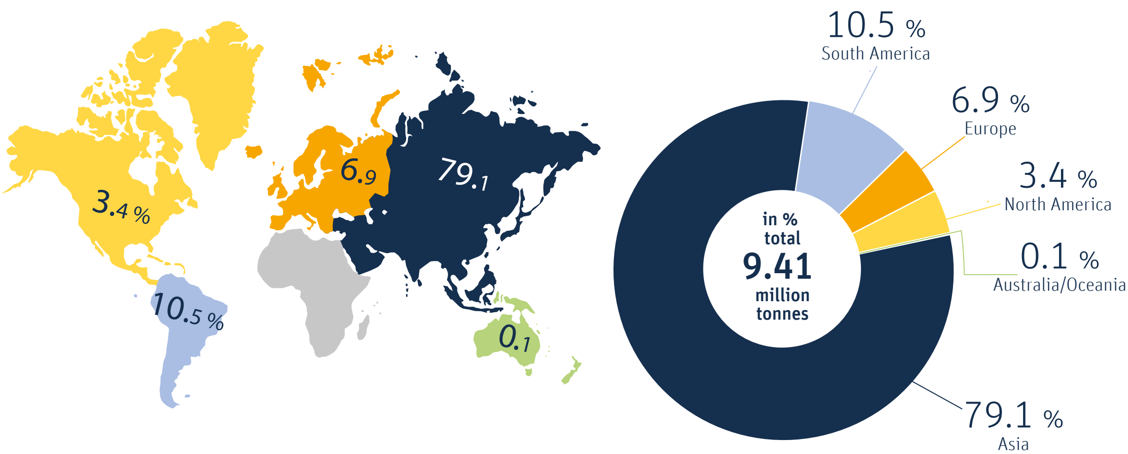
[1] Biodegradable cellulose esters
[2] Compostable hydrated cellulose foils
[3] Bio-based content amounts 30%
[4] Contains PBAT, PBS, PCL

3.3 New Economy bioplastics production capacities by region

2015

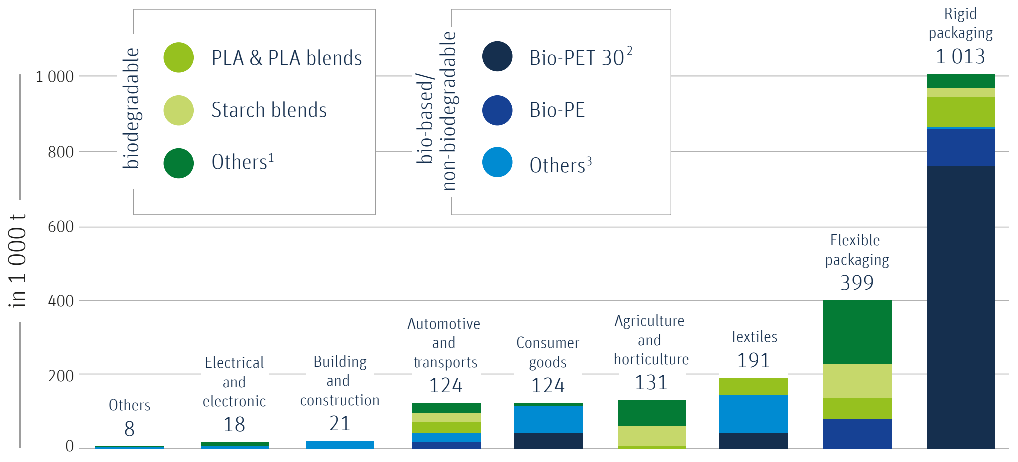


2020



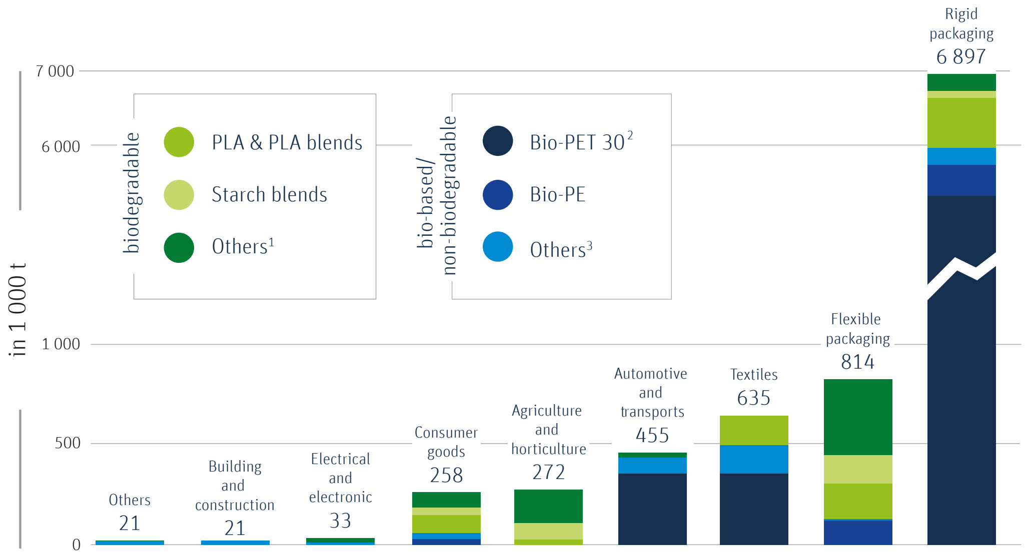
3.4 New Economy bioplastics production capacities by market segment

2015



[1] Contains regenerated cellulose and biodegradable cellulose ester
[2] Bio-based content amounts to 30%
[3] Contains durable starch blends, Bio-PC, Bio-TPE, Bio-PUR (except thermosets), Bio-PA, PTT

2020

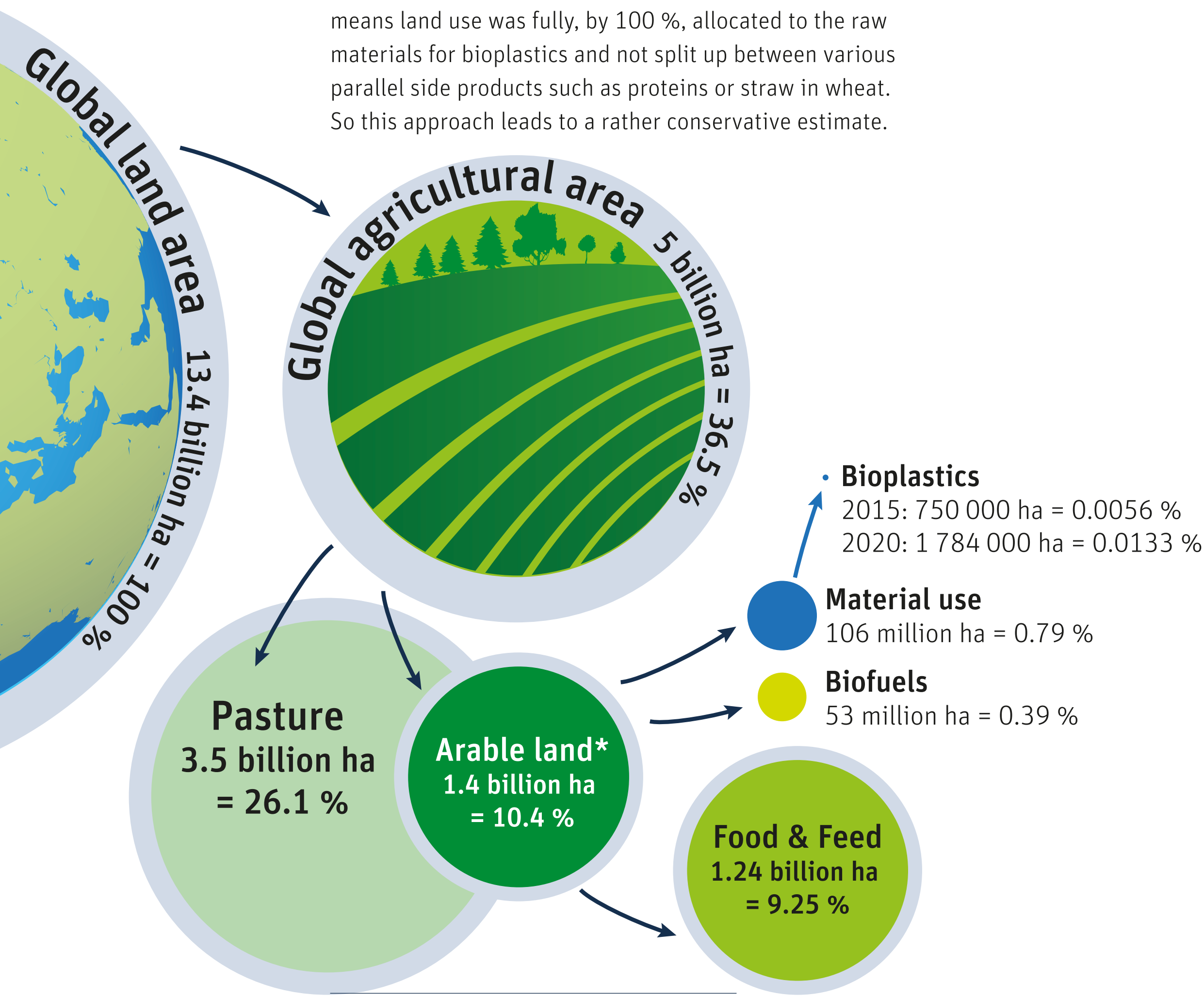


[1] Contains regenerated cellulose and biodegradable cellulose ester
[2] Bio-based content amounts to 30%
[3] Contains durable starch blends, Bio-PC, Bio-TPE, Bio-PUR (except thermosets), Bio-PA, PTT

3.5 Land use for New Economy bioplastics 2015 and 2020

For final land use calculation only the most commonly used crop was taken into consideration. Yield data from FAO statistics served as a basis for calculation (global, non-weighted average over the past 10 years). To calculate land use in this bottom-up approach, the producer-specific production capacities of a type of bioplastics were multiplied by the output data of the corresponding process routes.

In all of the calculations no allocation was made, which means land use was fully, by 100 %, allocated to the raw materials for bioplastics and not split up between various parallel side products such as proteins or straw in wheat. So this approach leads to a rather conservative estimate.



* Also includes area growing permanent crops as well as approx. 1 % fallow land. Abandoned land resulting from shifting cultivation is not included.

IfBB
Institute for Bioplastics and Biocomposites

A large amount of additional information is also available at **www.ifbb-hannover.de**

Hochschule Hannover | Heisterbergallee 12
D-30453 Hannover | Germany

Phone: +49 511 9296-2268
Fax: +49 511 9296-99 2268
E-mail: info@ifbb-hannover.de

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