Introduction to BIO-PLASTICS EUROPE and EUROPEAN BIOPLASTICS RESEARCH NETWORK

By: Dr. Jelena Barbir

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BIO-PLASTICS EUROPE

Developing and Implementing Sustainability-Based Solutions for Bio-Based Plastic Production and Use to Preserve Land and Sea Environmental Quality in Europe

October 2019 – September 2023

Project kicked-off in October 2019

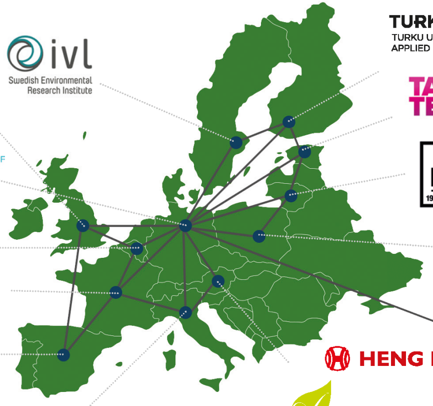
HAW Hamburg

Prof. Walter Leal
Project Coordinator

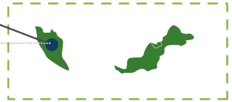
Our Team

Ms. Silke Kuehl	Dr. Jelena Barbir	Ms. Cintia Nunes	Ms. Franziska Wolf	Ms. Caroline Paul	Ms. Liza Tuladhar	Ms. Maren Fendt	Ms. Marie Hornbogen
							
Financial Officer	Lead Project Manager	Project Manager	Senior Project Manager	Student Assistant	Student Assistant	Student Assistant	Student Assistant

PARTNERSHIP



MALAYSIA



Fraunhofer LBF

ALFRED-WEGENER-INSTITUT HELMHOLTZ-ZENTRUM FÜR POLAR- UND MEERESFORSCHUNG

HWWI Hamburg Institute of International Economics

HAMBURG UNIVERSITY OF TECHNOLOGY

Manchester Metropolitan University

ivl Swedish Environmental Research Institute

prospex institute

NaturePlast Bioplastics Expert

ecoembes El poder de la colaboración

LTICASS

Assobioplastiche

Consiglio Nazionale delle Ricerche

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

acib austrian centre of industrial biotechnology

HENG HIAP

TURKU AMK TURKU UNIVERSITY OF APPLIED SCIENCES

ABM COMPOSITE Arctic Biomaterials

TAL TECH

ktu kaunas university of technology 1922

Lodz University of Technology

22 partners
13 countries
8.5 million Euros

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SCAN ME

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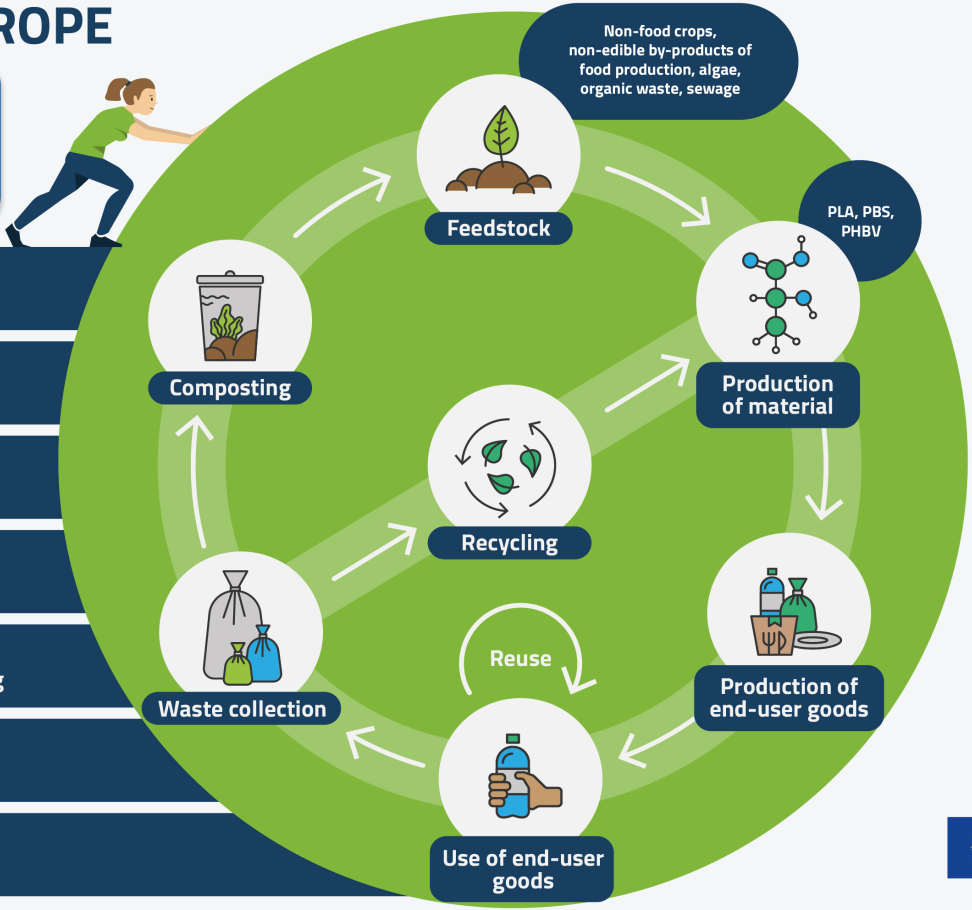
BIO PLASTICS EUROPE

BIO-PLASTICS EUROPE

Pushes towards circular economy

- **WP3** Identification and test of innovative product design
- **WP4** Plastic waste collection, recycling and littering
- **WP5** Prenormative research and field tests
- **WP6** Health and environmental safety
- **WP7** Replication, policy-making, capacity-building and upscaling
- **WP8** Life cycle assessment environmental and economic
- **WP9** Information, communication, and dissemination of results



HAW HAMBURG

EXPECTED RESULTS

FOCUS
Cutlery, Soft and Rigid Packaging,

Agricultural Mulch Film, Toys and Aquatic Materials

INNOVATIVE MATERIALS
to foster and encourage deployment of innovative bio-based and biodegradable materials

STAKEHOLDERS ENGAGEMENT
to ensure strong commitment of producers, politicians, industrial and private consumers

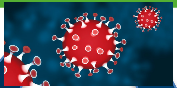
BUSINESS MODELS
to experiment with innovative business models by incorporating circularity and sustainability to maximize the value of materials along the entire value chain

SAFETY PROTOCOLS
to ensure the safe use and end-of-life management on innovative bio-based plastics

5 MATERIALS:
The materials under investigation are:

1. **BPE-FP-PBS**
2. **BPE-RP-PLA**
3. **BPE-T-PHBV**
4. **BPE-AMF-PLA**
5. **BPE-C-PLA**

From this list mainly PLA is already commercially in use and well available according to very recent application notes from various companies.



SENT FOR LABORATORY AND FIELD TESTS

- **Samples prepared-received**
- **Test Protocols finished**
- **Tests started 1st of September**
- **First preliminary results beginning 2021**

MODIFICATION of the materials after 1st round tests

2nd round of TESTS

Besides focusing on research….

STAKEHOLDER ENGAGEMENT

12 ONLINE STAKEHOLDER PROMOTION EVENTS

September – December 2020

PROMOTE PROJECT CLUSTER stakeholders FUTURE INVOLMENT

CHAT

NETWORKS

2nd event
4th of November

- LinkedIn: over 220 members
- Preparing events
- Foster communication
- Share experience

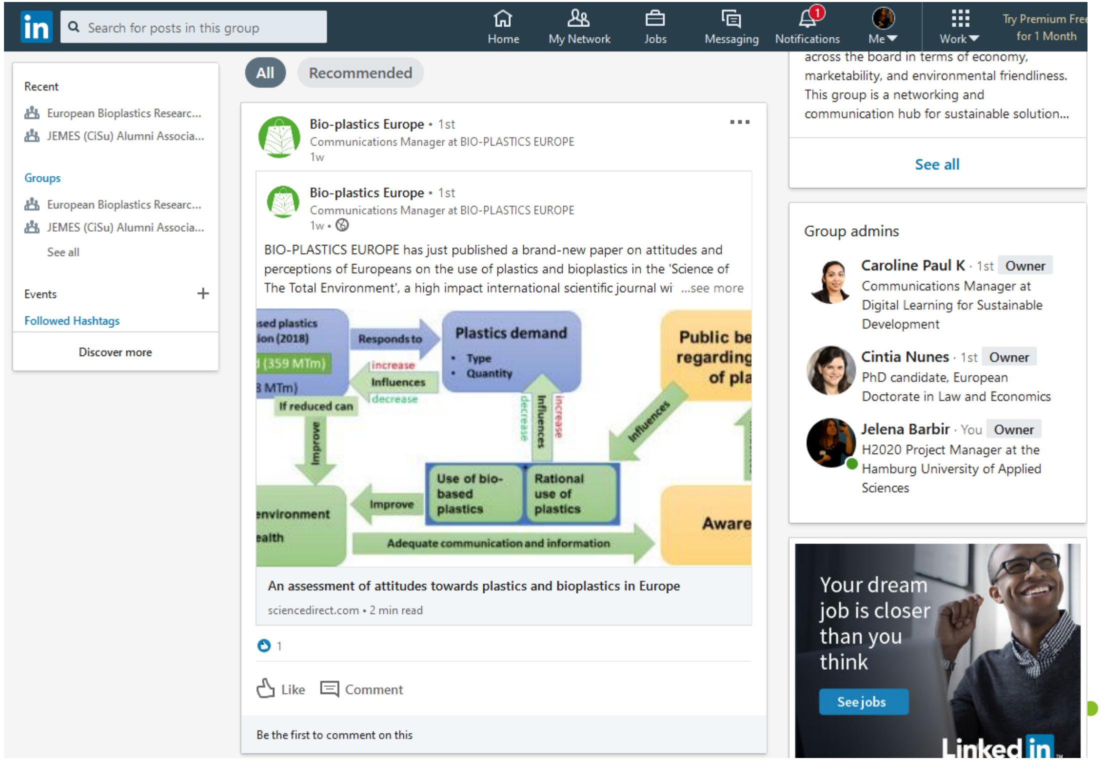
- Connect cities
- Preparing events
- Exchange experience
- Offer solutions

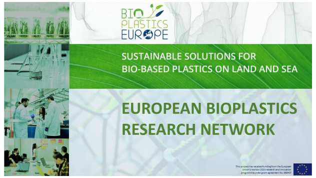
2nd event
15th of December

BIO PLASTICS EUROPE

CHAT

European Bioplastics Research Network





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European Bioplastics Research Network

- NEXT EVENT:

- 17th of February 2021 (10-12h) – VIRTUAL MEETING!

- **BIO-BASED PLASTICS: challenges in production of bio-based materials**

- **In order to be informed and updated: register for newsletter**

BIO PLASTICS EUROPE

CHAT

THANK YOU FOR ENGAGING WITH US…..

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Website: https://bioplasticseurope.eu/

…… THANK YOU FOR YOUR ATTENTION!

HAW Hamburg

Horizon 2020

BIO PLASTICS EUROPE

Bio-based Plastics: Feedstock and End-of-life

Constance Ißbrücker, Head of Environmental Affairs, European Bioplastics (EUBP)

2nd & 3rd Generation for biobased and biodegradable plastics | 4 Nov 2020 | EBRN Virtual Meeting

*Members of European Bioplastics – The value chain**

Renewable raw materials / Green chemistry

Cargill, Corbion, NESTE

Certification

TÜV AUSTRIA, TÜVRheinland® DIN CERTCO Precisely Right.

Bioplastics manufacturers and auxiliaries

BASF We create chemistry, BIOTEC Bioplastics for a better life, NatureWorks LLC, NOVAMONT, TOTAL Corbion

Plastic converters

IMMER GROUP, Kompuestos, POLIFILM, SIG, SPHERE, BioBag®

Brand owners

Tetra Pak® Protects what's good, FERRERO, LAVAZZA

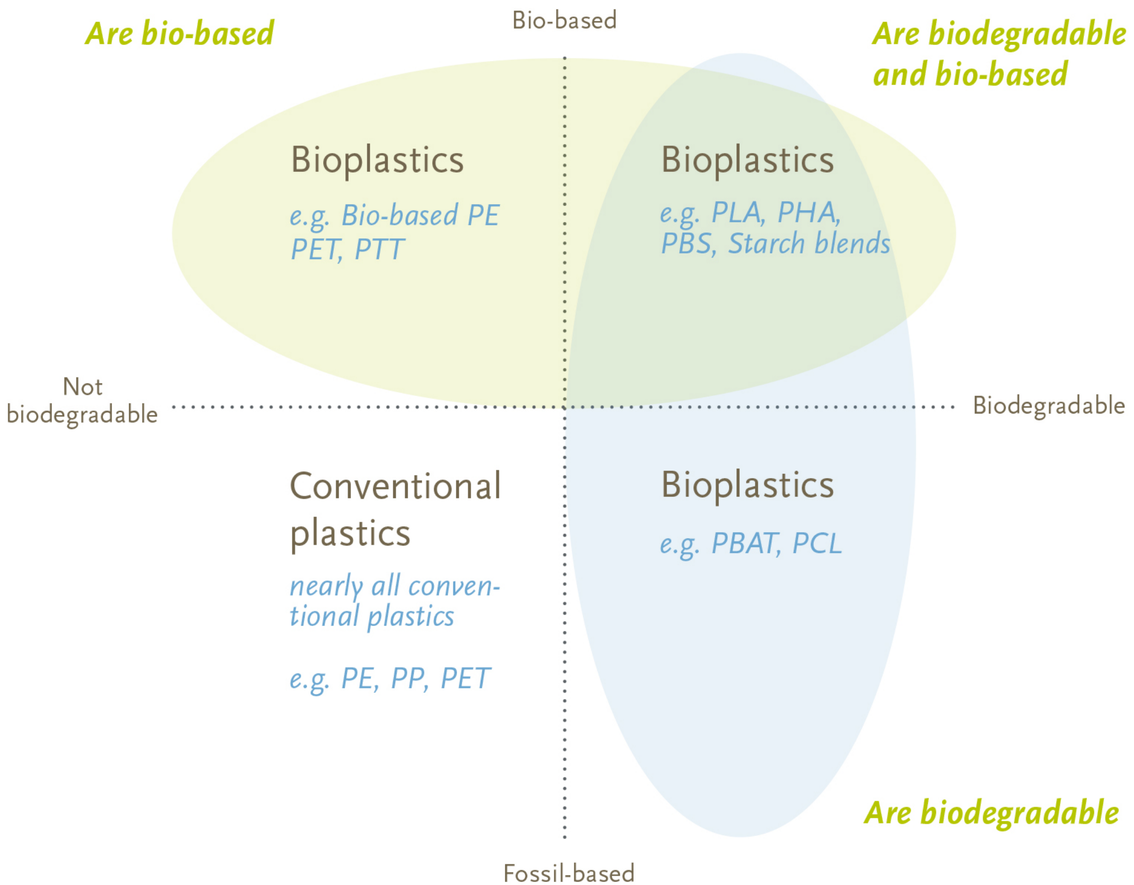
Research

AIMPLAS Instituto Tecnológico del Plástico, Fraunhofer ISC, Alma Mater Studiorum Università di Bologna

*selection of EUBP members in 2020

Material coordinate system for bioplastics

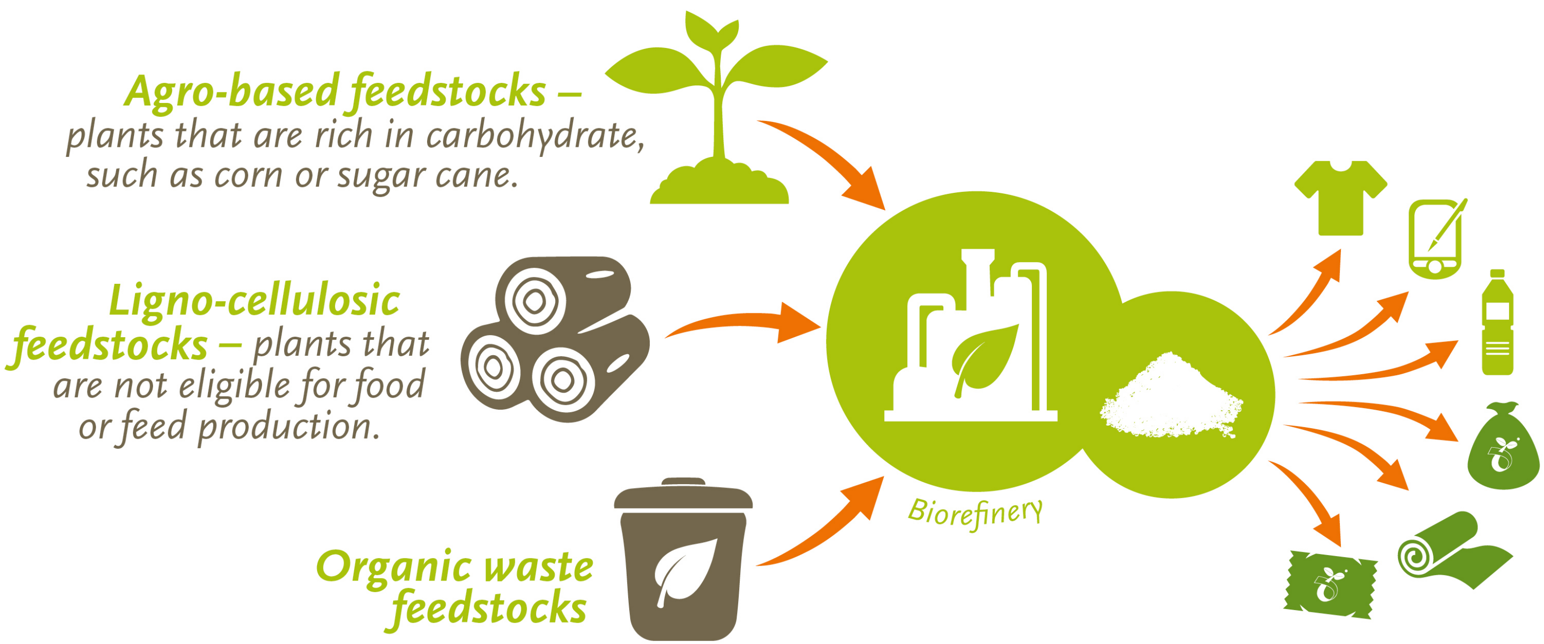
Bioplastics are bio-based, biodegradable or both.
(European Bioplastics)



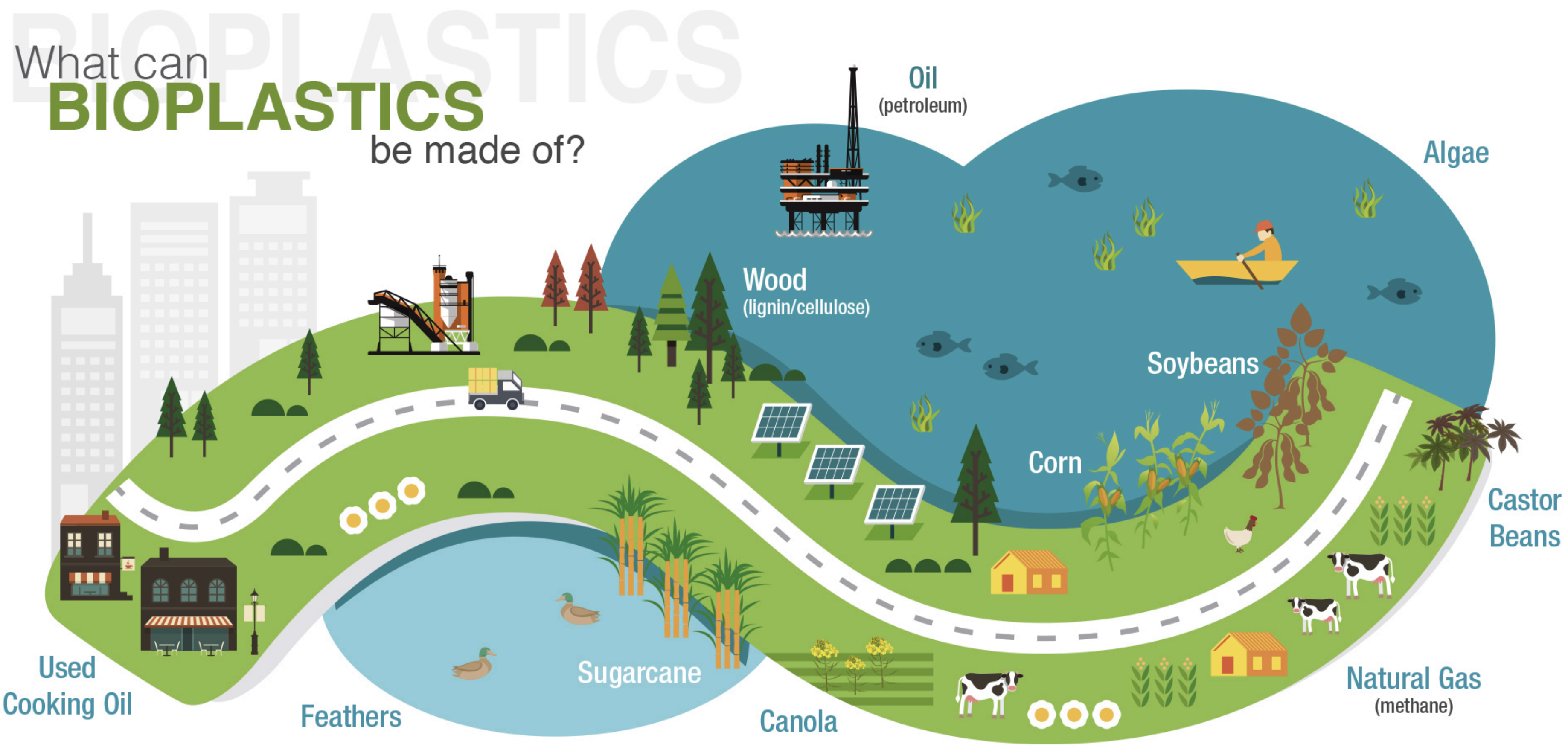
Source: Institute for Bioplastics and Biocomposites (IfBB) and European Bioplastics (EUBP)

Feedstock options for bioplastics

Bio-based plastics *are made from* **a wide range**
of renewable **BIO-BASED feedstocks.**



Feedstock options for bioplastics



Source: Plastics Industry Association, www.thisisplastics.com

Land use estimation for bioplastics production

GLOBAL AGRICULTURAL AREA

Pasture
3.3 billion ha

Food & Feed
1.24 billion ha = 26%*

Material use***
106 million ha = 2%*

Biofuels
53 million ha = 1%*

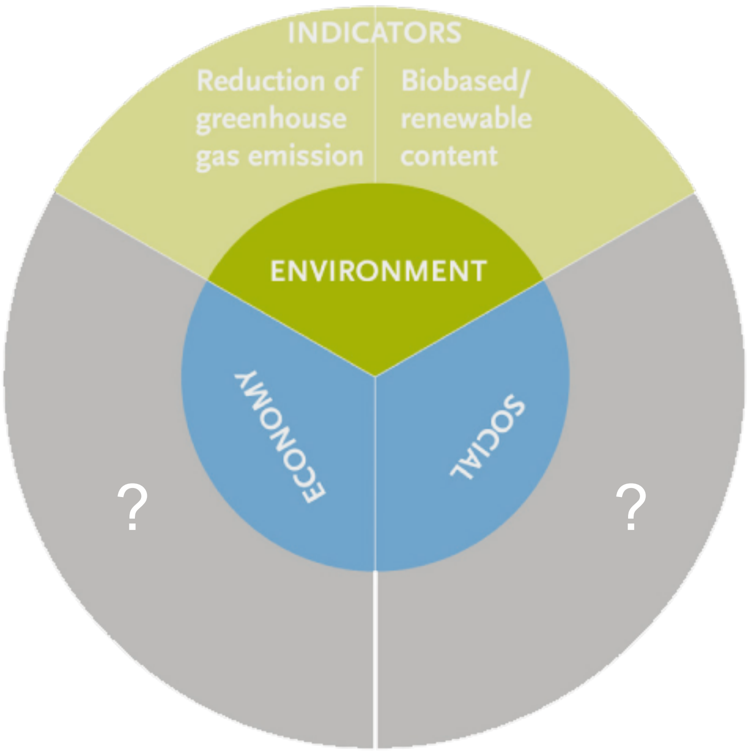
Bioplastics
2019: 0.79 million ha ≈ 0.016 %*
2024: 1.00 million ha ≈ 0.021 %*

Arable land**
1.4 billion ha

Source: European Bioplastics (2019), FAO Stats (2017), nova-Institute (2019), and Institute for Bioplastics and Biocomposites (2019). More information: ***www.european-bioplastics.org***

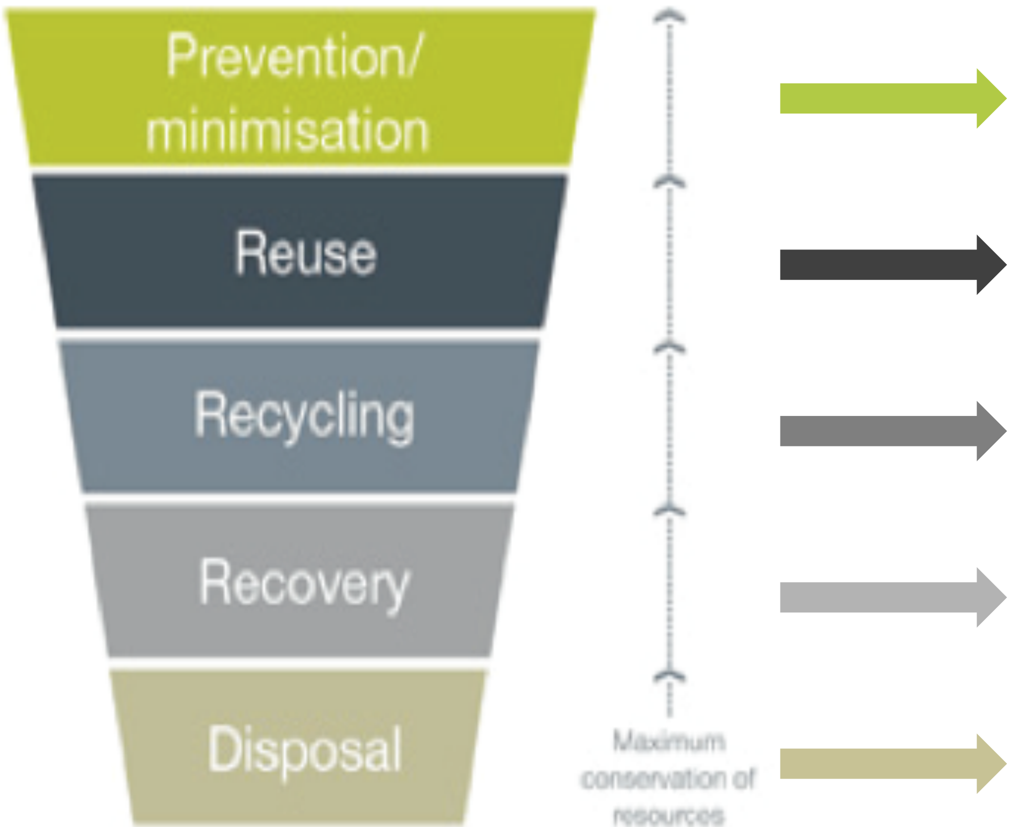
* *In relation to global agricultural area*
** *Including approx. 1% fallow land*
*** *Land-use for bioplastics is part of the 2% material use*

Sustainability assessment of bio-based feedstock



- Sustainability certification schemes are available, e.g.:
  - FSC and PEFC for wood/paper
  - ISCC PLUS for industrial and feed use
  - Roundtable Sustainable Biomaterials (RSB)
- EN 16751 was developed to standardise sustainability criteria of bio-based products
- Life cycle assessment (LCA) as a tool to assess environmental impacts
- EN 16760 provides specific LCA requirements and guidance for bio-based products based on the ISO 14040 series
- EU research projects (e.g. STAR-ProBio)

Bioplastics plastics and the waste hierarchy



Min. resources, max. performance, e.g. through improved barrier properties

Multiple and cascading use of certain apllications

Mechanical/chemical/organic recycling

Generation of renewable energy

Gradual phase out of recycable waste nessesary

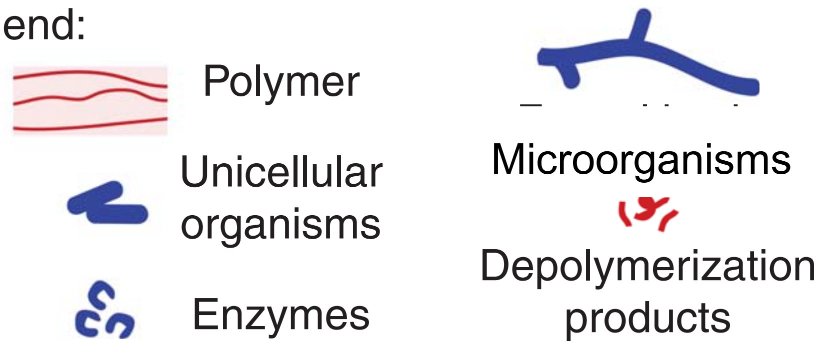
Graph: EU waste hierarchy

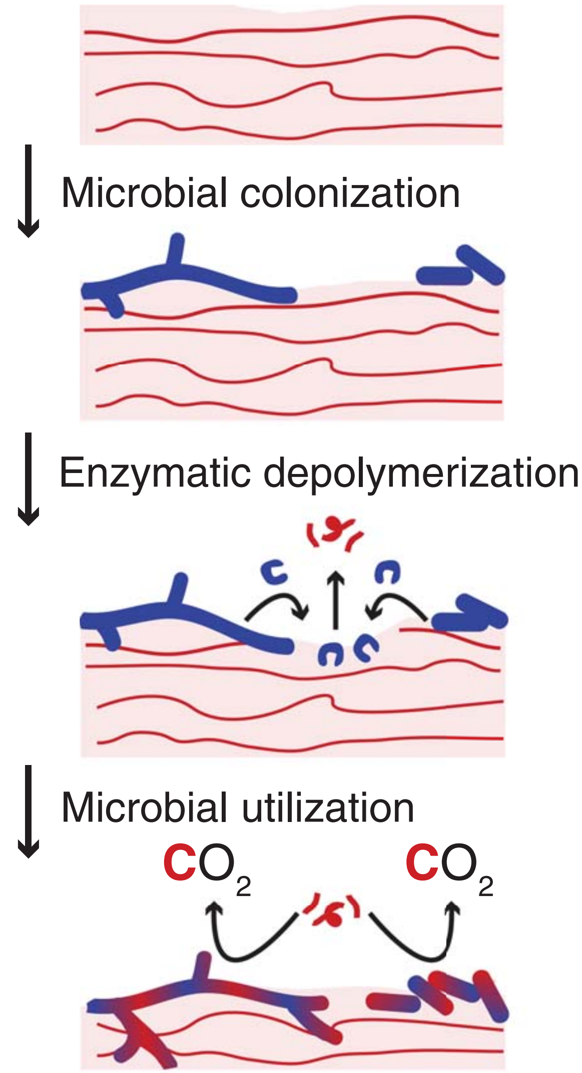
How biodegradation of plastics works

- Biodegradation = microorganisms metabolise material into water, CO_2 and biomass
- Depends on environmental conditions – temperature, humidity, inoculum – and on material/application itself

The term ‘biodegradability’ is only unambiguous, if environment and time are specified.

Legend:





Source: Zumstein et al., *Sci. Adv*. 2018

Biodegradation of plastics in different environments

Industrial and home composting

- **“Compostability”** describes a controlled process of biodegradation of a product under specific conditions (certain temperature, humidity, timeframe, presence of certain microorganisms
- For **certification** purposes materials and products have to pass disintegration, biodegradation, and ecotoxicity testing, control of regulated metals
- **Industrial composting**: min. 90% disintegration in 12 weeks, min. 90% biodegradation in 6 months, thermophilic conditions, plant growth test
  → e.g. EN 13432/EN 14995, ISO 18606/ISO 17088, ASTM D6400
- **Home composting:** min. 90% disintegration in 6 months, min. 90% biodegradation in 12 months, ambient temperature, plant grow test
  → e.g. NF-T51 800, FprEN 17427, AS 5810

compostable

INDUSTRIAL COMPOSTABLE DIN Geprüft

HOME OK compost TÜV AUSTRIA HOME

Biodegradation of plastics in different environments

Soil

- "**Biodegradable in soil**" should not be considered a licence to littering
- Standards and certification apply to e.g. **agricultural products**
- Min. 90% biodegradation in 2 years at ambient temperature, comprehensive ecotoxicity testing, **best practice guides**
- **EN 17033** *Biodegradable mulch films for use in agriculture and horticulture – Requirements and test methods"* - biodegradable mulch films, which are not intended to be removed

Marine or fresh water environments

- Biodegradability in water an intrinsic polymer characteristic, but **no dedicated end-of-life option** (except applications prone to get lost in such environments e.g. fishing gear)
- Diversity and concentration of **microbes vary** - conditions at the sea floor will differ from those found in a water column.
- **Marine environments:** ISO 22403 plus several test methods on ASTM/ISO level
- **Certification schemes** for biodegradability in fresh water and in the marine environment

https://www.european-bioplastics.org/events/eubp-conference/registration/

Thank you!

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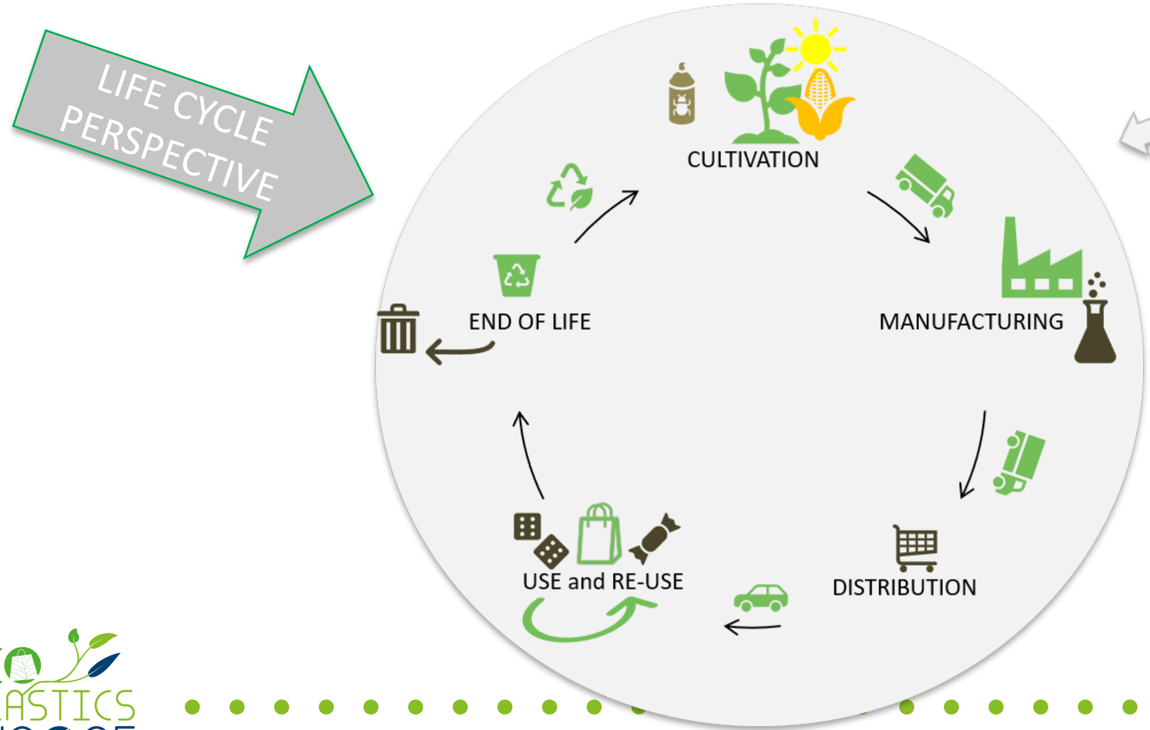
THE ROLE OF FEEDSTOCKS IN THE ENVIRONMENTAL LIFE CYCLE ASSESSMENT OF BIO-BASED PLASTIC PRODUCTS

BIO PLASTICS EUROPE

Claudia Wellenreuther, Hamburg Institute of International Economics (HWWI)

HWWI

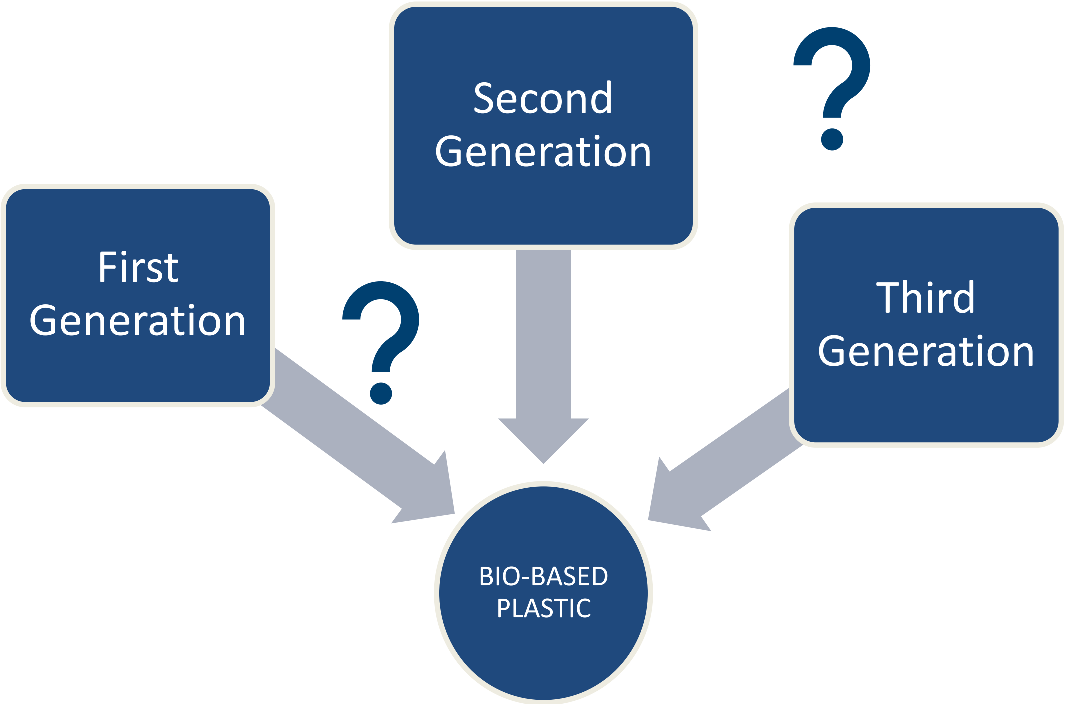
WP 8: ENVIRONMENTAL AND ECONOMIC ASSESSMENTS



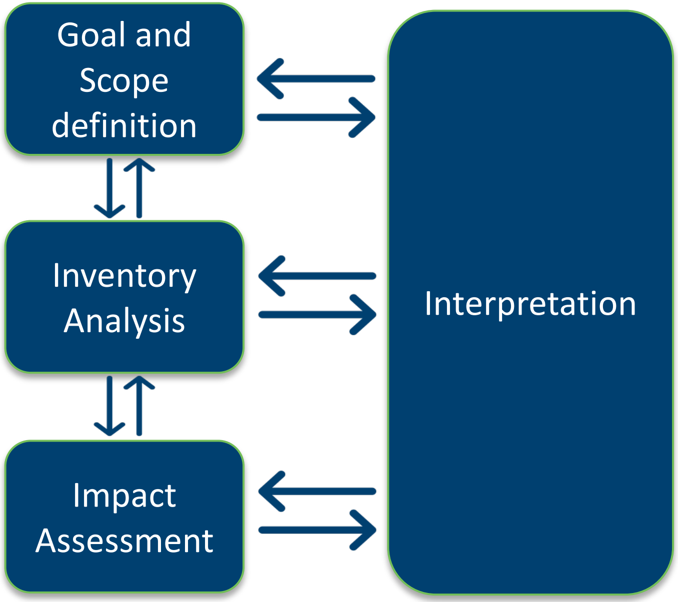
- WATER
- LAND
- ENERGY AND MINERAL RESOURCES
- PESTICIDE
- FERTILIZER
- ...

- CO_2
- WASTE WATER
- POLLUTANT
- NUTRIENTS
- TOXIN
- ...

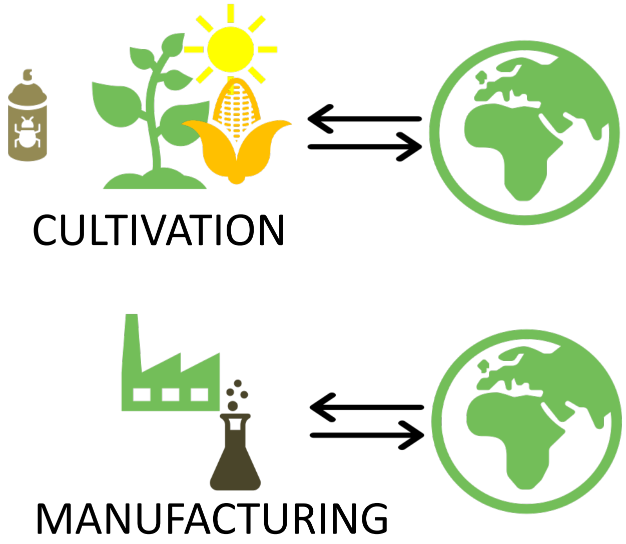
THREE GENERATIONS OF FEEDSTOCKS



ENVIRONMENTAL LIFE CYCLE ASSESSMENT



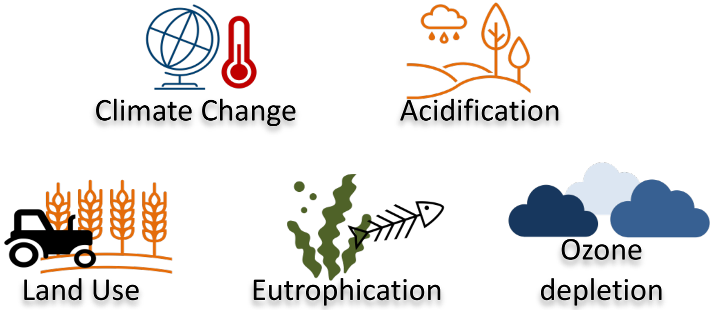
ROLE OF FEEDSTOCKS: RELEVANT LIFE CYCLE STAGES



Input flows: water, land, energy, pesticides, fertilizers, carbon sequestration

Output flows: emissions into air, water and land

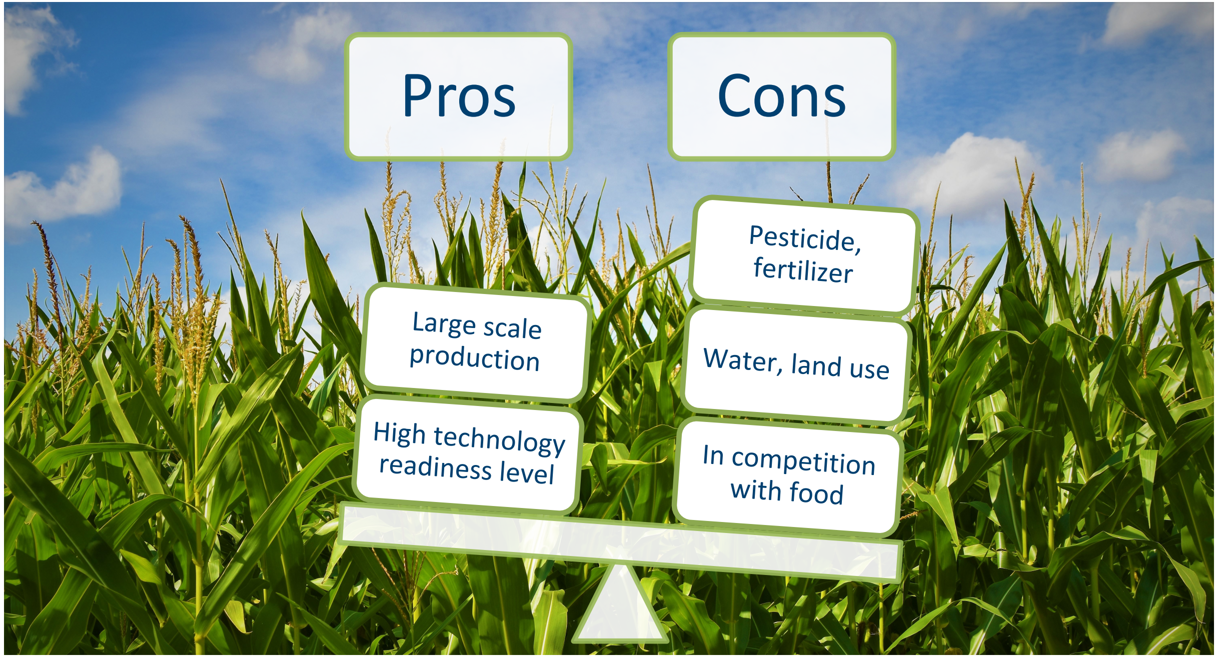
Potential environmental impacts:



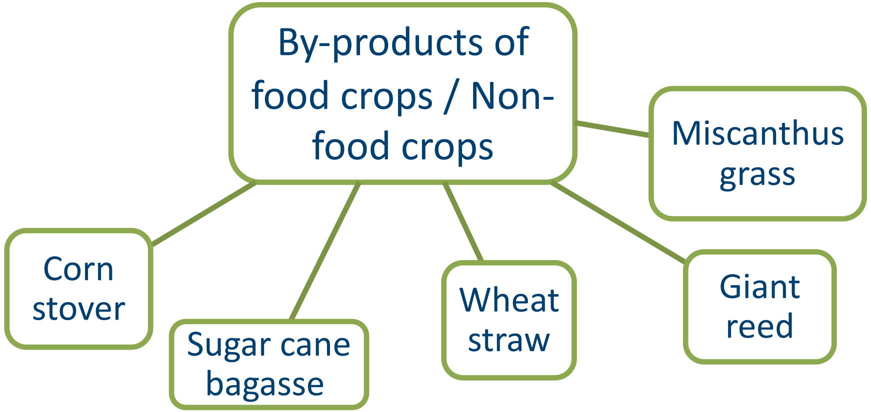
ELCA LITERATURE WITH FOCUS ON FEEDSTOCKS

- ELCA literature on innovative feedstocks has emerged
- Most literature analyses the life cycle of plastics based on first generation feedstocks and compares them to fossil-based plastics
- Challenge: comparability issues of the studies (different reference materials, assessment methods, impact categories, system boundaries…)
- For many innovative feedstocks only technical papers but no ELCA papers are available

FIRST GENERATION FEEDSTOCKS (E.G. CORN, SUGAR)



SECOND GENERATION FEEDSTOCKS



− Compared to first generation lower maturity level of processing, loss of ecosystem services by plant parts

+ No or limited issues related to land use and food competition; allocation of emissions in cultivation between co-products

! Allocation of emissions (food crop vs. by-product)
Opportunity costs of alternative use

THIRD GENERATION FEEDSTOCKS

Waste

- **Liquid organic waste**
  - wastewater from food industry
  - Industrial or municipal wastewater
- **Solid organic waste**
  - slaughterhouse waste
  - organic residues from material recovery

Seaplants

Biogas

− Low maturity level of processing technology; high energy intensity of refinery processes (-> GHG contribution)

\+ No issues related to land use and food competition; avoidance (or at least delay) of emissions in landfilling, limited alternative use, avoids final disposals

! In the future
- efficiency increases through scale effects and process innovation
- higher shares of renewables in the energy mix of producer countries

CONCLUSION

- No feedstock optimal in every respect is in sight
- Common **benefits** of second and third-generation feedstocks:
  - Avoidance (or reduction) of land use/transformation issues and related emissions
  - No competition with food production or other critical supply chains
  - Potential to use by-products as energy sources
- Common **drawbacks** of currently second and third-generation feedstocks:
  - Low degree of technical maturity → High energy intensity of refinery processes (especially fermentation and extraction)
- **Trade-off** in several dimensions (time, environmental categories…)

MANY THANKS FOR YOUR ATTENTION!

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Transition to Bioeconomy

Davide Viaggi

Department of Agricultural and Food Sciences, University of Bologna, Italy

davide.viaggi@unibo.it

EUROPEAN BIOPLASTICS RESEARCH NETWORK

2nd VIRTUAL MEETING:

"2nd & 3rd Generation Feedstock for Bio-based and Biodegradable Plastics"

Outline

1. Drivers & scenarios
2. Policy background
3. What kind of innovations
4. Markets, time and organisation
5. Project examples
6. Key issues for the future
7. Post-covid thoughts

Drivers & scenarios

Population needs + climate change+….

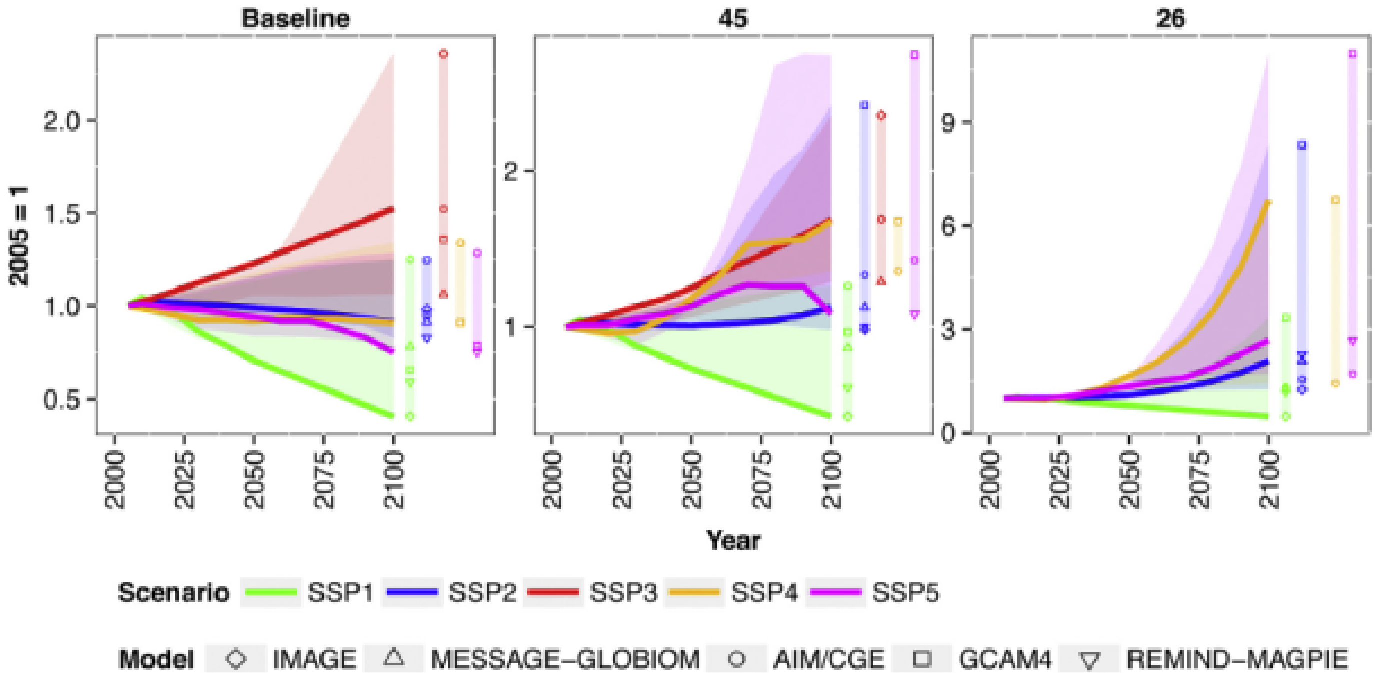


Fig. 8. Change in world market prices [2005 = 1] aggregated across all crop and livestock commodities of the five SSP marker scenarios for the baseline (left column), RCP4.5 (middle column) and RCP2.6 (right column) cases (Note that baseline, RCP4.5 and RCP2.6 have indivudal scales). Colored lines indicate the marker model results for each SSP. Colored bars indicate the range of data in 2100 across all marker and non-marker projections for each SSP (models are depicted by icon).

Popp et al., 2017

Policy background

UN Sustainable Development Goals

EU New Green deal

Upcoming Farm to fork strategy

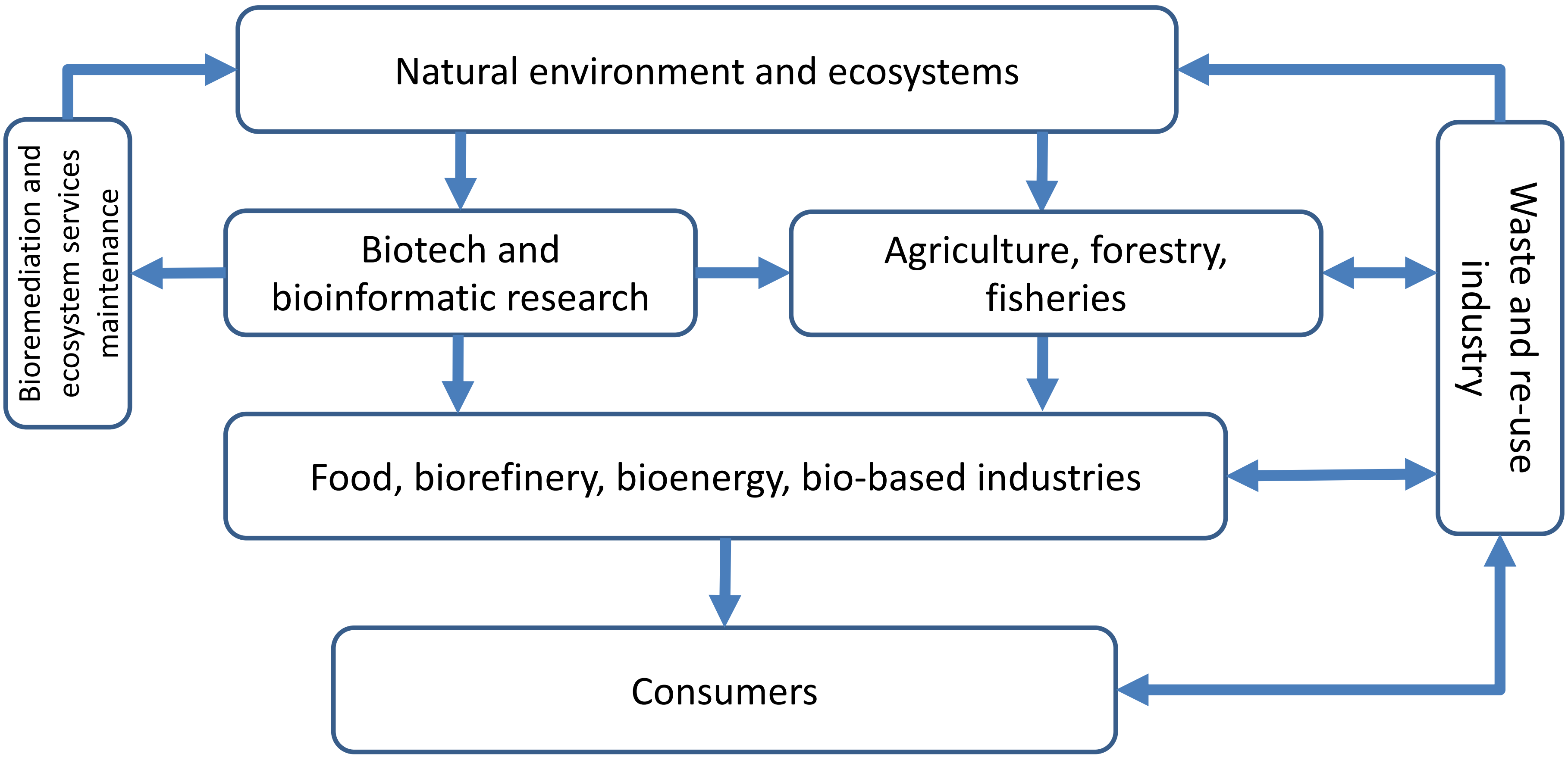
New CAP

…..

Growing emphasis on innovation

…. But acknowledgement of difficulties from lab to fork

Feedstocks & the bioeconomy



Source: Viaggi, 2018

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What kind of innovation?

Genetics/biodiversity

ICT, digitalisation, precision farming

Organic, agroecology, ….

Small scale organisational innovation

Social innovation, contractualisation, networking

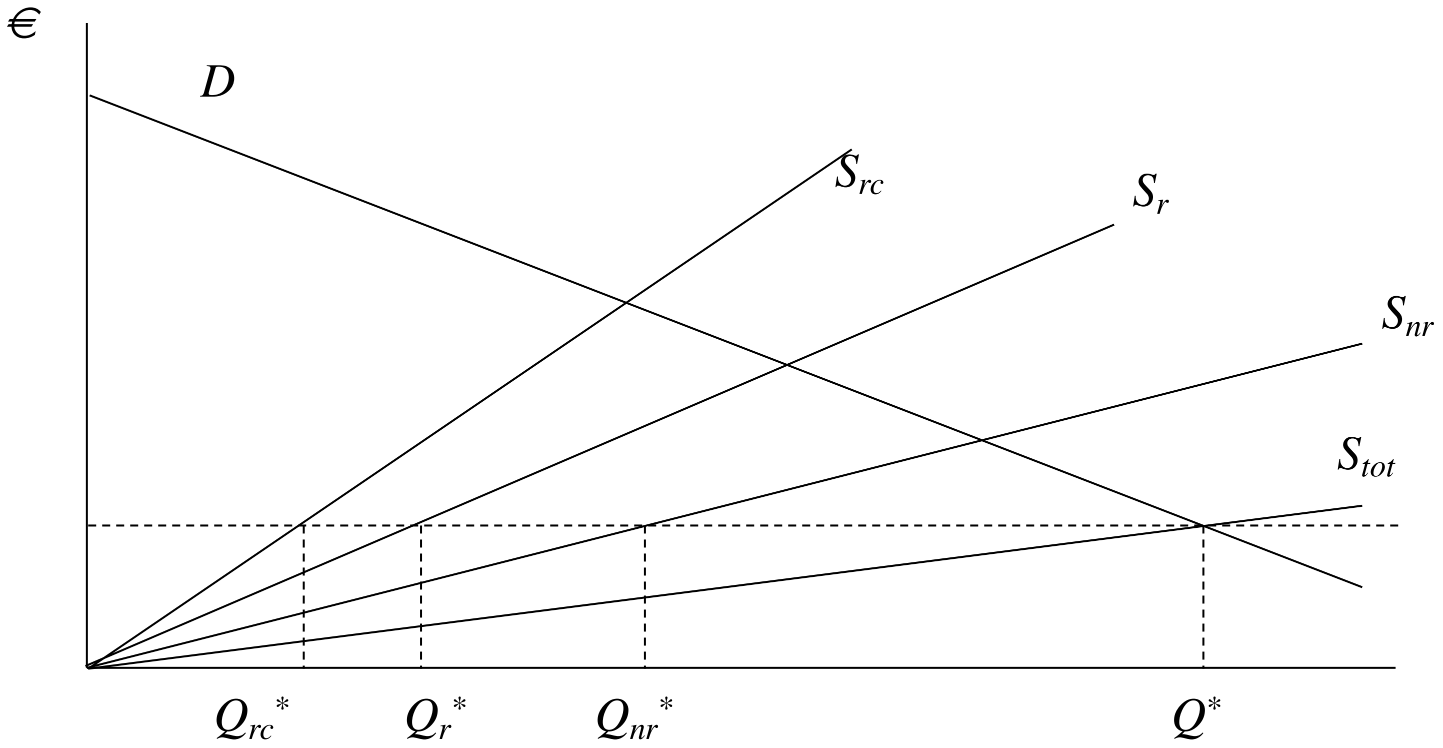
->towards a higher information content (more information per hectare)

->behavioural changes and segmentation->higher need for coordination

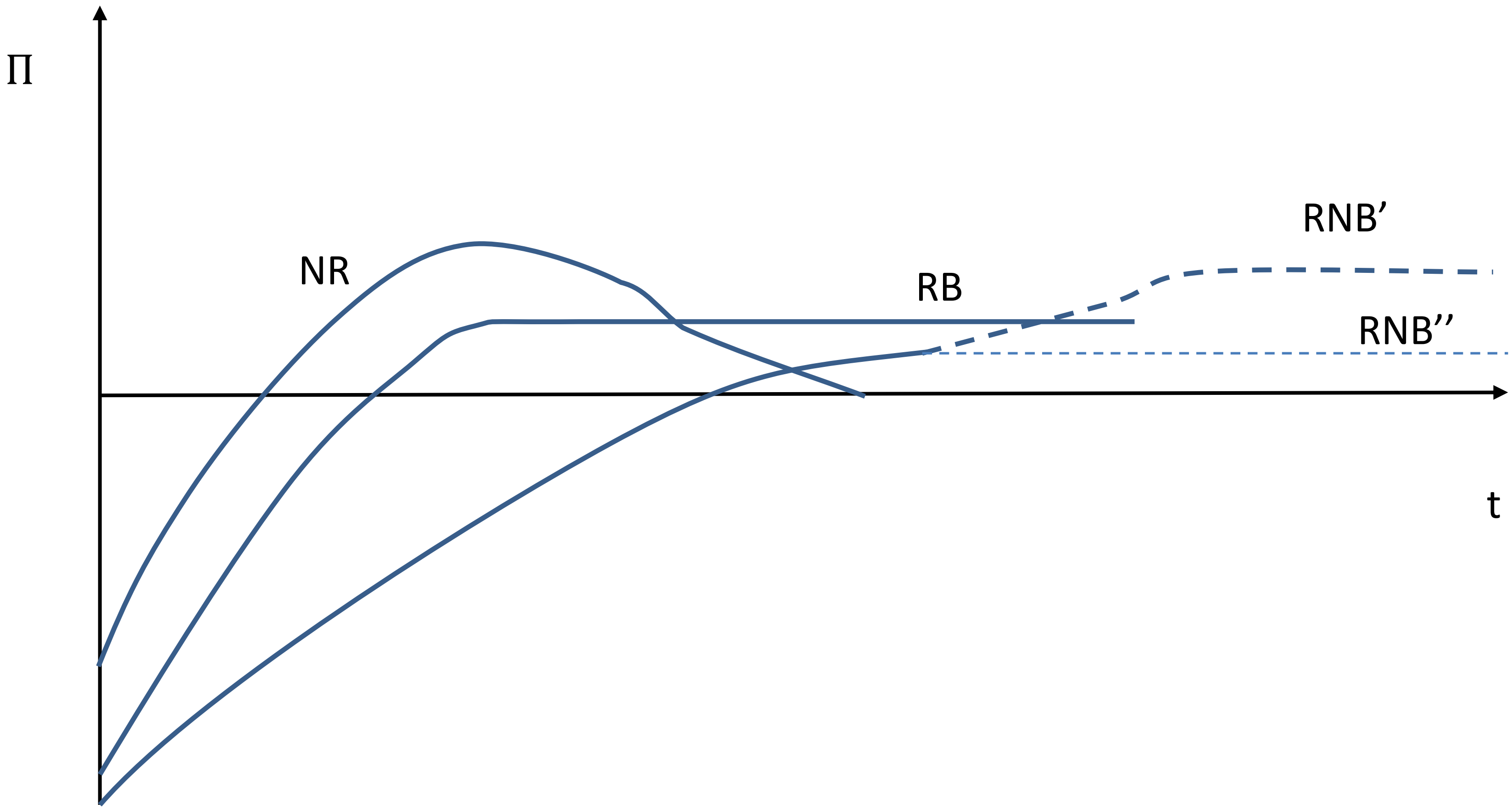
->dependence on context factor (e.g. oil prices)

->public good components

Equilibrium across supply sources



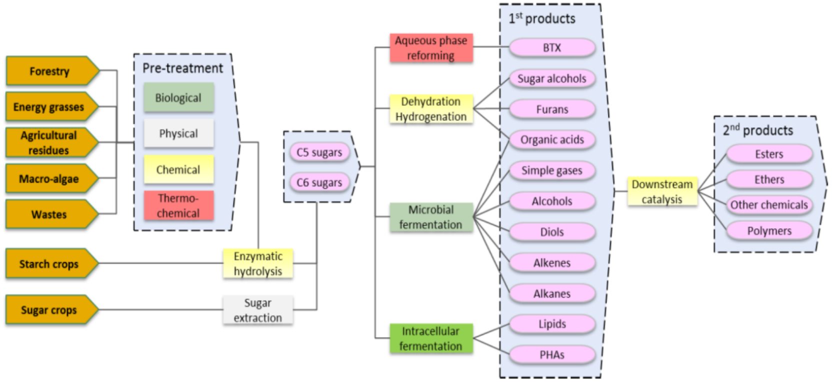
Bioeconomy over time



Source: Viaggi, 2018

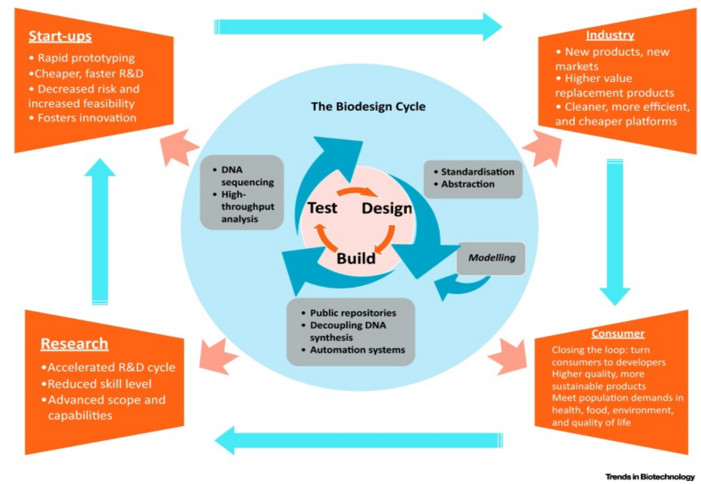
Changing organisational concepts

Biomass de- and re-composition



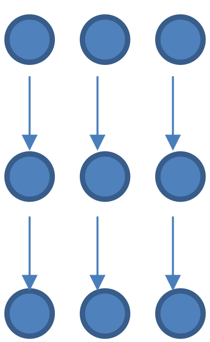
Taylor *et al*. (2015)

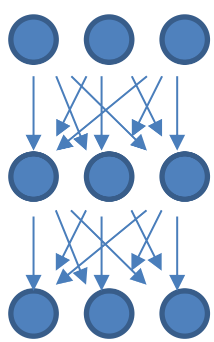
Biodesign



Flores Bueso & Tangney (2017)

From value chains to biomass value web and beyond





Focus on strategie, policy integration and policy mix

Are business models the right synthesis (vs. production costs)???

Some features of EU innovative business models:

- Heterogeous and locally adapted
- Integrating food & non-food
- Integrating private and public values
- Success and failure
- Role of context, networks, etc.
- **Role of entrepreneurship**

- https://rubizmo.eu/

Rubizmo

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Changing reasearch focus: The example of CONSOLE

Tenure solutions

+

Collective arrangements

+

Value chain mechanism (link to market)

+

Results-based payment options

https://console-project.eu/

Key issues for the future

Decoupling from land & resources

Future of marginal & remote areas

Ecosystem services, social perception and system's sustainability

Post covid-19 reflections

- Flexibility and resilience
- Importance of centralised timely decisions
- Role of infrastructures and information
- Role of networks
- Stock of knowledge and information as an important public good
- Long run knowledge accumulation vs very short run response
- Fast conversion of research on new themes (balance with strong expertise)
- But also change in market drivers…
- ->LONGER TERM EFFECTS STILL TO BE UNDERSTOOD

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Davide Viaggi

THANK YOU VERY MUCH

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Universität für Bodenkultur Wien
Department IFA-Tulln

Phototrophic biopolymer production

PHB made in Europe

Ines Fritz
Institute for Environmental Biotechnology

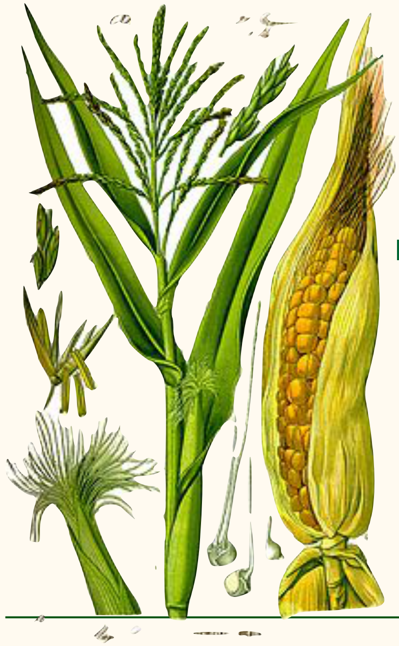
General Overview

- Why even think about phototrophic biotechnology?
  - the consume question
  - the resource question
  - old knowledge and hipp new technology
- PHB from cyanobacteria as an example
  - the project CO2USE - and what we learned from it
  - the holistic approach brought to praxis
- How to make phototrophic production viable in Europe?
  - co-evolution of science and economy
  - prospect for a better future?

The questions
consume & resources

- Plastic was invented to overcome natural material limits
- 400 Mio t konventional plastic in 2019
  - obsolescence & single use products to fight the „endless“ lifetime
  - but: „endless“ lifetime of waste

Image: cbc.ca, 2020



- Substitution of 400 Mio t plastic
  - requires ca. 131 % of global maize yield
  - and there are serious ethical concerns
  - btw: current market share of biobased plastic is < 1% maize yield

The resource question
culminates

We need to replace 5 km^3 mineral oil equivalent a^{-1}

to feed the global material AND energy consumption
in a sustainable way

at present level!

The resource question
phototrophic biotechnology

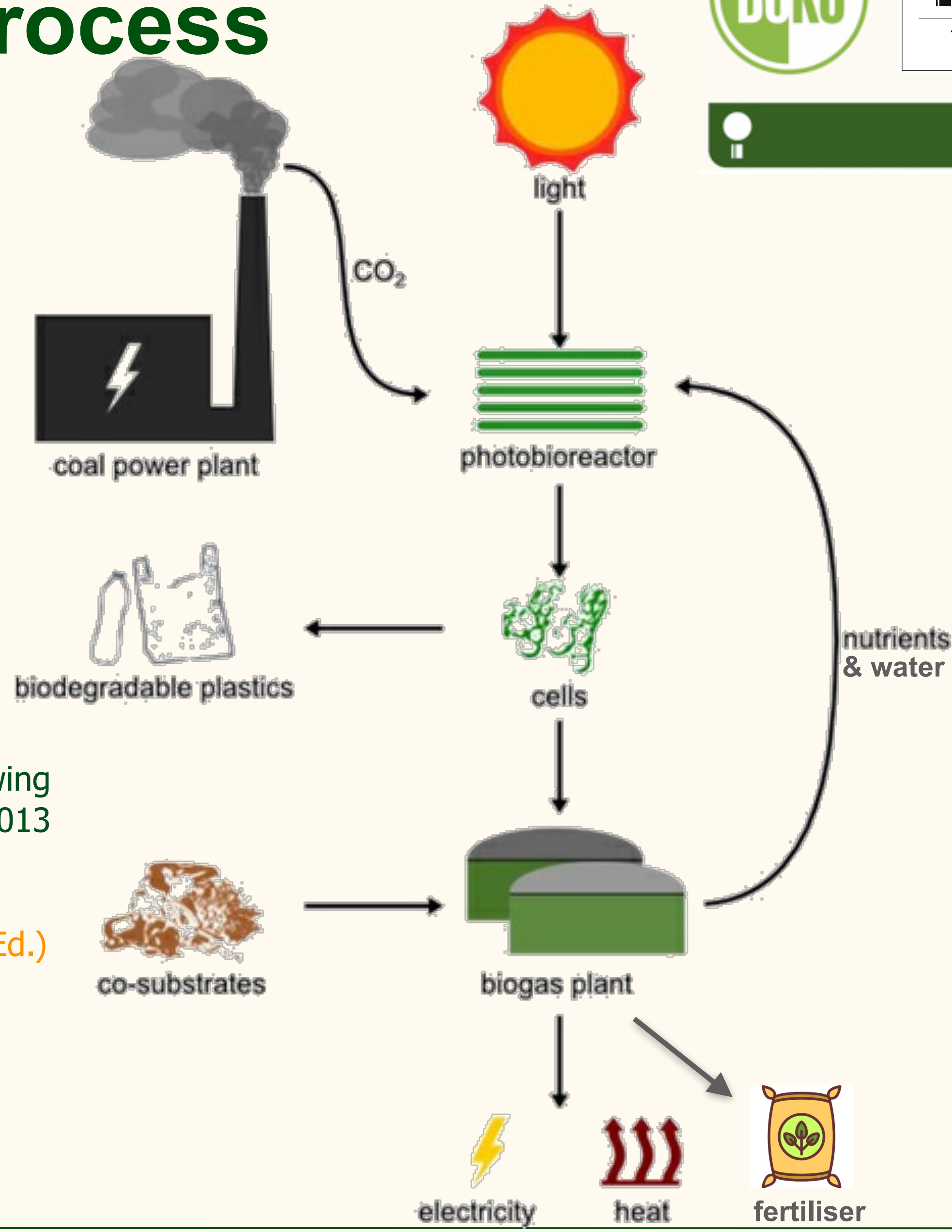
- Algae carbohydrate productivity in the photobioreactor
  - ca. 3-6 $t\ ha^{-1}\ a^{-1}$ (calculated)
  - reminder: some single years of (molecular) breeding, strains by far not optimised
- Ethically acceptable
  - no agricultural land needed
  - already occupied areas are suitable (industrial buildings, parking places, etc.)
- 5 km^3 fossil oil equivalent a^{-1}
  - would require ca. 3% of ocean surface as photobioreactor

Source: founterior.com, 2020

The example process

PHB from cyanobacteria

- Scheme of the CO2USE process
  - 6 project partner Austria and Czech Republic
  - FFG supported
  - 2 parts, 6 years



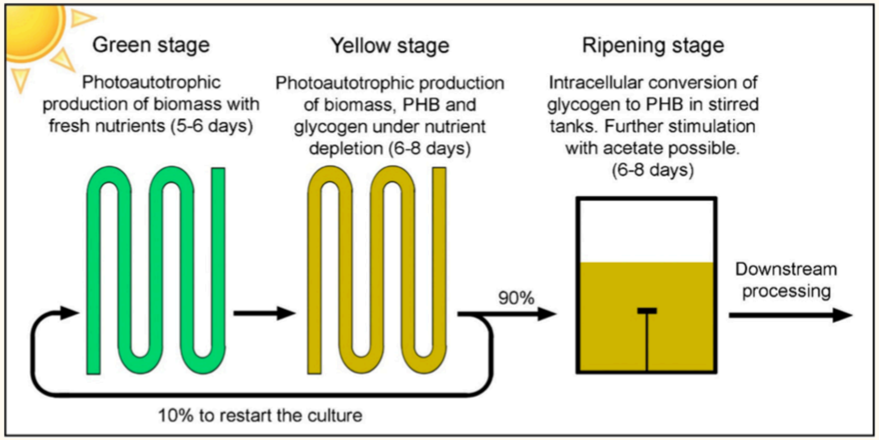
Drawing
© CO2USE, 2013

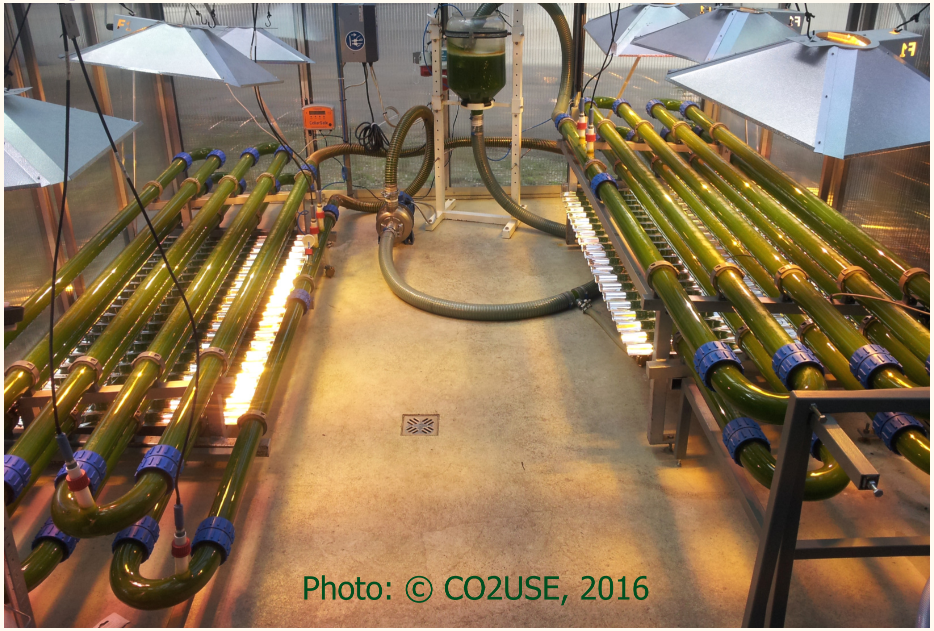
process first published:
Drosg & Fritz. In: Wörgetter (Ed.)
Biobased future, 06/2012

The project outcome

CO2USE - lessons learned

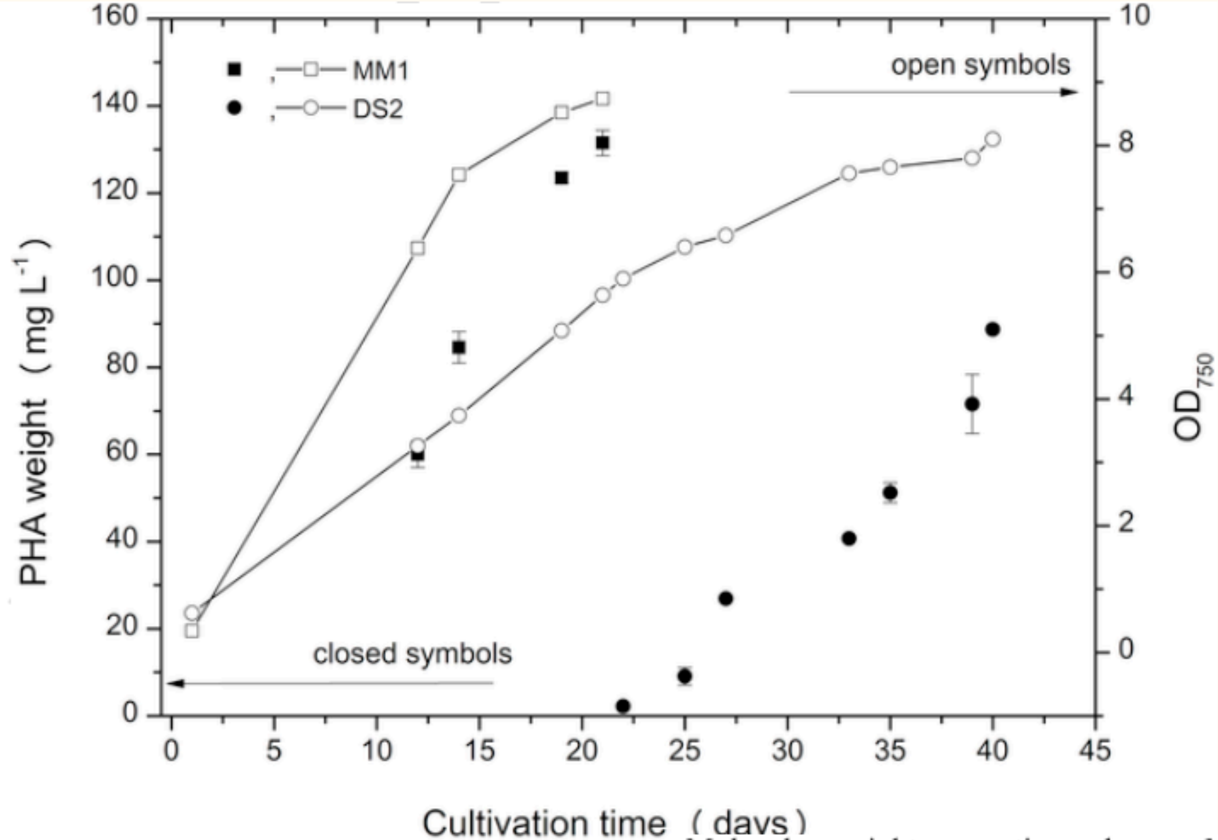
- Production strain — Silvestrini et al 2016 J. Proteomics & Bioinformatics 9:2
  - *Synechocystis sp.* CCALA192, *pha*-genes sequenzed
- Project parts demonstrated
  - PHB production, anaerobic digestion, nutrient recycling, water recycling, non-sterile pilot scale production, cost calculation
- Production strategy
  - Troschl C. et al 2018 Algal Res. 34





The project outcome

some selected data



MM1 = mineral medium
DS2 = digestate supernatant

Graph & table from:

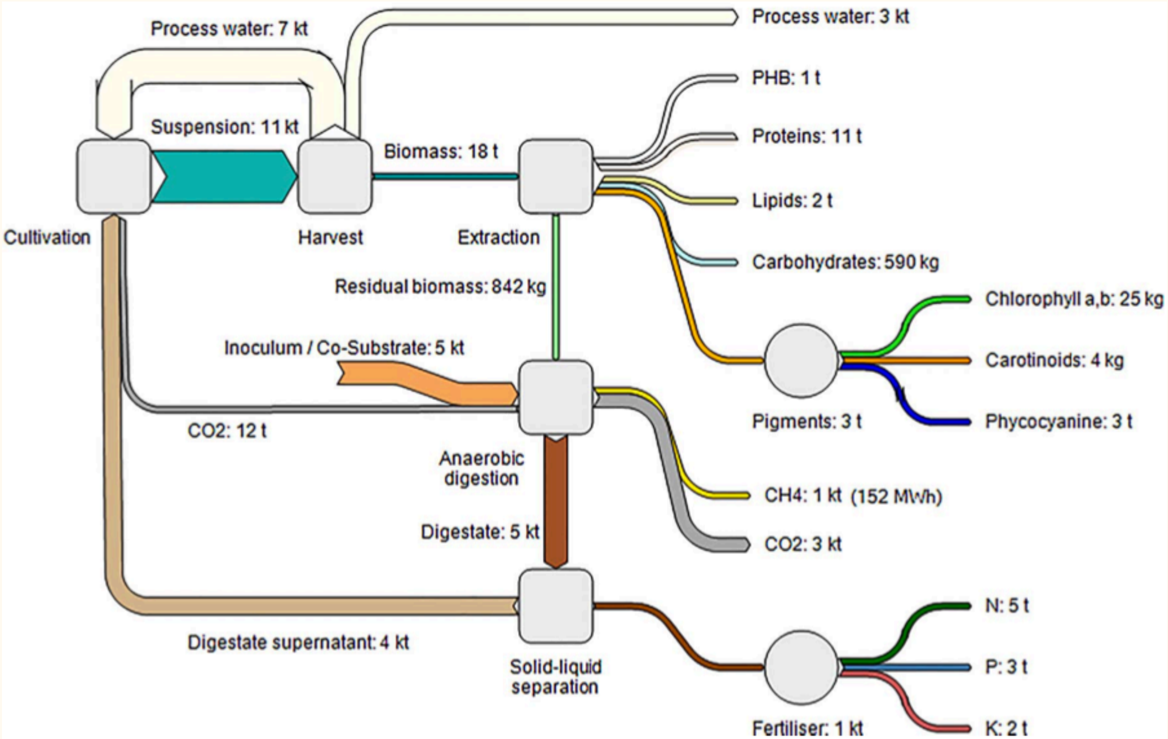
Kovalcik et al 2017 Int. J. Biological materials 102.

Molecular weight properties polymers MM1 and DS2 synthesised by *Synechocystis salina* MM1 and DS2 polymers and P3HB reference.

Sample	M_n (MDa)	M_w (MDa)	$Đ_M$
Reference	0.12	0.80	6.5
MM1	1.52	5.82	3.8
DS2	2.66	7.98	3.0

The project outcome

more selected data



Biorefinery concept (left)
and
Valuable substances
obtained from cyanobacteria

Graph & table from:

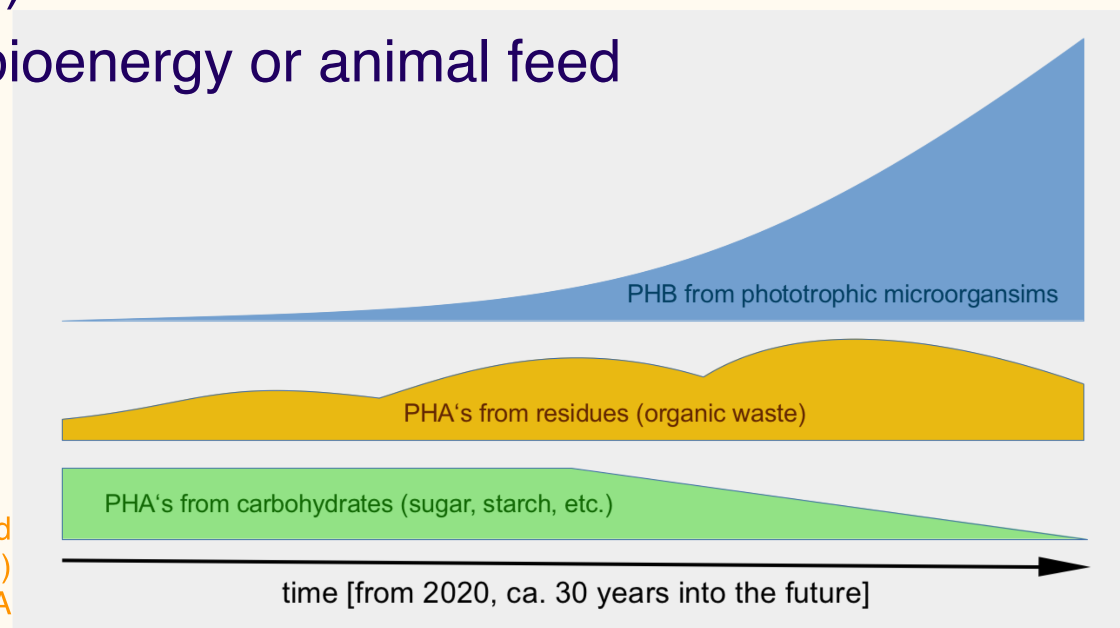
Meixner et al 2018 J. Biotechnology 265.

Parameter	Unit	*S. salina* cultivated in	
		mineral medium	digestate supernatant
PHB	[% TS]	7.3 ± 0.8	6.2 ± 0.8
$Chlorophyll_a$	[mg g^{-1} TS]	2.0 ± 1.0	1.1 ± 0.8
$Chlorophyll_b$	[mg g^{-1} TS]	0.4 ± 0.8	0.3 ± 0.8
Total carotenoids	[mg g^{-1} TS]	1.5 ± 0.8	0.2 ± 0.8
C-phycocyanin	[mg g^{-1} TS]	–	127.3 ± 3.6
Allophycocyanin	[mg g^{-1} TS]	–	42.6 ± 1.5

Production cost details:
Panuschka et al 2019 Algal Res. 41.

Production in Europe?

- Productivity would be higher in tropical regions
  - reminder: the same is valid for agriculture!
- Combined material and energy production
  - PHB (mid-range value) + valuable side products (pigments, vitamins, amino acids) contribute to the economic success
  - residual biomass → bioenergy or animal feed



Fritz et al. Comparison of Heterotrophic and Phototrophic PHA Production. In: Koller M. (ed) 2020 Handbook of PHA

We may see the future clearly if we open our eyes today!

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     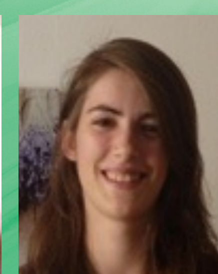

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Use of Algae as innovative feedstocks in PLA production

In a sustainability perspective at early stage of development

Ólafur Ögmundarson

Adjunct Professor, University of Iceland

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BIO PLASTICS EUROPE

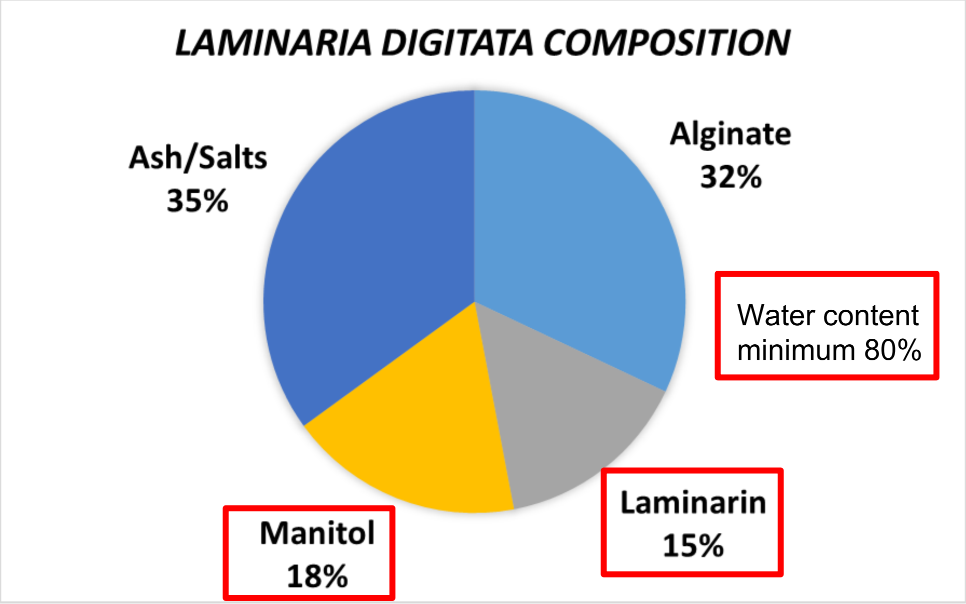
EUROPEAN BIOPLASTICS RESEARCH NETWORK
2nd VIRTUAL MEETING:
“2nd & 3rd Generation Feedstock for Bio-based and Biodegradable Plastics”

Background

- Production of Lactic Acid from macroalgae
  - Research project at the Novo Nordisk Foundation Center for Biosustainability
  - Lab research, small scale, low TRL
  - The necessity to look beyond Environmental Sustainability to avoid tradeoffs with Economic Sustainability

Pros and cons of three different feedstock generations

	1st Generation	2nd Generation	3rd Generation
Feedstock	Corn	Corn stover	Macroalgae
Pros	Easily fermented sugars	Non-food biomass	No land use competition
Cons	Land use, edible food	Technological challenges	Low dry matter content



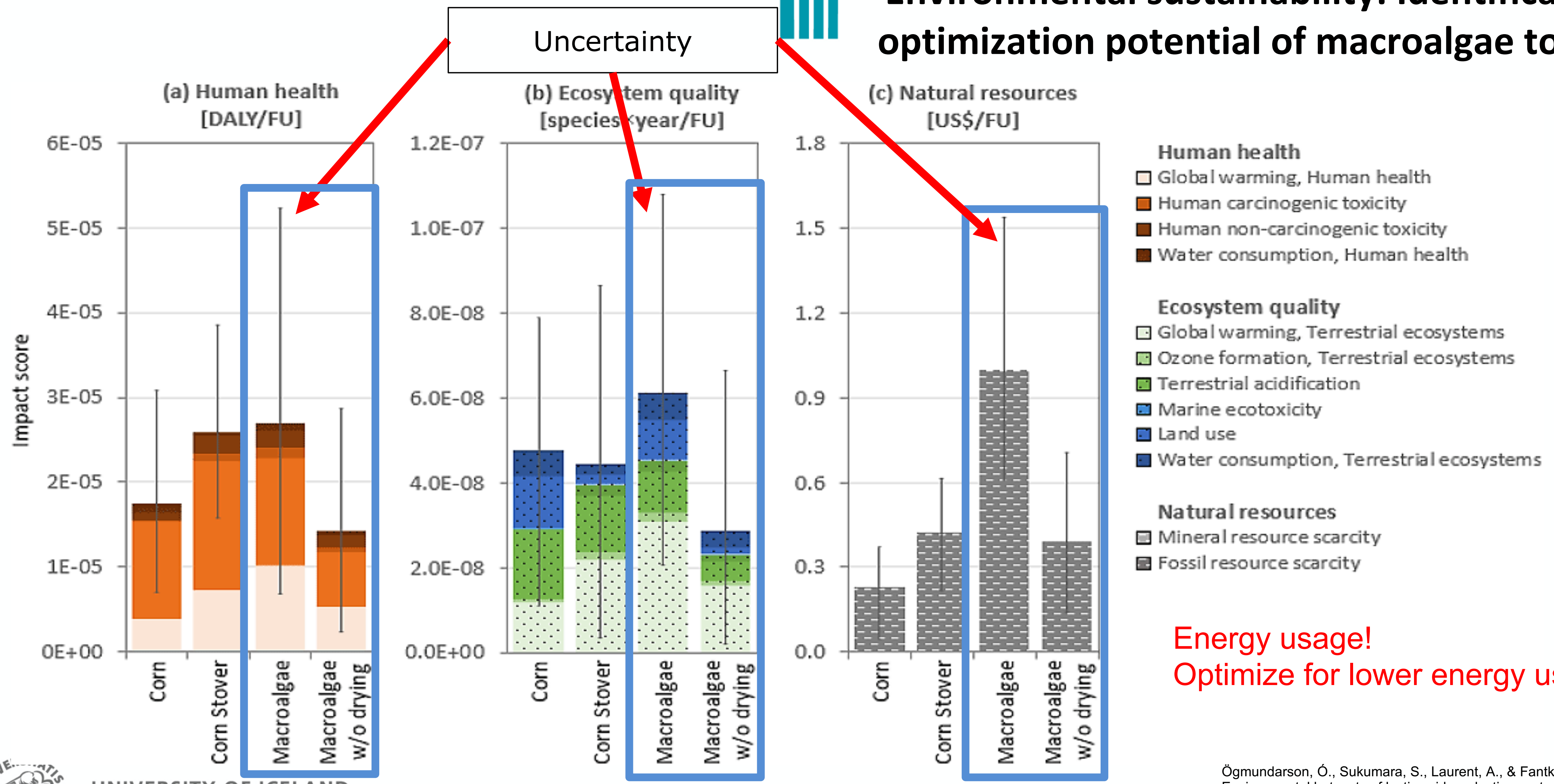
Konda NVSNM, Singh S, Simmons BA and Klein-Marcuschamer D, An investigation on the economic feasibility of macroalgae as a potential feedstock for biorefineries. Bioenergy Res 8:1046–1056 (2015).

High water content currently requires drying of macroalgae to

1. Make biomass more digestible for microbes
2. Biomass contamination (Kill unwanted spores before fermentation)
3. Make transportation easier

Ögmundarson, Ó., Sukumara, S., Laurent, A., & Fantke, P. (2020). Environmental hotspots of lactic acid production systems. GCB Bioenergy, 12(1), 19–38. https://doi.org/10.1111/gcbb.12652

Environmental sustainability: Identification optimization potential of macroalgae to PLA



Energy usage!
Optimize for lower energy use

Ögmundarson, Ó., Sukumara, S., Laurent, A., & Fantke, P. (2020). Environmental hotspots of lactic acid production systems. GCB Bioenergy, 12(1), 19–38. https://doi.org/10.1111/gcbb.12652

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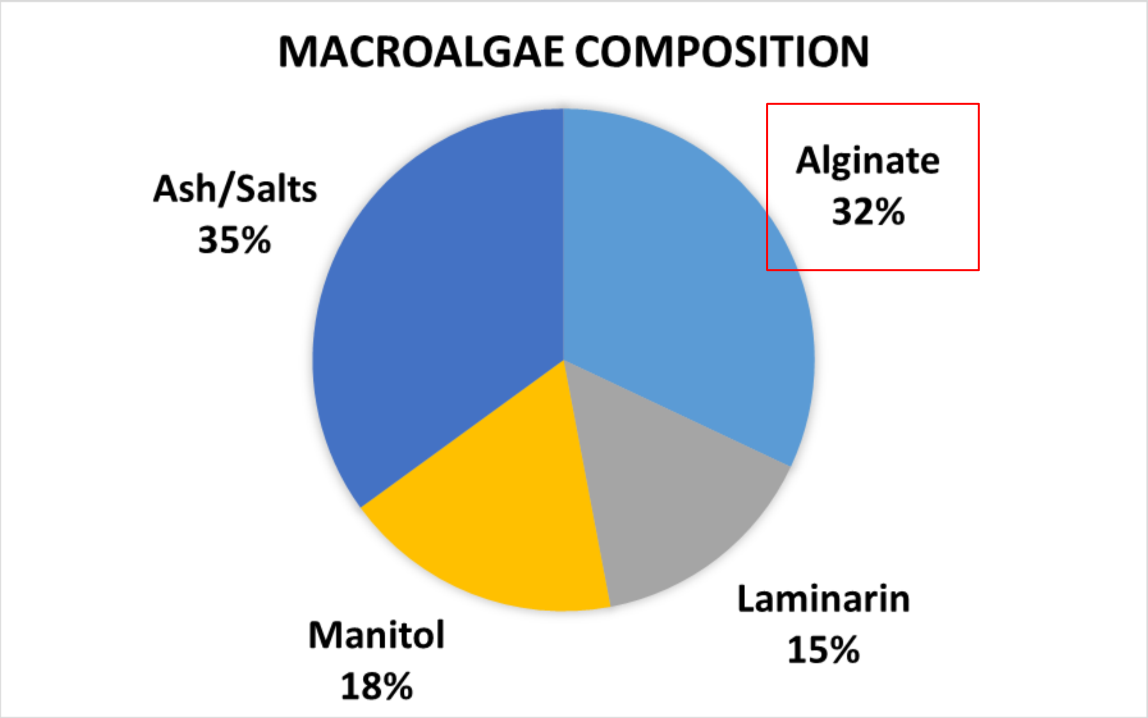
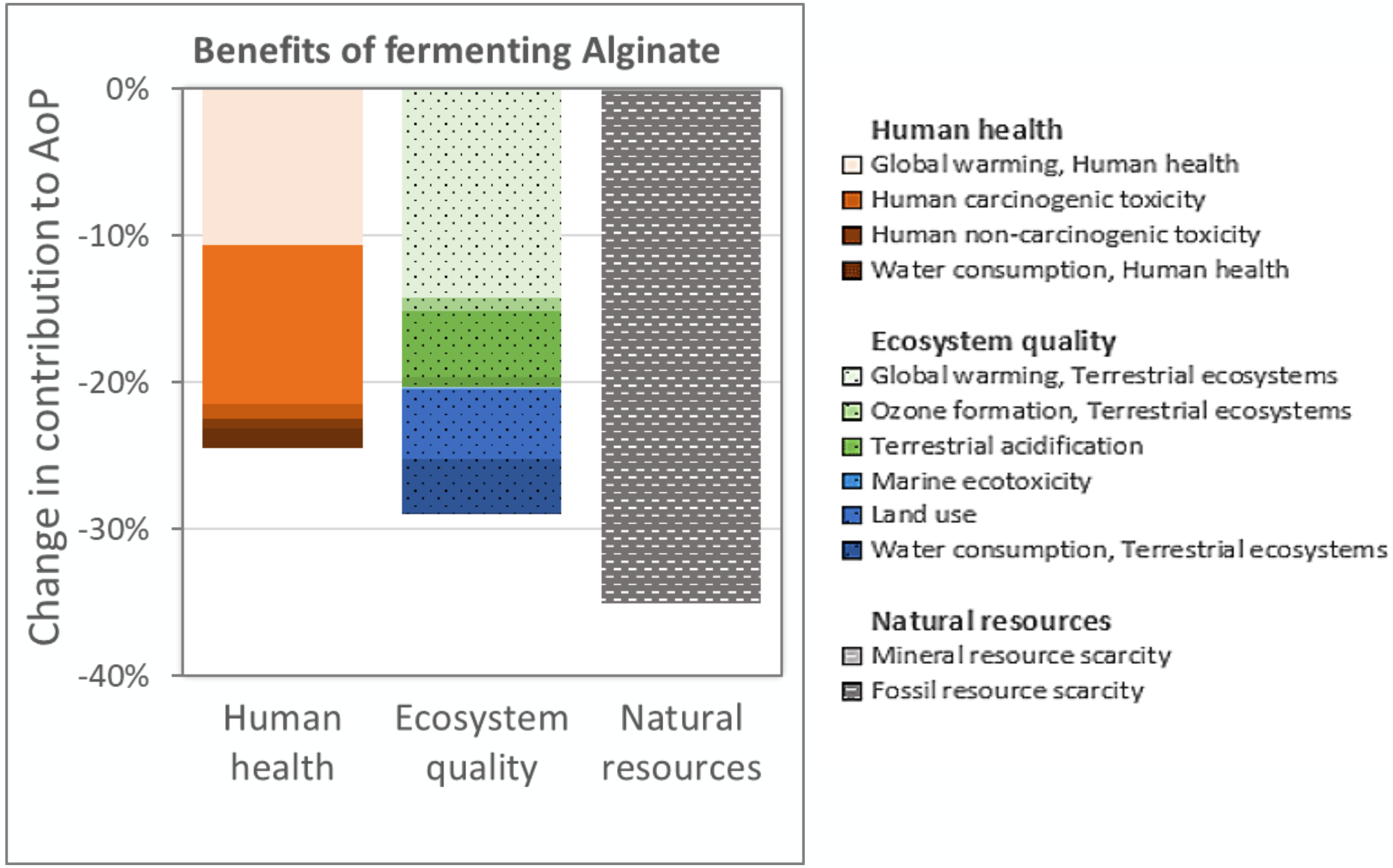
Optimization potential of macroalgae as feedstock

Process optimization potential	High: process optimization (utilities), integrated process development (e.g., alginate fermentation)
Assessment results uncertainty	High (poor data and system description available at TRL 2–3)

Ögmundarson, Ó., Sukumara, S., Laurent, A., & Fantke, P. (2020). Environmental hotspots of lactic acid production systems. GCB Bioenergy, 12(1), 19–38. https://doi.org/10.1111/gcbb.12652

Alginate as carbon source





Konda NVSNM, Singh S, Simmons BA and Klein- Marcuschamer D, An investigation on the economic feasibility of macroalgae as a potential feedstock for biorefineries. Bioenergy Res 8:1046–1056 (2015).

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The potential of macroalgae as innovative feedstocks in PLA production from an environmental sustainability perspective lies in

- Identification of **optimization potential** → Energy use
- Identification of **optimization potential** → Fermentation of Alginate

But what about the economic sustainability?

The necessity of combining Environmental and Economic Sustainability

Tradeoffs between Environmental (LCA) and Economic (TEA) Sustainability results

Though cutting energy utility usage by 39%
it only reduces the TEA results by 7%

3rd generation LCA results			**TEA results**			
DALY	2.70	$				
Species.year	0.004	$				
USD	1.00	$				
Total	**3.7**	$ Cost per funtional unit	**4.5**	$ Cost per funtional unit	**8.2**	$ Cost per funtional unit

3rd generation LCA results without drying			**TEA results**			
DALY	1.42	$				
Species.year	0.002	$				
USD	0.003	$				
Total	**1.4**	$ Cost per funtional unit	**4.2**	$ Cost per funtional unit	**5.6**	$ Cost per funtional unit

Cutting energy utility usage by 39%, gives a 62% reduction in environmental cost

Ögmundarson, Ó., Sukumara, S., Herrgård, M. J., & Fantke, P. (2020). Combining Environmental and Economic Performance for Bioprocess Optimization. *Trends in Biotechnology*, *38*(11), 1203–1214. https://doi.org/10.1016/j.tibtech.2020.04.011

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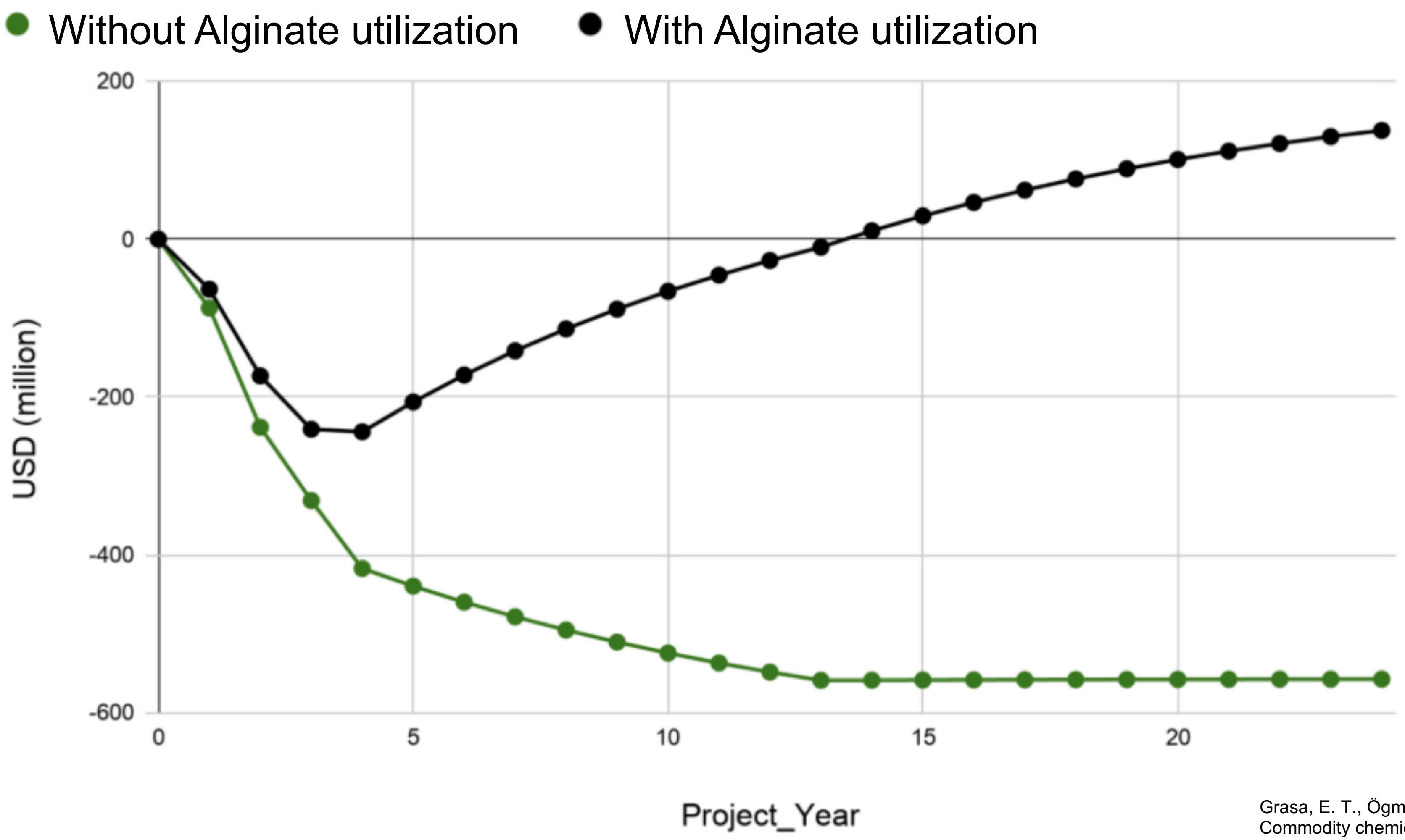
Cumulative cash flow analysis, with and without alginate utilization



Grasa, E. T., Ögmundarson, Ó., Gavala, H. N., & Sukumara, S. (2020). Commodity chemical production from third-generation biomass: a techno-economic assessment of lactic acid production. Biofuels, Bioproducts and Biorefining. https://doi.org/10.1002/bbb.2160

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Macroalgae has potential, if we optimize production processes with Sustainability as the goal

Thank you!

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