IfBB
Institute for Bioplastics and Biocomposites

Biopolymers

facts and statistics

2021

Production capacities, processing routes, feedstock, land and water use

HOCHSCHULE HANNOVER
UNIVERSITY OF APPLIED SCIENCES AND ARTS
–
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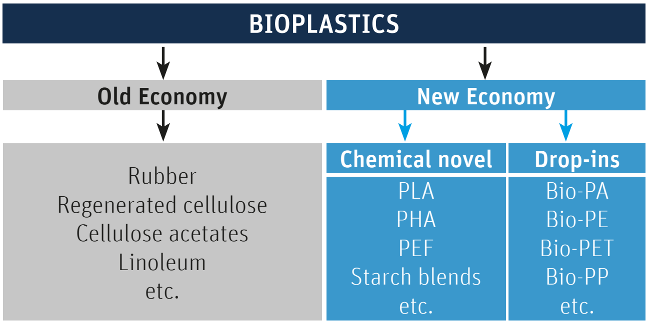
1 Introduction and background

The IfBB – Institute for Bioplastics and Biocomposites is a research institute within the Hochschule Hannover, University of Applied Sciences and Arts. The IfBB was established in 2011 after more than a decade of on-going research activities in the field of bioplastics to respond to the growing need for expert knowledge in this area. 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 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 are being presented here in a concise format, in addition to the more detailed and comprehensive publication "Engineering Biopolymers" (cf. Endres & Siebert-Raths 2011). If figures or data from this or other publication of IfBB is being used, we kindly ask any person or institution to quote IfBB's authorship.

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 easily and quickly provide specific, qualified answers 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 into 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.



The first man-made polymer materials 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 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 and conversation 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 without assuming allocations (especially no feedstock allocation) and 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 feedstocks and resulting and requirements in hectare (ha) or the production of one metric ton (t) of bioplastics. Feedstock requirements were calculated for the use of different crops. Yields of the most important crops and renewable raw materials used for feedstocks are shown in the chart below on page 6.

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.

The conservative calculation used in this publication delivers a resilient approach for adjustments to be made out of invididual needs.

For calculating water use data, information on water use for different raw materials originally collected by the 'Water Footprint Network' has been used (cf. Hoekstra et al. 2011; Mekonnen & Hoekstra 2011). 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[1] (Crop)	Average content of raw material	Resulting amount (raw material)
Calculations			->	x ->	=
Sugar cane	Sugar cane (without cane tops)	fermt. Sugar	73.1 t/ha	13 % [3, 4, 5, 6]	9.5 t sugar/ha
Sugar beet	Beet (without leaves)	fermt. Sugar	62.7 t/ha	16 % [3, 6, 7]	10.03 t sugar/ha
Corn	Maize kernel	Starch	7 t/ha	70 % [8]	4.9 t starch/ha
Potatoes	Potato tuber	Starch	24 t/ha	18 % [8, 9]	4.32 t starch/ha
Wheat	Wheat grains	Starch	3.97 t/ha	46 % [8]	1.83 t starch/ha
Wood	Standing timber, residual wood	Cellulose	1.64 t atro[2]/ha	40 % [13]	0.66 t cellulose/ ha
Castor oil plant	Castor bean (seeds)	Castor oil	1.5 t seeds/ha (given one harvest per year)	40 % [10, 11, 12]	0.6 t oil/ha (given one harvest per year)

1 Global mean yield over a period of 10 years (2010 - 2019), weighted by respective production amount (based on FAOSTAT 2010 - 2019).
2 Absolutely dry.
3 Cf. FAO 1994.
4 Cf. Perez 1997.
5 Cf. Alexander 1988.
6 Cf. Li & Yang 2015.
7 Cf. FAO 1999.
8 Cf. BeMiller & Whistler 2009.
9 Cf. Jang & Lim 2011.
10 Cf. Rojas-Barros et al. 2004.
11 Cf. Anjani 2012.
12 Cf. Yeboah et al. 2020.
13 Calculated from various forest statistics and reports, Federal Forest Inventory (Germany).

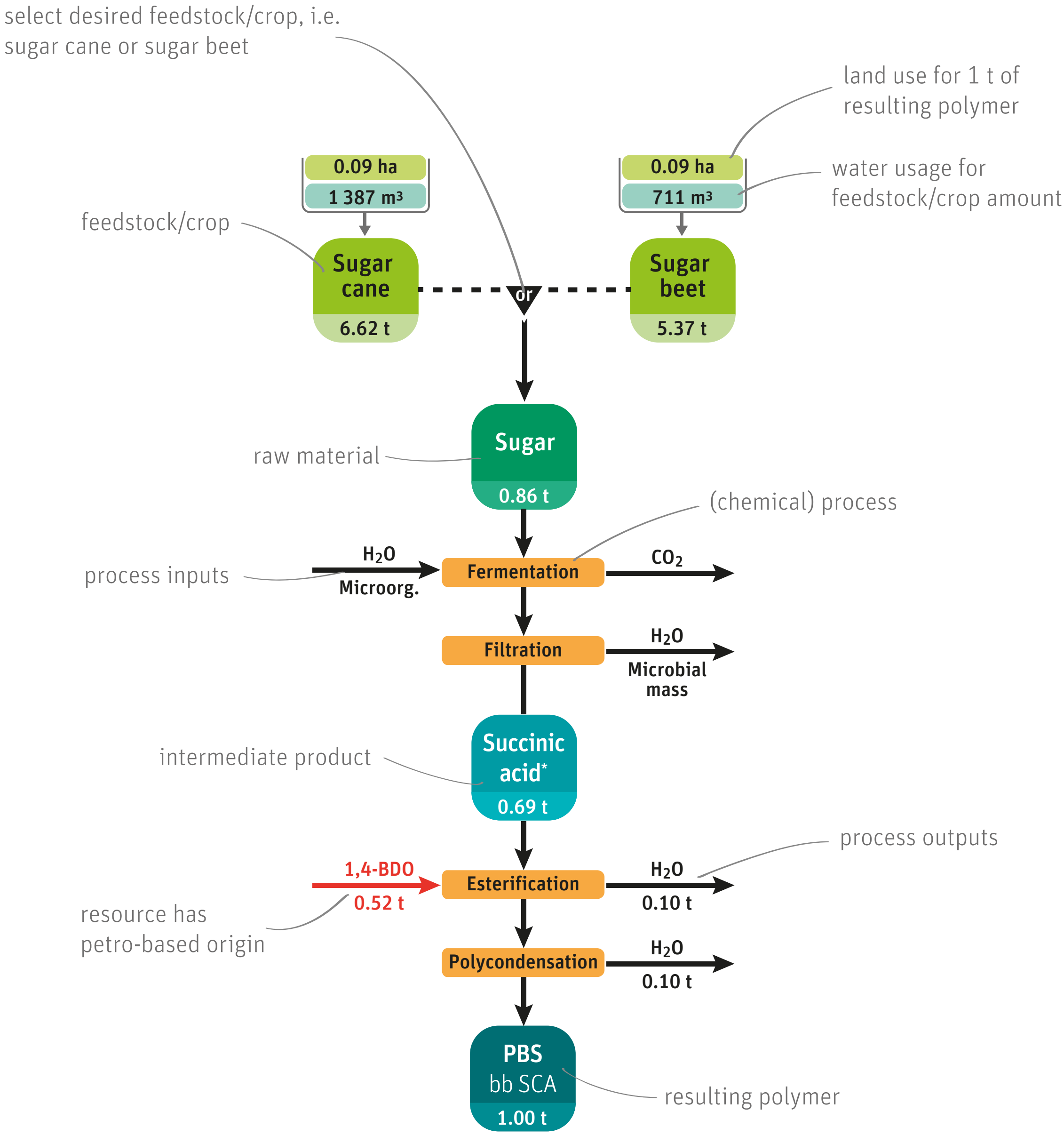
Glossary

Abbreviations used:

atro = bone dry
bb = bio-based
BDO = Butanediol
DMDA = Decamethylene diamine
fermt. = fermentable
ha = hectare = 0,01 km^2
HMDA = Hexamethylene diamine
m^3 = cubic metres = 1 000 litres
MEG = Monoethylene glycol
PDO = Propanediol
PMDA = Pentamethylene diamine
PTA = Purified terephthalic acid
SCA = Succinic acid
t = metric ton = 1 000 kg
TMDA = Tetramethylene diamine
red coloured resources have a petro-based origin

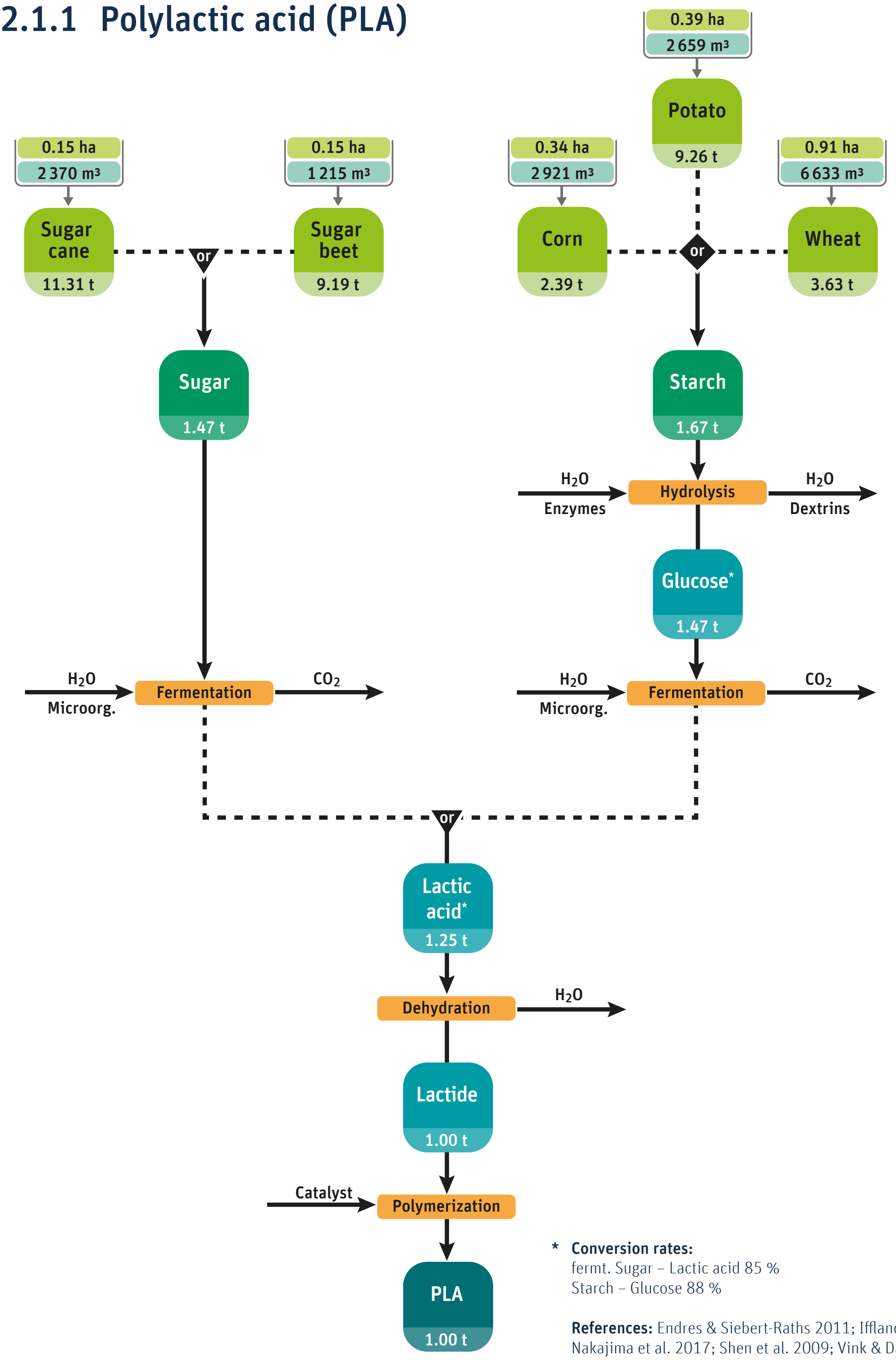
A large amount of additional information is also available at: **www.ifbb-hannover.de**.

Sample process route



2.1 Bio-based polyesters

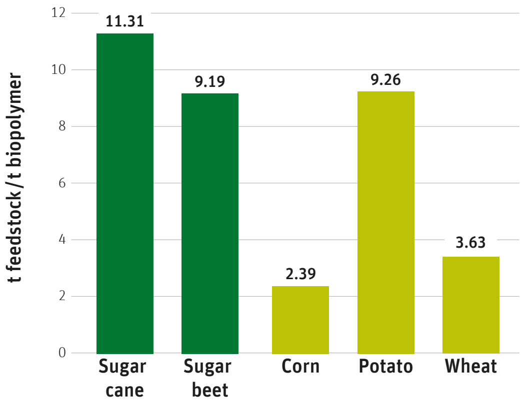
2.1.1 Polylactic acid (PLA)



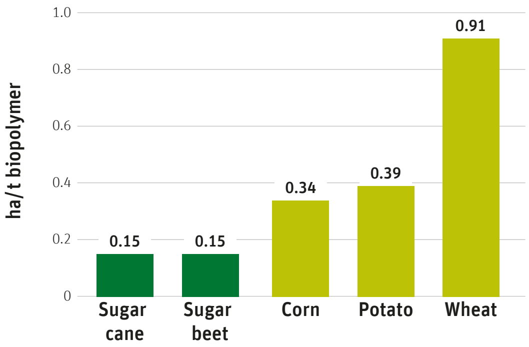
* **Conversion rates:**
fermt. Sugar – Lactic acid 85 %
Starch – Glucose 88 %

References: Endres & Siebert-Raths 2011; Iffland et al. 2015; Nakajima et al. 2017; Shen et al. 2009; Vink & Davies 2015

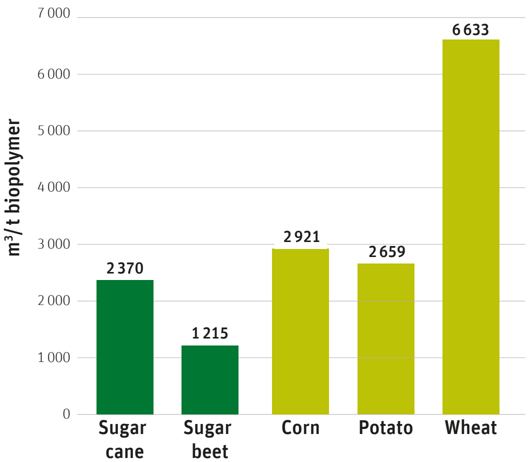
PLA – Feedstock requirements in t (different feedstocks)



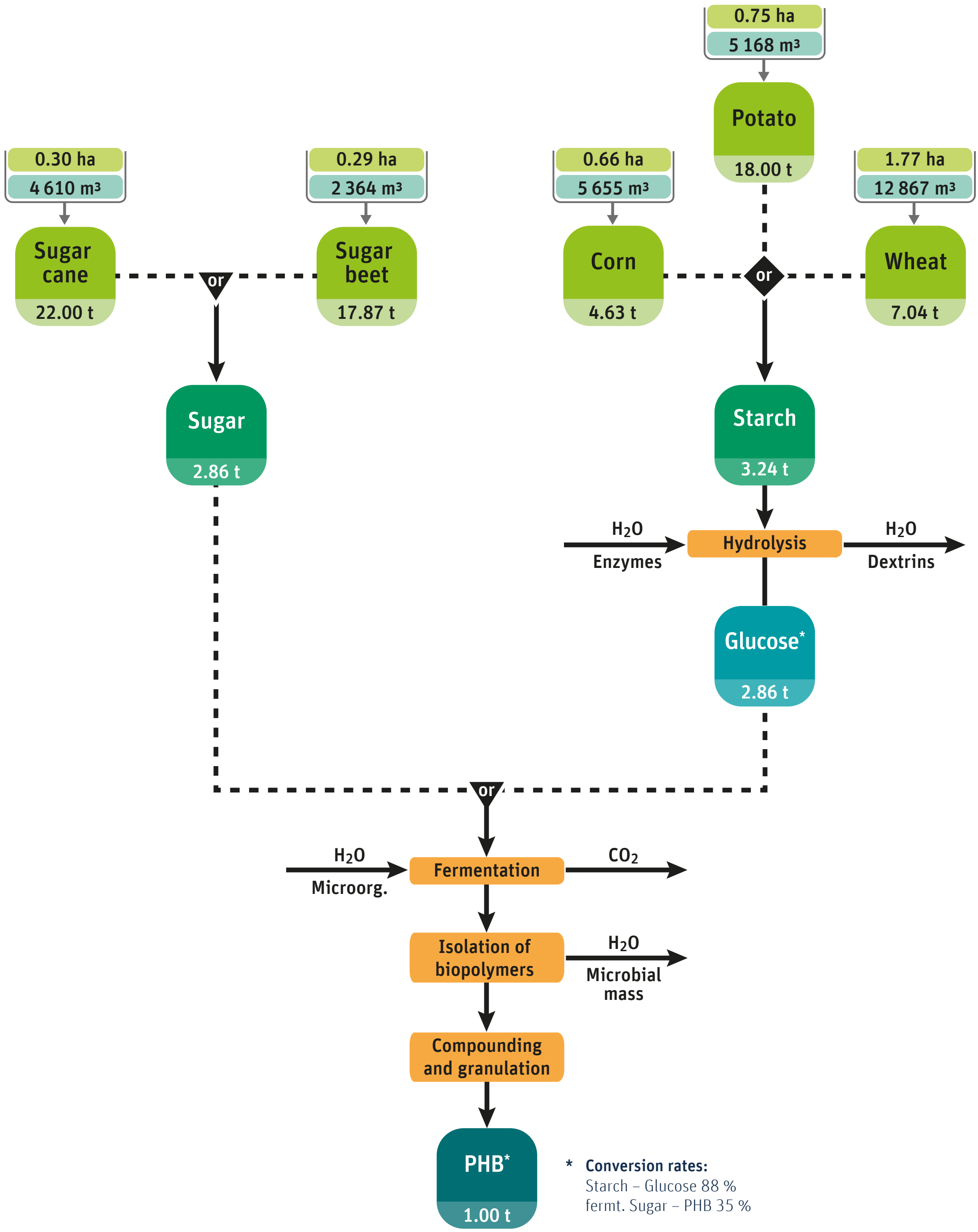
PLA – Land use in ha (different feedstocks)



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



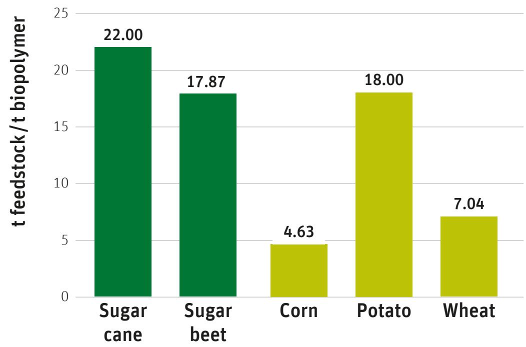
2.1.2 Polyhydroxybutyrate (PHB)



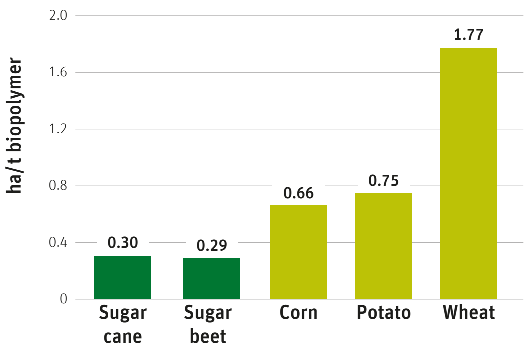
* **Conversion rates:**
Starch – Glucose 88 %
fermt. Sugar – PHB 35 %

References: Chen 2010; Endres & Siebert-Raths 2011; Iffland et al. 2015; Kootstra et al. 2017; Nakajima et al. 2017; Shen et al. 2009

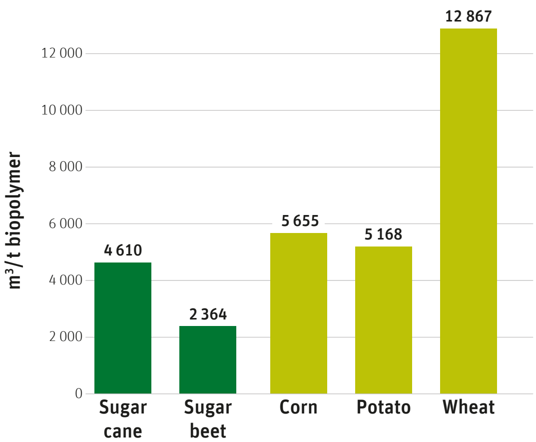
PHB – Feedstock requirements in t (different feedstocks)



PHB – Land use in ha (different feedstocks)

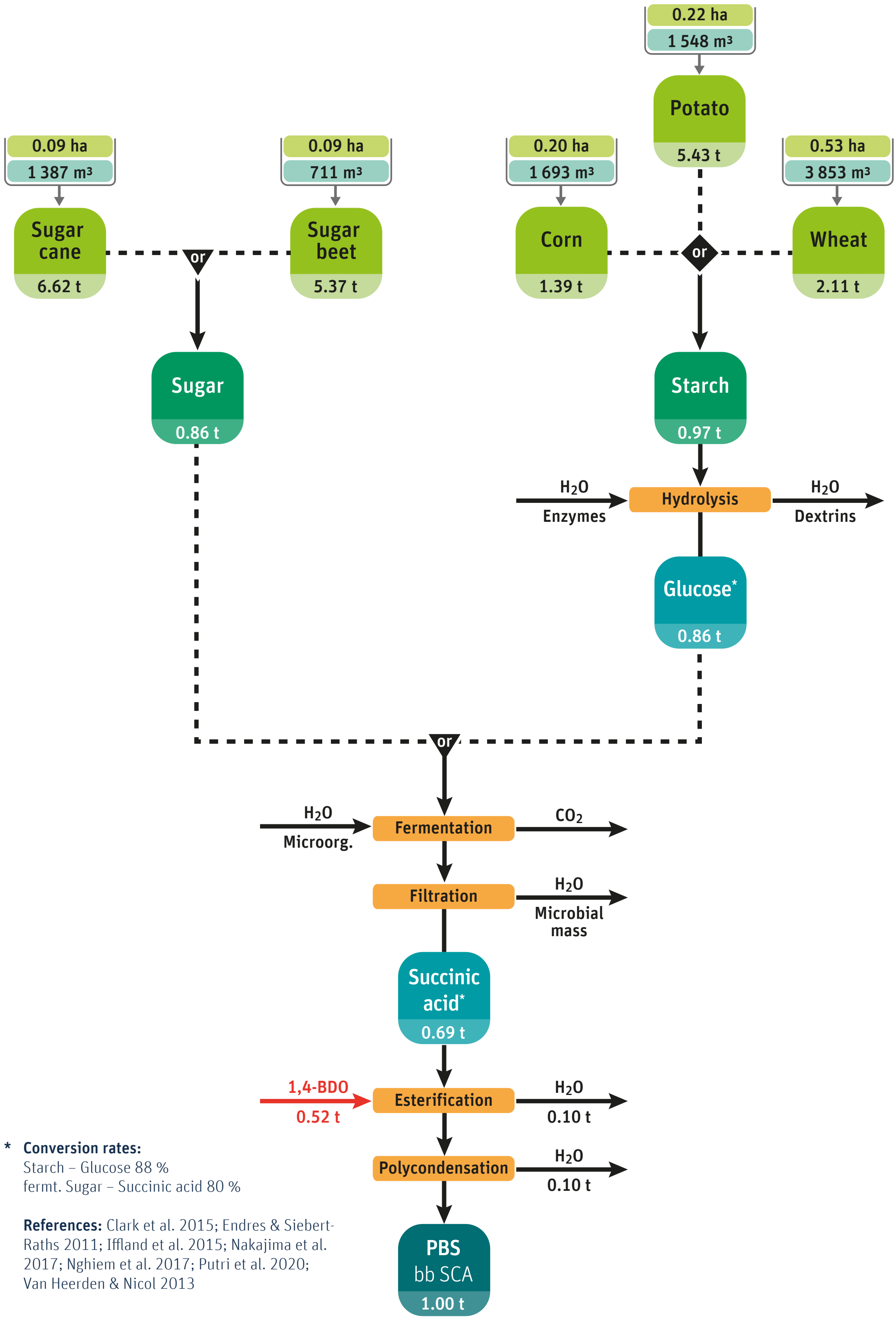


PHB – Water use in m³ (different feedstocks)



2.1.3 Polybutylene succinate (PBS)

with bio-based succinic acid (PBS bb SCA)

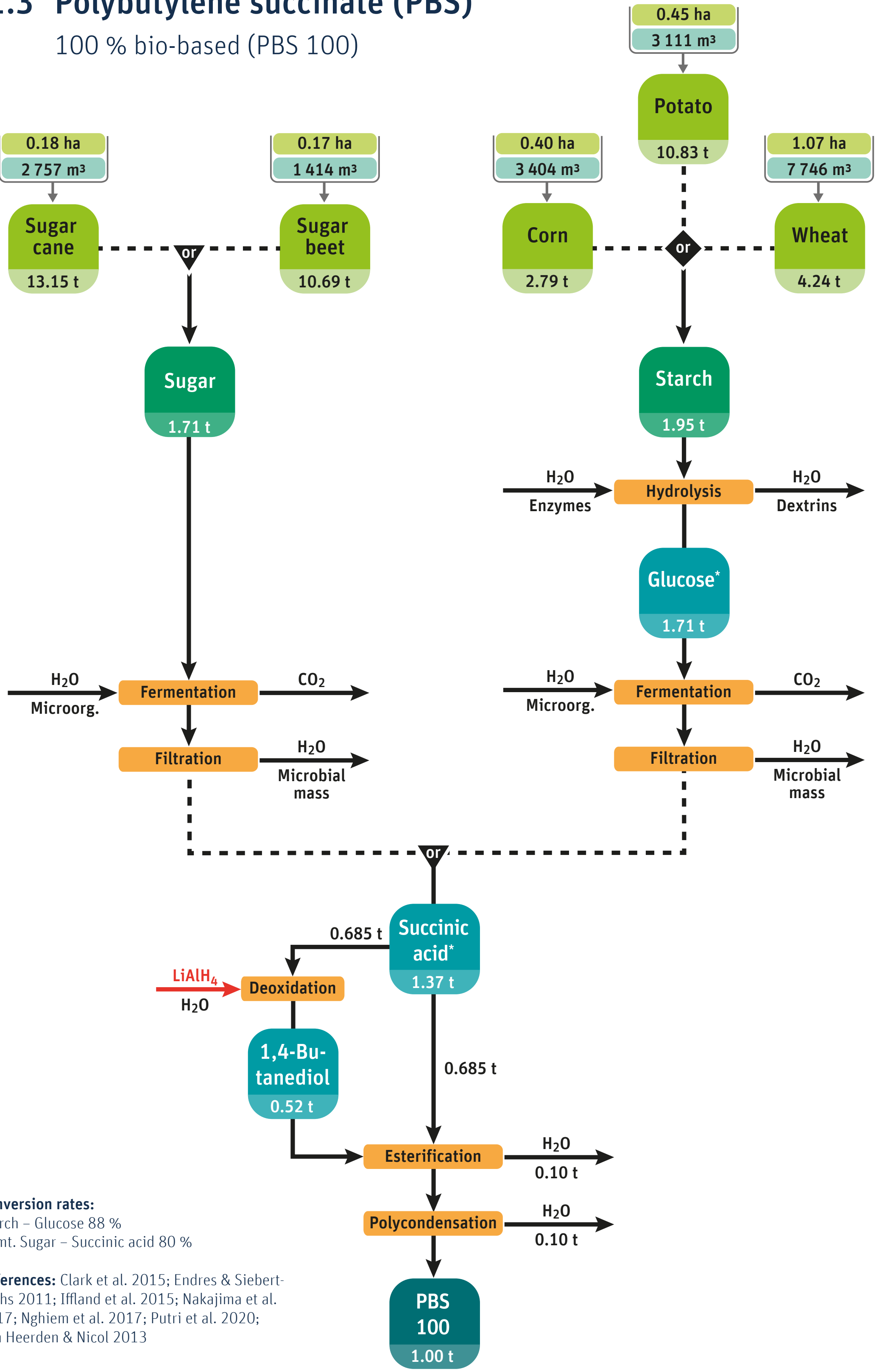


* **Conversion rates:**
Starch – Glucose 88 %
fermt. Sugar – Succinic acid 80 %

References: Clark et al. 2015; Endres & Siebert-Raths 2011; Iffland et al. 2015; Nakajima et al. 2017; Nghiem et al. 2017; Putri et al. 2020; Van Heerden & Nicol 2013

2.1.3 Polybutylene succinate (PBS)

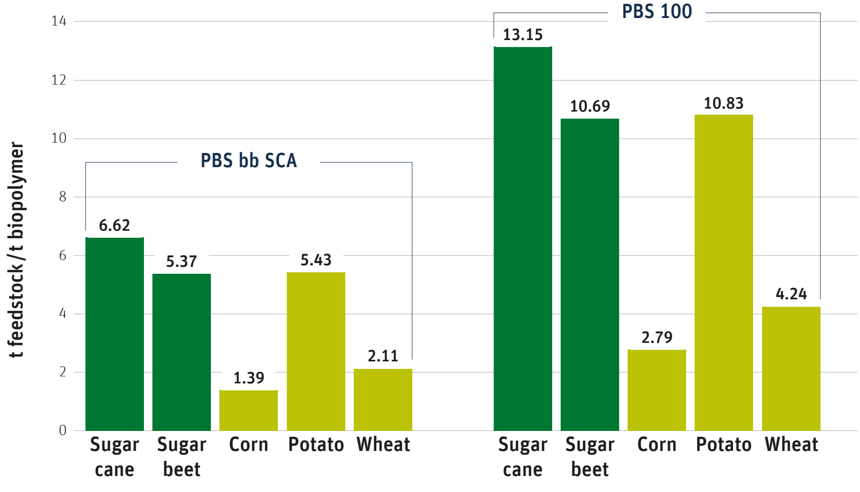
100 % bio-based (PBS 100)



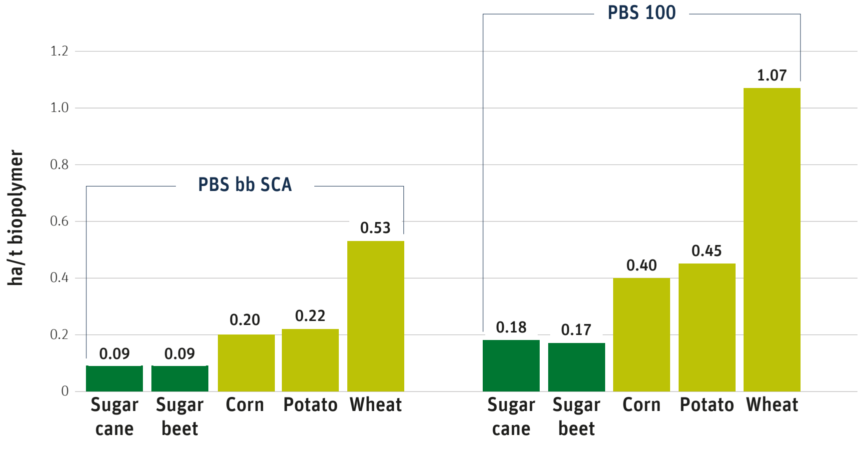
* **Conversion rates:**
Starch – Glucose 88 %
fermt. Sugar – Succinic acid 80 %

References: Clark et al. 2015; Endres & Siebert-Raths 2011; Iffland et al. 2015; Nakajima et al. 2017; Nghiem et al. 2017; Putri et al. 2020; Van Heerden & Nicol 2013

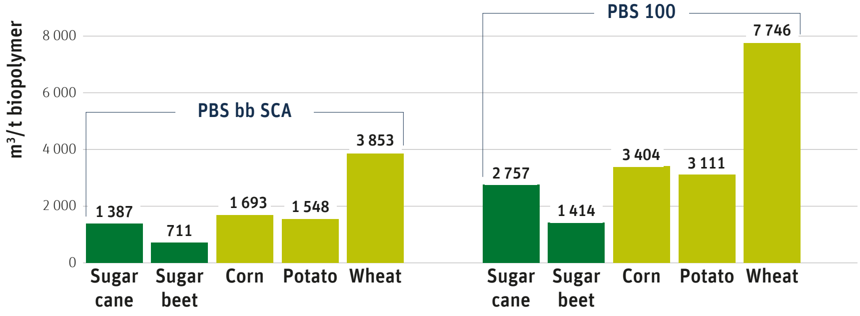
PBS variations – Feedstock requirements in t (different feedstocks)



PBS variations – Land use in ha (different feedstocks)

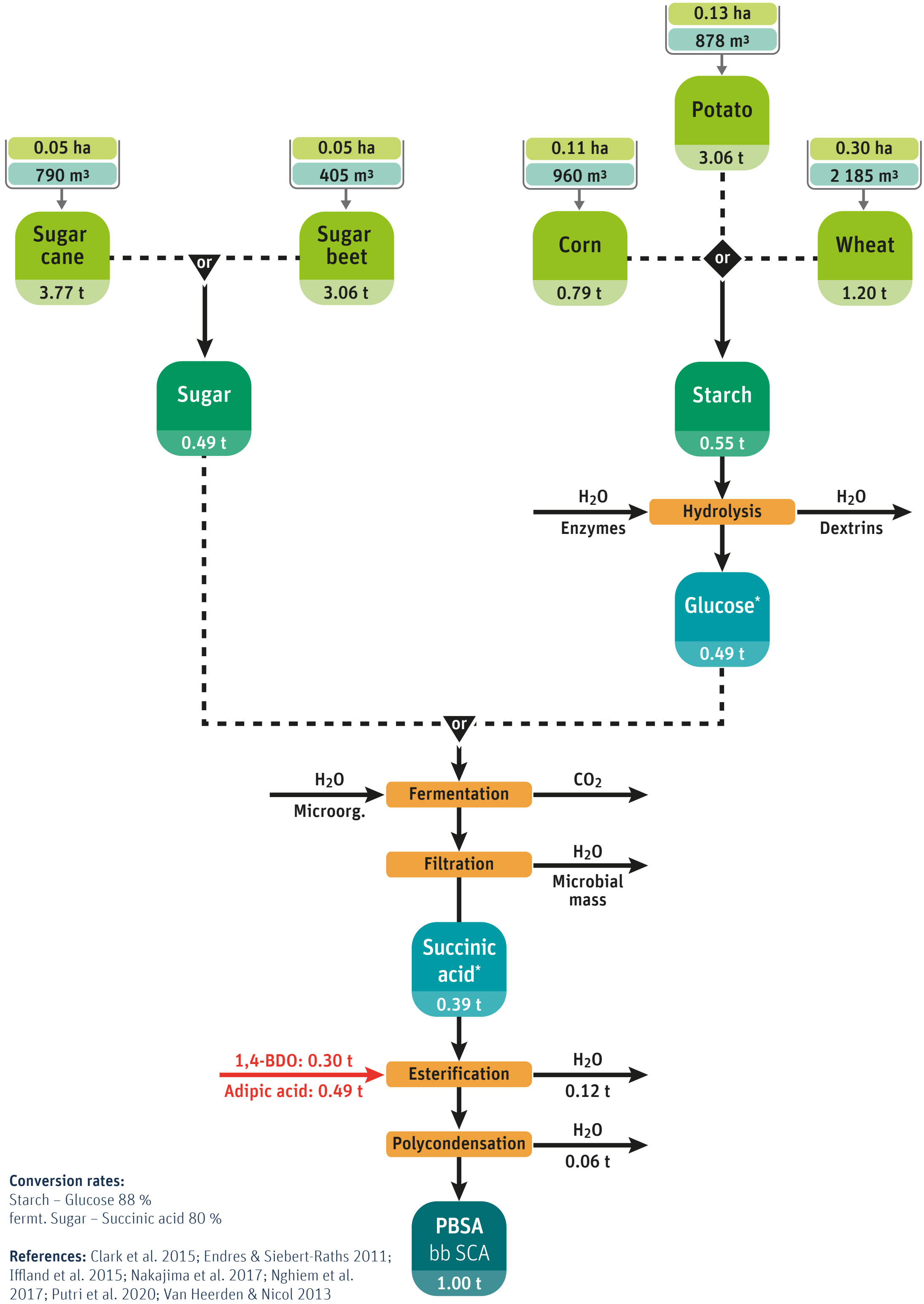


PBS variations – Water use in m³ (different feedstocks)



2.1.4 Polybutylene succinate adipate (PBSA)

with bio-based succinic acid (PBSA bb SCA)

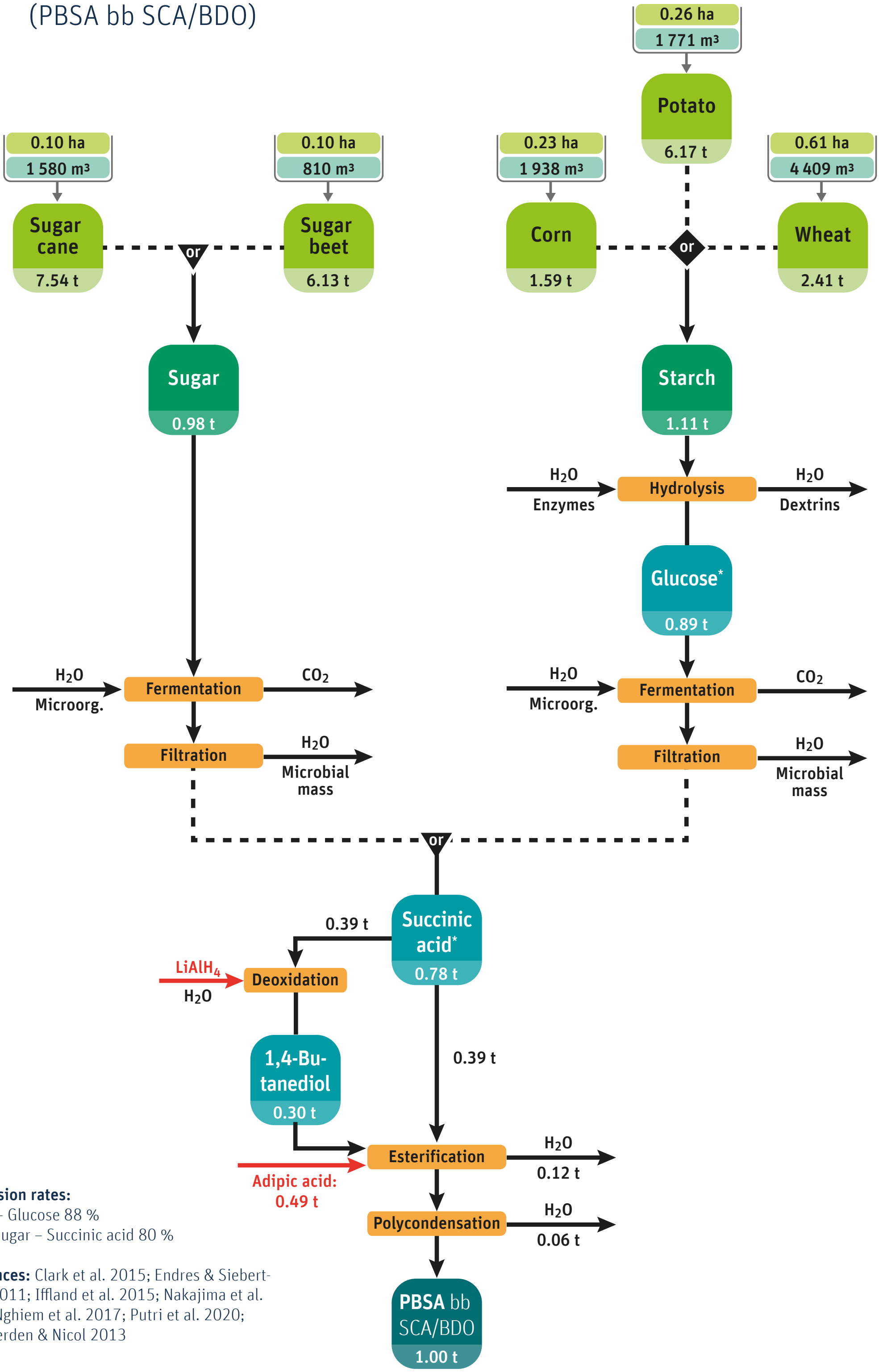


* **Conversion rates:**
Starch – Glucose 88 %
fermt. Sugar – Succinic acid 80 %

References: Clark et al. 2015; Endres & Siebert-Raths 2011; Iffland et al. 2015; Nakajima et al. 2017; Nghiem et al. 2017; Putri et al. 2020; Van Heerden & Nicol 2013

2.1.4 Polybutylene succinate adipate (PBSA)

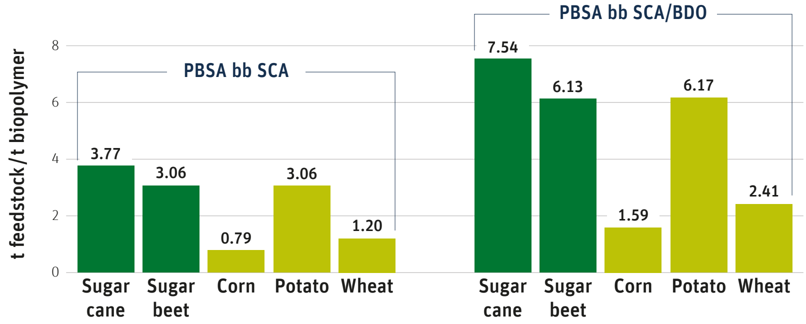
with bio-based succinic acid and 1,4-butanediol (PBSA bb SCA/BDO)



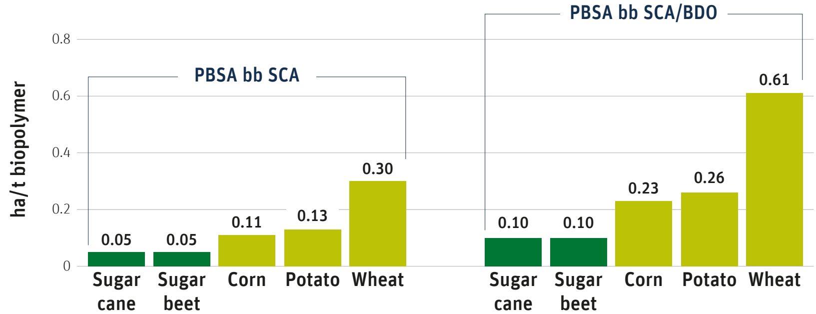
* **Conversion rates:**
Starch – Glucose 88 %
fermt. Sugar – Succinic acid 80 %

References: Clark et al. 2015; Endres & Siebert-Raths 2011; Iffland et al. 2015; Nakajima et al. 2017; Nghiem et al. 2017; Putri et al. 2020; Van Heerden & Nicol 2013

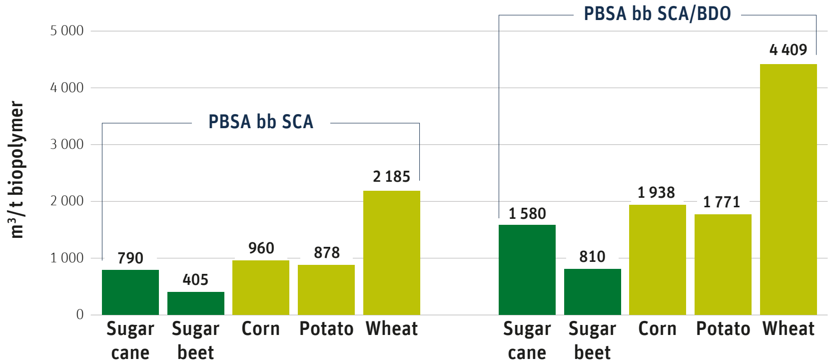
PBSA variations – Feedstock requirements in t
(different feedstocks)



PBSA variations – Land use in ha (different feedstocks)

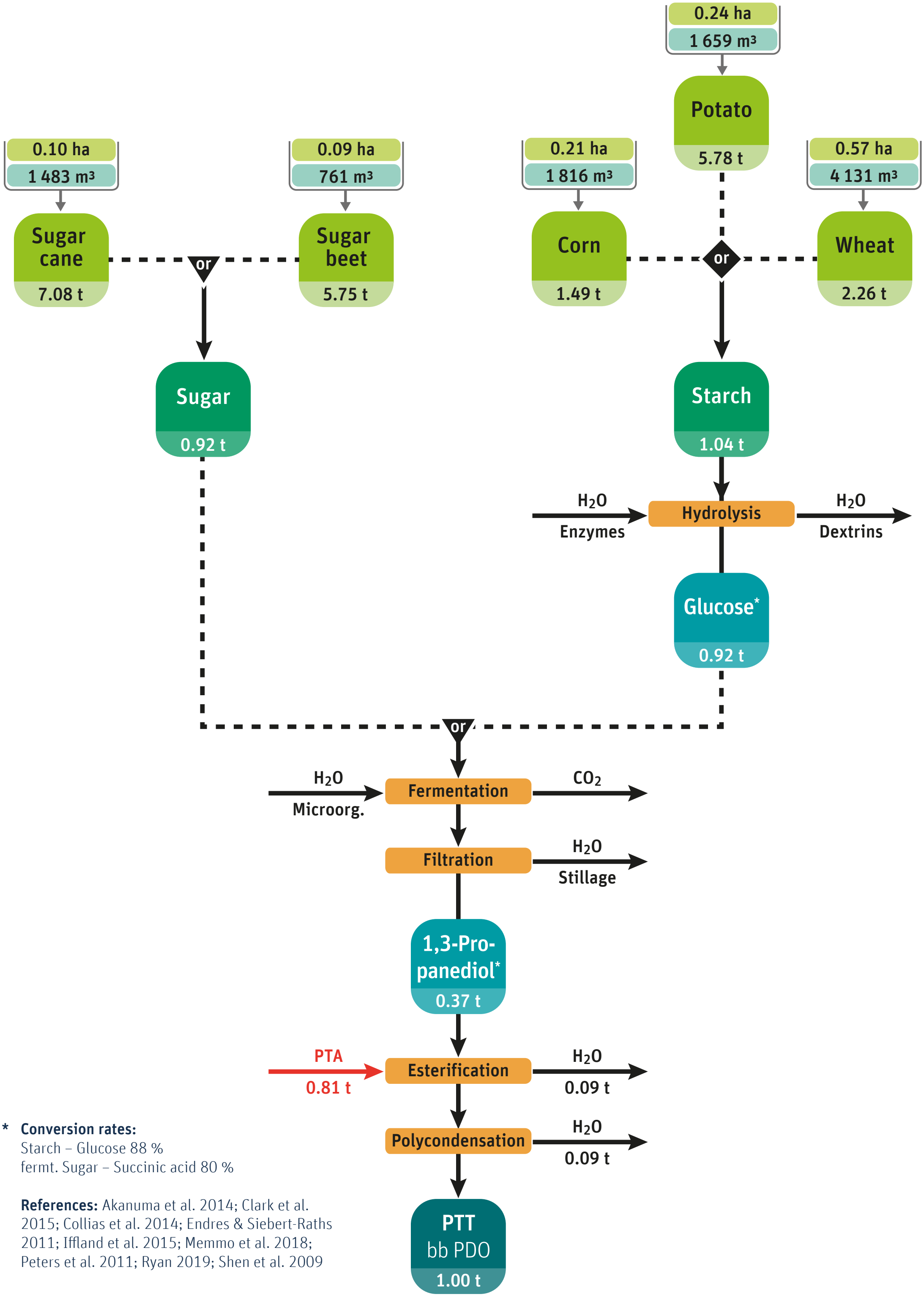


PBSA variations – Water use in m^3 (different feedstocks)



2.1.5 Polytrimethylene terephthalate (PTT)

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

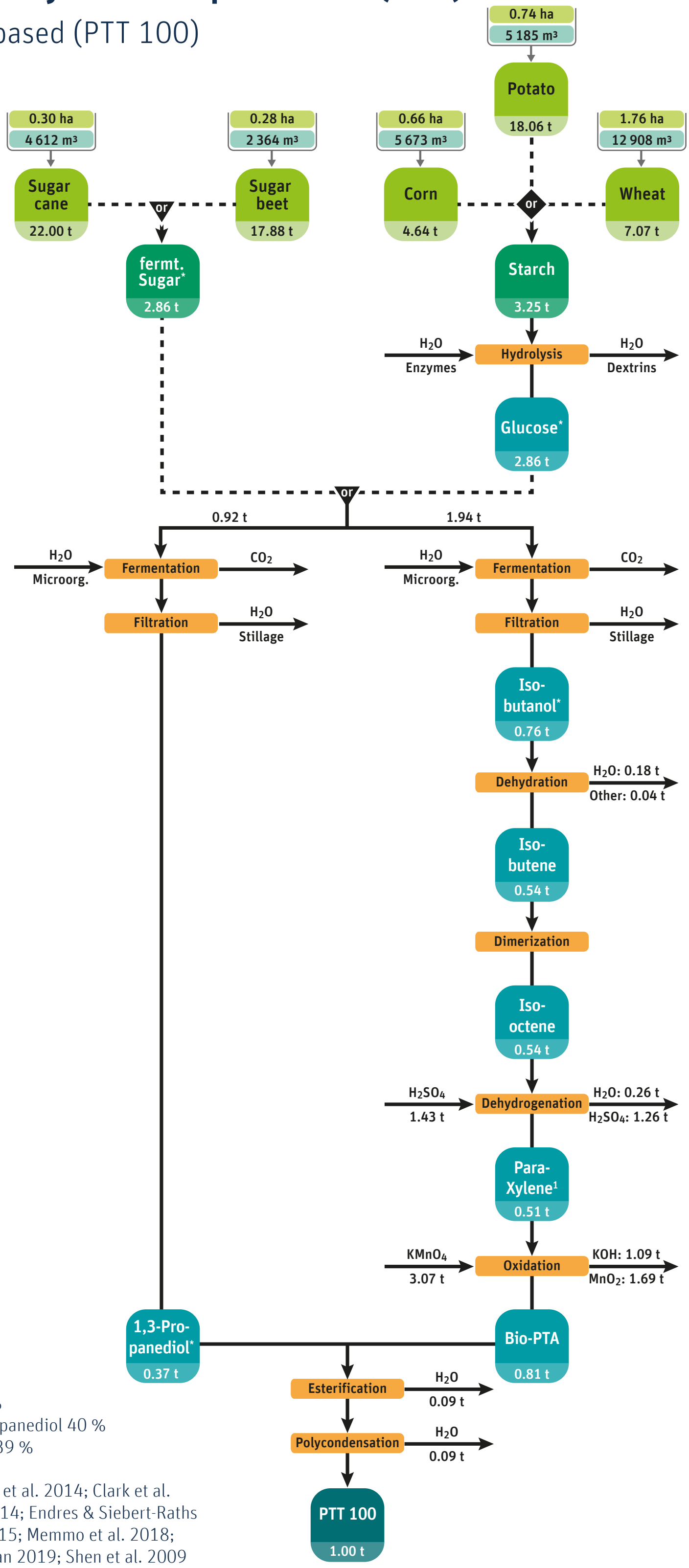


* **Conversion rates:**
Starch – Glucose 88 %
fermt. Sugar – Succinic acid 80 %

References: Akanuma et al. 2014; Clark et al. 2015; Collias et al. 2014; Endres & Siebert-Raths 2011; Iffland et al. 2015; Memmo et al. 2018; Peters et al. 2011; Ryan 2019; Shen et al. 2009

2.1.5 Polytrimethylene terephthalate (PTT)

100 % bio-based (PTT 100)

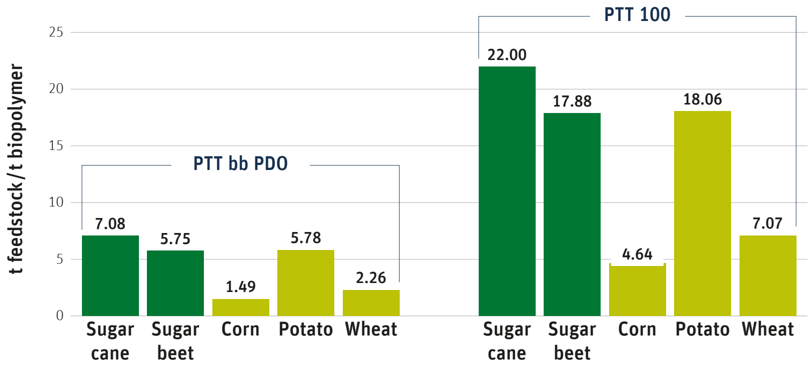


[1] GEVO-Process

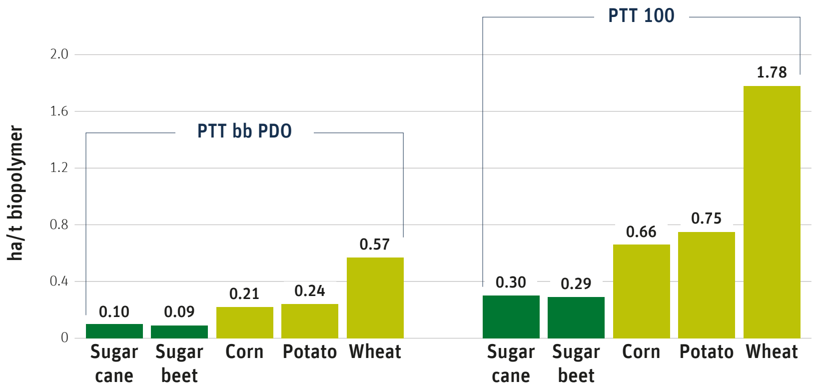
* **Conversion rates:**
Starch – Glucose 88 %
fermt. Sugar – 1,3-Propanediol 40 %
Glucose – Isobutanol 39 %

References: Akanuma et al. 2014; Clark et al. 2015; Collias et al. 2014; Endres & Siebert-Raths 2011; Iffland et al. 2015; Memmo et al. 2018; Peters et al. 2011; Ryan 2019; Shen et al. 2009

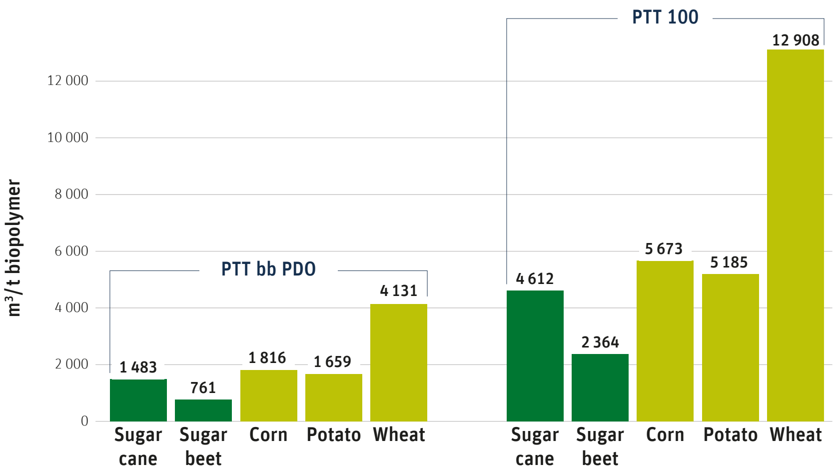
PTT variations – Feedstock requirements in t (different feedstocks)



PTT variations – Land use in ha (different feedstocks)

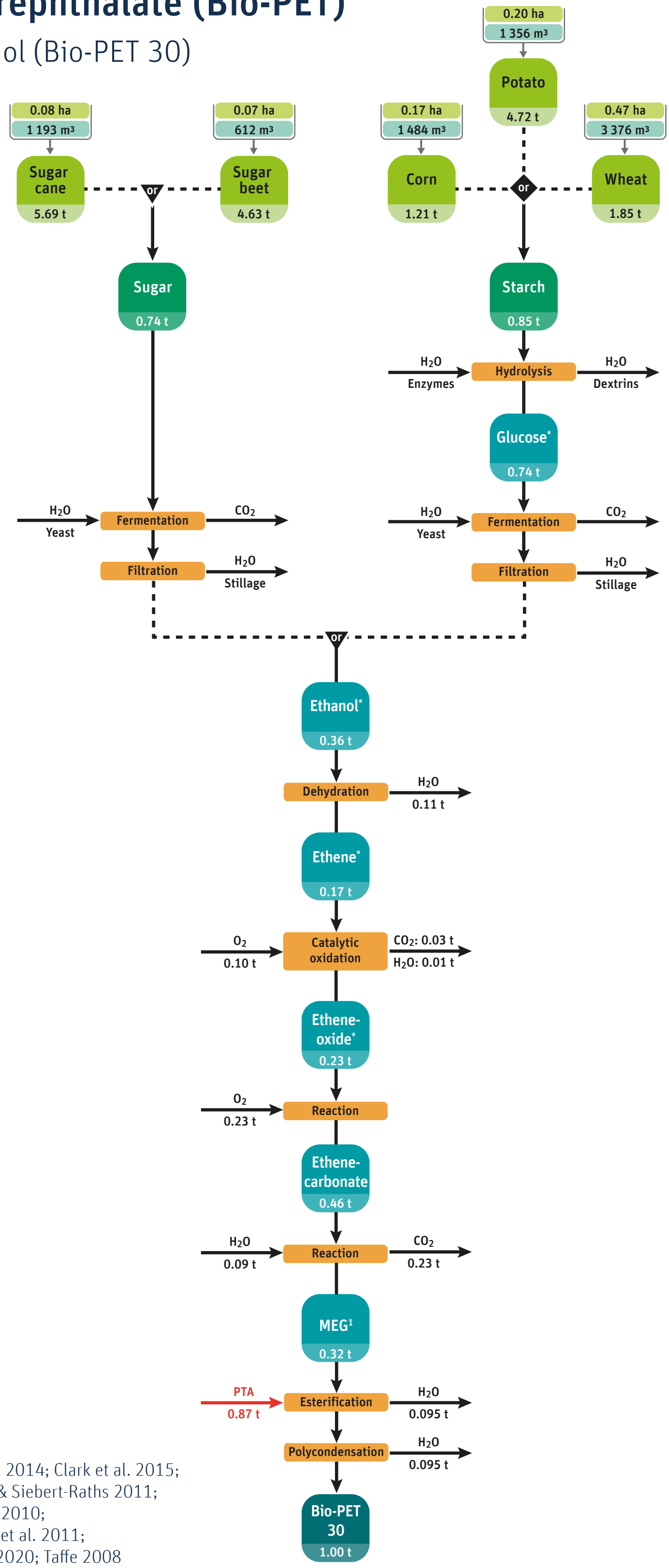


PTT variations – Water use in m³ (different feedstocks)



2.1.6 Polyethylene terephthalate (Bio-PET)

with bio-based ethanol (Bio-PET 30)



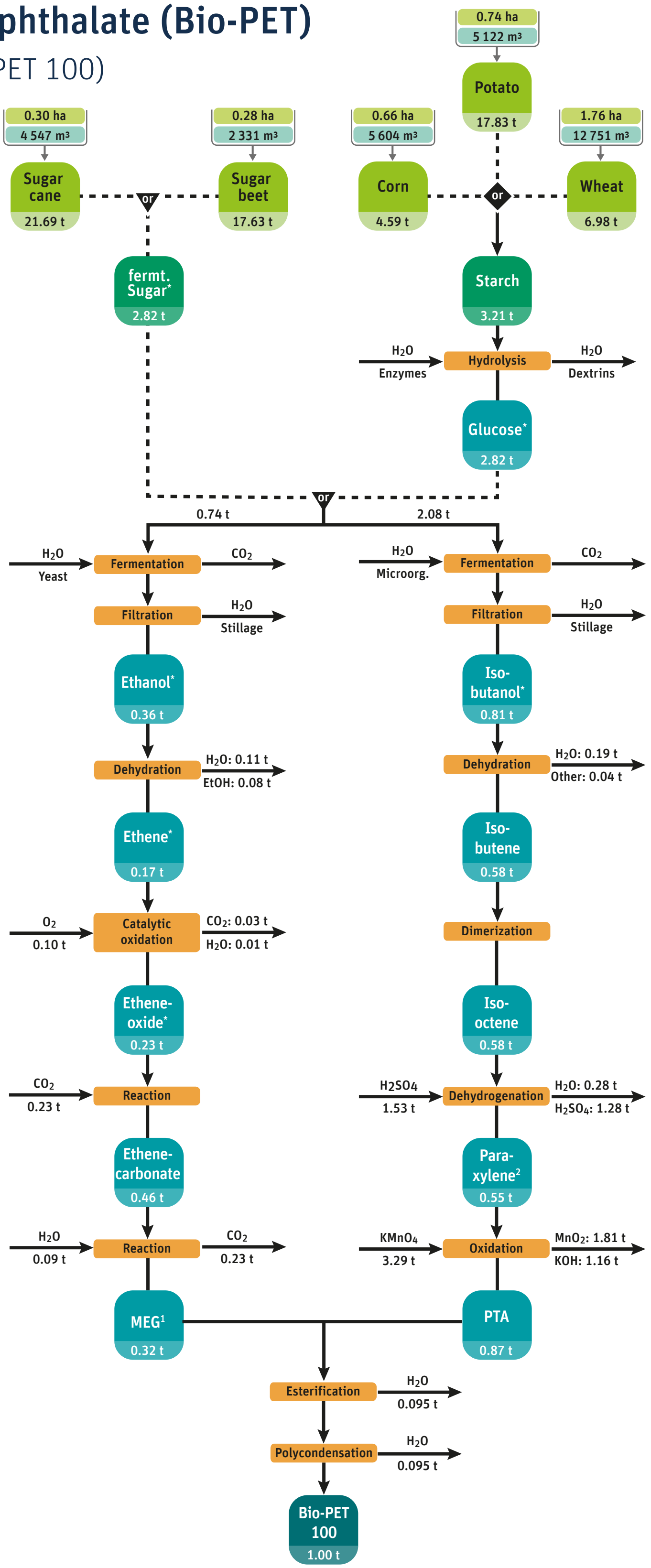
1 Omega-Process (Shell)

* **Conversion rates:**
Starch – Glucose 88 %
Glucose – Ethanol 48 %
Ethanol – Ethene 48 %
Ethene – Etheneoxide 85 %

References: Akanuma et al. 2014; Clark et al. 2015; Collias et al. 2014; Endres & Siebert-Raths 2011; Iffland et al. 2015; Kawabe 2010; Memmo et al. 2018; Peters et al. 2011; Ryan 2019; Siracusa et al. 2020; Taffe 2008

2.1.6 Polyethylene terephthalate (Bio-PET)

100 % bio-based (Bio-PET 100)

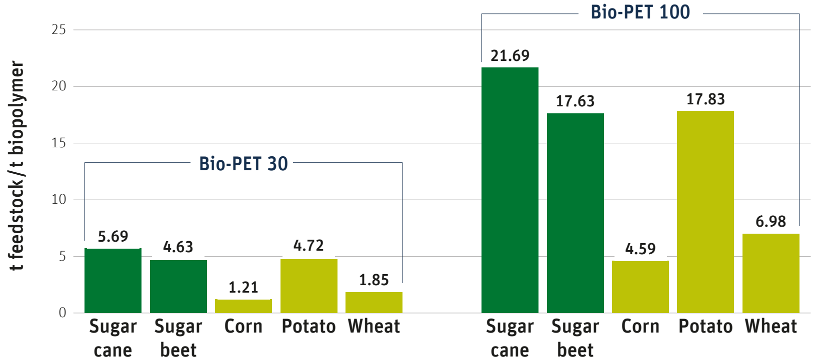


[1] Omega-Process (Shell)
[2] GEVO-Process

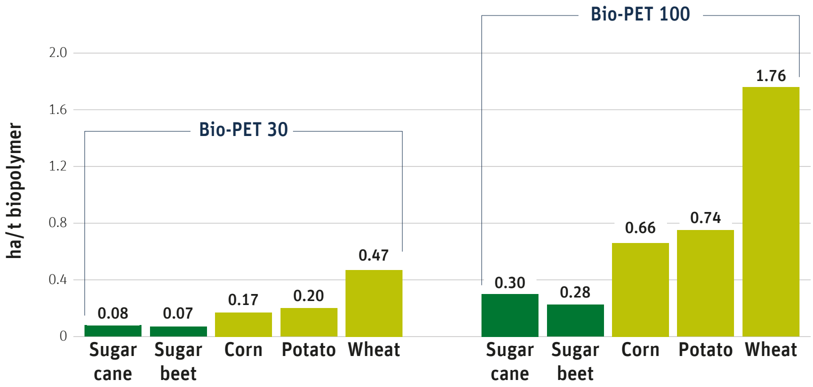
*** Conversion rates:**
Starch – Glucose 88 %
Glucose – Ethanol 48 %
Glucose – Isobutanol 39 %
Ethanol – Ethene 48 %
Ethene – Etheneoxide 85 %

References: Akanuma et al. 2014; Clark et al. 2015; Collias et al. 2014; Endres & Siebert-Raths 2011; Iffland et al. 2015; Kawabe 2010; Memmo et al. 2018; Peters et al. 2011; Ryan 2019; Siracusa et al. 2020; Taffe 2008

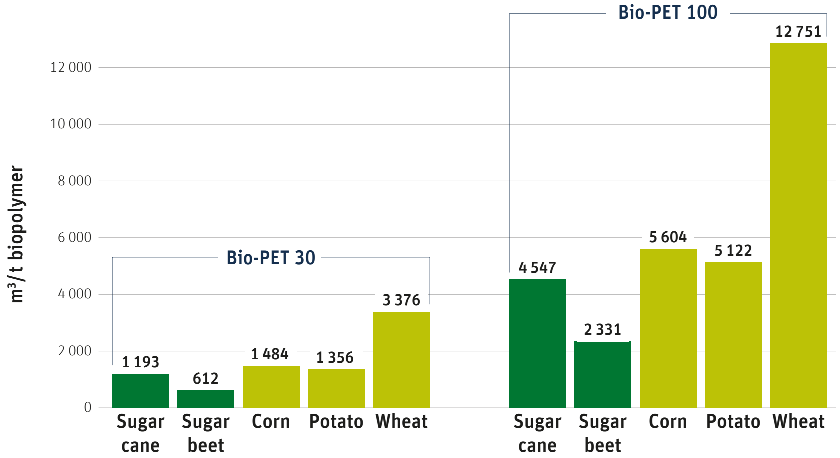
Bio-PET variations – Feedstock requirements in t
(different feedstocks)



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

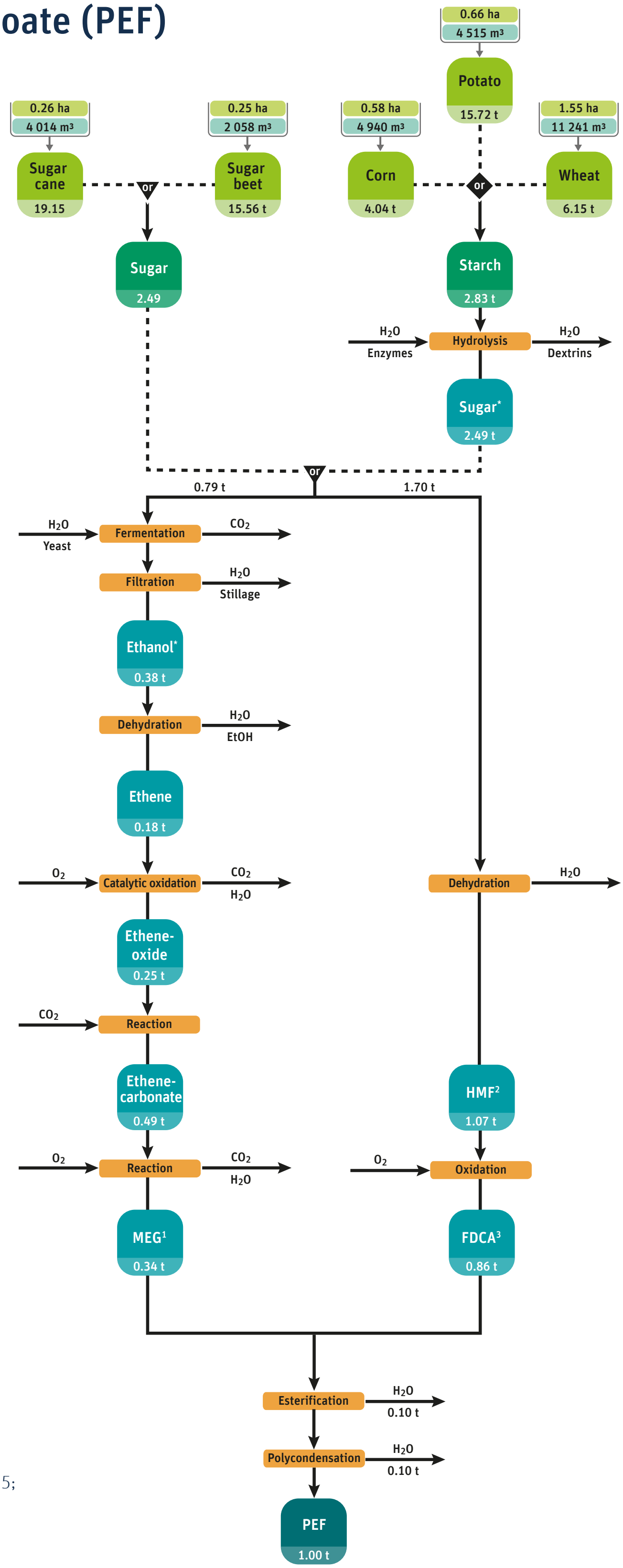


Bio-PET variations – Water use in m³ (different feedstocks)



2.1.7 Polyethylene furanoate (PEF)

100 % bio-based

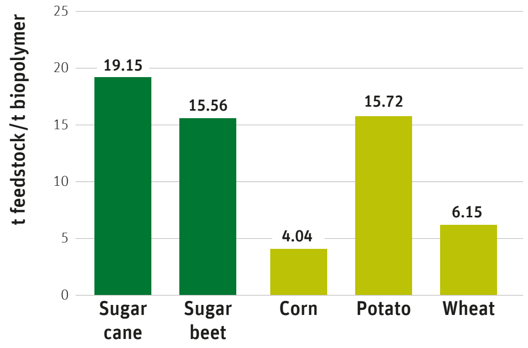


1 MEG = Ethylene glycol
2 Hydroxymethylfurfural
3 FDCA= 2,5-Furandicarboxylic acid

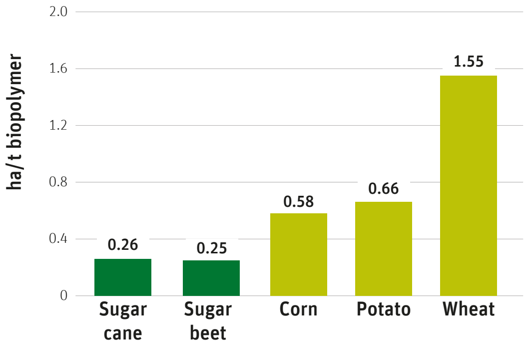
*** Conversion rates:**
Starch – Sugar 88 %
Glucose – Ethanol 48 %
Ethanol – Ethene 48 %
Ethene – Etheneoxide 85 %
HMF – FDCA 80 %
Sugar (Fructose) – HMF 63 %

References: Andreeßen 2019; Eerhart et al. 2012; Hajid et al. 2018; Hwang et al. 2020; Iffland et al. 2015; Kawabe 2010; Nakajima et al. 2017; Taffe 2008; Van Putten 2011

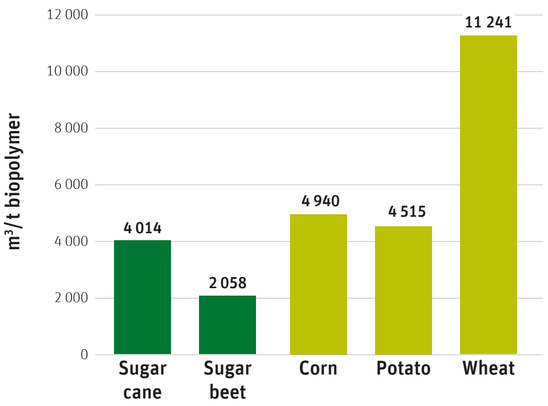
PEF – Feedstock requirements in t (different feedstocks)



PEF – Land use in ha (different feedstocks)

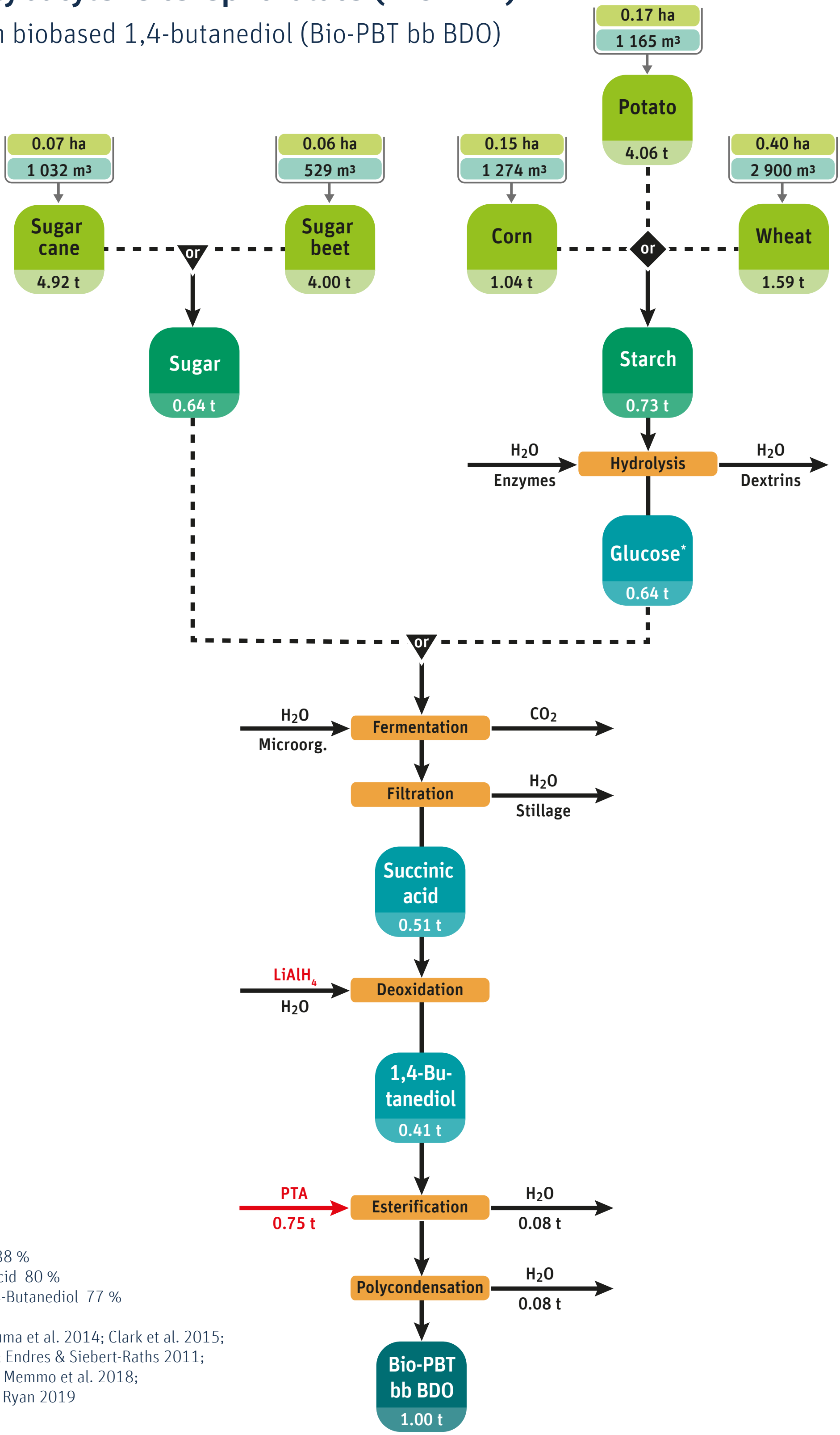


PEF – Water use in m^3 (different feedstocks)



2.1.8 Polybutylene terephthalate (Bio-PBT)

with biobased 1,4-butanediol (Bio-PBT bb BDO)

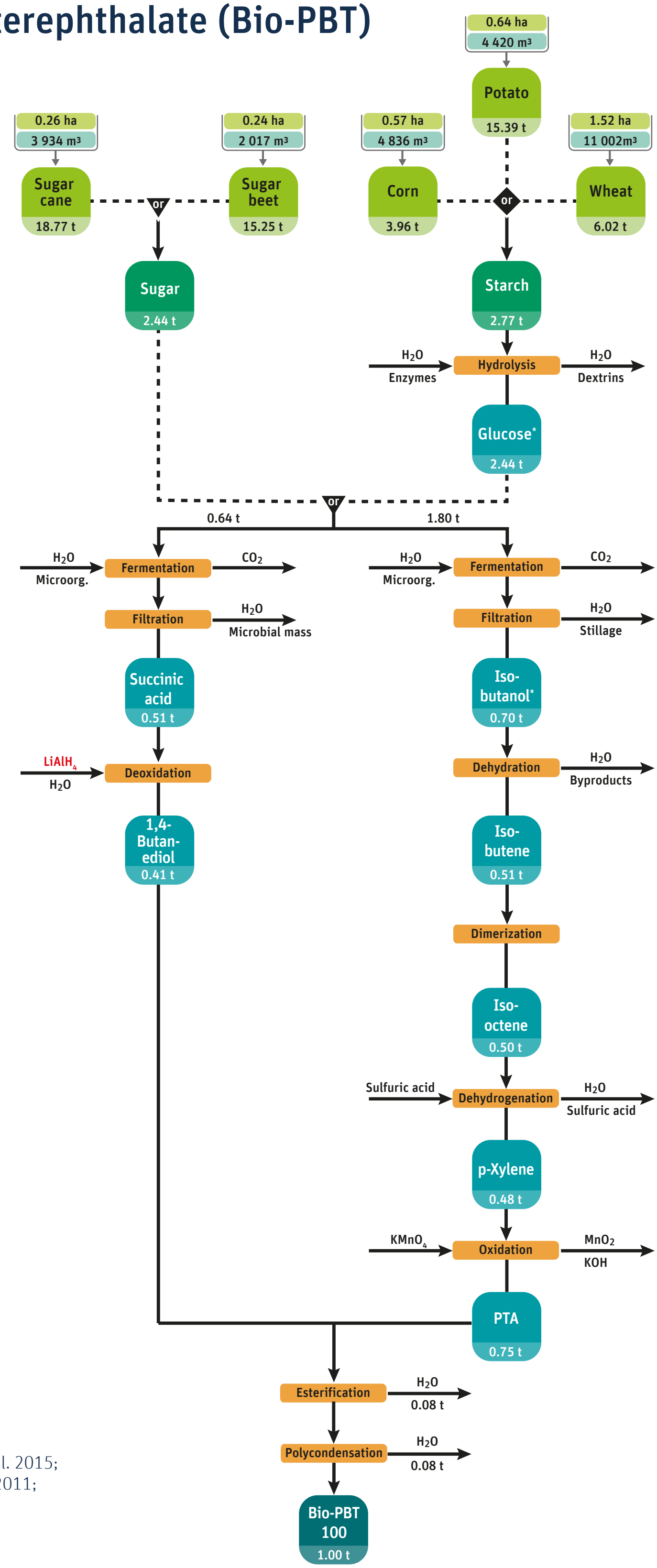


* **Conversion rates:**
Starch – Glucose 88 %
Sugar – Succinic acid 80 %
Succinic acid – 1,4-Butanediol 77 %

References: Akanuma et al. 2014; Clark et al. 2015; Collias et al. 2014; Endres & Siebert-Raths 2011; Iffland et al. 2015; Memmo et al. 2018; Peters et al. 2011; Ryan 2019

2.1.8 Polybutylene terephthalate (Bio-PBT)

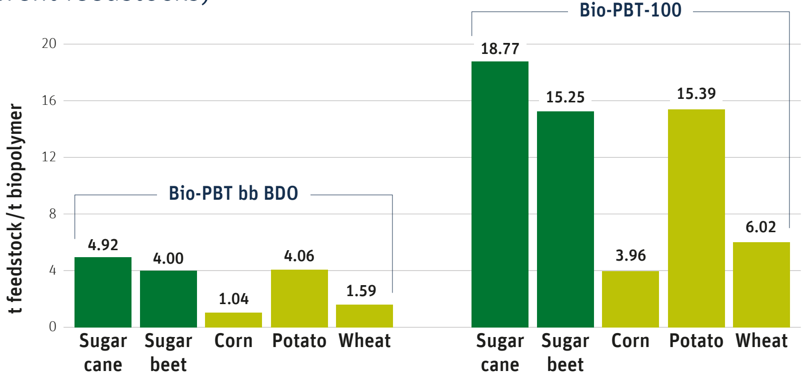
100% biobased



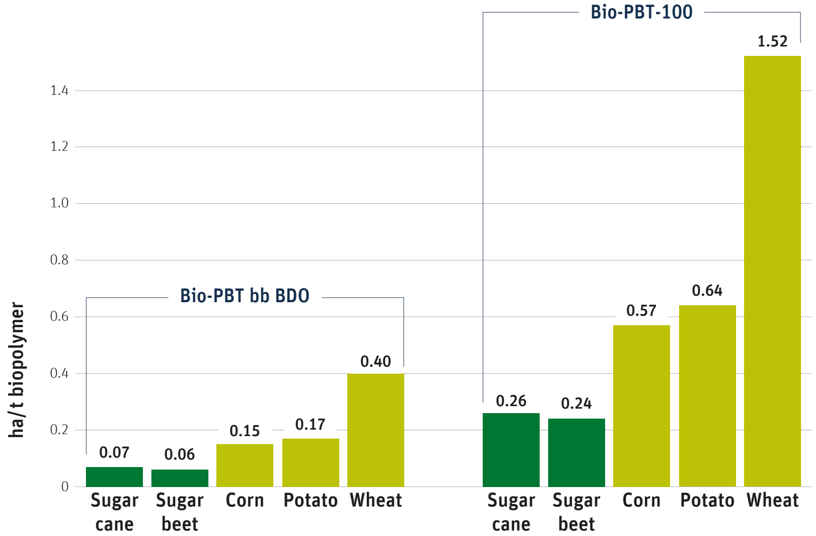
* **Conversion rates:**
Starch – Glucose 88 %
Glucose – Isobutanol 39 %
Isobutanol – p-Xylene 68 %
Sugar– Succinic acid 80 %
Succinic acid – 1,4 Butanediol 77 %

References: Akanuma et al. 2014; Clark et al. 2015; Collias et al. 2014; Endres & Siebert-Raths 2011; Iffland et al. 2015; Memmo et al. 2018; Peters et al. 2011; Ryan 2019

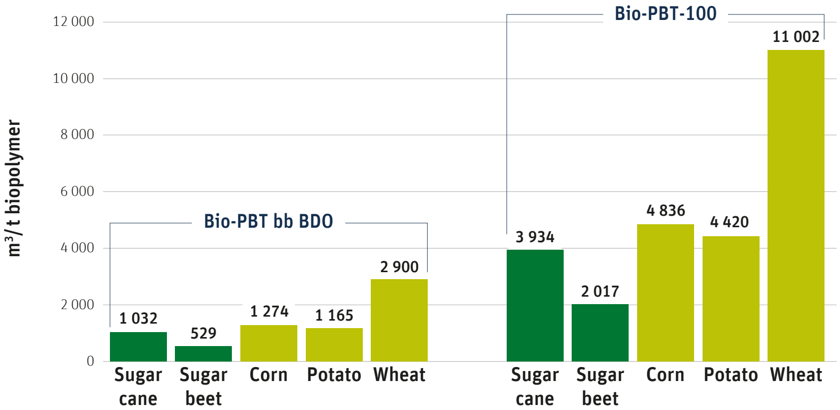
Bio-PBT variations – Feedstock requirements in t
(different feedstocks)



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

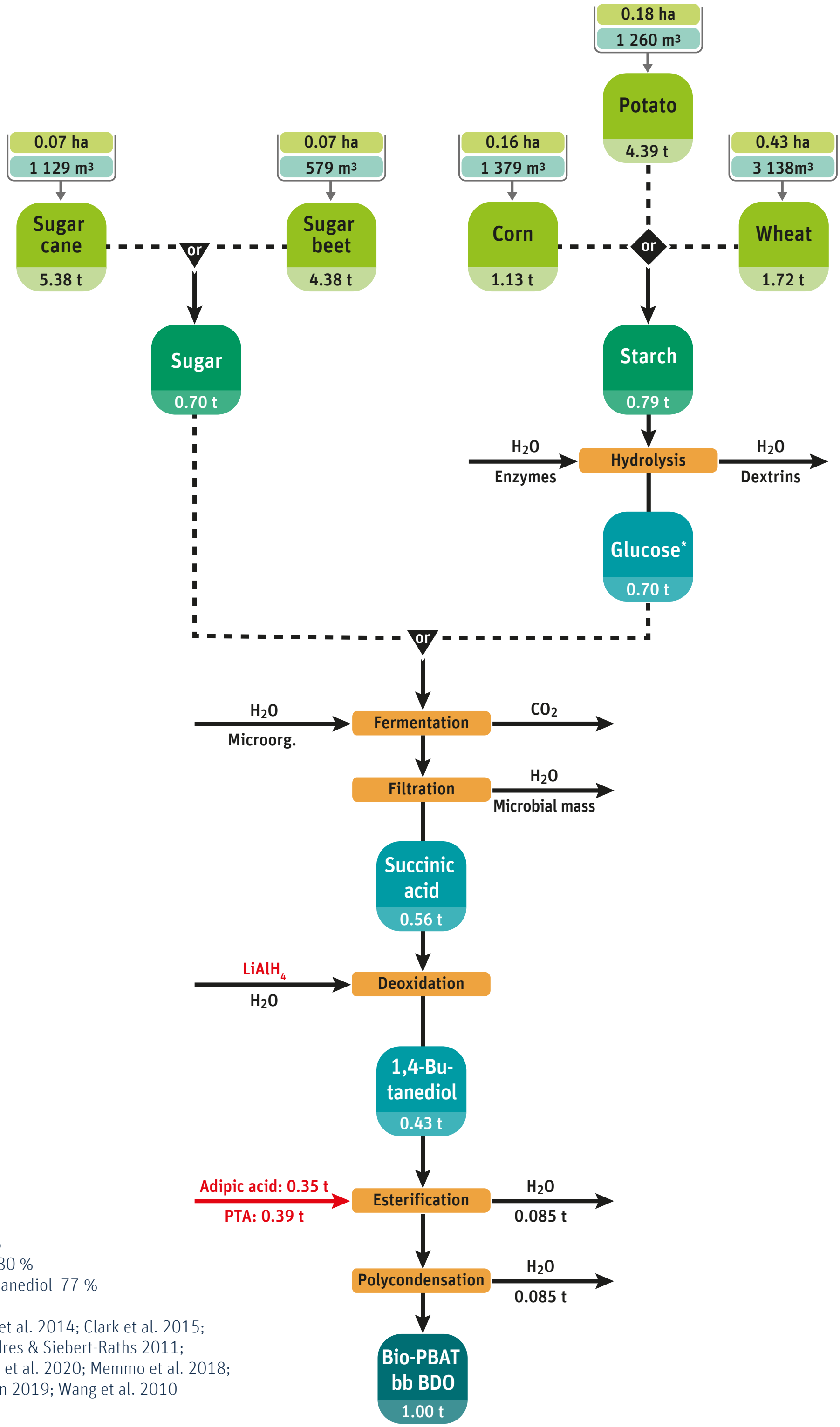


Bio-PBT variations – Water use in m³ (different feedstocks)



2.1.9 Polybutylene adipate terephthalate (Bio-PBAT)

with biobased 1,4-butanediol (Bio-PBAT bb BDO)

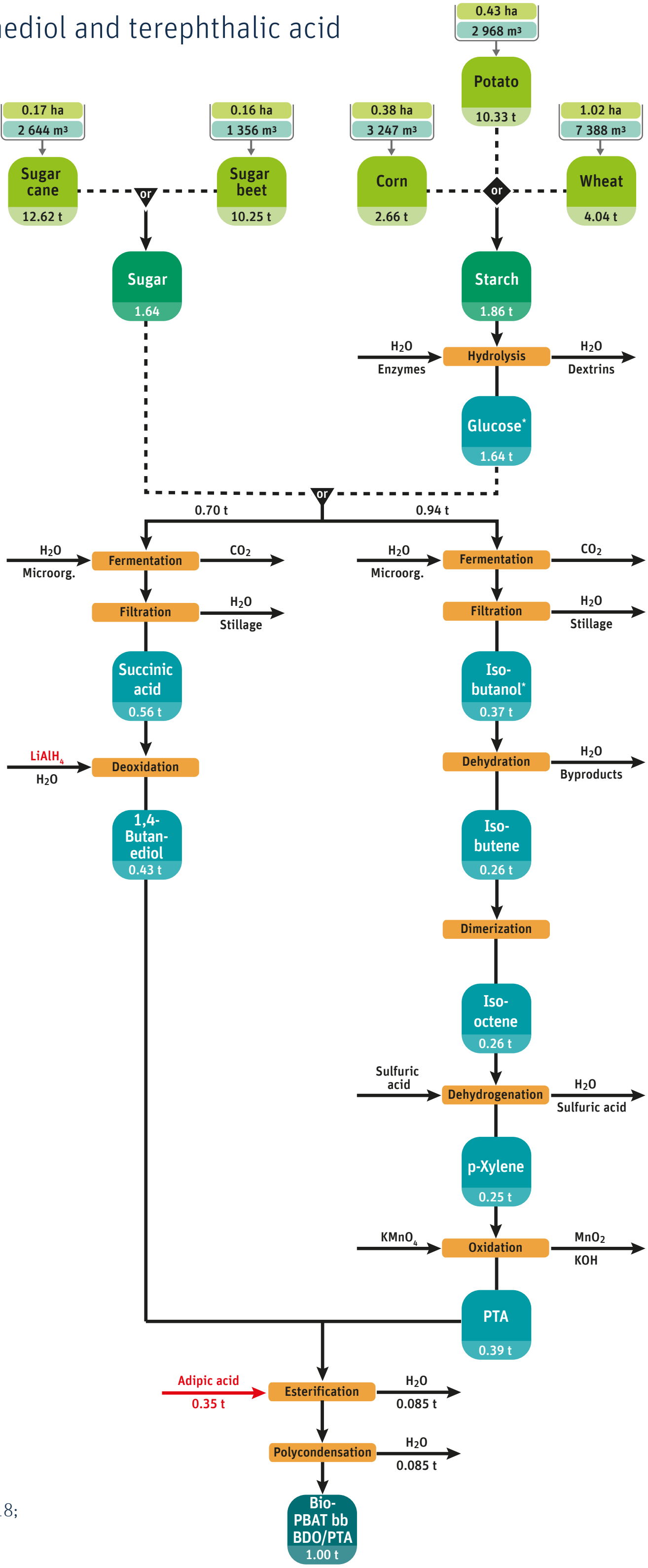


* **Conversion rates:**
Starch – Glucose 88 %
Sugar – Succinic acid 80 %
Succinic acid – 1,4-Butanediol 77 %

References: Akanuma et al. 2014; Clark et al. 2015; Collias et al. 2014; Endres & Siebert-Raths 2011; Iffland et al. 2015; Jian et al. 2020; Memmo et al. 2018; Peters et al. 2011; Ryan 2019; Wang et al. 2010

2.1.9 Polybutylene adipate terephthalate (Bio-PBAT)

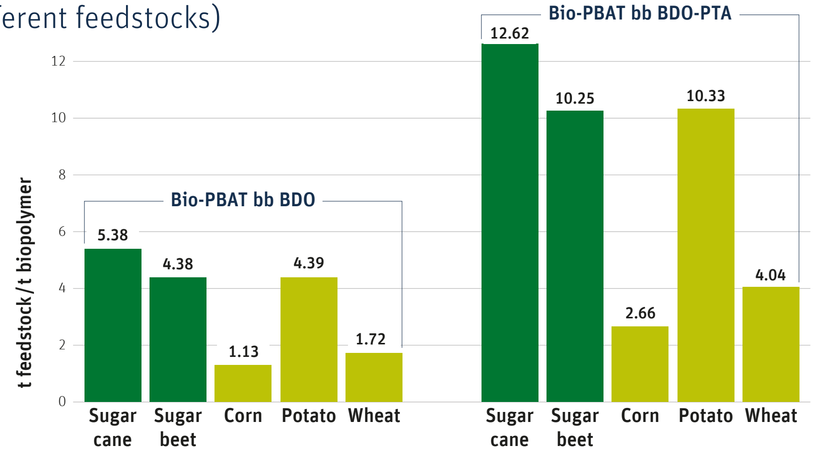
with biobased 1,4-butanediol and terephthalic acid (Bio-PBAT bb BDO/PTA)



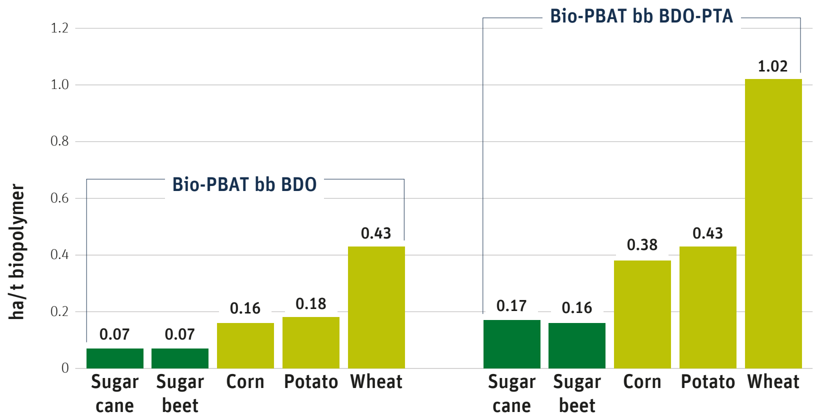
* **Conversion rates:**
Starch – Glucose 88 %
Glucose – Isobutanlo 39 %
Isobutanol– p-Xylene 68 %
Sugar– Succinic acid 80 %
Succinic acid – 1,4 Butanediol 77 %

References: Akanuma et al. 2014; Clark et al. 2015; Collias et al. 2014; Endres & Siebert-Raths 2011; Iffland et al. 2015; Jian et al. 2020; Memmo et al. 2018; Peters et al. 2011; Ryan 2019; Wang et al. 2010

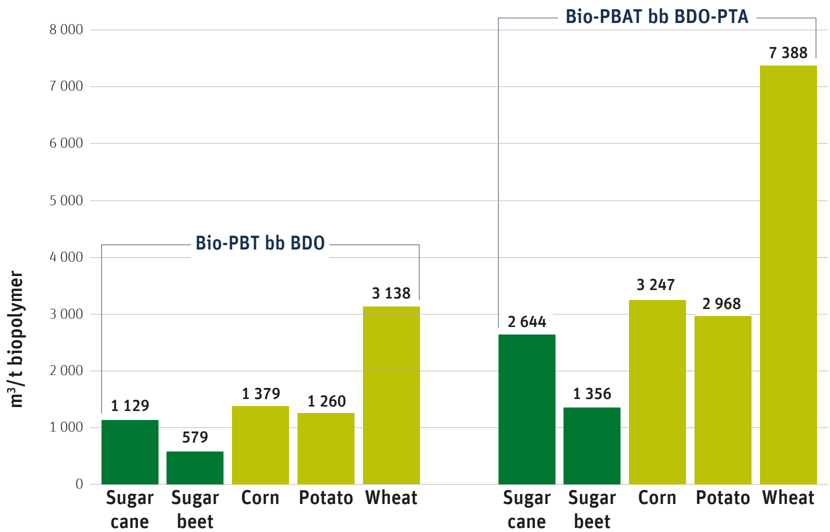
Bio-PBAT variations – Feedstock requirements in t
(different feedstocks)



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

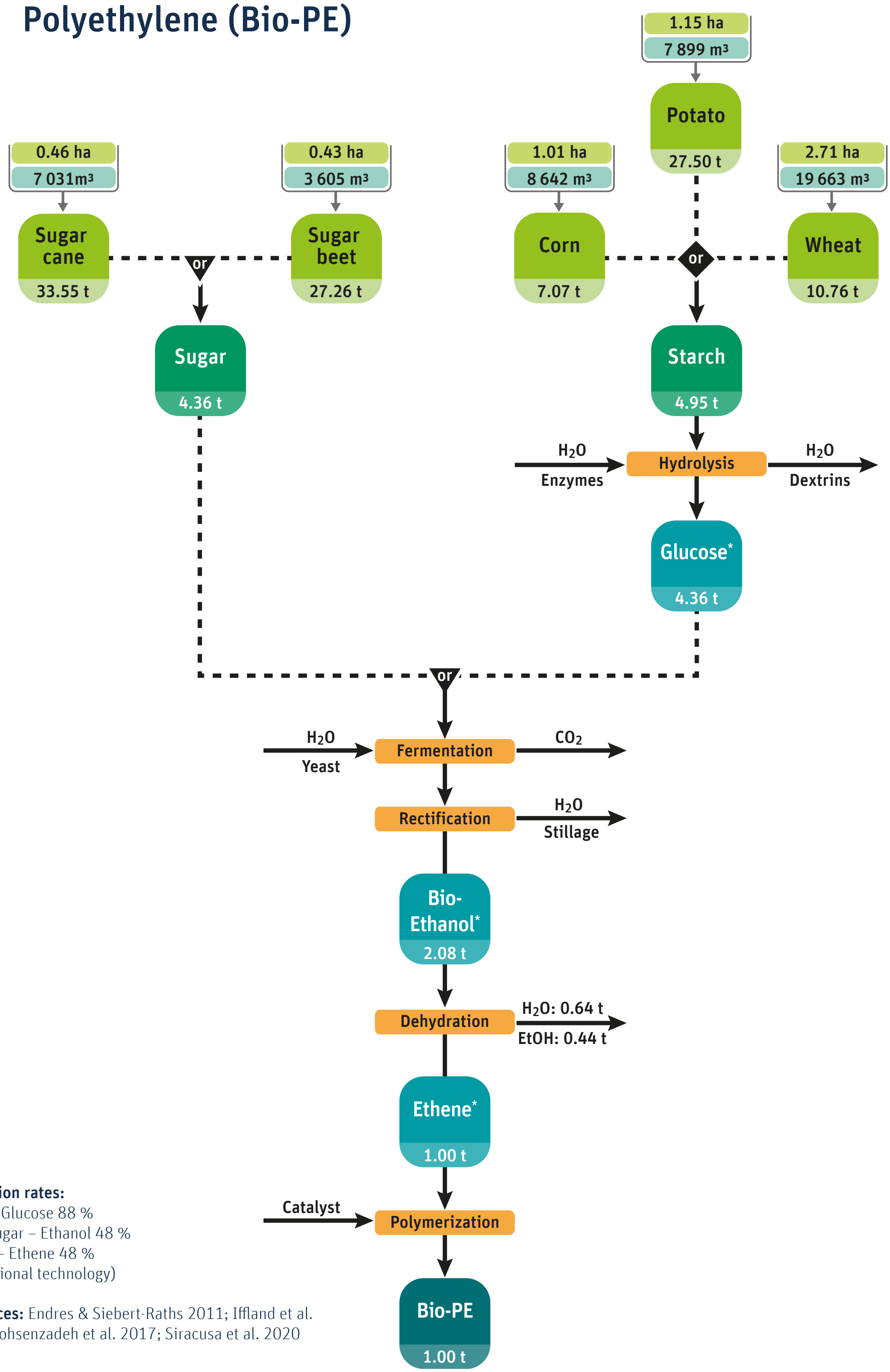


Bio-PBAT variations – Water use in m^3 (different feedstocks)



2.2 Bio-based polyolefins

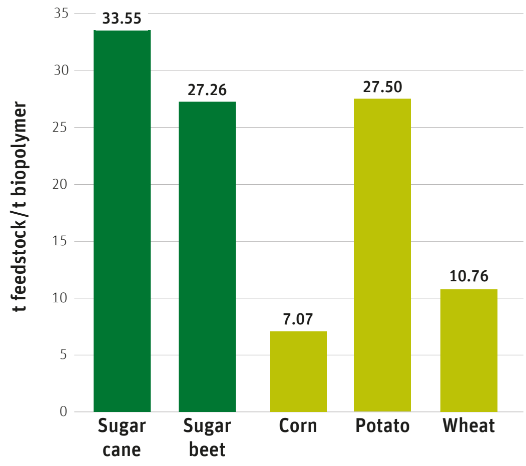
2.2.1 Polyethylene (Bio-PE)



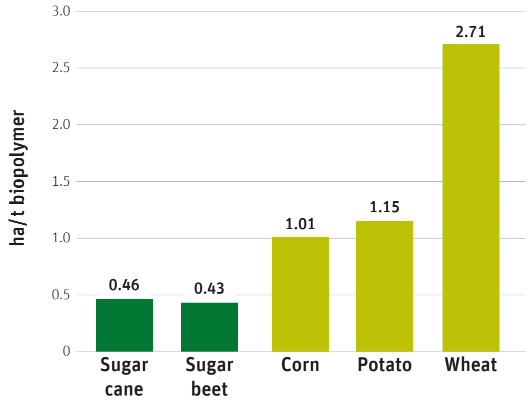
* **Conversion rates:**
Starch – Glucose 88 %
fermt. Sugar – Ethanol 48 %
Ethanol – Ethene 48 %
(conventional technology)

References: Endres & Siebert-Raths 2011; Iffland et al. 2015; Mohsenzadeh et al. 2017; Siracusa et al. 2020

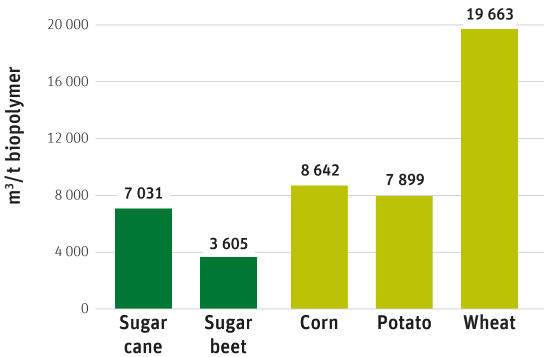
Bio-PE – Feedstock requirements in t (different feedstocks)



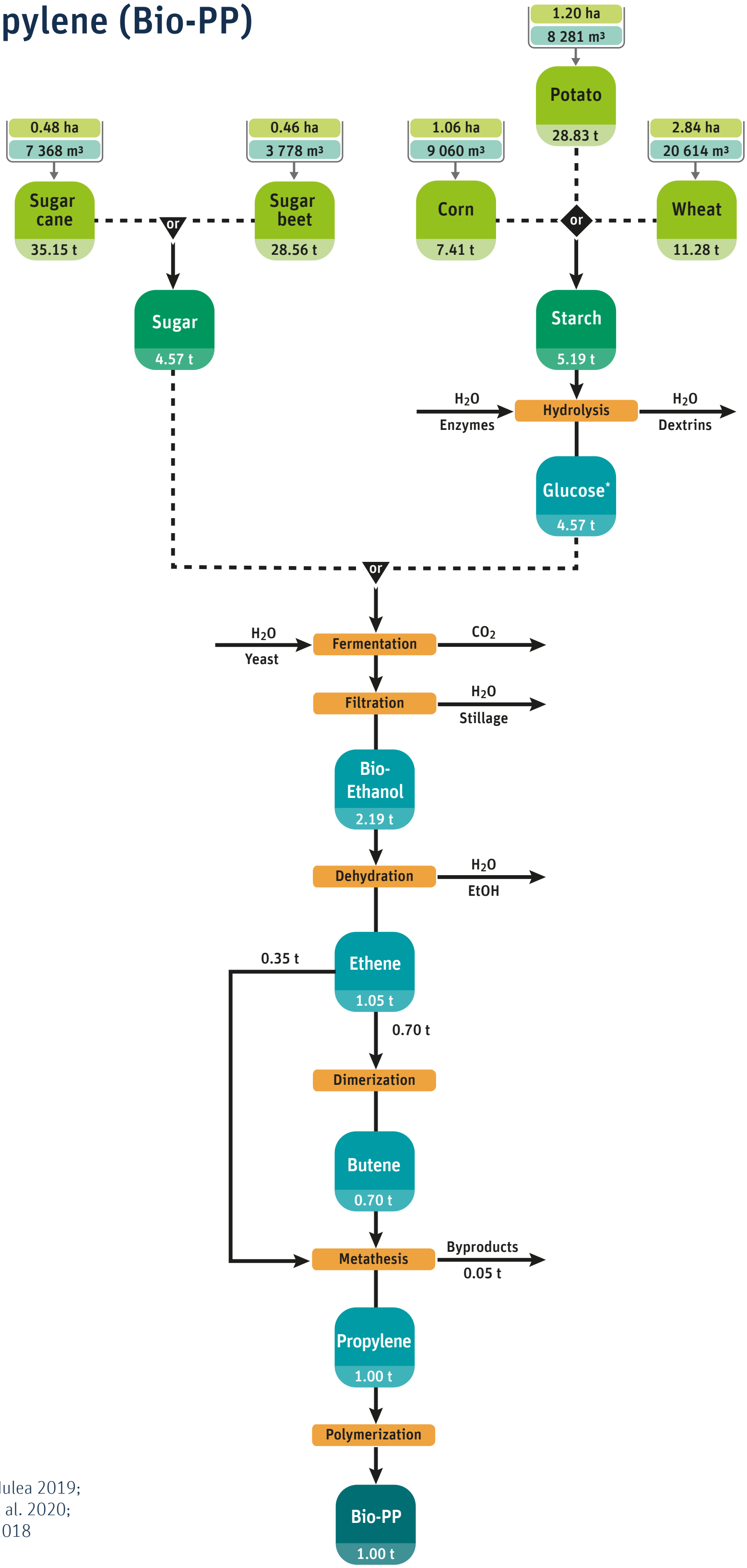
Bio-PE – Land use in ha (different feedstocks)



Bio-PE – Water use in m³ (different feedstocks)



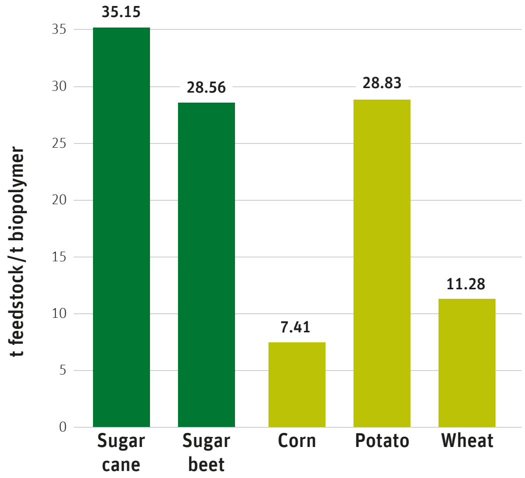
2.2.2 Polypropylene (Bio-PP)



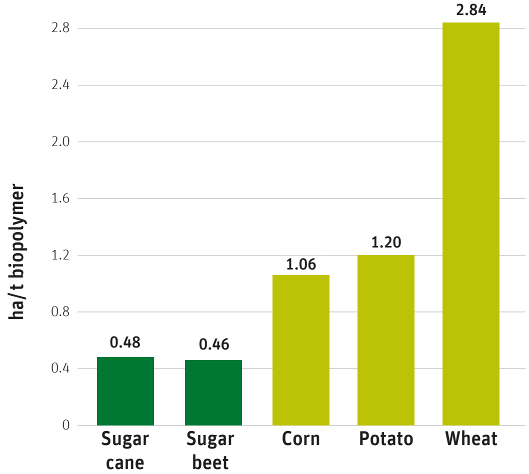
* **Conversion rates:**
Starch – Glucose 88 %
Glucose – Ethanol 48 %
Ethanol – Ethene 48 %
Butene – Propylene 68 %

References: Andreeßen 2019; Hulea 2019; Mahdaviani et al. 2010; Nessi et al. 2020; Siracusa et al. 2020; Zou et al. 2018

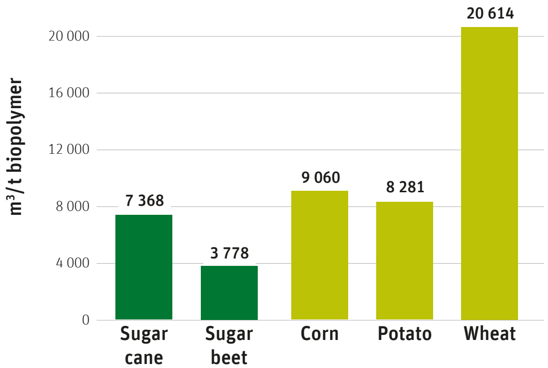
Bio-PP – Feedstock requirements in t (different feedstocks)



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



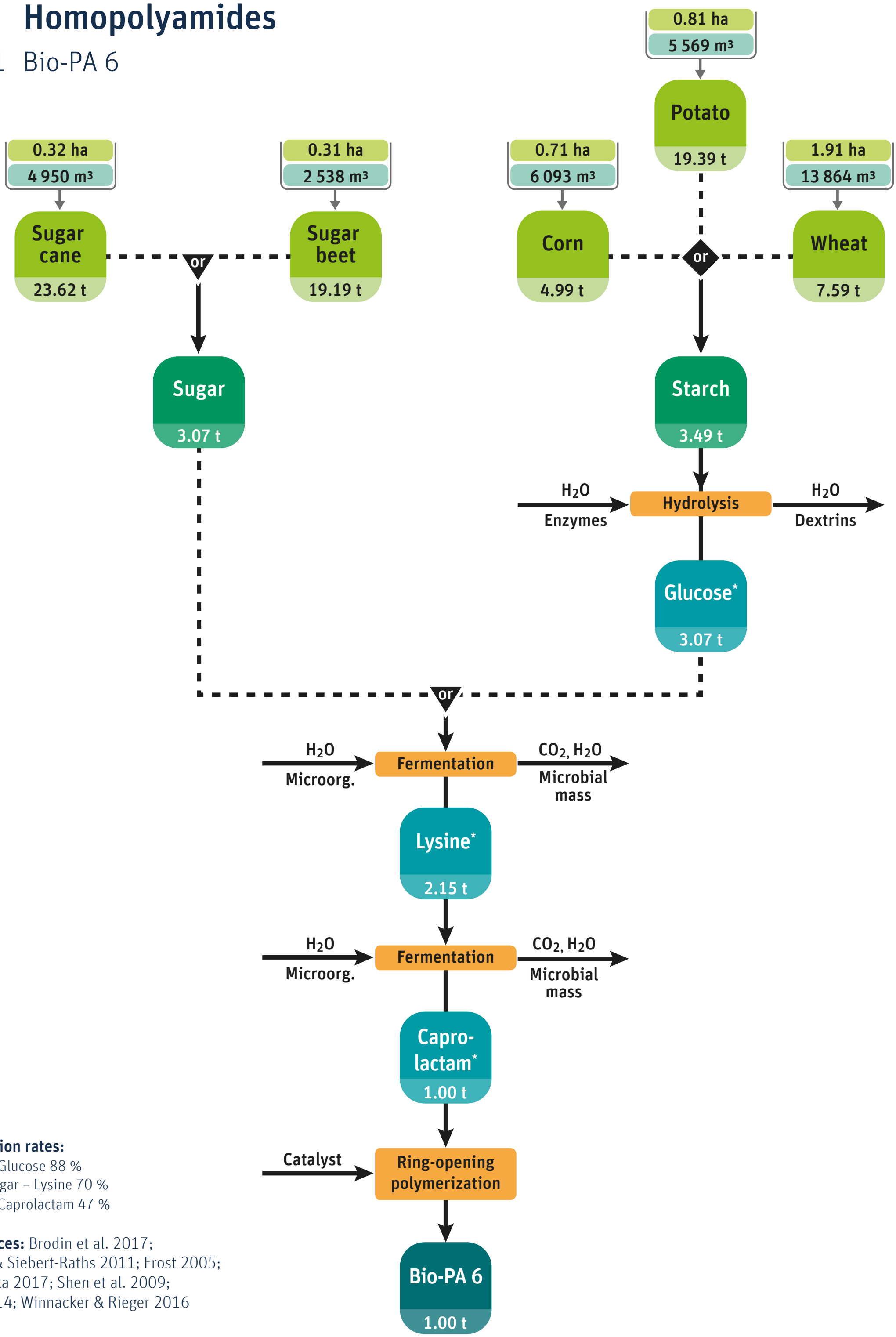
Bio-PP – Water use in m^3 (different feedstocks)



2.3 Bio-based polyamides (Bio-PA)

2.3.1 Homopolyamides

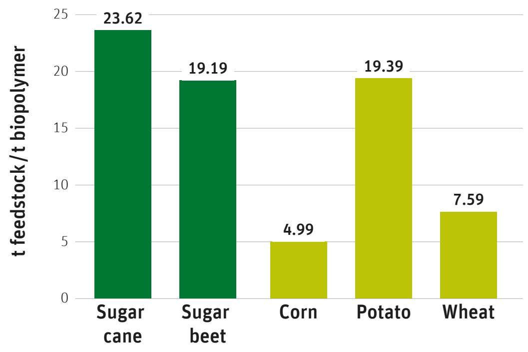
2.3.1.1 Bio-PA 6



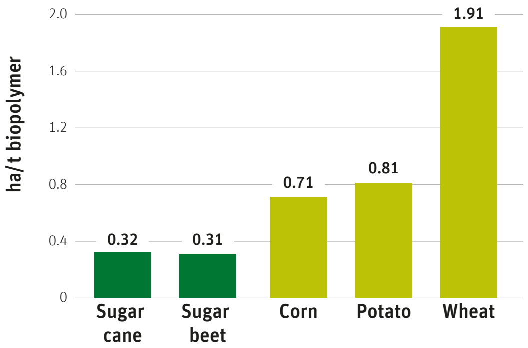
* **Conversion rates:**
Starch – Glucose 88 %
fermt. Sugar – Lysine 70 %
Lysine – Caprolactam 47 %

References: Brodin et al. 2017; Endres & Siebert-Raths 2011; Frost 2005; Kyulavska 2017; Shen et al. 2009; Türk 2014; Winnacker & Rieger 2016

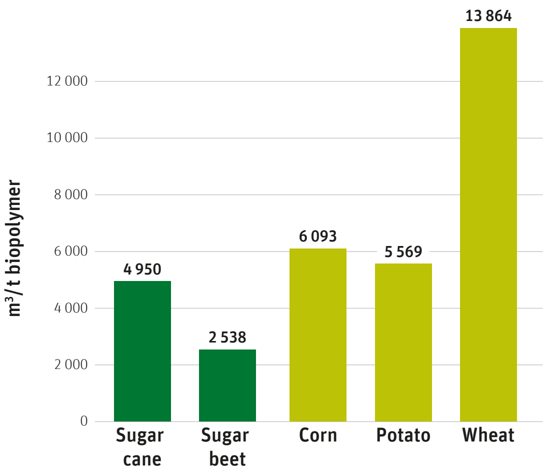
Bio-PA 6 – Feedstock requirements in t (different feedstocks)



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

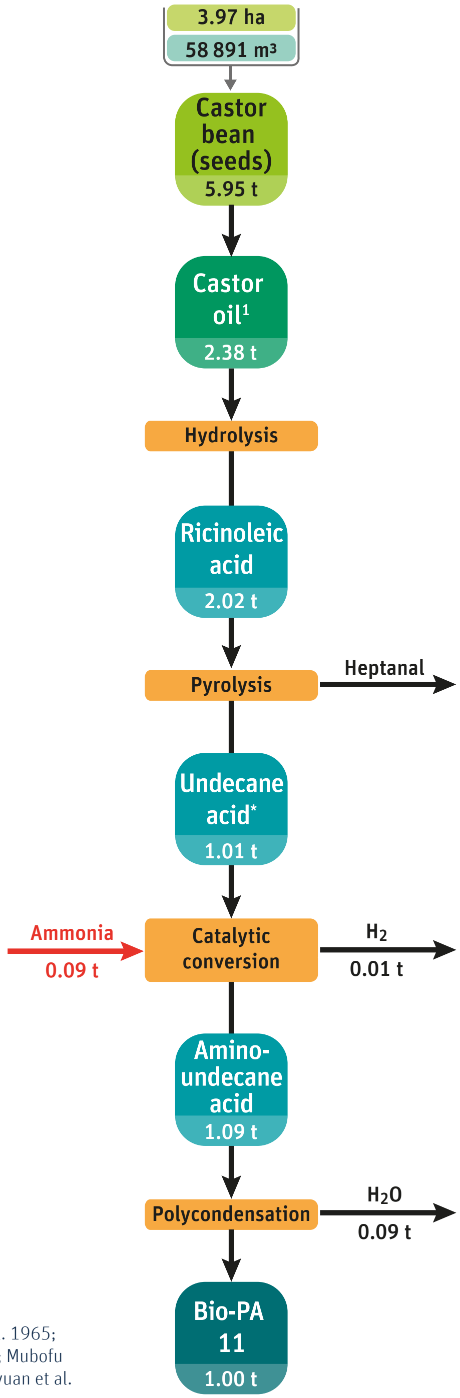


Bio-PA 6 – Water use in m³ (different feedstocks)



2.3.1 Homopolyamides

2.3.1.2 Bio-PA 11



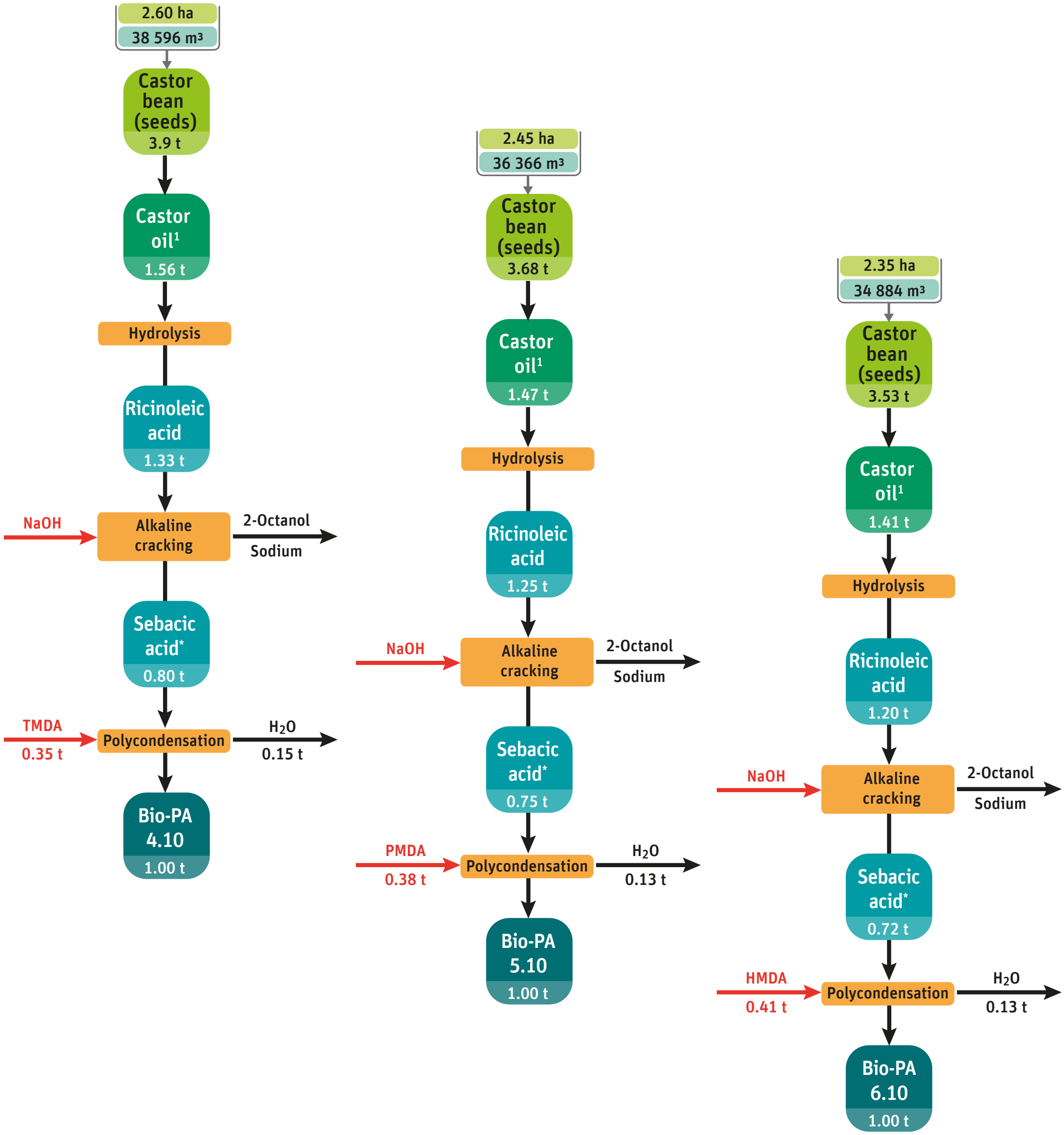
[1] one harvest per year

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

References: Devaux et al. 2011; Diamond et al. 1965; Endres & Siebert-Raths 2011; Kyulavska 2017; Mubofu 2016; Radzik et al. 2020; Shen et al. 2009; Siyuan et al. 2019; Türk 2014; Winnacker & Rieger 2016

2.3.2 Copolyamides

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



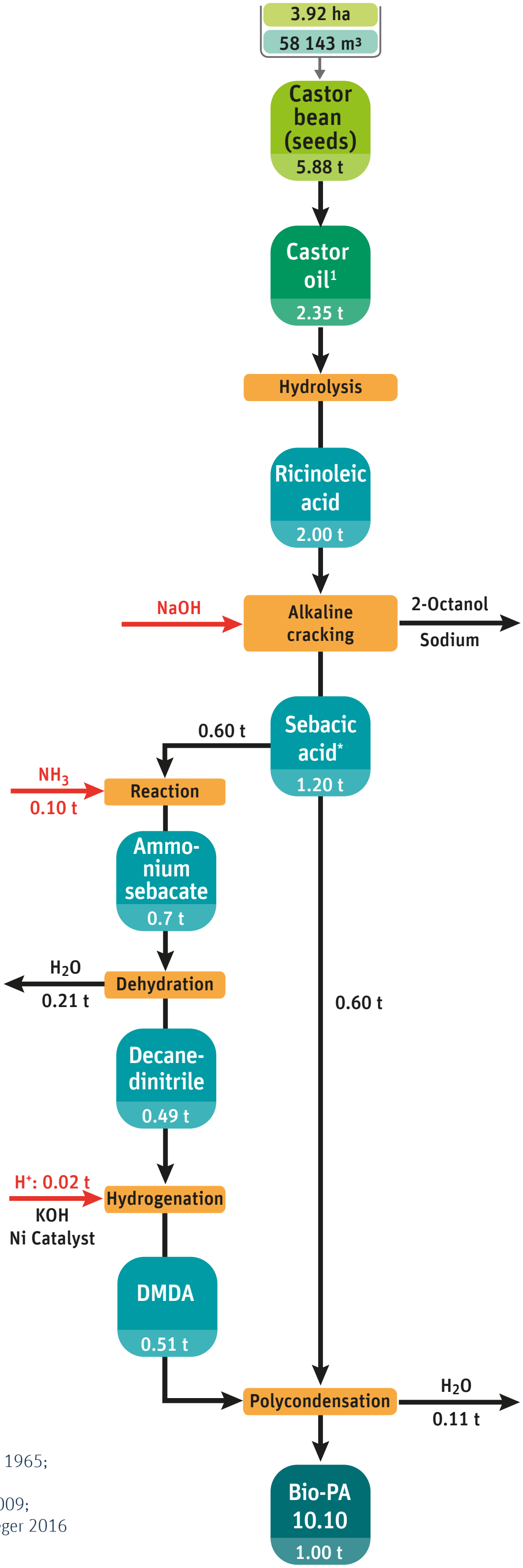
[1] one harvest per year

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

References: Devaux et al. 2011; Diamond et al. 1965; Endres & Siebert-Raths 2011; Kyulavska 2017; Mubofu 2016; Radzik et al. 2020; Shen et al. 2009; Siyuan et al. 2019; Türk 2014; Winnacker & Rieger 2016

2.3.2 Copolyamides

2.3.2.2 Bio-PA 10.10

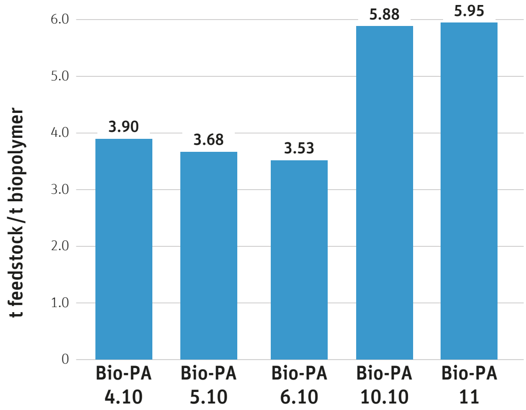


[1] one harvest per year

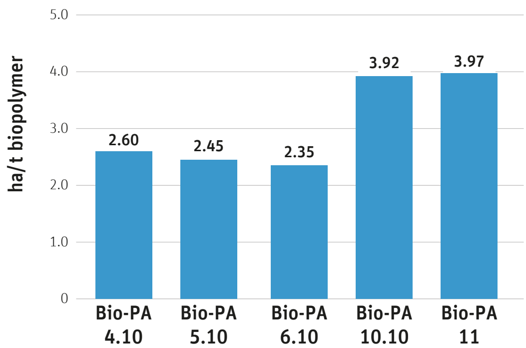
* **Conversion rates:**
Ricinoleic acid – Sebacic acid 60 %

References: Devaux et al. 2011; Diamond et al. 1965; Endres & Siebert-Raths 2011; Kyulavska 2017; Mubofu 2016; Radzik et al. 2020; Shen et al. 2009; Siyuan et al. 2019; Türk 2014; Winnacker & Rieger 2016

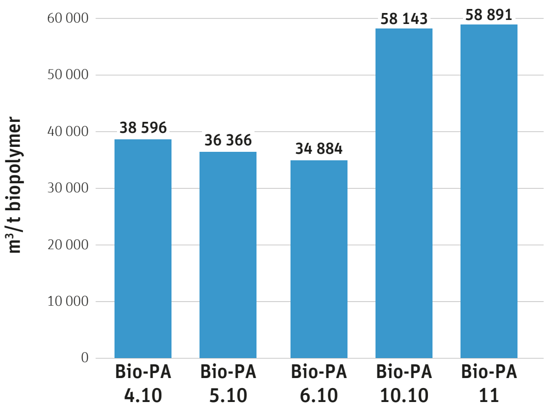
Bio-PA variations – Feedstock requirements in t (feedstock castor bean)



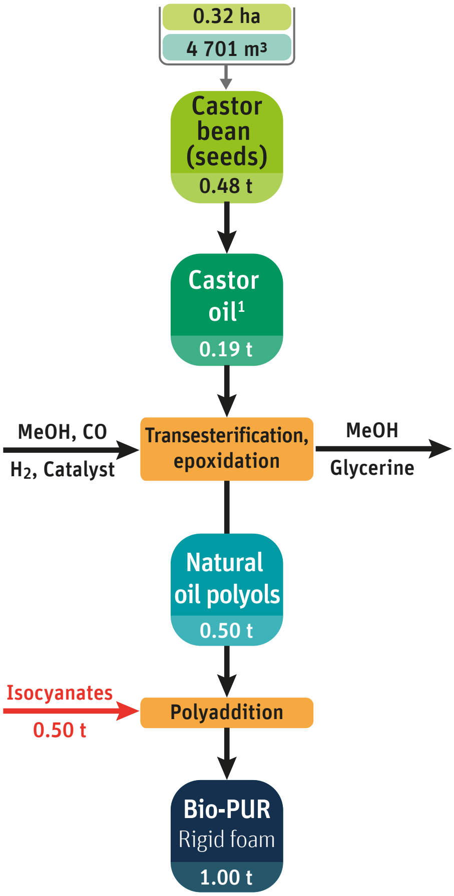
Bio-PA variations – Land use in ha (feedstock castor bean)

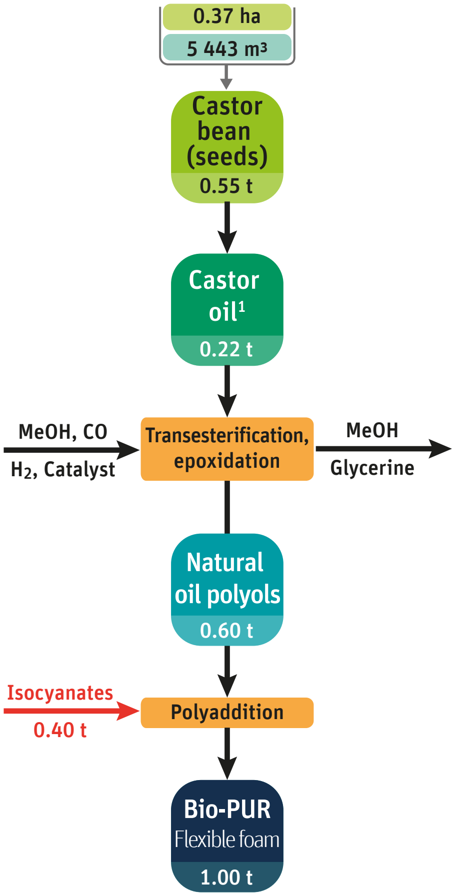


Bio-PA variations – Water use in m^3 (feedstock castor bean)



2.4 Polyurethanes



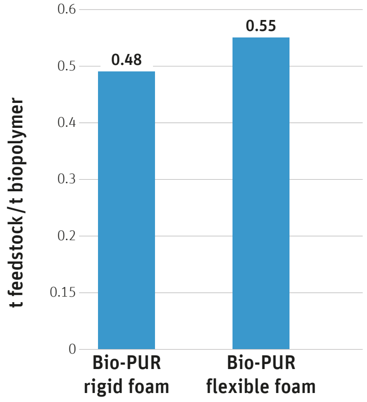


[1] one harvest per year

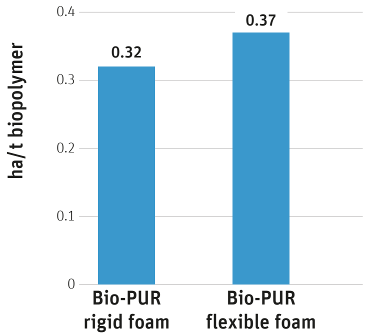
References: Andreeßen 2019; Endres & Siebert-Raths 2011; Shen et al. 2009

Bio-PUR variations – Feedstock requirements in t

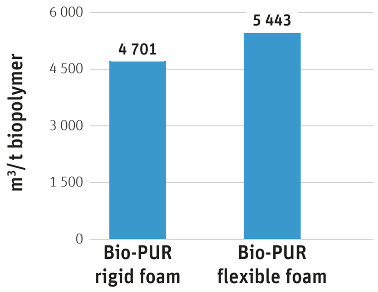
(feedstock castor bean)



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



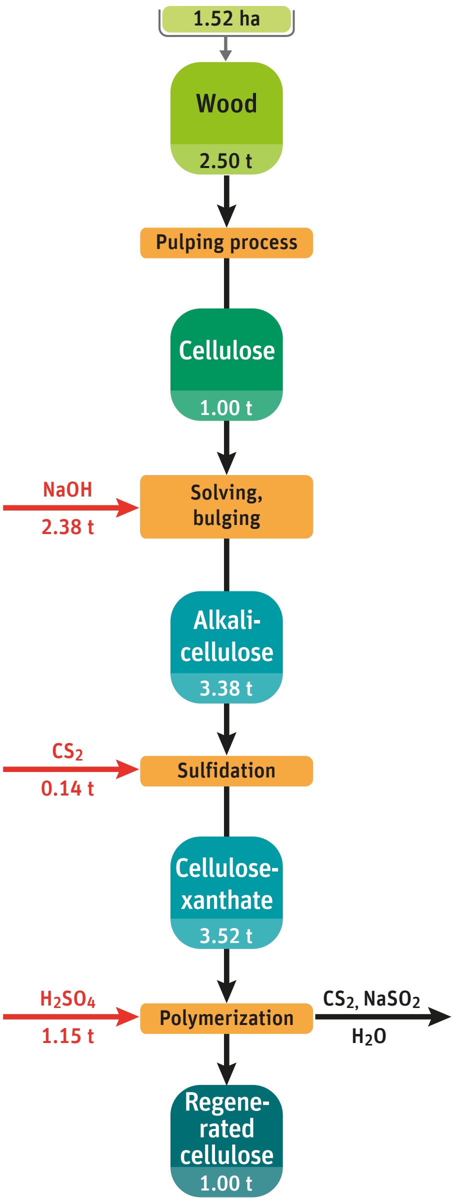
Bio-PUR variations – Water use in m³ (feedstock castor bean)



2.5 Polysaccharide polymers

2.5.1 Cellulose-based polymers (Cellulosics)

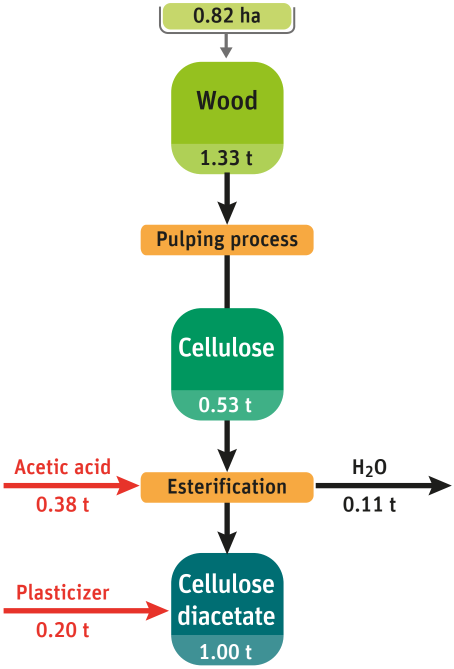
2.5.1.1 Regenerated cellulose

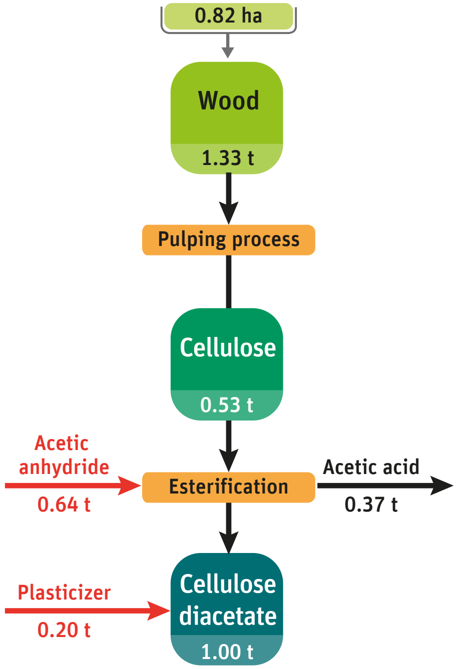


References: Endres & Siebert-Raths 2011; Sayyed et al. 2019; Xiaoya et al. 2020

2.5.1 Cellulose-based polymers (Cellulosics)

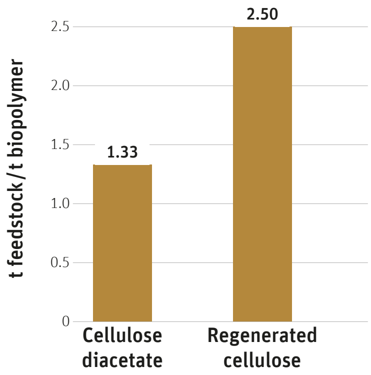
2.5.1.2 Cellulose diacetate



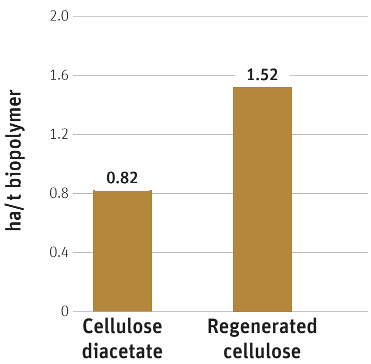


References: Endres & Siebert-Raths 2011; Sayyed et al. 2019

Cellulosics – Feedstock requirements in t
(feedstock wood)

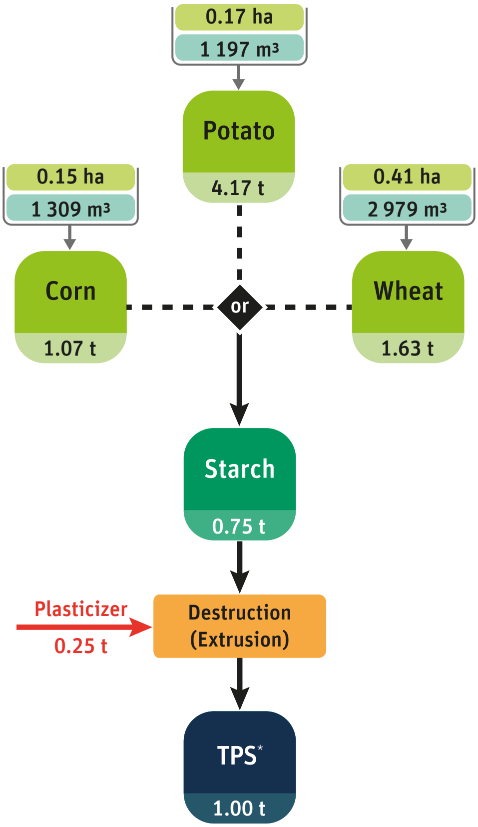


Cellulosics – Land use in ha
(feedstock wood)



2.5.2 Starch-based polymers

2.5.2.1 Thermoplastic starch (TPS)

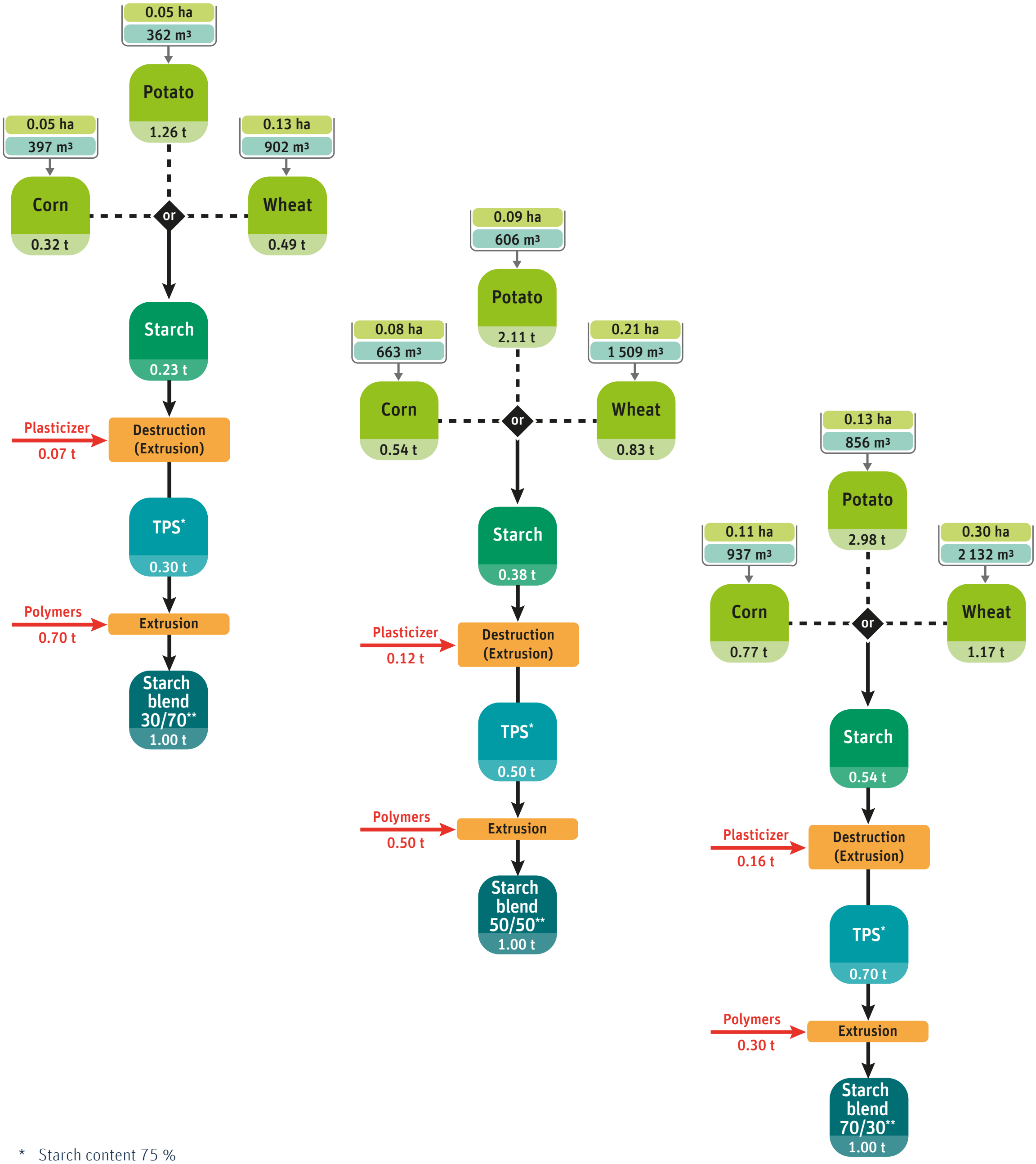


* Starch content 75 %

References: Endres & Siebert-Raths 2011; Iffland et al. 2015

2.5.2 Starch-based polymers

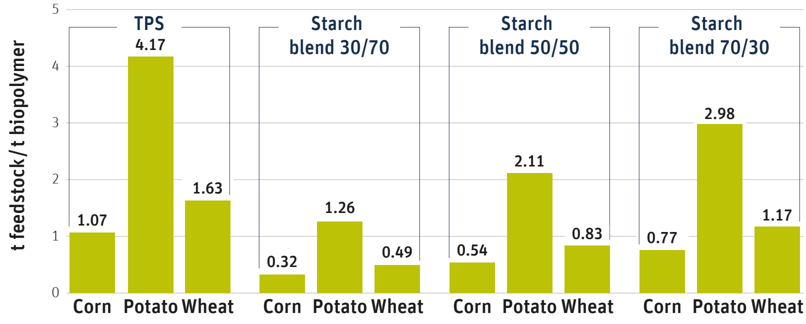
2.5.2.2 Starch blends



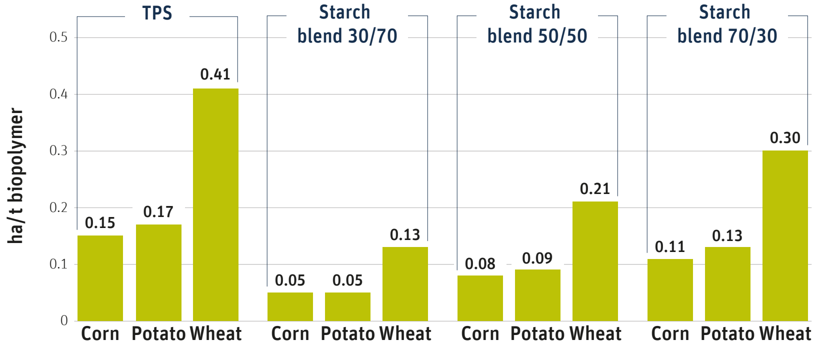
* Starch content 75 %
** Ratio TPS/Polymer

References: Endres & Siebert-Raths 2011; Iffland et al. 2015

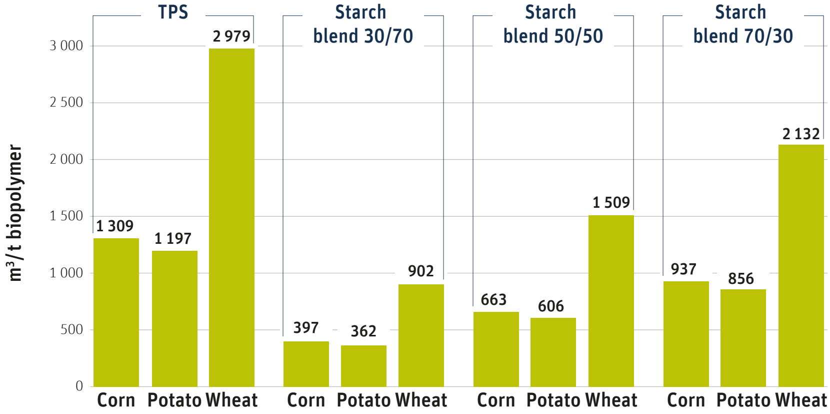
Starch-based polymers – Feedstock requirements in t
(different feedstocks)



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

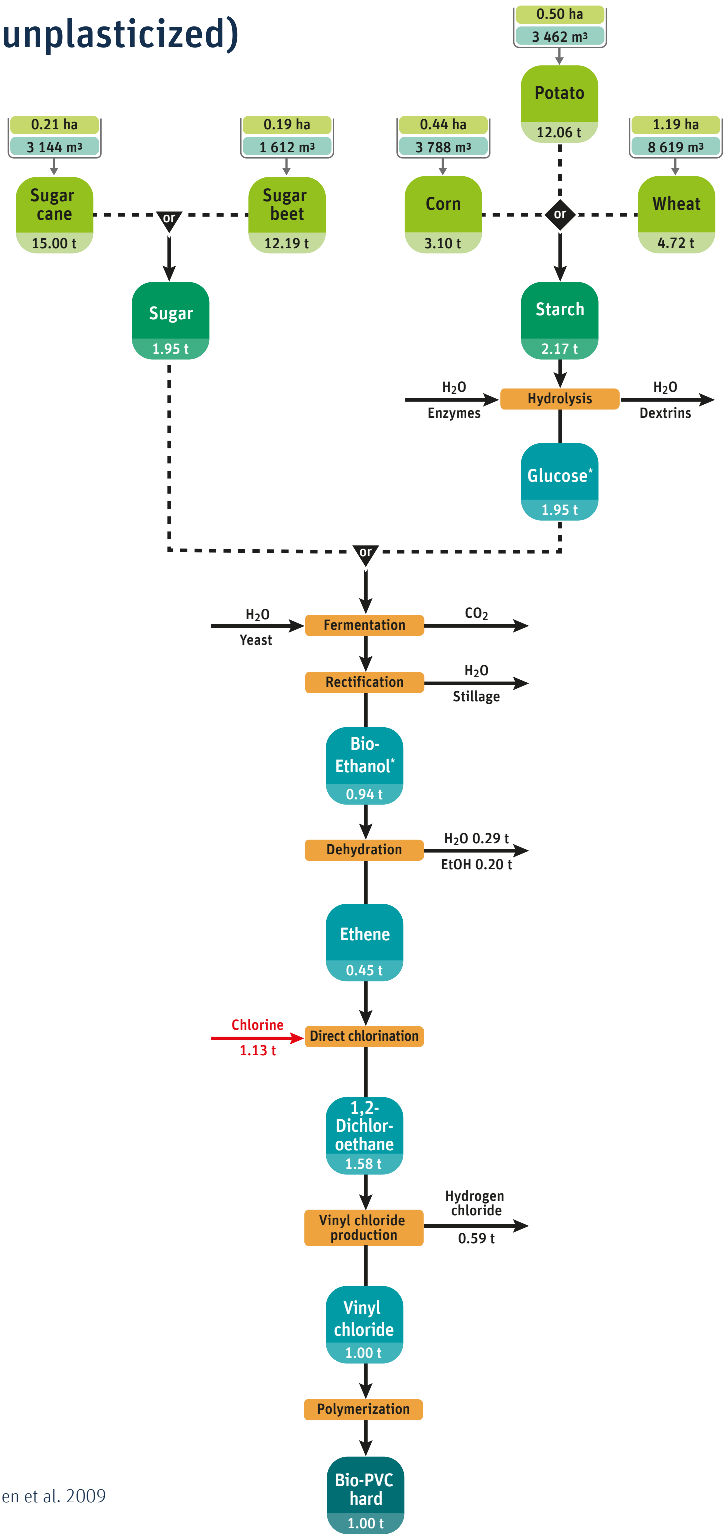


Starch-based polymers – Water use in m³ (different feedstocks)



2.6 Polyvinyl chloride (Bio-PVC)

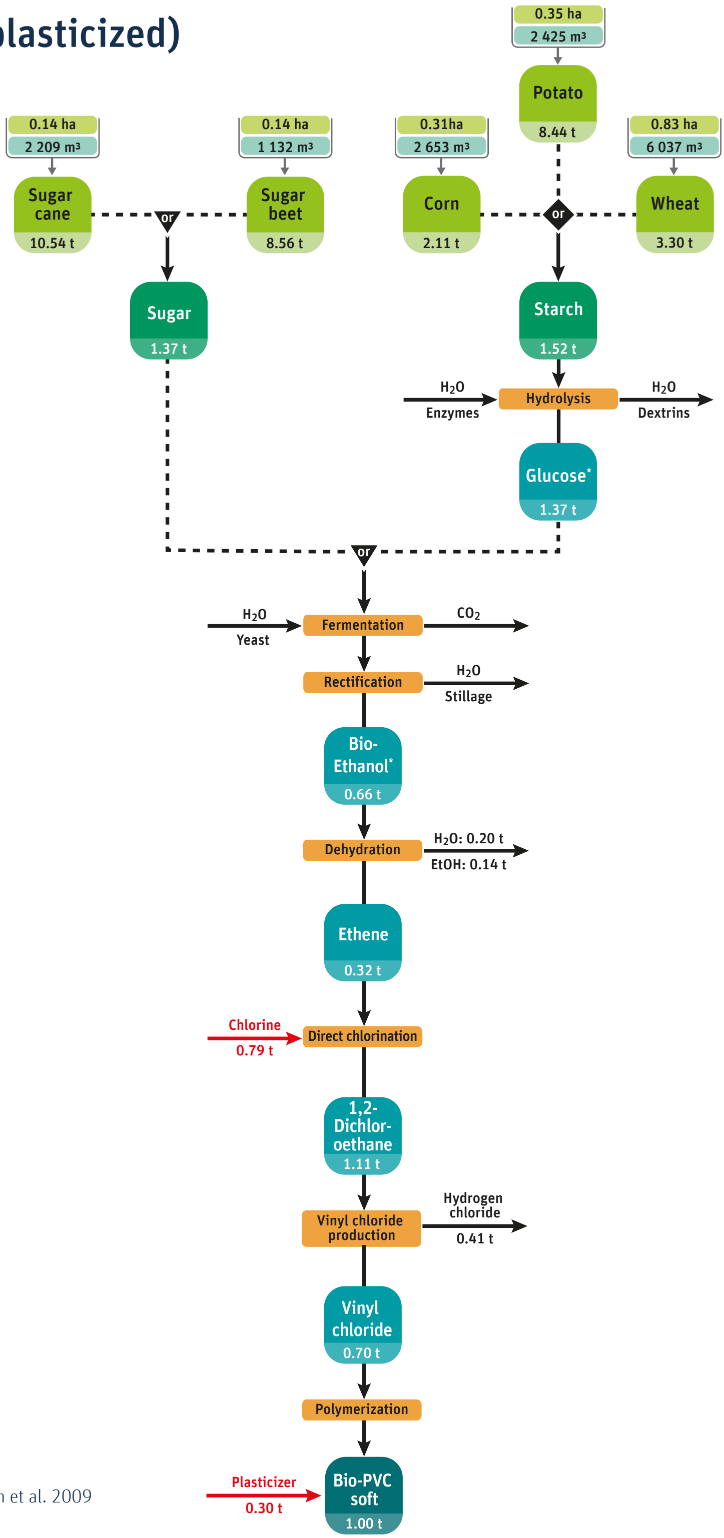
2.6.1 Bio-PVC-U (unplasticized)



* **Conversion rates:**
Starch – Glucose 88 %
Glucose – Ethanol 48 %
Ethanol – Ethene 48 %

References: Alvarenga et al. 2013; Shen et al. 2009

2.6.2 Bio-PVC-P (plasticized)

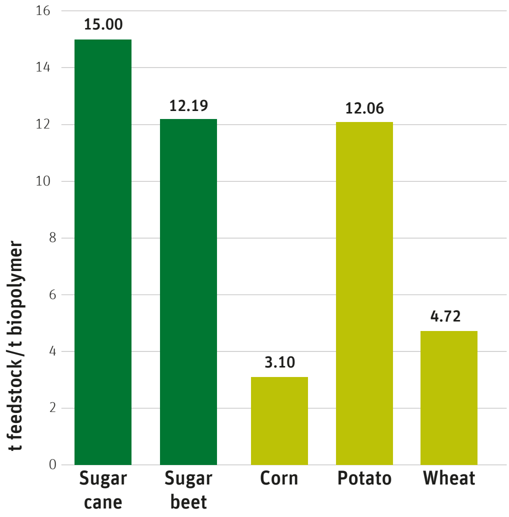


* **Conversion rates:**
Starch – Glucose 88 %
Glucose – Ethanol 48 %
Ethanol – Ethene 48 %

References: Alvarenga et al. 2013; Shen et al. 2009

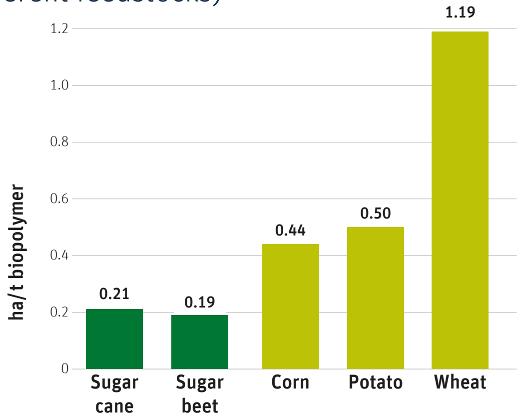
Bio-PVC-hard – Feedstock requirements in t

(different feedstocks)



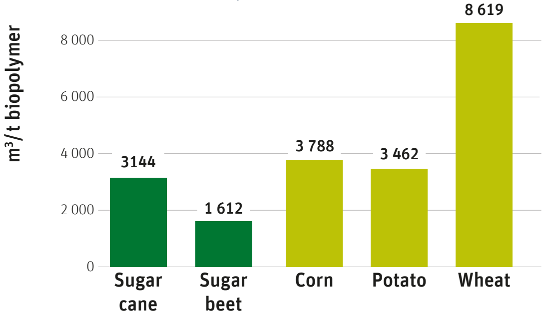
Bio-PVC-hard variations – Land use in ha

(different feedstocks)



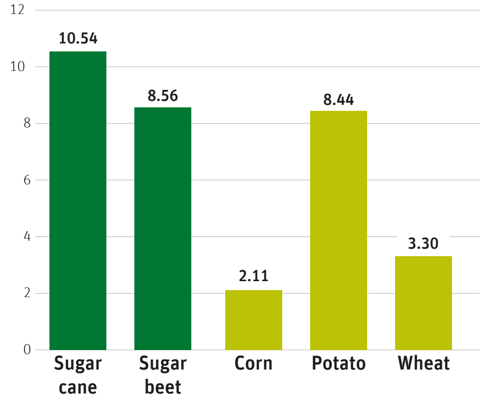
Bio-PVC-hard variations – Water use in m^3

(different feedstocks)



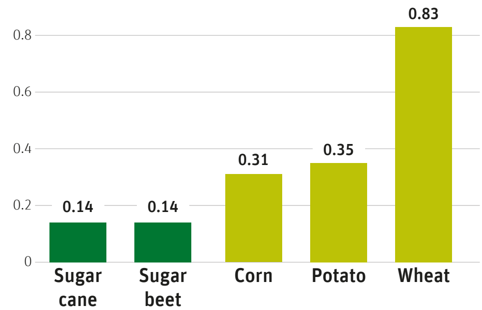
Bio-PVC-soft – Feedstock requirements in t

(different feedstocks)



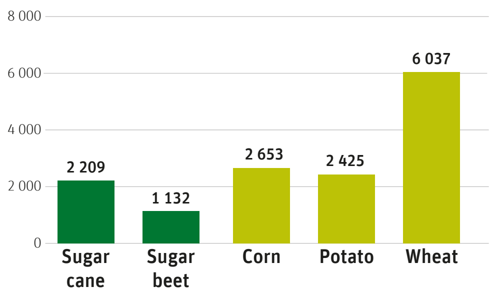
Bio-PVC-soft variations – Land use in ha

(different feedstocks)



Bio-PVC-soft variations – Water use in m^3

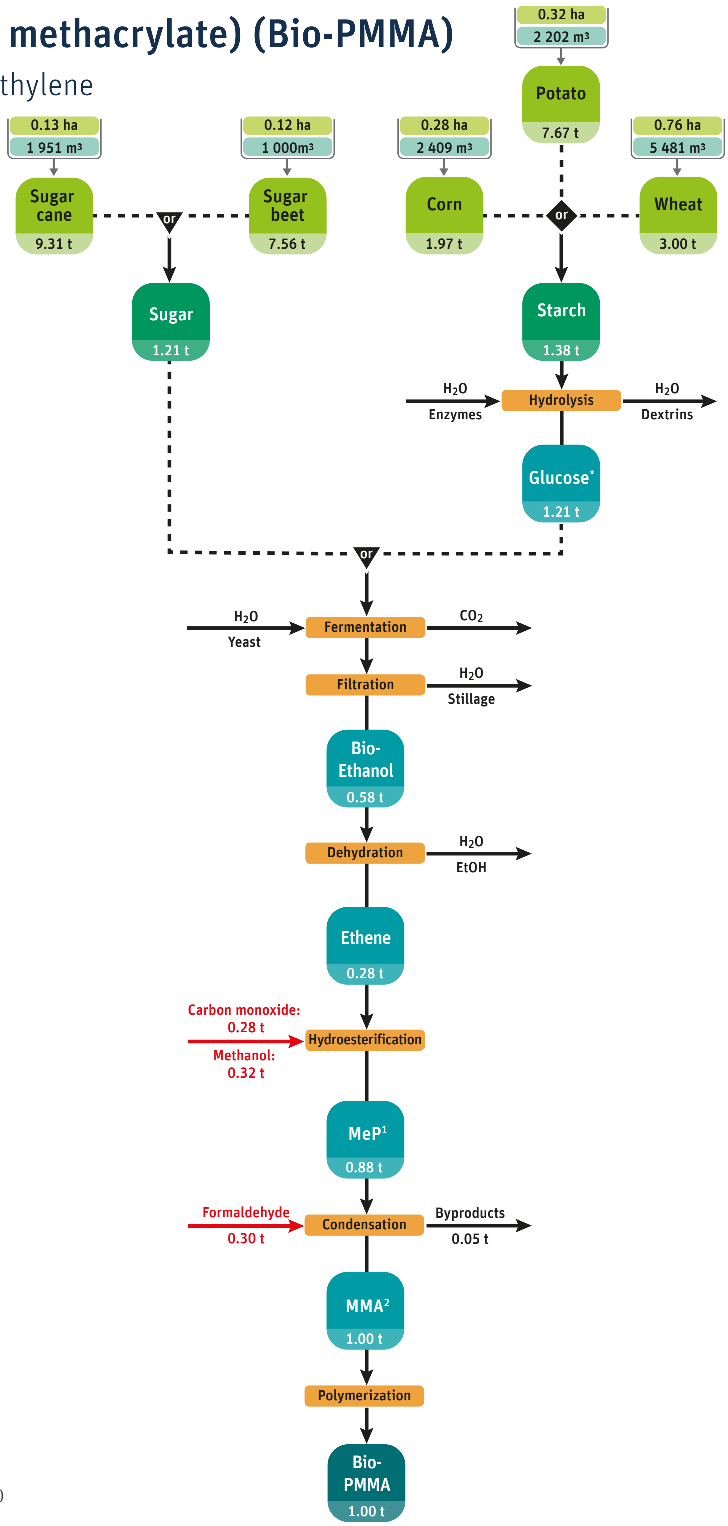
(different feedstocks)



2.7 Bio-based polyacrylates

2.7.1 Poly(methyl methacrylate) (Bio-PMMA)

with biobased ethylene

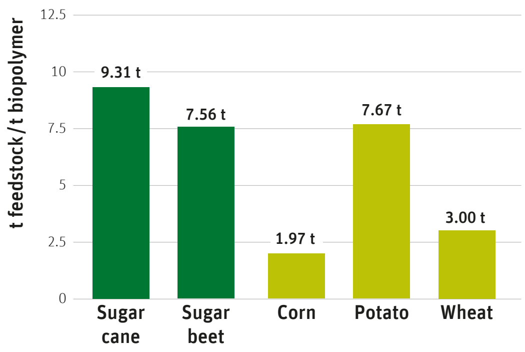


[1] MeP = Methylpropionate
[2] MMA = Methylmethacrylate

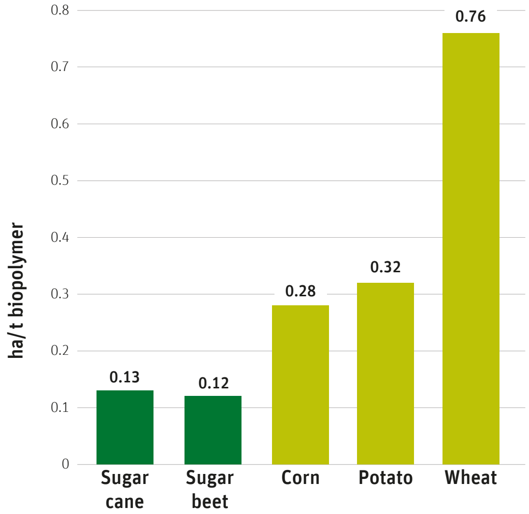
* **Conversion rates:**
Starch – Glucose 88 %
Glucose – Ethanol 48 %
Ethanol – Ethene 48 %

References: Barnicki 2012;
Lebeau & Lynch 2020; Veith et al. 2020

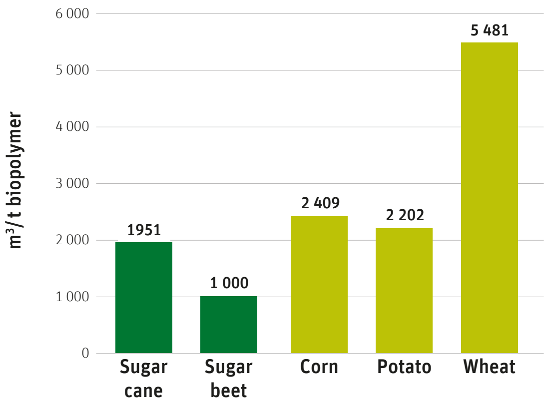
Bio-PMMA – Feedstock requirements in t (different feedstocks)



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



Bio-PMMA – Water use in m^3 (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 the following pages contain a summary of IfBB's research.

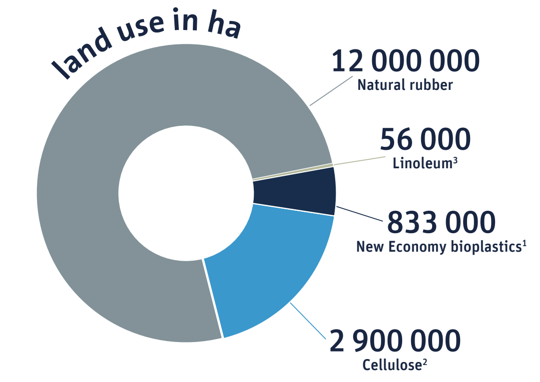
When considering the most important Old Economy bioplastics with their global production capacity of about 17 million tonnes annually, it turns out that the share of New Economy bioplastics is almost 10 times lower, i.e. 11 % of the market volume of all bio-based plastics (Old and New Economy Bioplastics included), with rising tendency.

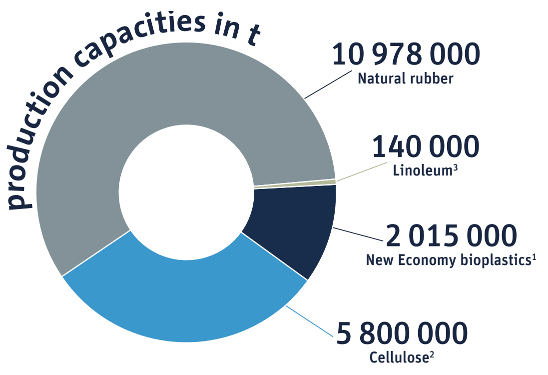
By size and large, Old and New Economy bioplastics (about 19 million tonnes) have a combined share of presently nearly 6 % of the global plastics market. The corresponding land use of Old and New Economy bioplastics is currently at approximately 15.8 million hectares, which is equivalent to only 0.3 % 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 still kept at a very low level. While the market for new bioplastics has been growing during the last years and a sustained growth is anticipated in the future, it can be assumed that land use for New Economy bioplastics by 2025 (2.9 million tonnes), for example, will be around 0.022 % of the global agricultural area or about 0.8 % of the arable land (see figures on page 58 and pages 62/63). 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. paper industry
[3] Calculations include linseed oil only

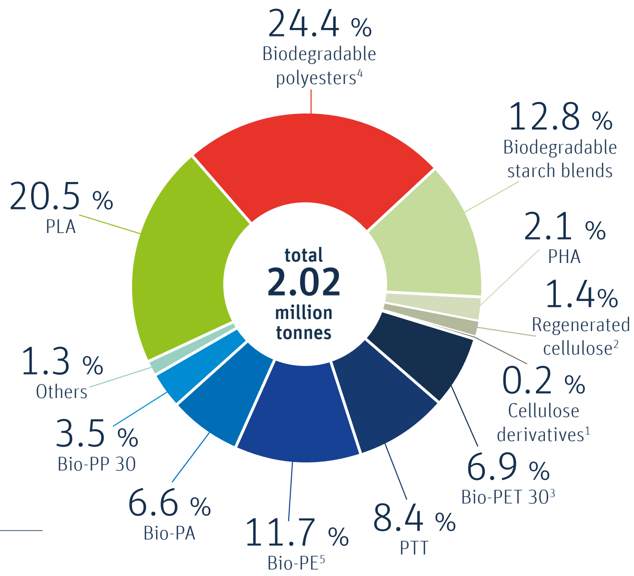
3.1 New Economy bioplastics global production capacities

3.2 New Economy bioplastics production capacities by material type

2020

38.5%
bio-based/non-biodegradable

61.5 %
biodegradable

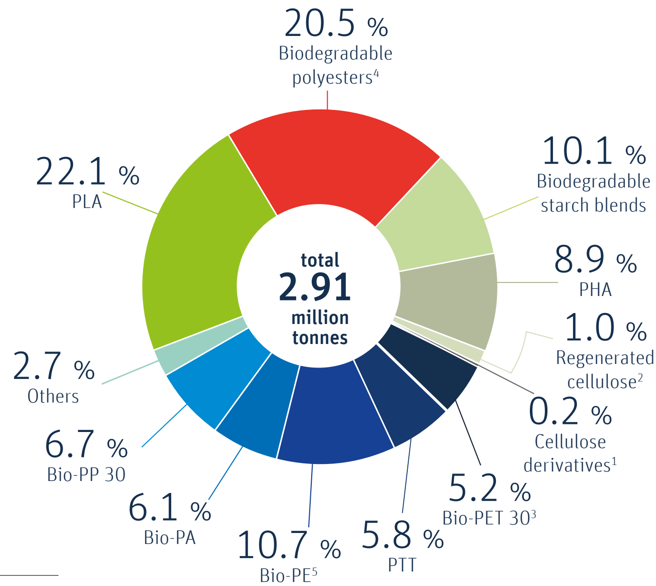


[1] Biodegradable cellulose esters
[2] Compostable hydrated cellulose foils
[3] Bio-based content amounts 30 %
[4] Contains PBAT, PBS, PCL
[5] Contains Bio-PE 30 and Bio-PE 100

2025

37.2 %
bio-based/non-biodegradable

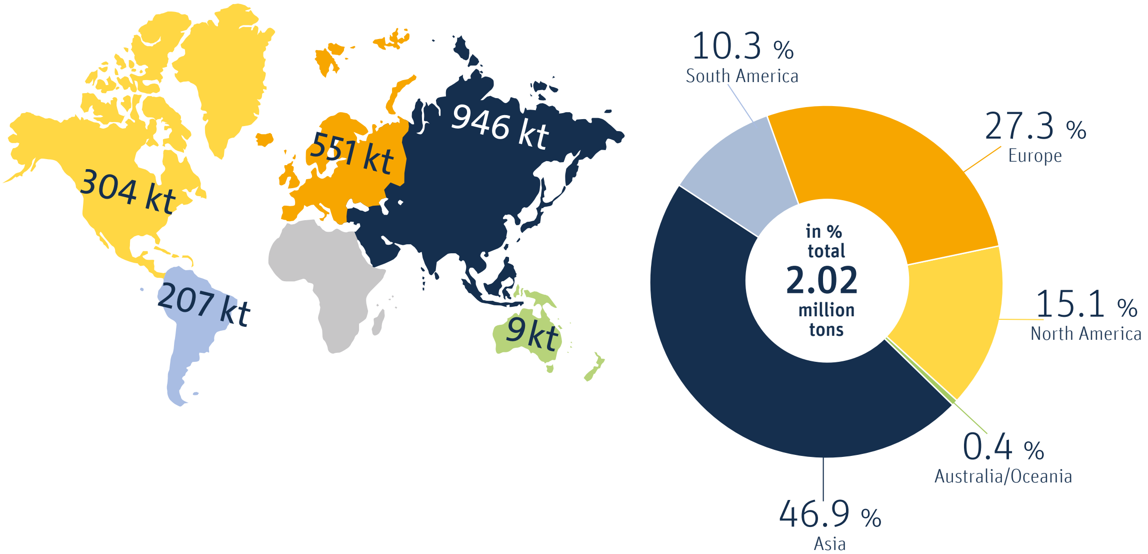
62.8 %
biodegradable



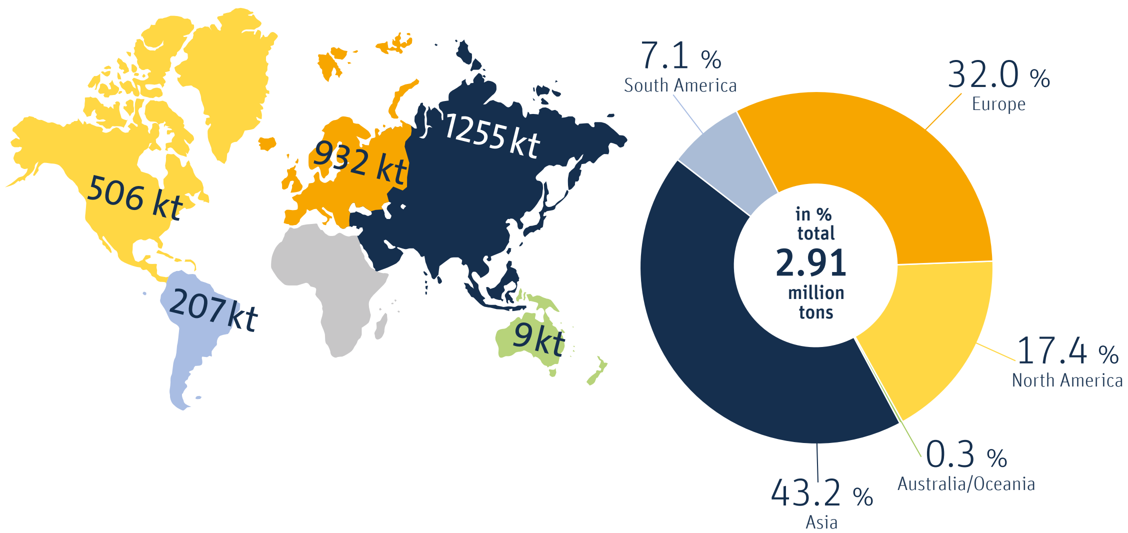
[1] Biodegradable cellulose esters
[2] Compostable hydrated cellulose foils
[3] Bio-based content amounts 30 %
[4] Contains PBAT, PBS, PCL
[5] Contains Bio-PE 30 and Bio-PE 100

3.3 New Economy bioplastics production capacities by region

2020

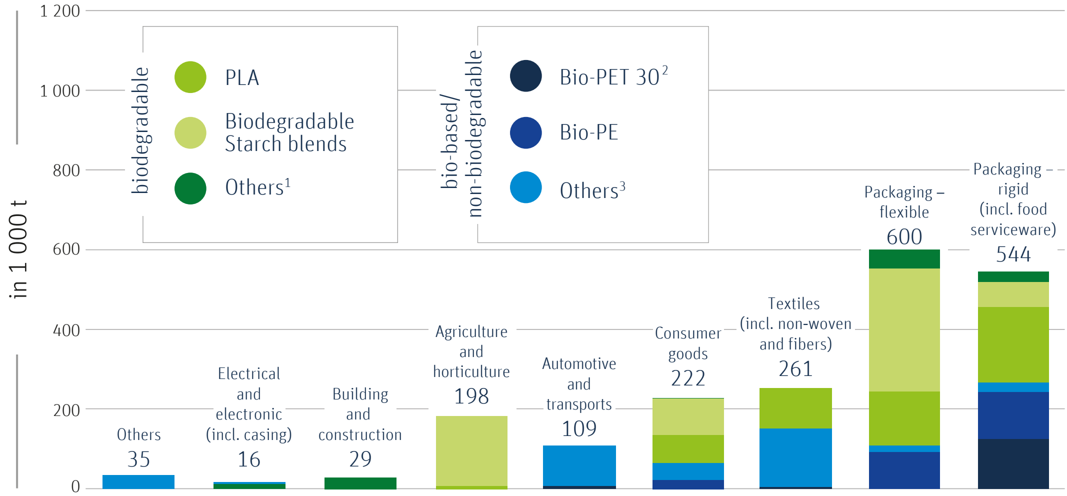


2025



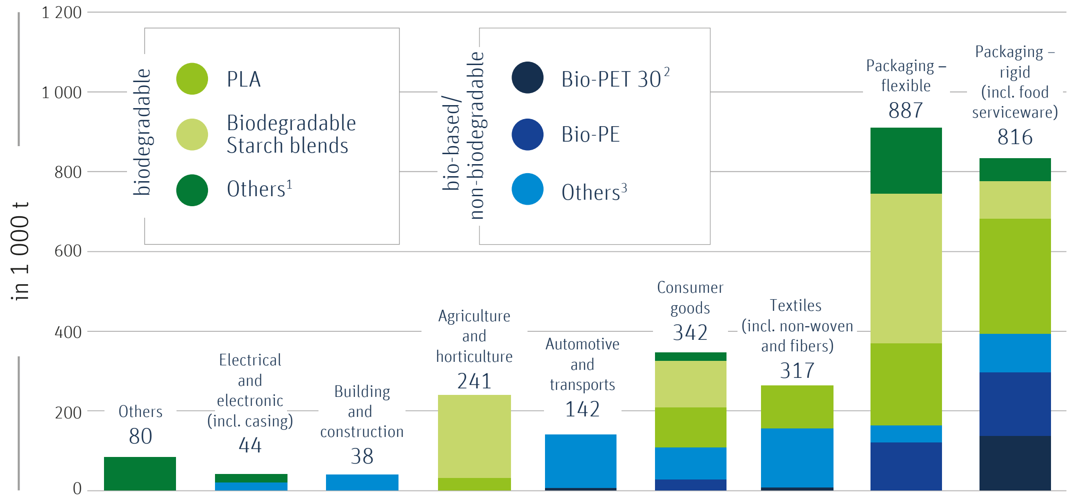
3.4 New Economy bioplastics production capacities by market segment

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

2025

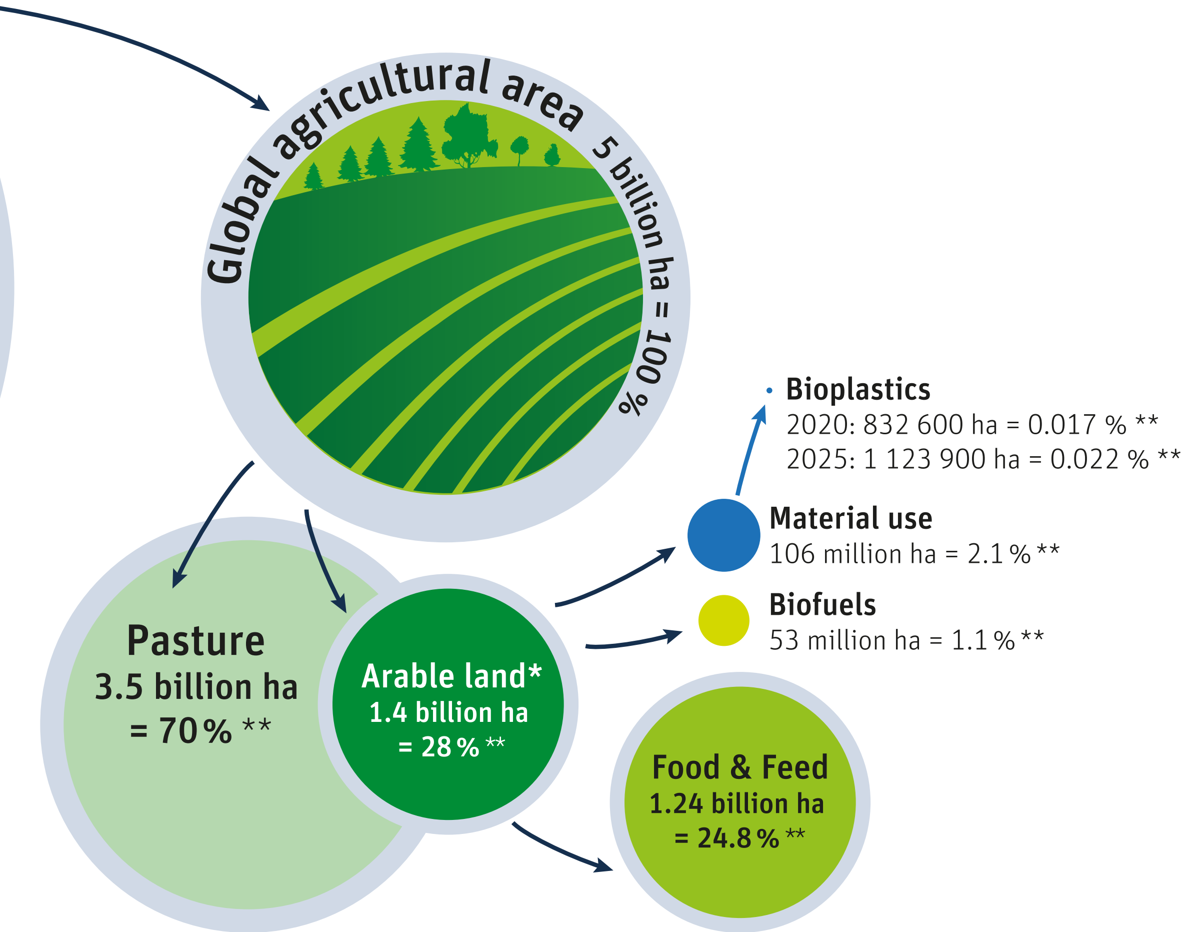


[1] Contains regenerated cellulose and biodegradable cellulose ester
[2] Bio-based content amounts to 30 %
[3] Contains durable starch blends, Bio-PC, Bio-TPE, Bio-PUR (except thermosets), Bio-PA, PTT

3.5 Land use for New Economy bioplastics 2020 and 2025

For final land use estimation only the most commonly used crop was taken into consideration. Yield data from FAO statistics served as a basis for calculation (global, weighted average over the past 10 years). To approximate 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 case a producer-specific feedstock type for was not known, the most commonly used crop for this bioplastic type was taken into calculation.

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.

** Percentage compared to total agricultural area

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