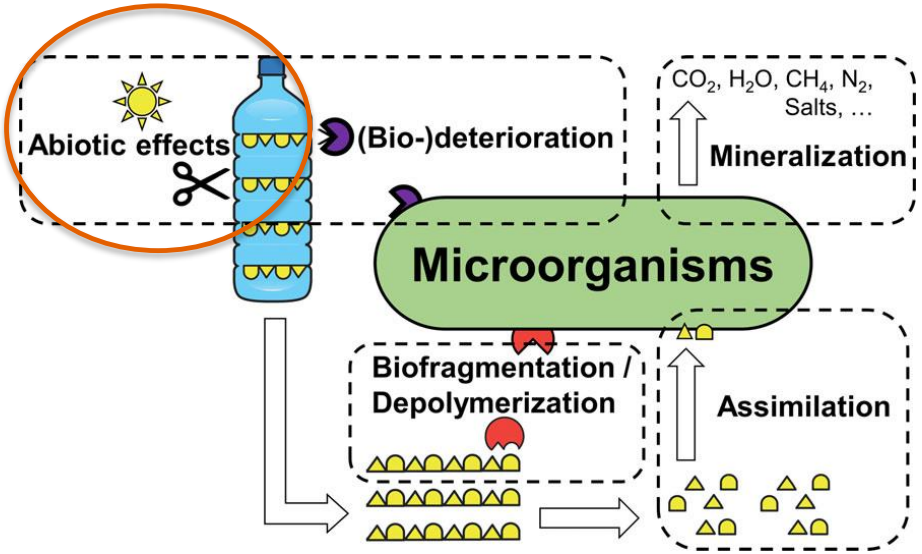
PlastBug – Projekti ja muovien biohajoavuus

Kirsi Immonen / VTT

CLIC Event: Muovi – mahdollisuuksien materiaali
Bank 20.11.2018

In biodegradation crucial question is the time!

- In most plastics the abiotic degradation due to UV, moisture, temperature, oxygen, chemical oxidants causes formation of microplastics before enzymatic action can take place.
- **Abiotic degradation may last from tens to several hundred years or longer before micro-organisms can act.**
- With polyolefins (PP, LDPE) the degradation may take longer before micro-organisms can act.
- Biologically degradable polymers such as PLA, PCL, polyhydroxyalkanoates (PHAs), PBS, starch etc. are more readily attacked by micro-organisms
- **The degradation time is always in relation to temperature, moisture conditions and other environmental conditions!**



- Schematic illustration of plastic biodegradation (Lucas et al., Polymer biodegradation: mechanisms and estimation techniques - a review. Chemosphere (2008) 73: 429–442.).

Biodegradation additives

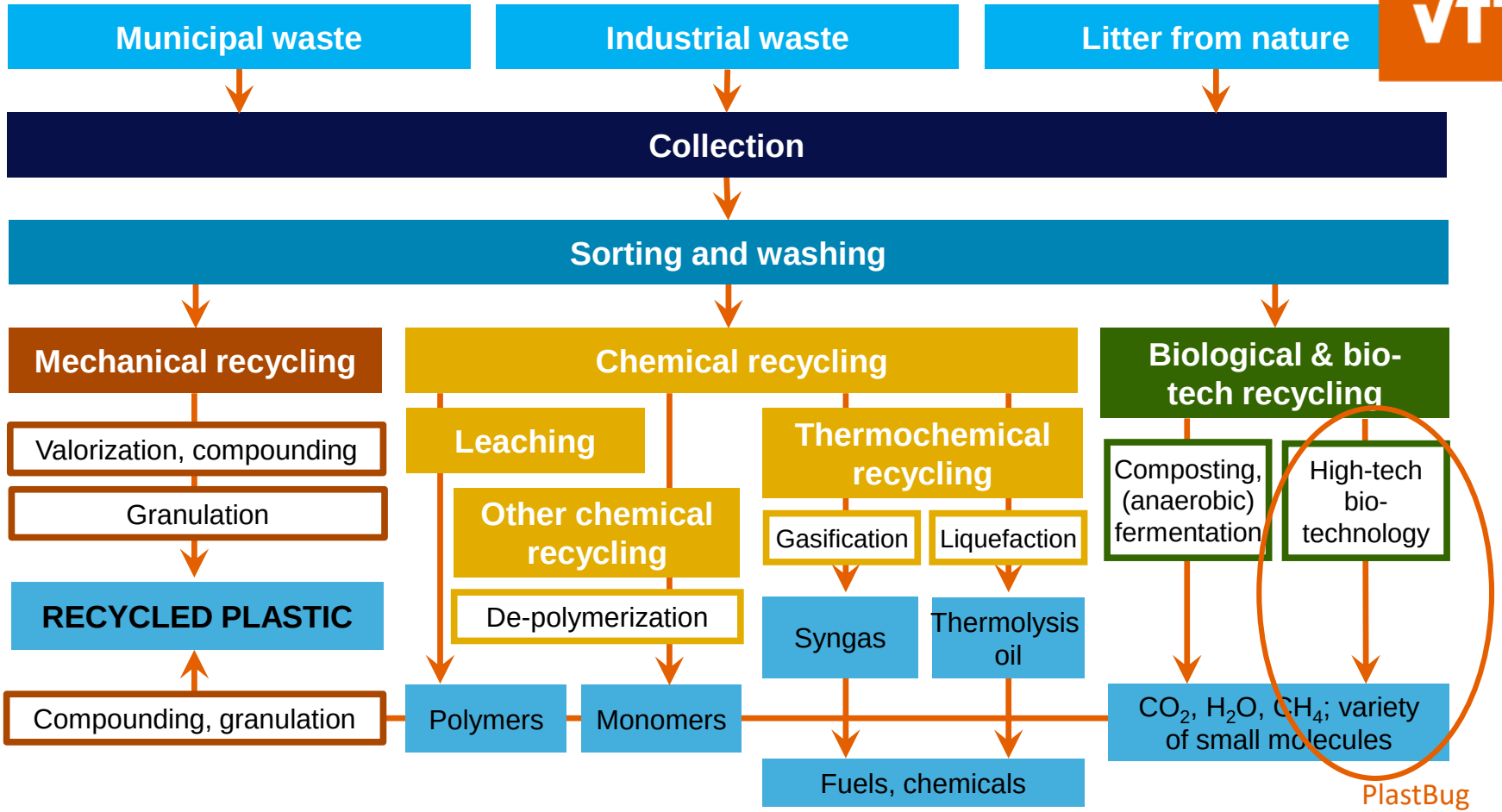
- Additives developed to speed-up biological degradation of plastics
  - Solutions for PLA, PET, PS, PA, PE, PP etc. exist by at least three commercial companies

-> **Good** solutions when introduced to collected plastics waste to speed-up recycling process
-> **Bad** if introduced to virgin plastics -> may speed-up the microplastic formation for an unknown time period in environment

- OXO-degradation additives: According to current knowledge increase the amount of microplastics in environment.
- EU Commission has started work with the intention to restrict the use of oxo-plastics in the EU.(http://ec.europa.eu/environment/circular-economy/pdf/plastics-strategy.pdf)

- Nature brings its own solutions:
- 'Plastic-eating bacteria might help explain why the amount of debris in the ocean has levelled off, despite continued pollution. But researchers don't yet know whether the digestion produces harmless by-products, or whether it might introduce toxins into the food chain.' T.Mincer, *Nature 2011*, doi:10.1038/news.2011.191

State of the art in plastic recycling



Pohjakallio, Vuorinen, VTT 2018

PlastBug – A mobile unit removing plastic waste

VTT PlastBug team:
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1950 - 2015

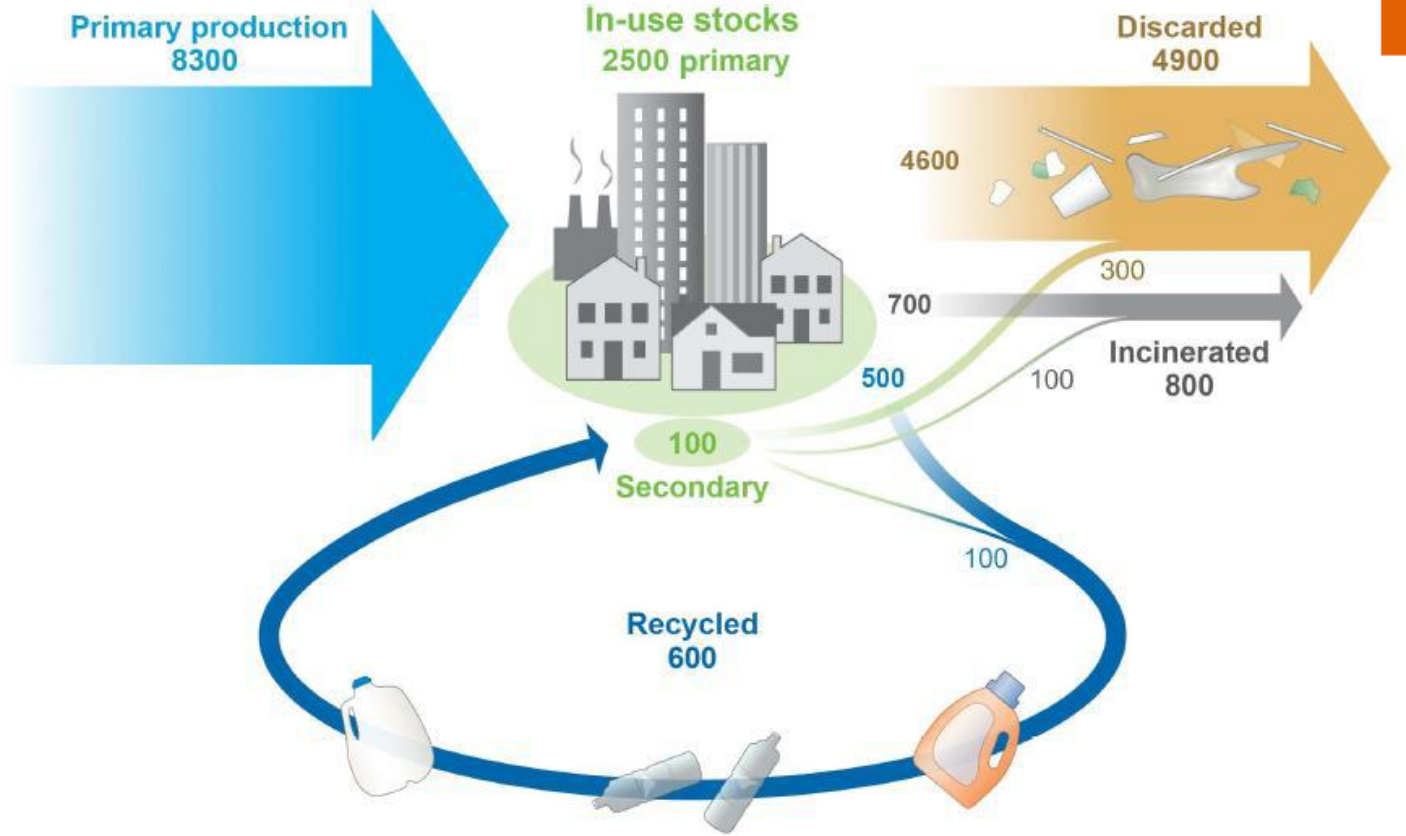


Fig. 2. Global production, use, and fate of polymer resins, synthetic fibers, and additives (1950 to 2015; in million metric tons).

Geyer et al 2017 *Science Advances*, 3(7), p.e1700782

Today in archipelago

plastic waste (if collected) is transformed to mainland mainly to be burned in waste burning plants (CO_2 emission!)

Local plastic waste removing/ recycling system will be needed!

PlastBug is a mobile, semi-autonomous, small scale factory (a container on land or in a ship), where microbes degrade mixed plastic waste to valuable products

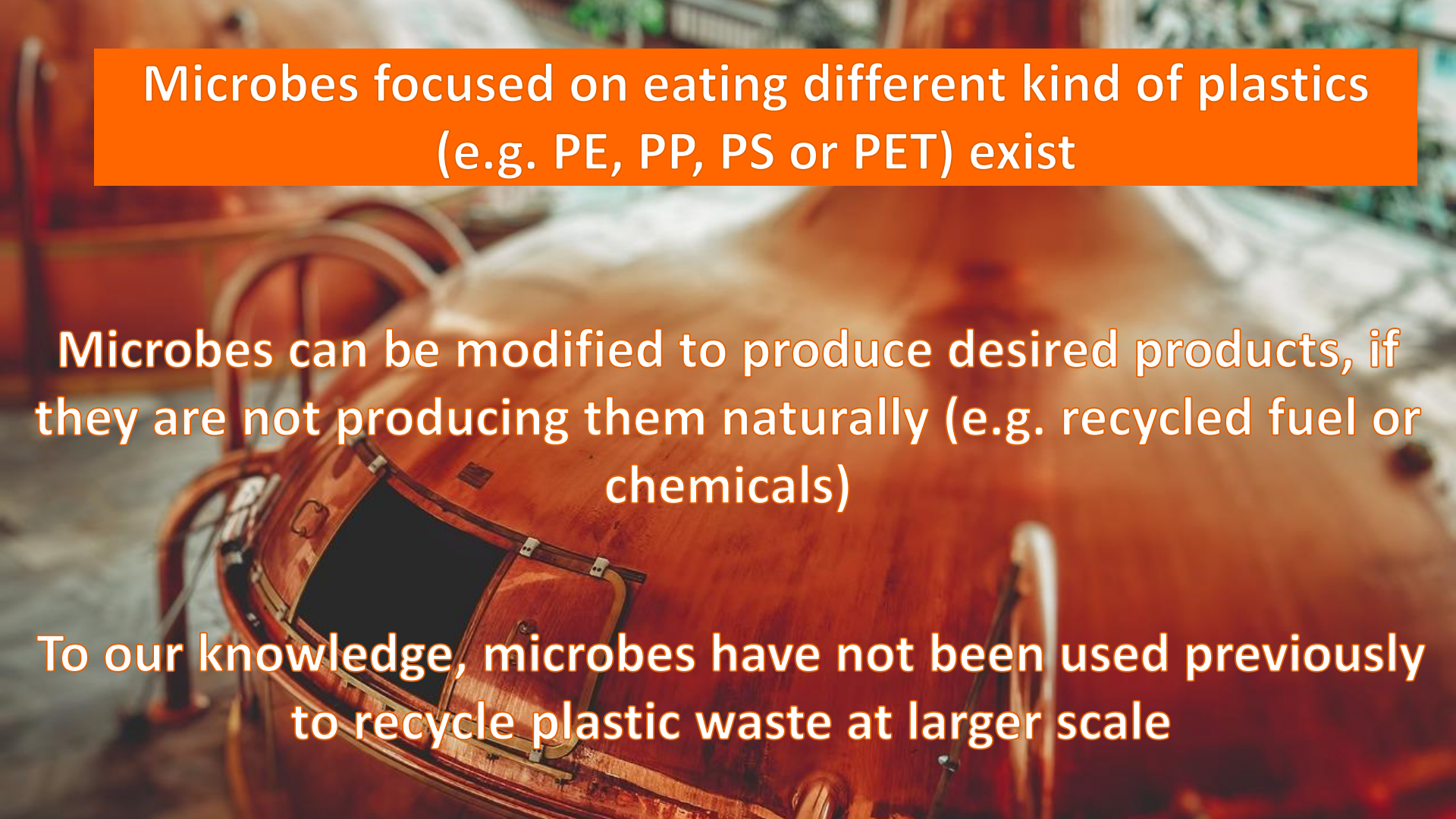
PlastBug

This system can be set up globally to different areas:

The basic unit (a container) can be located on a beach in Finnish archipelago or on an island in Pacific Ocean

iBEX-PlastBug project

- Project started at the beginning of February 2018
- The goal in the project is:
  - To screen plastic degrading microbes
  - To carry out preliminary planning of the factory concept
  - To carry out preliminary techno-economical calculations
  - To evaluate energy sources


Microbes focused on eating different kind of plastics (e.g. PE, PP, PS or PET) exist
Microbes can be modified to produce desired products, if they are not producing them naturally (e.g. recycled fuel or chemicals)
To our knowledge, microbes have not been used previously to recycle plastic waste at larger scale

Plastic waste is a mixture of different plastics

Polyethylene

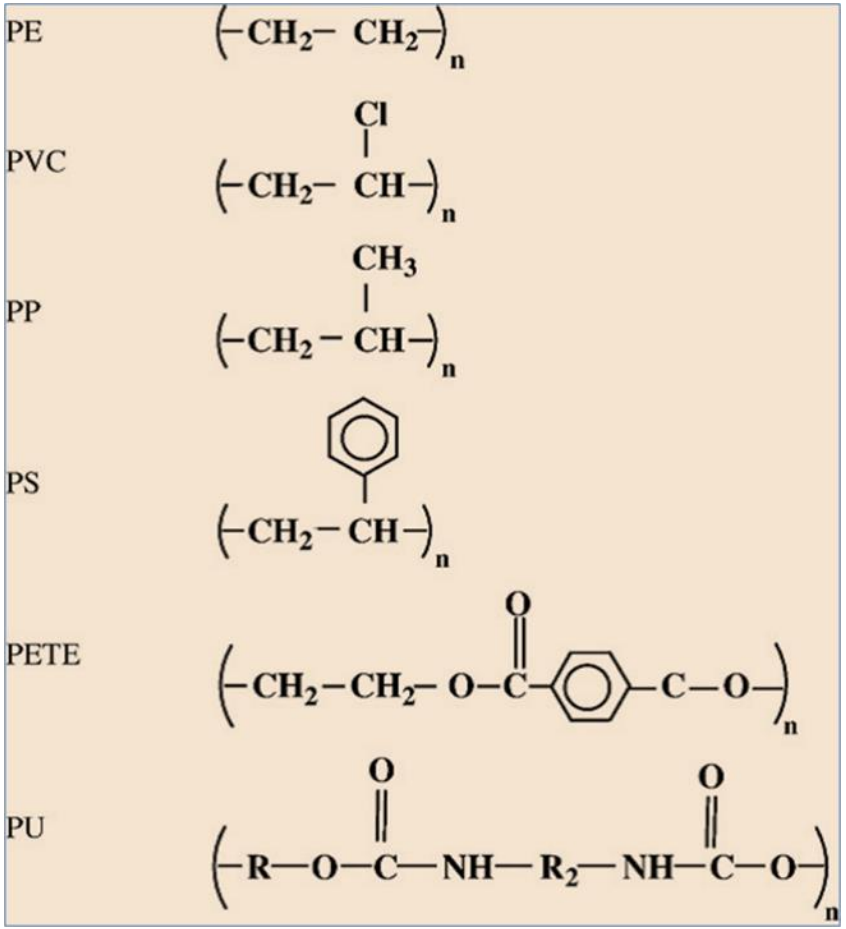
Polyvinyl chloride

Polypropylene

Polystyrene

Polyethylene terepthalate

Polyuretane



Plastics in marine litter:

LDPE 21%

HDPE 17%

PP 24%

PVC 19%

PET 7%

PS 6%

PA 3%

Alshehrei 2017. J Appl Environ Microbiol 5:8-19

Polymers are one part of plastic

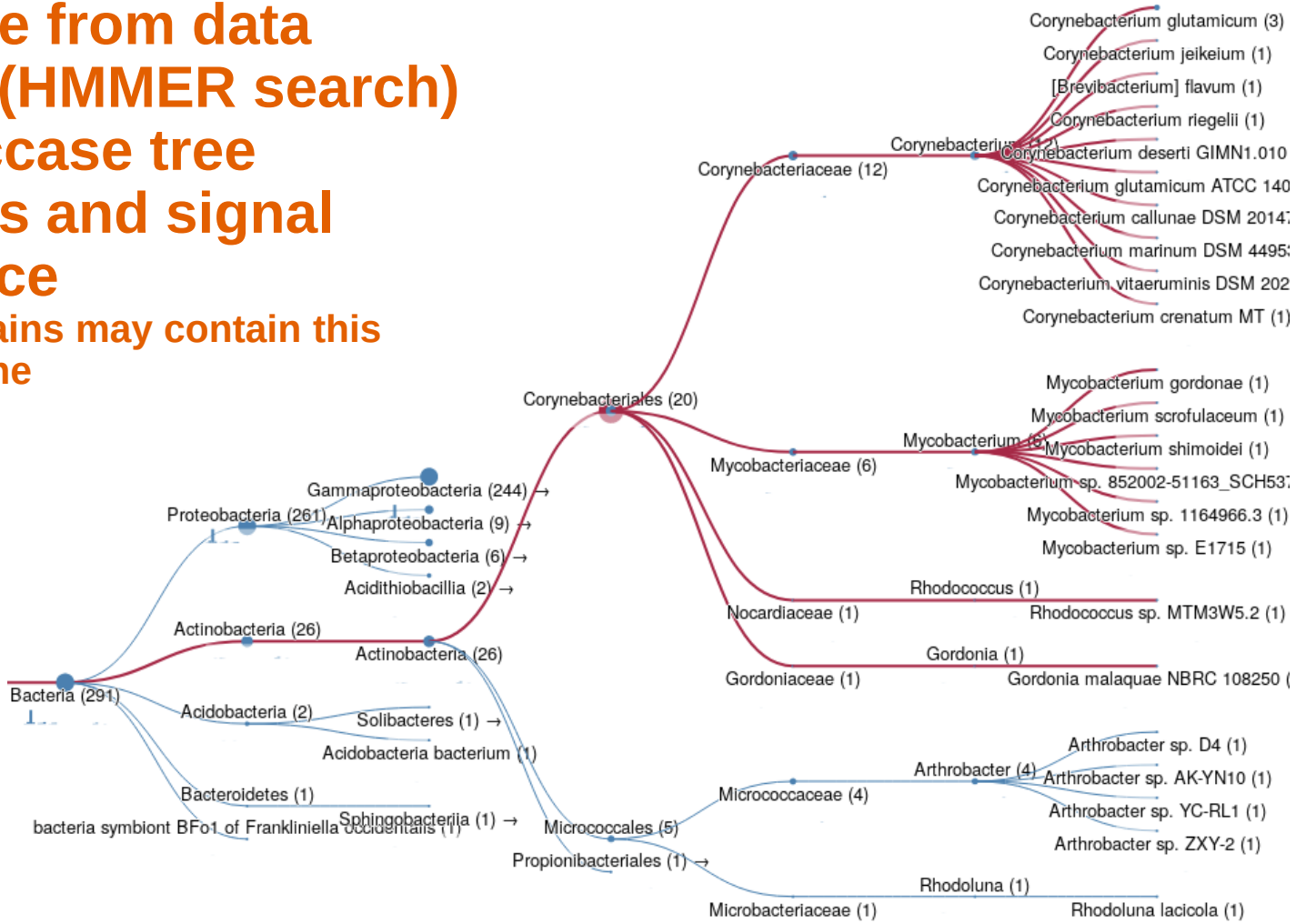
- In addition to polymers plastics contain several kind of additives:
  - These additives are needed e.g. in polymerization processes
  - They are also affecting plastic properties
  - Additives can be:
    - Plasticizers
    - Colors
    - Stabilizers
    - Etc.
  - Some of the additives are “good” carbon sources to microbes

Microbes based on data mining

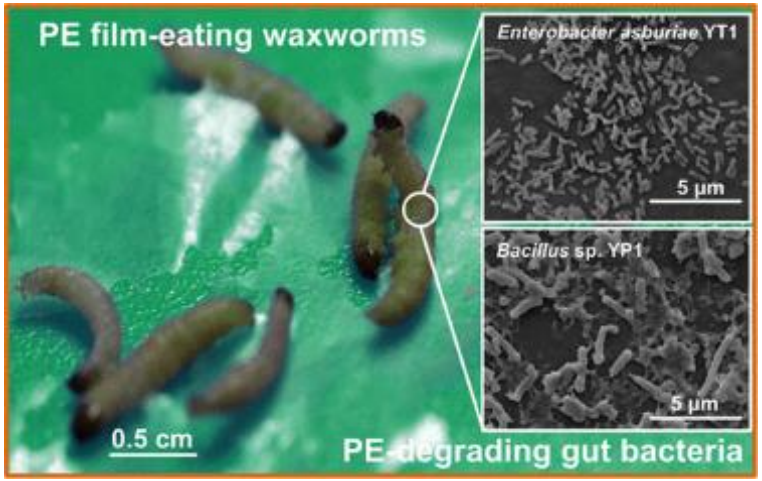
- The idea was to find specific microbes which could degrade plastics by using data mining
- Data mining was based on existing data from literature
  - Microbes which are shown to degrade plastic and which genomes are known
  - Enzymes which were shown to degrade plastic and which nucleotide sequences are known
- According to data mining results candidate strains were collected from VTT's strain collection (VTT as an owner)

Example from data mining (HMMER search) with laccase tree domains and signal sequence

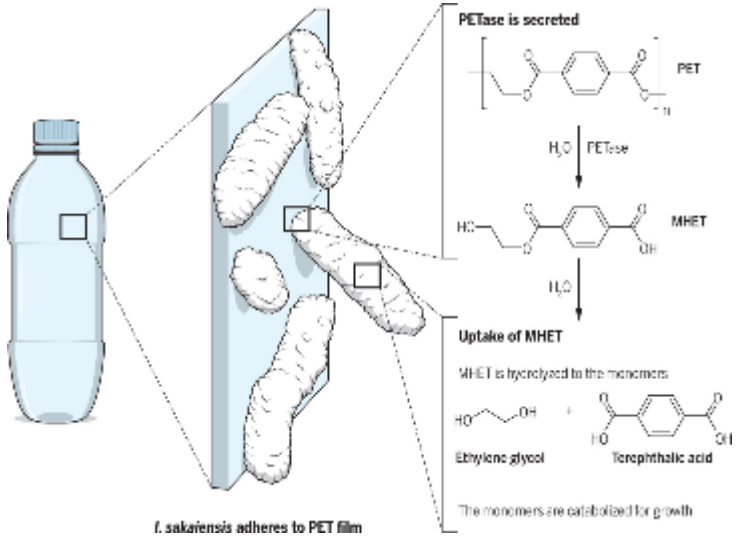
- These strains may contain this laccase gene



From literature



- Yang, J., et al. **Evidence of Polyethylene Biodegradation by Bacterial Strains from the Guts of Plastic-Eating Waxworms,** *Environ. Sci. Technol.*, **2014**, *48* (23), pp 13776–13784
- Yang, Y., et al., **Biodegradation and Mineralization of Polystyrene by Plastic-Eating Mealworms: Part 2. Role of Gut Microorganisms,** *Environ Sci Technol.* 2015 Oct 20;49(20):12087-93



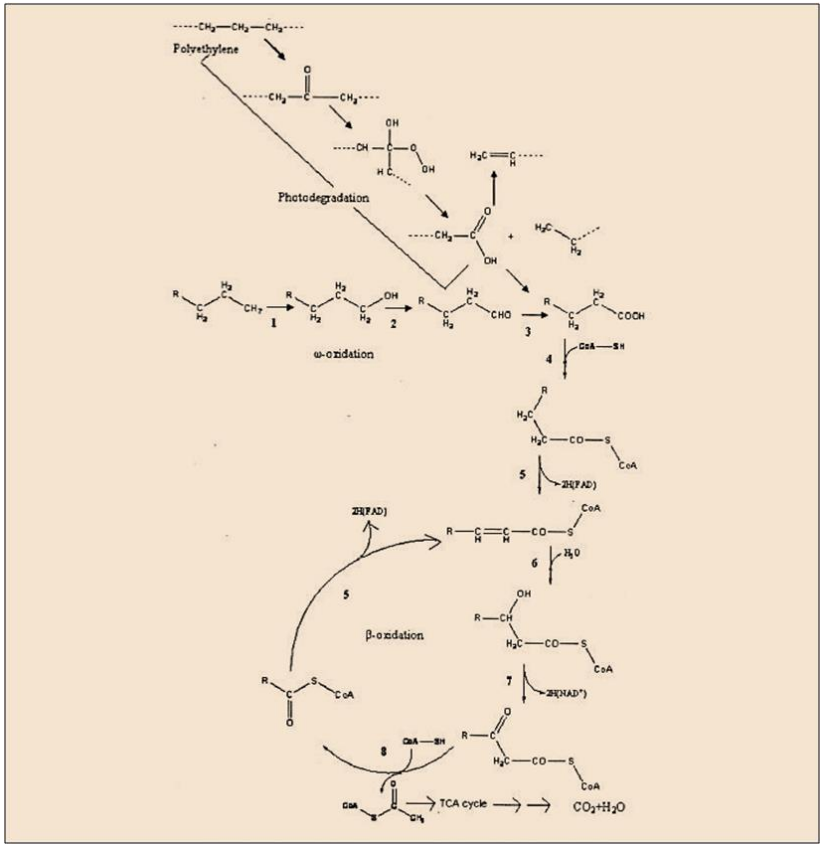
The *I. sakaiensis* bacterium discovered by Yoshida *et al.* (**5**) can attach to PET. It produces two hydrolytic enzymes (PETase and MHETase) that catalyze the degradation of the PET fibers to form the starting monomers. The monomers are then catabolized by the bacterium as its sole carbon source. *Bornscheuer, U.T., et al., Science* 11 Mar 2016: Vol. 351, Issue 6278, pp. 1154-1155

Known microbes degrading plastic

Microbes which have been shown to degrade some plastics (PE and PET) and from which there are some genome data

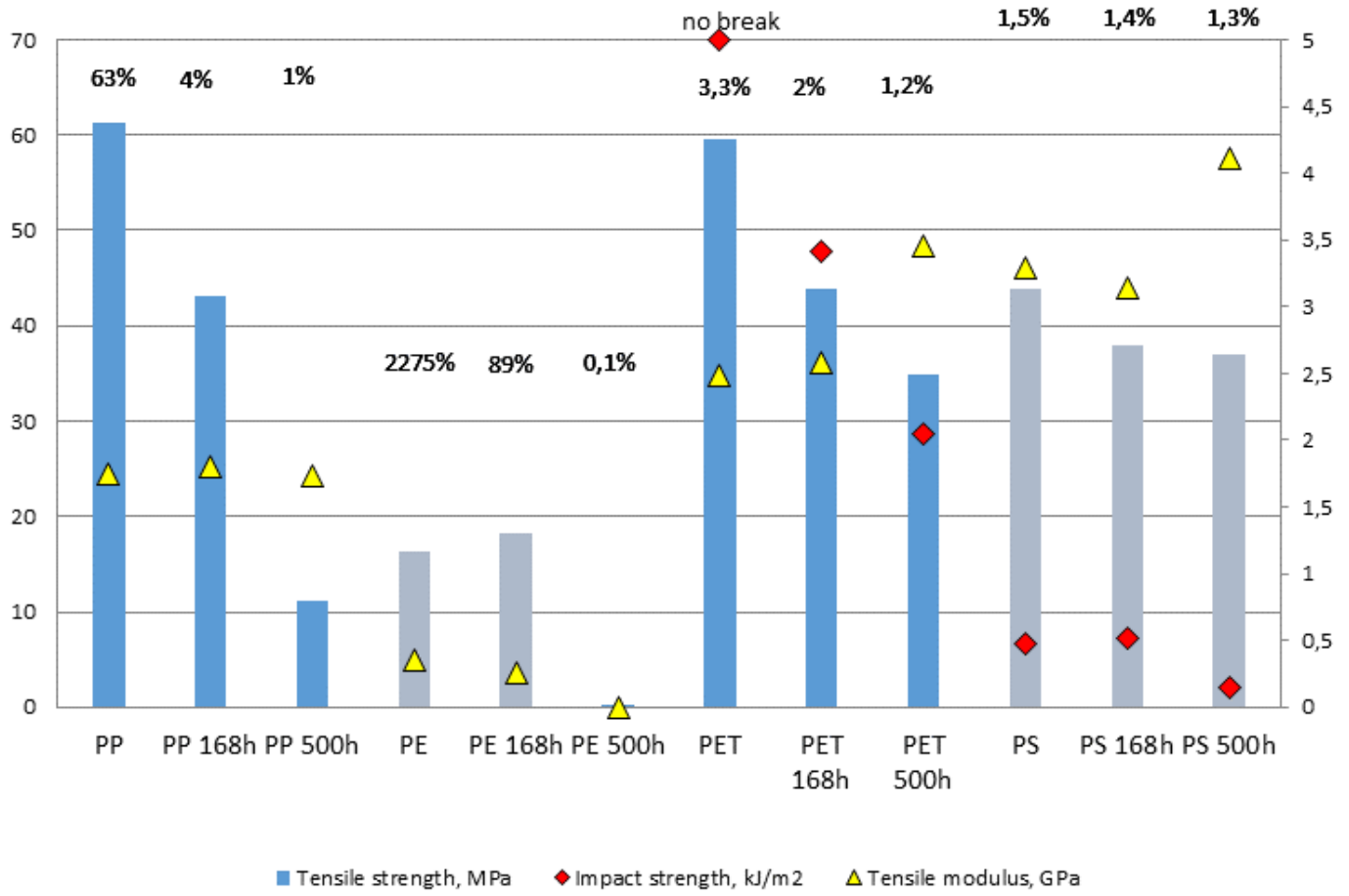
- *Enterobacter asburiae*. Genome sequenced (Yang et al 2014)
- *Bacillus* sp. No more information (Yang et al 2014)
- *Penicillium simplicissimum*. Laccase ja manganese peroxidase. No information from gene sequence or genome sequence (Sowmya et al 2015)
- *Rhodococcus ruber*. Genome sequenced+laccase partly sequenced (Santo et al 2012)
- *Brevibacillus borstelensis*. Genome sequenced (Hadad et al 2005)
- *Ideonella sakaiensis*. PETase ja MHETase identified ja sequenced (Yoshida et al 2016)
- *Penicillium oxalicum*. Genome sequenced (Ohja et al 2017)
- *Penicillium chrysogenum*. Genome sequenced (Ohja et al 2017)
- *Bacillus licheniformis*. Genome sequenced??? (Mukherjee et al 2016)
- *Lysinibacillus fusiformis*. Genome sequenced (Mukherjee et al 2016)
- *Lysinibacillus xylanilyticus*. Genome sequenced (Esmaeili et al 2013)
- Many other…

With UV-treatment as pre-treatment we can generate substrates to microbes

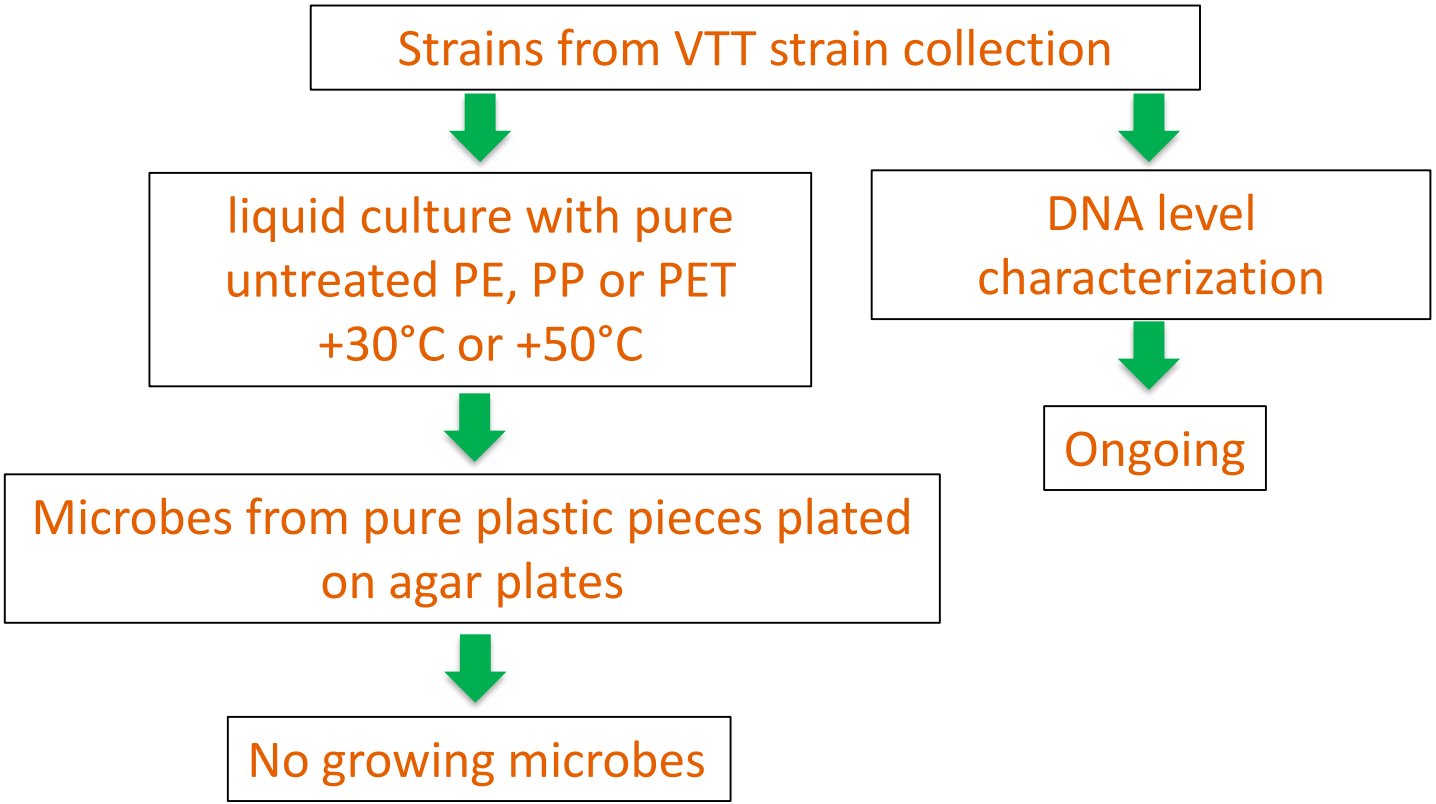


Alshehrei 2017. J Appl Environ Microbiol 5:8-19

Plastics in 500h weathering test (UV 60°C+moisture 50°C)



Screening of VTTCC strains



Screening of microbes from landfill samples

Plastic waste samples from Ämmässuo compost unit

Enrichment of plastic degrading microbes in controlled composting facilities

Pure plastic pieces untreated or UV-treated (PE, PP, PET or PS) added

Liquid cultivation with microbes isolated from pure plastics pieces added to compost

In the cultivation (NOTE! Only 1 month!):

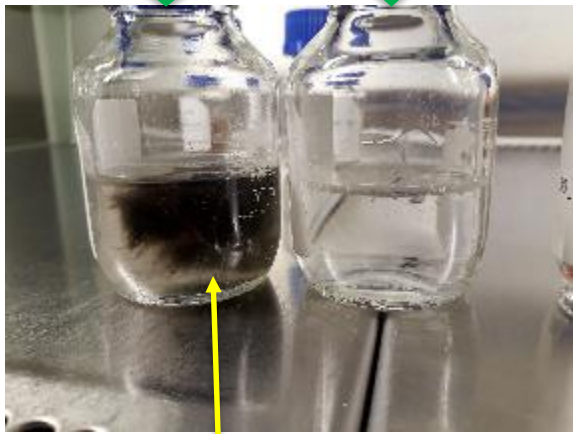
1) Salt solution + plastic (PE/PP/PET/PS)+ microbes
2) Salt solution + plastic (PE/PP/PET/PS)
3) Salt solution + microbes

ANALYTICS (e.g. FT-IR, GPC, GC-MS, SEM)

In the preliminary screening PET and PS degrading microbial populations found?

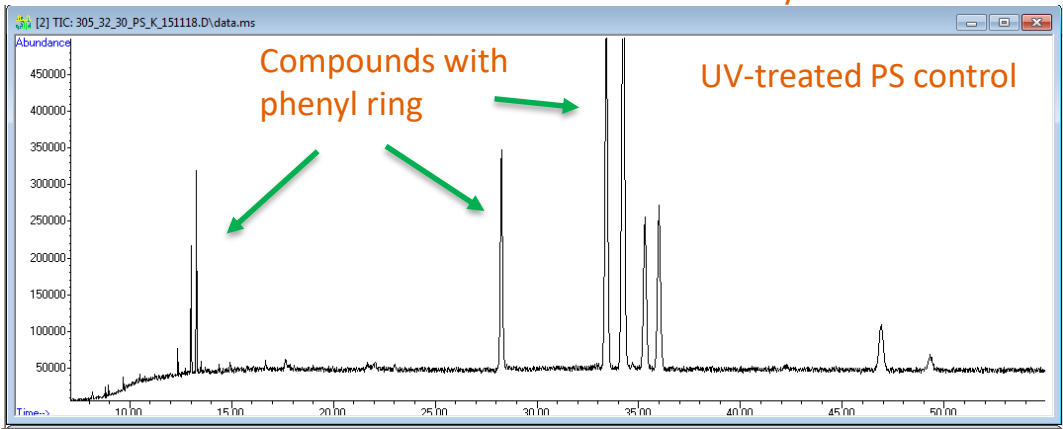
Salt solution + untreated PET plastic + microbes

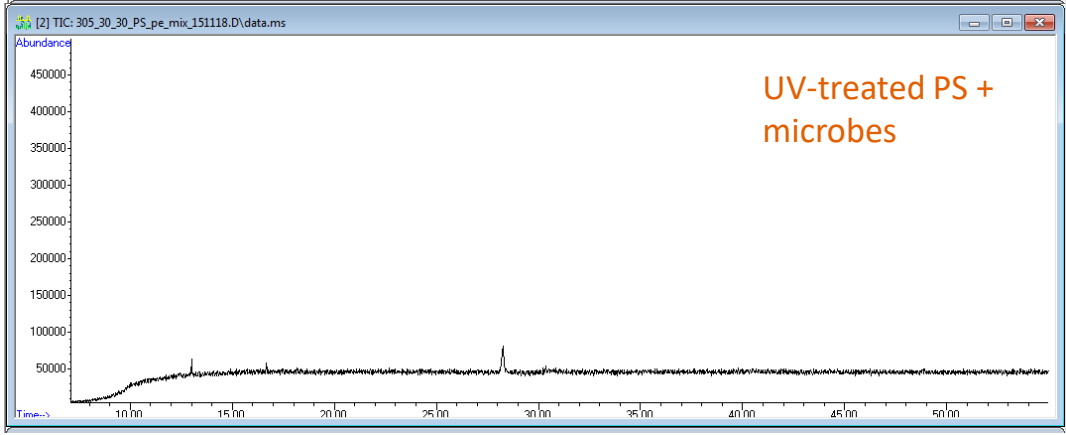
Salt solution + untreated PET plastic



Clear formation of biofilm

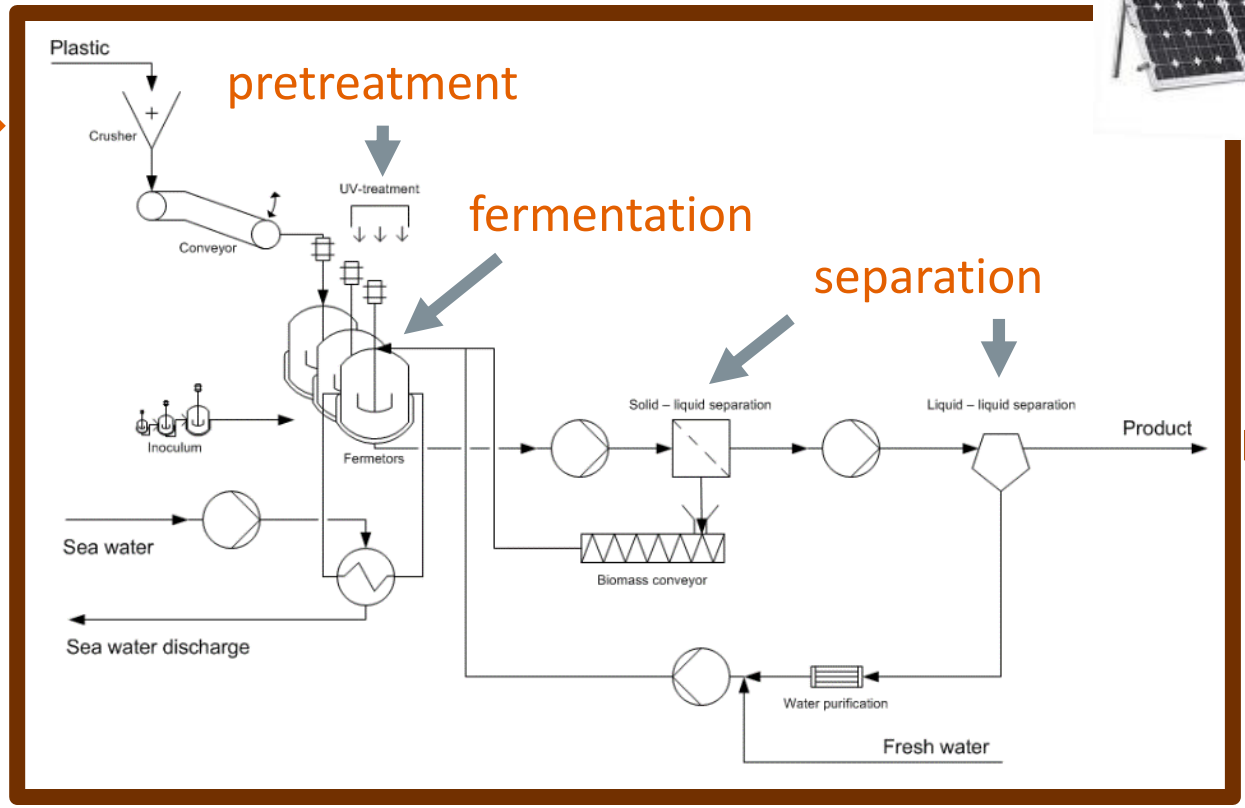
GC-MS analysis





We have also preliminary planned factory's setup

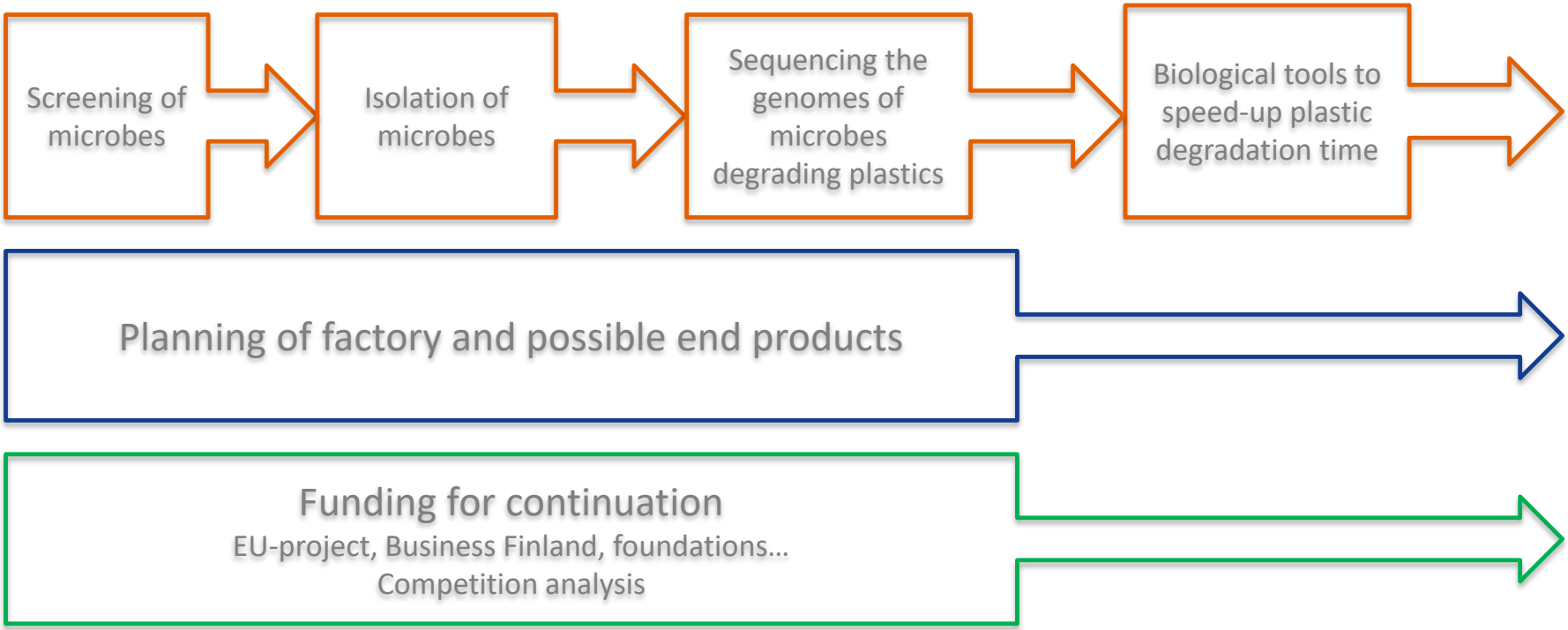
Mixed plastic waste



Power from sun or wind

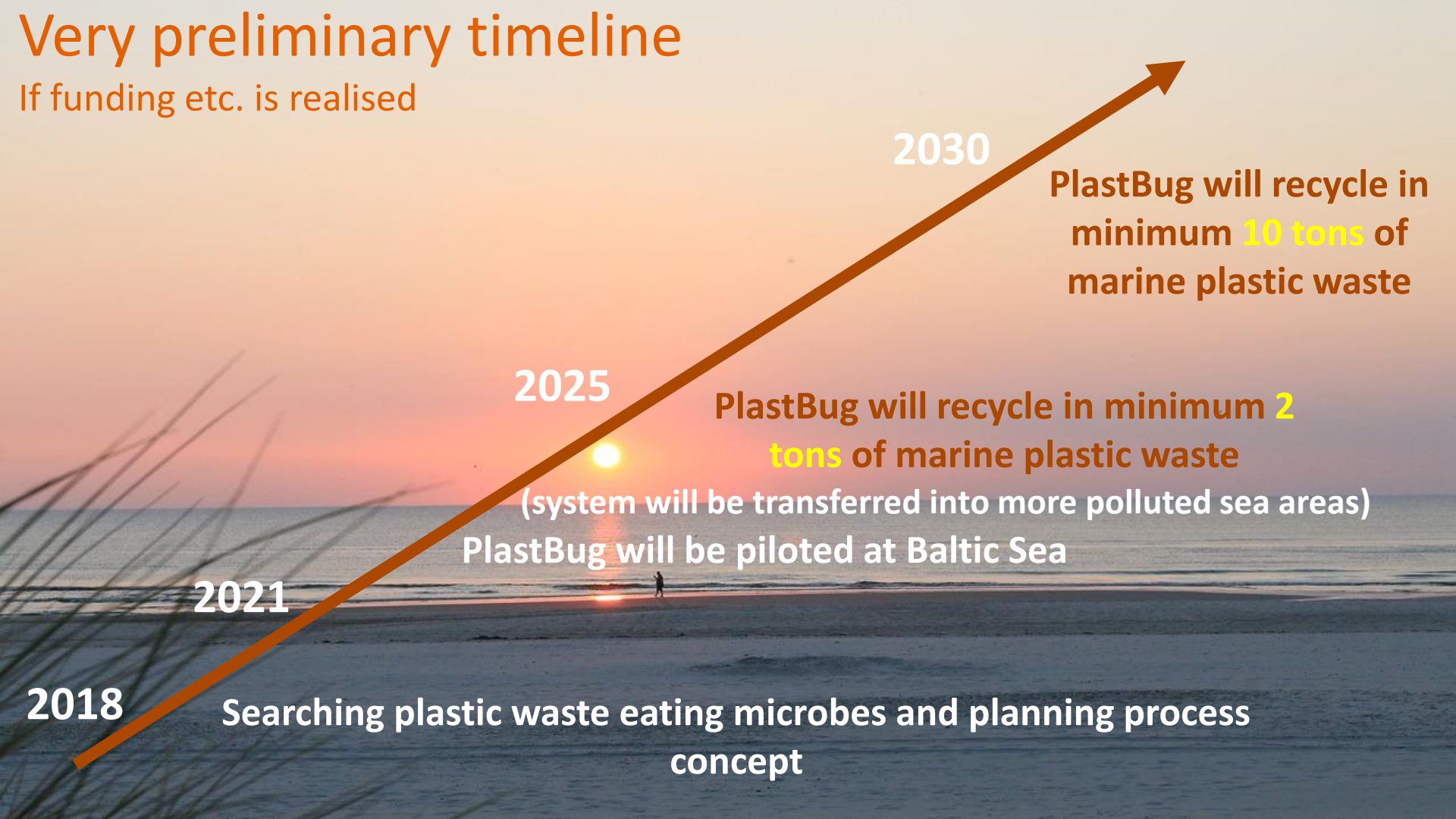
Wanted products. E.g. fuel or chemicals

Continuation



Very preliminary timeline

If funding etc. is realised

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