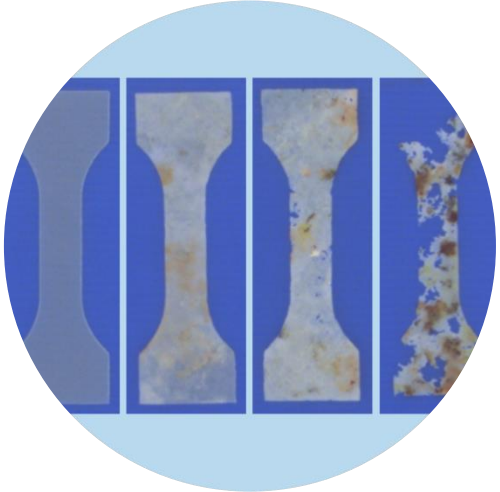
Strategies towards home compostable PLA products

Maarten van der Zee

8th PLA World Congress, Munich, Germany, 29 May 2024



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Outline

- About Wageningen Food & Biobased Research
- Strategies towards home compostable PLA products
    - Context
    - Some examples
- Conclusions and outlook

Wageningen University & Research

To explore the potential of nature to improve the quality of life

The Wageningen approach

Unique union of expertise leading to scientific breakthroughs that can quickly be put into practical solutions and incorporated into education

Wageningen University

3.415 employees (fte)
fundamental and strategic research
94 chair groups

Wageningen Research

± 3.327 employees (fte)
applied and pre-competitive research
9 independent research institutes

Year 2022

Wageningen Food & Biobased Research

Contract Research Organisation

Governments, NGO's, institutional funders, industrial companies

Highly engaged, proficient experts

World-class facilities and laboratories

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Sustainable plastics research at WFBR

Outline

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Need for biodegradable materials

- Strive for recycling, but leakage to the environment cannot be completely prevented for:
  - Products with a high risk of being littered
  - Products that are used in the open environment
- Biodegradable materials are needed to prevent accumulation of these products
- The biodegradation profile needs to match both the use phase and the end-of-life phase
- Application specific approach in which the capability of tailoring biodegradation behaviour is crucial

Strategies for home compostable PLA products

- Applying prodegradant additives
  - Encapsulated enzymes
  - Substances promoting hydrolysis or photo-degradation
- Blending with other home compostable polymers
- Introducing hydrolysable moieties in the polymer chemical structure

Experimental material development approach

- Compound development via twin screw extrusion
- Sample preparation via sheet extrusion
- Disintegration trials in controlled laboratory environment
    - e.g. in soil, 25°C, constant moisture content, inoculated
- Visual and mechanical testing to compare biodegradation rate



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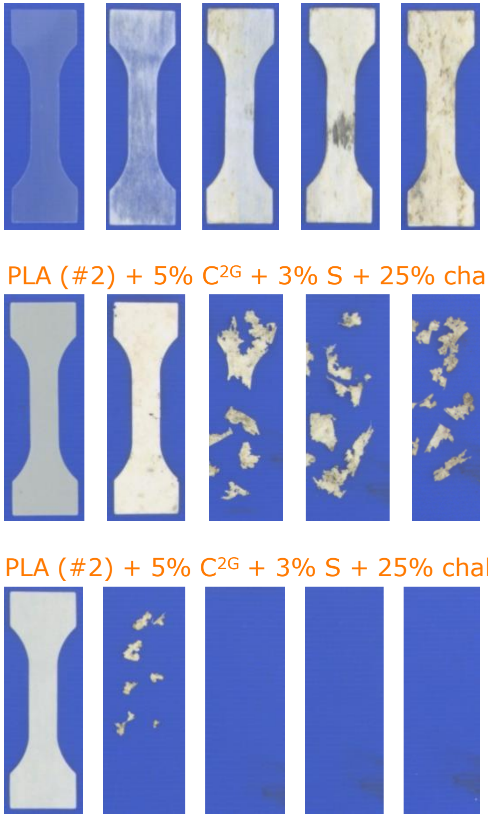
Prodegradant additives – encapsulated enzymes

Approach:

- Compounding PLA with CARBIOS Active
  - 1st and 2nd generation
- Application oriented processing
  - Injection moulding, thermoforming, foaming

Findings:

- Residual enzyme activity depends on processing conditions
  - Temperature, residence time, PLA-grade, shear



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Additives promoting hydrolysis of PLA

Approach:

- Production of PLA materials with up to 3% of additives, e.g.
  - 3% Fumaric acid
  - 3% Vanillic acid

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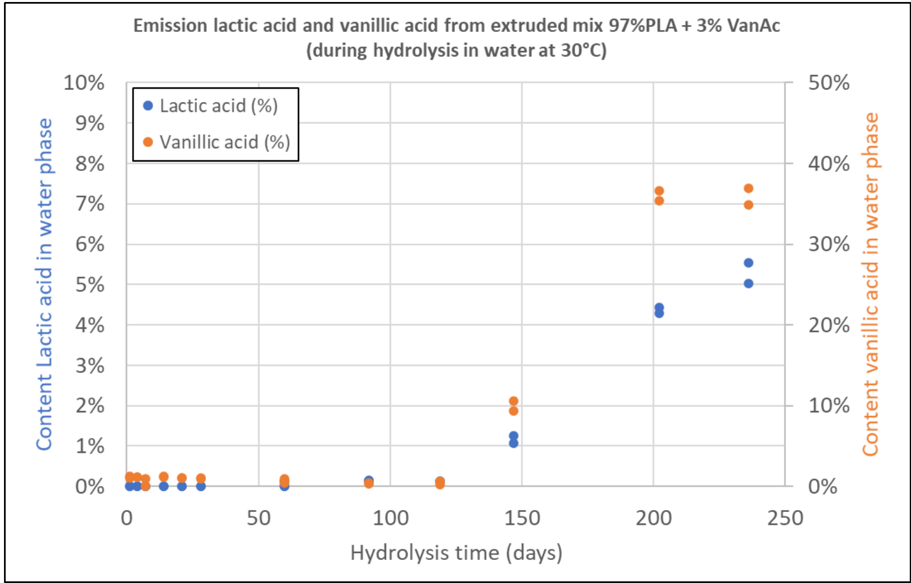
Additives promoting hydrolysis of PLA

Approach:

- Production of PLA materials with up to 3% of additives, e.g.
  - 3% Fumaric acid
  - 3% Vanillic acid
- Sufficient stability during processing
- Accelerated hydrolysis in water
  - some lactic acid formation
  - 10-fold M_w reduction



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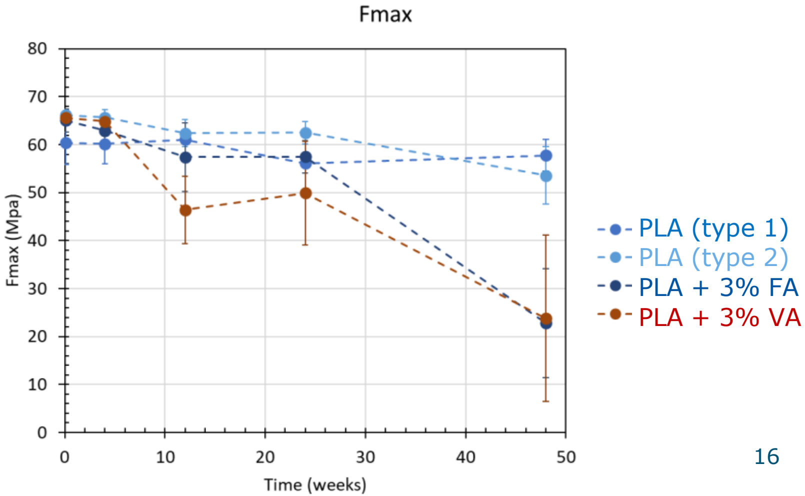
Additives promoting hydrolysis of PLA

Evaluation:

For PLA compounds containing 3% vanillic acid

- No disintegration in soil in 48 weeks (but some loss of mechanical properties)

PLA (type 1) + 3% VA

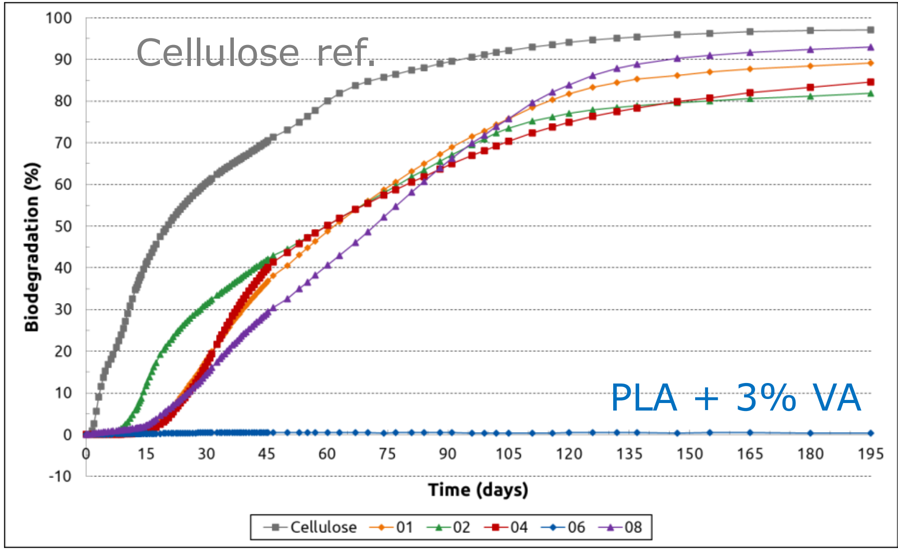


Additives promoting hydrolysis of PLA

Evaluation:

For PLA compounds containing 3% vanillic acid

- No disintegration in soil in 48 weeks (but some loss of mechanical properties)
- No biodegradation (conversion to CO_2) in home composting conditions



Home composting conditions: ISO 14855 (@ 28°C)

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Strategies for home compostable PLA products

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Biodegradable Polymers in Various Environments

According to Established Standards & Certification Schemes

Update 2021

NOTES

proven biodegradability

proven biodegradability for certain grades

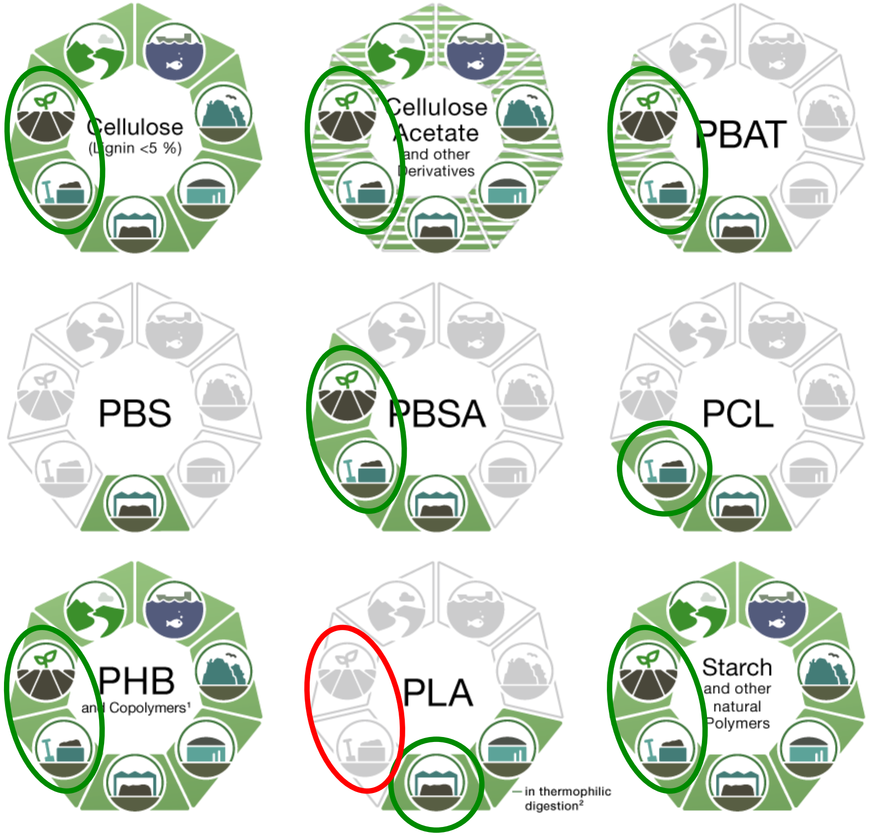
biodegradability not proven

The biodegradability of plastics derived from these biodegradable polymers can only be guaranteed if all additives and (organic) fillers are biodegradable, too. Dying and finishing of cellulosic fibres, for example, may prevent their biodegradation in the environment.

Biodegradability depends on the complex biogeochemical conditions at each testing site (e.g. temperature, available nutrients and oxygen, microbial activity, etc.). Therefore, these generalised claims about biodegradation can only serve as approximations and need to be confirmed by standardised testing under lab conditions. In-situ behaviour can vary, depending on the mentioned conditions, size of the plastic, grade of the polymer and other factors. For instance, biodegradation testing is often performed after milling, showing the inherent nature of the material to biodegrade. In reality, the same level of biodegradation will be obtained, be it possibly within a different timeframe.

SLOWER BIODEGRADING POLYMERS

The polymers shown in the poster are rapidly biodegraded in the labelled environments, within the time frame of the corresponding standards or certificates. Some biopolymers, such as PBS or PLA in soil and also lignin/wood for virtually all environments, also biodegrade, but (much) more slowly. Full biodegradation can take several years to decades to be achieved. In addition, for some applications with a use phase in a certain environment (e.g. geotextiles), too rapid biodegradation is not desired, as their function should first be given for a few years. However, for these cases no standards exist so far.



¹ incl. P3HB, P4HB, P3HB4HB, P3HB3HV, P3HB3HV4HV, P3HB3Hx, P3HB3HO, P3HB3HD

² PLA is likely to be biodegradable in thermophilic anaerobic digestion at temperatures of 52°C within the time frame mentioned in standards. This does not apply to mesophilic digestion.

ENVIRONMENTS

IMPORTANT TEST CONDITIONS, CERTIFICATION SCHEMES AND STANDARDS

For more details, refer to the original documents.

MARINE ENVIRONMENT

Temperature 30°C, 90 % biodegradation within a maximum of 6 months. Certification: TÜV Austria OK biodegradable MARINE. Research on standards (both on test methods and requirements) is on-going.

FRESH WATER

Temperature 21°C, 90 % biodegradation within a maximum of 56 days. Certification: TÜV Austria OK biodegradable WATER. Research on standards (especially on requirements) is on-going.

SOIL

Temperature 25°C, 90 % biodegradation within a maximum of 2 years. Certification: TÜV Austria OK biodegradable SOIL and DIN CERTCO DIN-Geprüft Biodegradable in Soil. DIN-Geprüft Biodegradable in Soil is based on the European standard EN 17033 dedicated to mulch films but can be used for other products as well.

HOME COMPOSTING

Temperature 28°C, 90 % biodegradation within a maximum of 12 months. Certification: TÜV Austria OK compost HOME and DIN CERTCO DIN-Geprüft Home Compostable.

LANDFILL

No European standard specifications or certification scheme available since this is not a preferred end-of-life option for biodegradable waste.

ANAEROBIC DIGESTION

Thermophilic 52°C / Mesophilic 37°C. A specific European standard or certification scheme for anaerobic digestion is not yet available. Anaerobic digestion in a biogas plant is mentioned in EN 13432 and EN 14995: 50 % biodegradation within two months, usually followed by aerobic digestion.

INDUSTRIAL COMPOSTING

Temperature 58°C, 90 % biodegradation within a maximum of 6 months. Certification: TÜV Austria OK compost INDUSTRIAL, DIN CERTCO DIN-Geprüft Industrial Compostable and both „Seedling". EN 13432 and EN 14995 are the European reference standards and the basis of these certification schemes.

More figures available at www.renewable-carbon.eu/graphics

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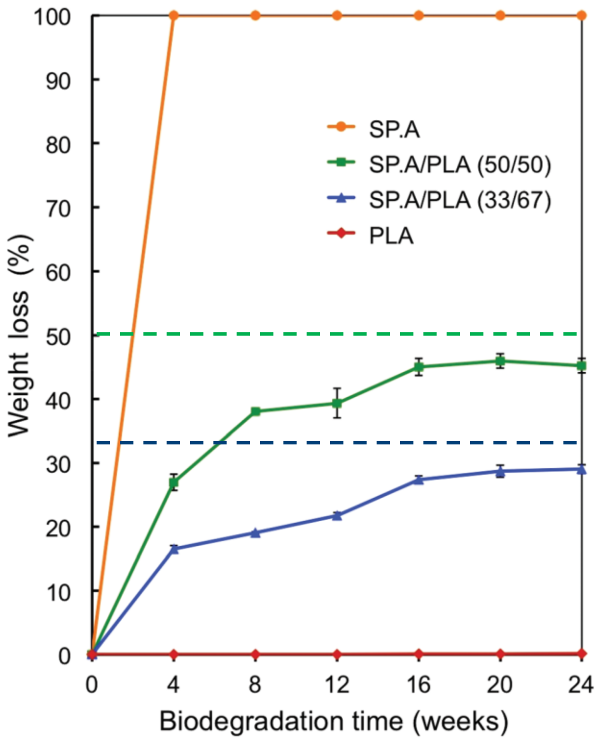
Your feedback is welcome: michael.carus@nova-institut.de

Typical observations with PLA blends

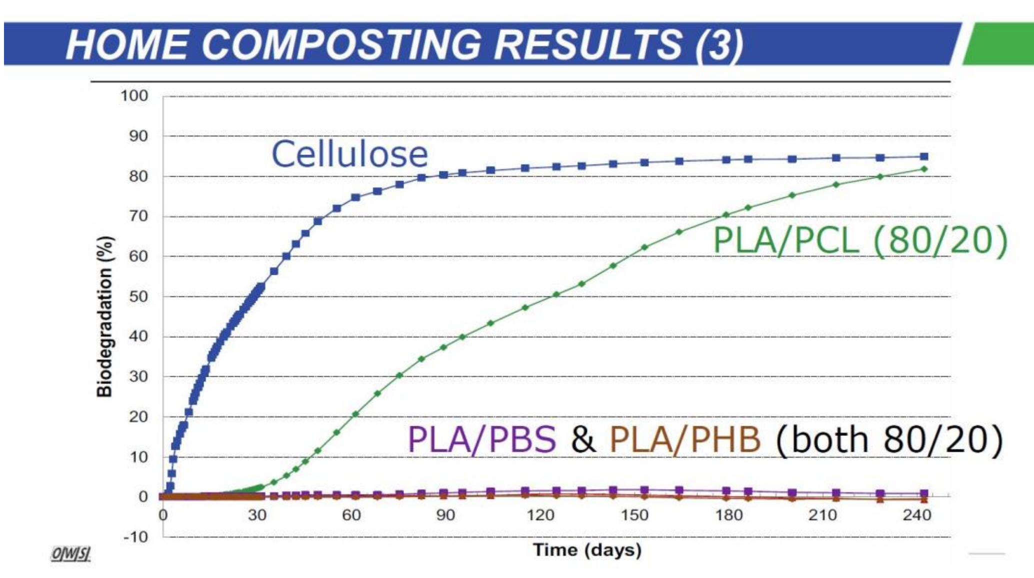
- Reported biodegradation corresponds with concentration of added component



Yang, S., et al. (2015) Green Chemistry, **7**(1): p. 380-393.

Typical observations with PLA blends

- Reported biodegradation corresponds with concentration of added component
- Different behaviour was observed for blends with PLA and PCL



Results from EU H2020 project 'SYNPOL'

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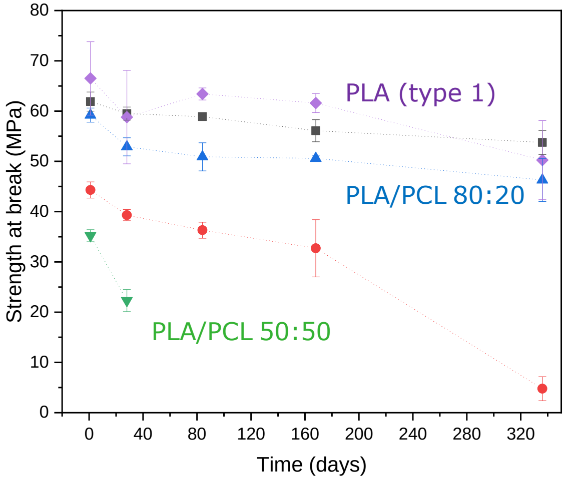
Disintegration of PLA blends in soil

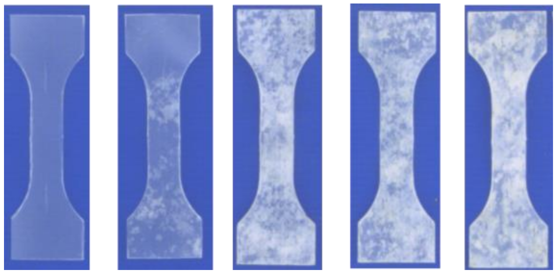
Blends of PLA + PCL

PLA (type 1)

Start 4w 12w 24w 42w

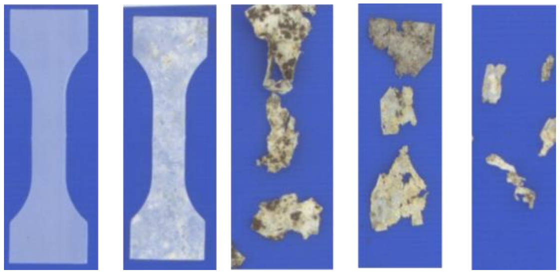


PLA/PCL 80:20



Start 4w 12w 24w 42w

PLA/PCL 50:50



Start 4w 12w 24w 42w

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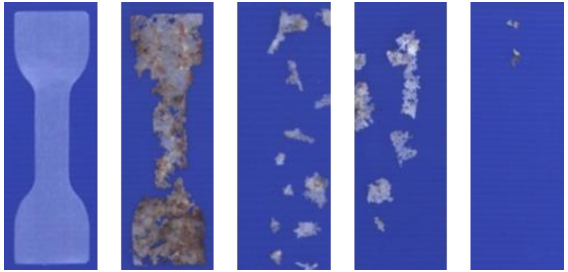
Disintegration in soil of PLA blends

Blends of PLA + PBSA

PLA (type 1)

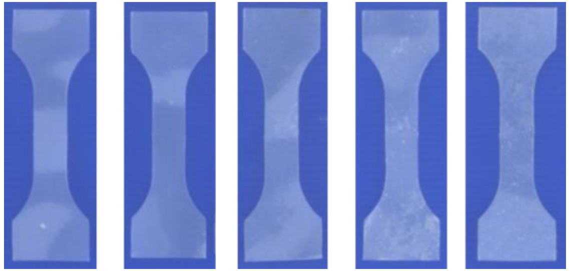
Start 4w 12w 24w 42w

PBSA



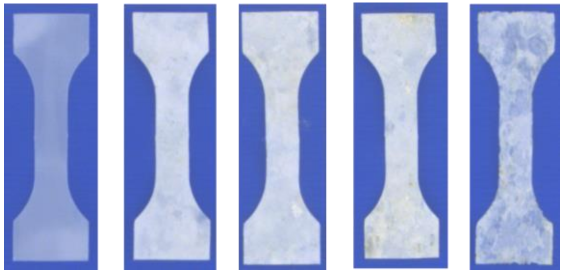
Start 4w 12w 16w 32w

PLA/PBSA 80:20



Start 4w 12w 24w 42w

PLA/PBSA 50:50



Start 4w 12w 24w 42w

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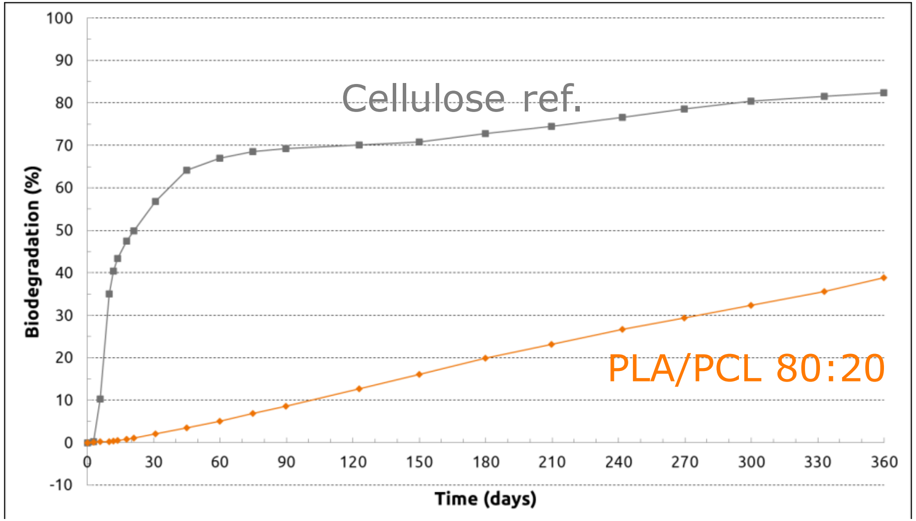
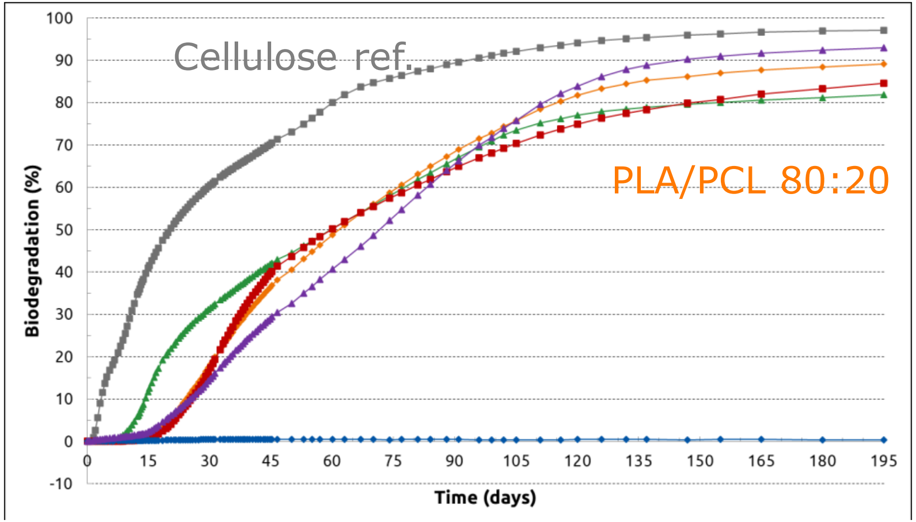
Biodegradation of polymer blends

- Blend PLA/PCL 80:20

In soil: ISO 17556 (@ 25°C)



Home composting conditions: ISO 14855 (@ 28°C)



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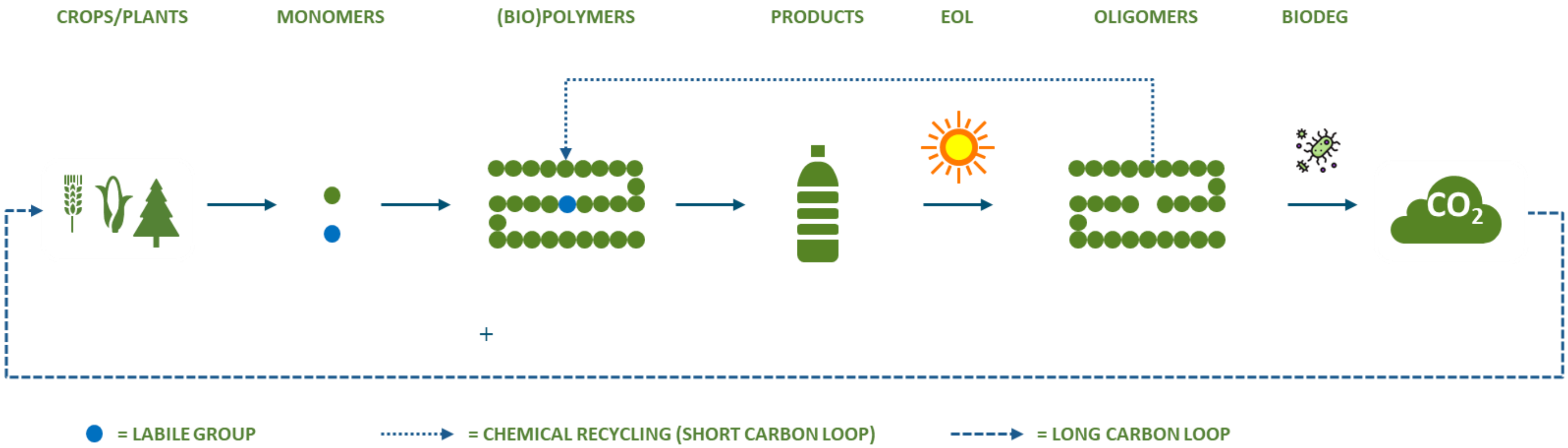
Introducing labile groups into polymer chain

Recently started project: schematic presentation of the concept



Link: Project LWV 22058 'ULTRA-DREAM'

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Conclusions and Outlook

- We explore various strategies to enhance the biodegradation of PLA in ambient conditions
  - Applying prodegradant additives
  - Blending with other home compostable polymers
  - Introducing hydrolysable moieties in the polymer chemical structure
- Masterbatches containing encapsulated enzymes promote disintegration of PLA in soil
  - Activity depends on PLA grade en processing conditions
- Substances promoting hydrolysis or photo-degradation proved not successful in an application-oriented setting

Conclusions and Outlook

- Polymer blending with e.g. PCL enhances the biodegradation of PLA in home composting conditions (and in soil)
    - Further studies are needed to reveal the mechanism
- Combination of knowledge on materials (chemistry), applications (processing) and biodegradability (biology) is required

Acknowledgements

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- TKI-LWV-19199 'Home compostable/Soil degradable PLA'
- TKI-LWV-22058 'UV-Light Triggered Rapid and Adjustable Degradable REnewAble Materials (ULTRA-DREAM)'

Questions?

To explore the potential of nature to improve the quality of life

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