# Understanding biodegradability – the science, the misuse, and hype

## Fundamentals &Learnings in Biodegradable-Compostable Plastics


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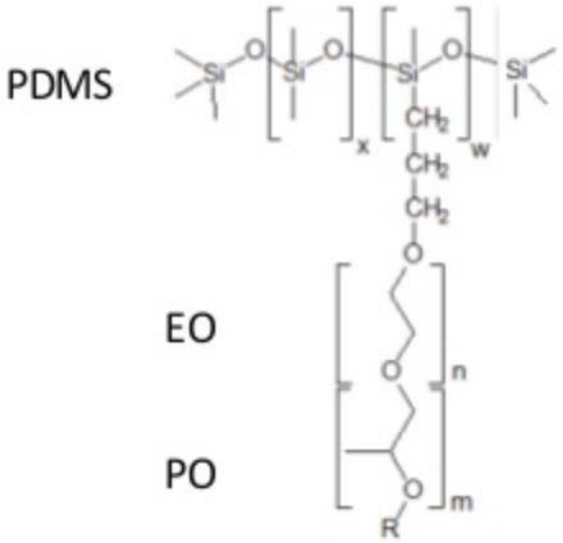
**Interactive session**

# Understanding Biodegradability – Environmental Persistence & Impacts

## Small molecules -- Chemicals

Chemicals used in textiles, paints, consumer and industrial products, surfactants, detergents, pesticides and other industrial/consumer applications




Silicone surfactants

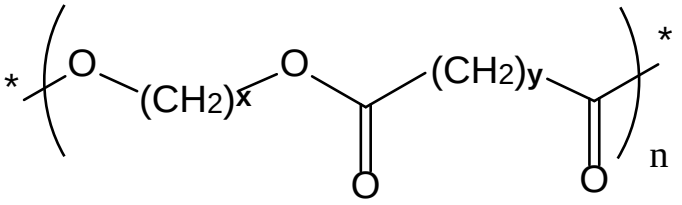
Governed by: OECD guideline for testing of chemicals

Ready biodegradability (60% aqueous biodegradability in 28 days; Intrinsic biodegradability --Guidance for hazard or risk assessment – aquatic hazard classification

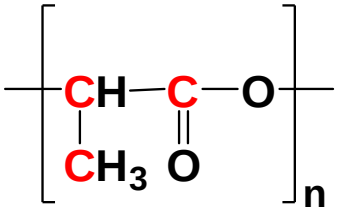
Estimation of the likely concentration in the environment is necessary. Allows to predict long term adverse effect on biota

# Understanding Biodegradability – Environmental Persistence & Impacts

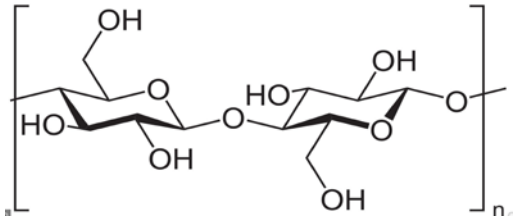
## Polymer molecules -- Plastics



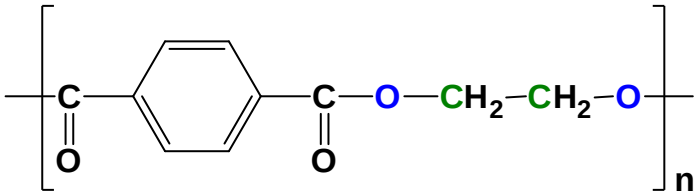

Biobased polyester



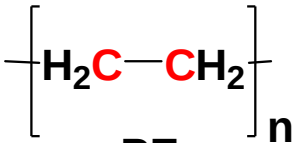

PLA




Cellulose




PET




PE

Biodegradability in target disposal systems like composting/anaerobic digestion or soil (agriculture) can be a viable and responsible "end-of-life" solution in harmony with the "Circularity Model" -- managed closed loop/systems

Unqualified use of the term "biodegradable" is wrong, misleading, and deceptive. It violates the law in the State of California and U.S. Federal Trade Commission (FTC) green guides.

- Need to define disposal environment, time/rate and extent of biodegradation – qualified biodegradability claim
- Complete removal from the environment

## Question?

When you read/view the term “biodegradable” on a packaging product – What is your immediate thought process?

**The product will biodegrade/disappear in:**

< 1 year  < 2 years  <5 years  < 10 years  < 50 years

What is the environmentally responsible end product of degradation/biodegradation?

(A) Breaks down into small inert/safe molecules

(B) Breaks down into particles that is not visually seen

(C) The product is utilized/assimilated by the microorganisms

(C-1) Completely

(C-2) Partially – for example 50% is utilized and the remaining 50% nothing happens or breaks down into small visible (or not) molecules

A typical print-ad for paper

**Notice: It's OK to print this e-mail. Paper is a biodegradable, renewable, sustainable product made from trees. Growing and harvesting trees provides jobs for millions of men and women, and working forests are good for the environment, providing clean air, clean water, wildlife habitat and carbon storage. When you are through, please remember to recycle it.**

## U.S. FTC

biodegradable – completely breaks down into elements found in nature ($CO_2$, water, and cell biomass)

## State of California

Labelling a product "biodegradable" for sale is against the law

Compostable products that meet ASTM D6400 – Specification standard for compostable products) is OK provided composting facilities is available in there

The FTC has charged xxx Corp., yyy Corp., and Z Int Corp with making false and unsubstantiated claims that their paper products were "biodegradable"

The U.S. FTC also prosecuted a company claiming that an "additive" can biodegrade PE, PP, PS in a landfill

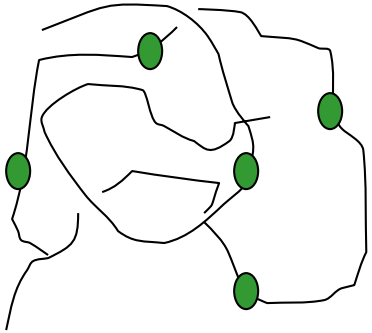
## Biodegradability – A misused and abused term

### QUESTION

- Can microorganisms present in the disposal environment utilize/assimilate the plastic carbon substrate – the biotic process
- **What extent and in what time frame & what disposal environment?**
- Need complete microbial assimilation and removal from the environmental compartment in a short time period otherwise may have environmental and health consequences
    - Degradable, partial biodegradable not acceptable – serious health and environmental consequences
        - Phil. Trans. Royal. Soc. (Biology) July 27, 2009; 364

# What does Biodegradable Mean?

Can the microorganisms in the target disposal system (composting, soil, anaerobic digestor) assimilate/utilize the carbon substrate as food source completely and in a short defined time period?

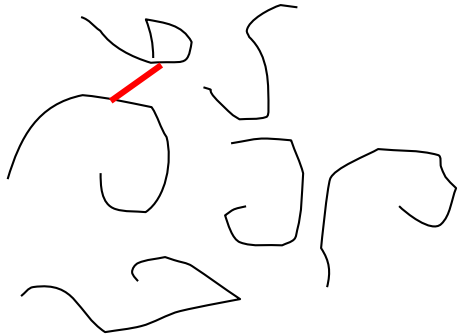


Polymer chains with susceptible linkages

Environment – soil, compost, waste water plant, marine

Hydrolytic
Oxidative
Enzymatic

STEP 1



Oligomers & polymer fragments

Complete microbial assimilation

defined time frame, no residues

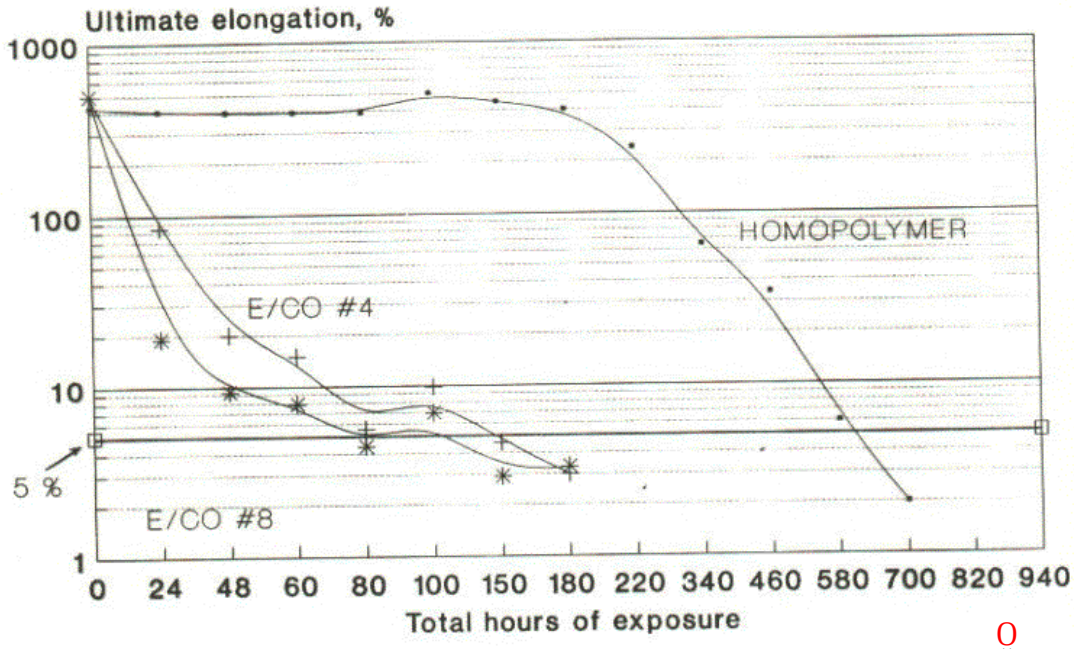
STEP 2

$CO_2 + H_2O +$ Cell biomass

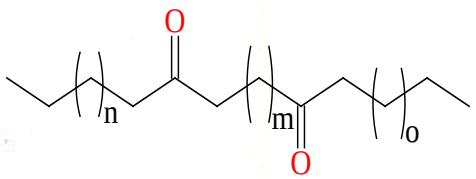
Biodegradation(Step 2): Only if all fragmented residues consumed by microorganisms as a food & energy source as measured by evolved $CO_2$ in defined time and disposal environment

## VII. E/CO v. PE Homopolymer

Q-U-V 50 Degrees C LAB 1




astm4




ECO Copolymer
Degradable resin

## Basics of microbial utilization -- biodegradability

- Microorganisms utilize carbon substrates as “food” to extract chemical energy for their life processes.
- They do so by transporting to the C-substrate inside their cells and:
- Under aerobic conditions, the carbon is biologically oxidized to $CO_2$ releasing energy that is harnessed by the microorganisms for its life processes. Under anaerobic conditions, $CO_2$+$CH_4$ are produced.
- Thus, a measure of the rate and amount of $CO_2$ or $CO_2$+$CH_4$ evolved as a function of total carbon input to the process is a direct measure of the amount of carbon substrate being utilized by the microorganism (percent biodegradation)

**Glucose/C-bioplastic + 6 $O_2$** ⟶ **6 $CO_2$↑ + 6 $H_2O$; $\Delta G^{0'}$ = -686 kcal/mol**

**Glucose/C-bioplastic** ⟶ **2 lactate;** $\Delta G^{0'}$ **= -47 kcal/mol**

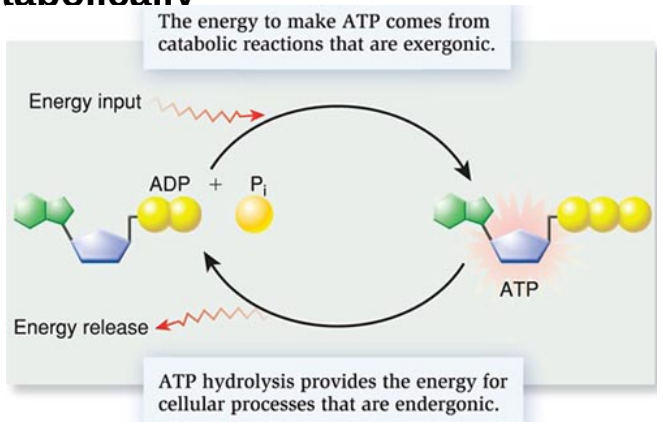
↳ **$CO_2$ + $CH_4$↑**

# More Biodegradation/Bioassimilation Facts

**The aerobic oxidation process (a highly specialized cellular phenomenon) requires the participation of three metabolically interrelated processes:**

1. **Tricarboxylic acid cycle (TCA cycle)**
2. **Electron transport**
3. **Oxidative phosphorylation**

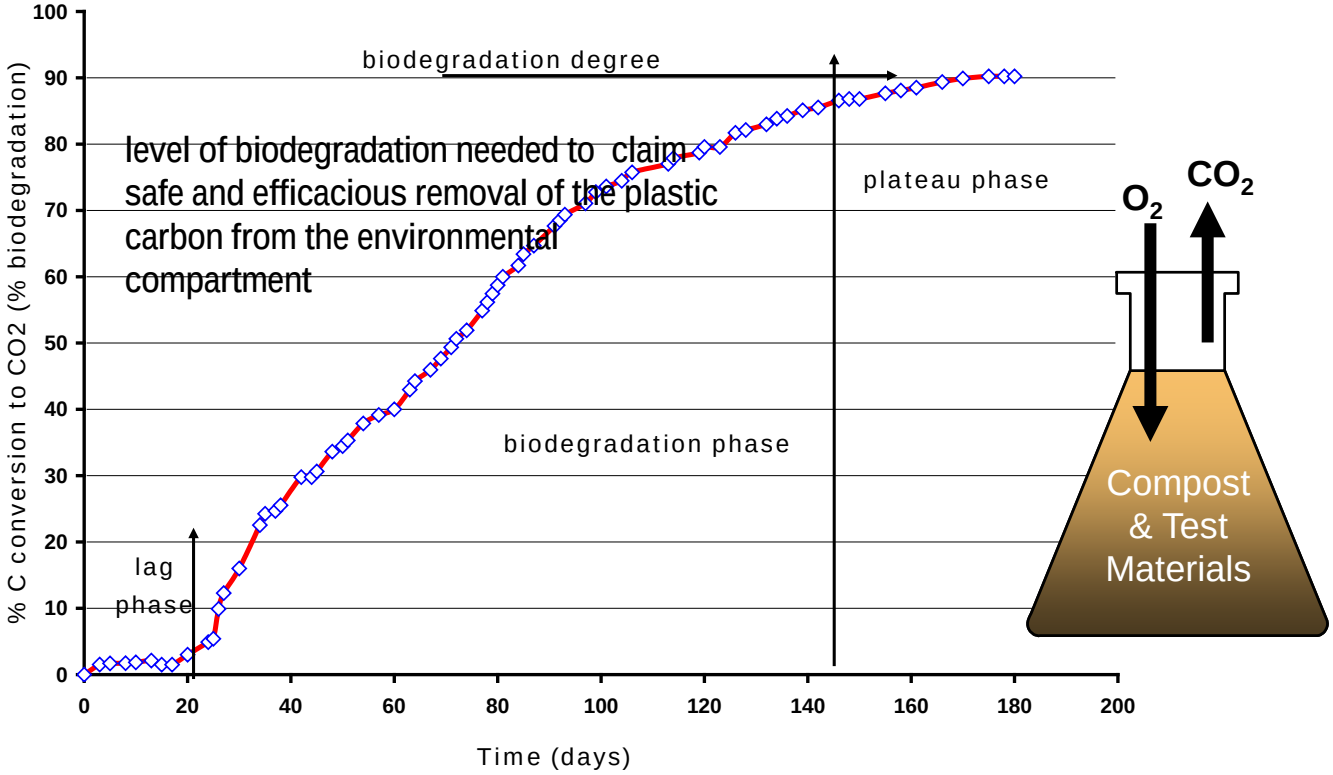
**All of the processes take place inside the cell**




**For these processes to occur:**

**The substrates needs to be transported inside the cell**

**Thus, molecular weight, hydrophobic/hydrophilic balance, other molecular and structural features govern transport across cell membrane into the cell for utilization of the C-substrate.**




**ASTM D5338; ISO 14855; ISO 18606; EN 13432**

**Figure 3. Measuring rate and extent of biodegradability using test plastic as the sole carbon source**

# So why is there confusion and issues relating to biodegradability?

Biodegradation definition says – "……. Degradation due to the action of microorganisms, enzymes

And so if you can show some colonization of microorganisms, or show some percent biodegradability (10 -20%) after which it levels off/plateaus; then a claim of biodegradability is made and an environmental value attribute claim is made

**extent of biodegradation, time, disposal environment , temperature especially for a marine environment are important parameters to be specified!**

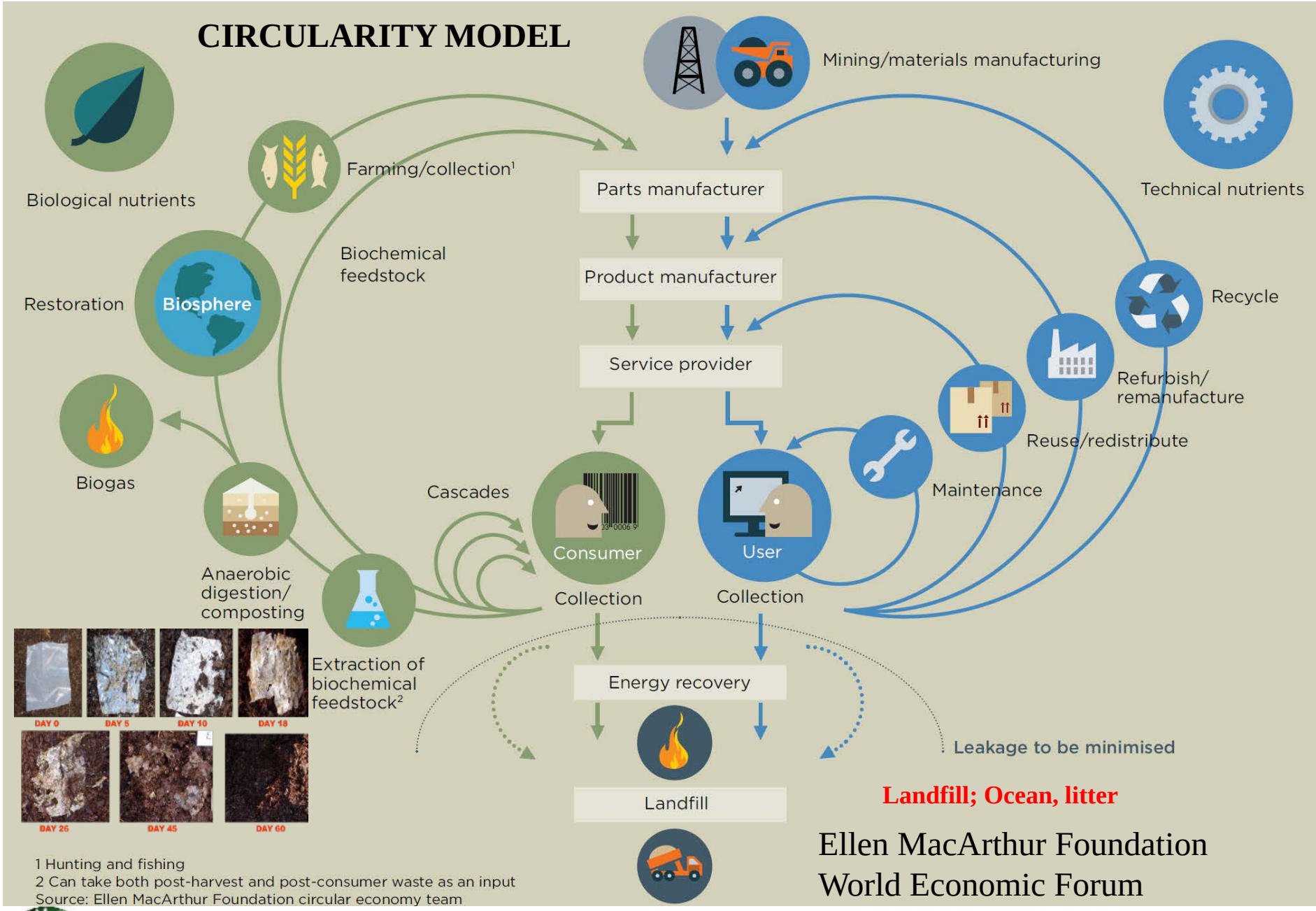
**Narayan, BioPlastics Magazine, 06/12, Vol 7, pg 38-40, 2013 & other articles**

**Question:**

**Is biodegradability a solution to plastics end-of-life?**

**Biodegradability in concert with (integrated to) managed, closed-loop disposal systems like composting/anaerobic digestion or soil (agriculture) can be a viable and responsible “end-of-life” solution in harmony with the “Circularity Model”**

# CIRCULARITY MODEL




**Landfill; Ocean, litter**

Ellen MacArthur Foundation
World Economic Forum

1 Hunting and fishing
2 Can take both post-harvest and post-consumer waste as an input
Source: Ellen MacArthur Foundation circular economy team

**CAUTION:**

**Unqualified use of the term "biodegradable" is wrong, misleading, and deceptive.** It violates the law in the State of California and U.S. Federal Trade Commission (FTC) green guides **& in Australia too**

- **Need to define disposal environment, time/rate and extent of biodegradation – qualified biodegradability claim**
  - **Integrated to Composting or AD coupled to composting or soil biodegradability (mulch films & ag products)**

- Need complete microbial assimilation and removal from the environmental compartment in a short time period otherwise may have environmental and health consequences
  - Degradable, partial biodegradable not acceptable – serious health and environmental consequences
    - Phil. Trans. Royal. Soc. (Biology) July 27, 2009; 364

**Certified/ Verified Compostable Plastics is the "enabling technology" to efficiently and efficaciously divert food and other organic wastes from landfills to environmentally responsible end-of-life solutions like composting and anaerobic digestion.**

**"Compostable" defines the boundary conditions under which complete biodegradation (microbial utilization) needs to be validated using ASTM/ISO International Standards**

**Enabler for the "Circularity Model"**

**Enabler for "Organics Recycling"**

- **Green Sports Alliance – sports team events**
- **Schools & College (U of Michigan, Penn State, Michigan State)**
- **Corporate campuses (Google)**
- **Venues and events, airport concourses**
- **Cities – San Francisco, Seattle and others**

## EPA, MSW numbers 2013

| Other wastes | Generated | Recovered | percent | Discarded |
|---|---|---|---|---|
| Food, other‡ | 37.06 | 1.84 | 5.0% | 35.22 |
| Yard trimmings | 34.20 | 20.6 | 60.2% | 13.60 |

| | Wt. recovered mtons | GHG benefits (MMT CO2-eq) | |
|---|---|---|---|
| Food, other^ | 1.84 | 1.7 | 308 thousand |
| Yard trimmings | 20.6 | 1.04 | 220 thousand |

EPA warm model , 2013

# Twins @ Target Field

- Newest MLB ballpark to embrace a *systems approach to waste diversion*
- Compostable packaging and front of house compost collection now complement other sustainability initiatives such as water and energy conservation
- A simple two bin system throughout the ballpark captures bottles and cans in one bin and everything else in another
- Because "everything else" is almost all compostable, contamination is kept to a minimum and a ***diversion rate of over 90% is within reach***
- Organic stream is sent to a county transfer station that sends material to The Mulch Store and Full Circle Organics compost facilities

# THE MISUSE OF BIODEGRADABILITY AS AN EOL OPTION

- Articles have appeared in literature and widely covered in print and E-media of macro-organisms like meal worms and wax moth eating plastics as solutions for plastic waste management.
- CNN news reported “the gut bacteria in worms can transform plastic into safe biodegradable waste”; News headlines proclaimed “Styrofoam-Eating Mealworms Could Happily Dispose of Plastic Waste”.
- Another one said “The Indian meal-moth, can degrade polyethylene”.
- Science and PNAS carried reports of microorganisms, and enzymes, including a mutant enzyme to break down PET molecule as the “breakthrough” to the PET and plastic waste pollution in the oceans.
- Biodegradable plastics as a solution for ocean plastics pollution and waste management abound in the literature

**Caterpillars & mealworms are NOT the^ next new biodegradable magical solution to plastic waste management?**

- **Such wild, unsubstantiated statements are misleading, troublesome and irresponsible**
- **It takes away from serious end-of-life solutions being developed**

**A bacterium that degrades and assimilates poly(ethyleneterephthalate)**
**Science, 2016**

Because the ability to enzymatically degrade PET has been thought to be limited to a few fungal species, biodegradation (should read biocatalysis) is not yet a viable remediation or recycling strategy.

Novel bacterium, Ideonella sakaiensis 201-F6, grown on PET produces two enzymes **capable** of hydrolyzing PET. Both enzymes are required to enzymatically convert PET to terephthalic acid and ethylene glycol. Acts only on amorphous PET

A PNAS paper reports development of a "mutant enzyme" that breaks down the crystallinity. However, there is no data on the kinetics and formation of TPA and EG in acceptable yields – no yield data generated.

**Narayan comment – C&EN News June 18th 2018:**
We already have mature, scalable, cost effective technologies to recycle PET (bottle to bottle) or bottle to other products or depolymerize to the individual constituent monomers.

The world does not need another technology to degrade/depolymerize PET. This work will not solve the fundamental problem of recovery and waste management.
We cannot and should not entertain the idea of releasing GMOs or wild type microorganisms/enzymes into the oceans to break PET down? -- such actions would be irresponsible.

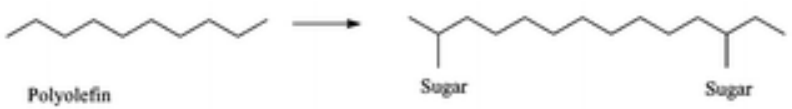
## TAKE HOME MESSAGE

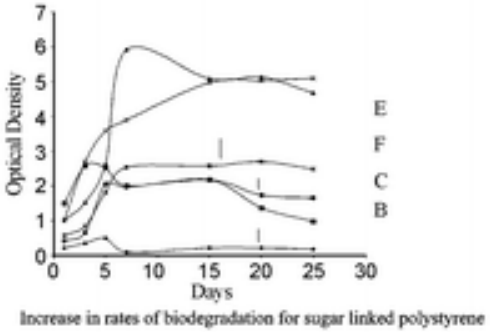
- Recent articles in literature and widely covered in print and E-media of macro-organisms like meal worms and wax moth eating plastics as solutions for plastic waste management are misleading, troublesome and irresponsible.
- It takes away from serious end-of-life solutions in place and being developed
- Biodegradability is not a magical solution for plastics waste management.
- Complete biodegradation of single use disposable plastics along with food and other biowastes in managed, closed loop disposal systems like composting and anaerobic digestion is environmentally responsible. This helps divert food and other biowastes from landfills and oceans.
  - Certified Compostable BioPlastics
- Degradation resulting in release of small fragments (microplastics) into the terrestrial and ocean environment has been shown to cause harm to the environment and to human health.
  - Many papers in the literature document that such fragments pick up toxins from the environment like a sponge and become a vehicle to transport toxins up the food chain.
- Use biobased, renewable carbon feedstocks (carbon footprint reductions) and in harmony with the new “Circular Economy” model

# ADDITIONAL QUESTIONS

BIODEGRADABILITY CLAIM

- *Chem. Commun.*, 2002, (23), 2884 - 2885
  - A hypothesis was developed, and successfully tested, to greatly increase the rates of biodegradation of polyolefins, by anchoring minute quantities of glucose, sucrose or lactose, onto functionalized polystyrene (polystyrene-co-maleic anhydride copolymer) and measuring their rates of biodegradation, which were found to be significantly improved
- PRESS
  - Sugar turns plastics biodegradable. Bacteria make a meal of sweetened polythene and polystyrene.




Increase in rates of biodegradation for sugar linked polystyrene

weight loss of 2-12%,

Acceptable/Not acceptable – Why?

Caution -- BIODEGRADABILITY CLAIMS

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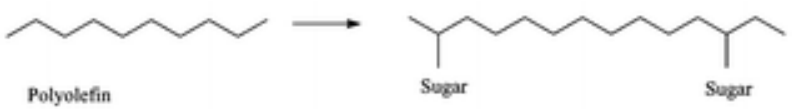
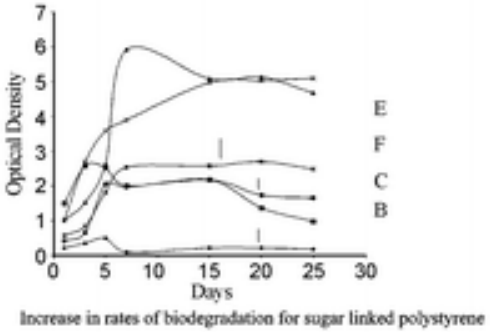


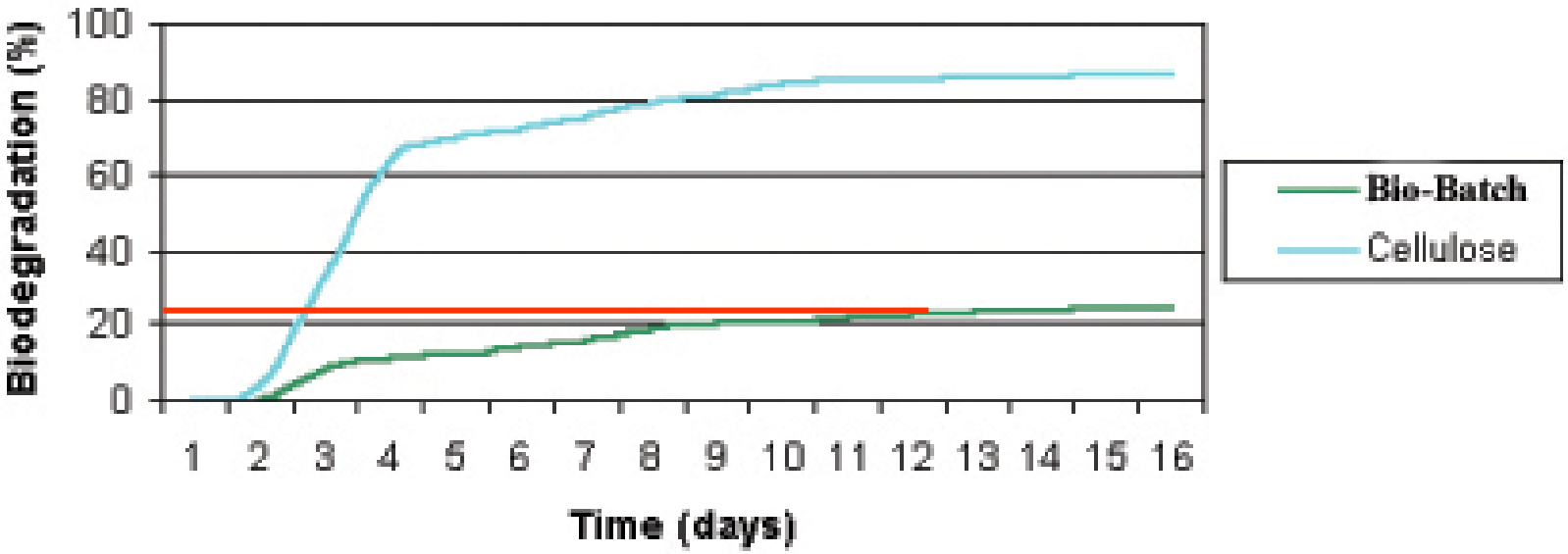

Increase in rates of biodegradation for sugar linked polystyrene

weight loss of only 2-12%,

Only sugar is being assimilated, PE chain intact – Is this a genuine example of biodegradable plastic?

# Additive Technology

- *"Plastic products with our additives at 1% levels will fully biodegrade in 9 months to 5 years wherever they are disposed like composting, or landfills under both aerobic and anaerobic conditions"*



# Green Washing Claims -- Additive Technology

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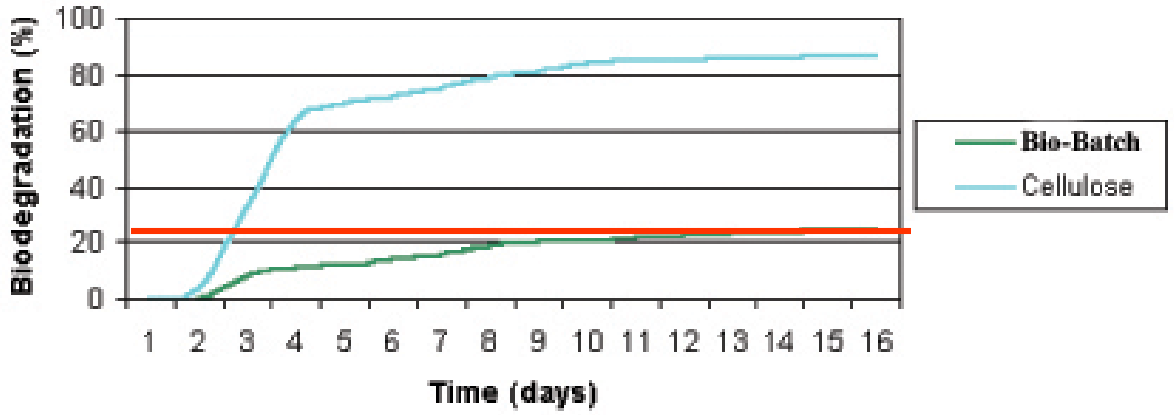
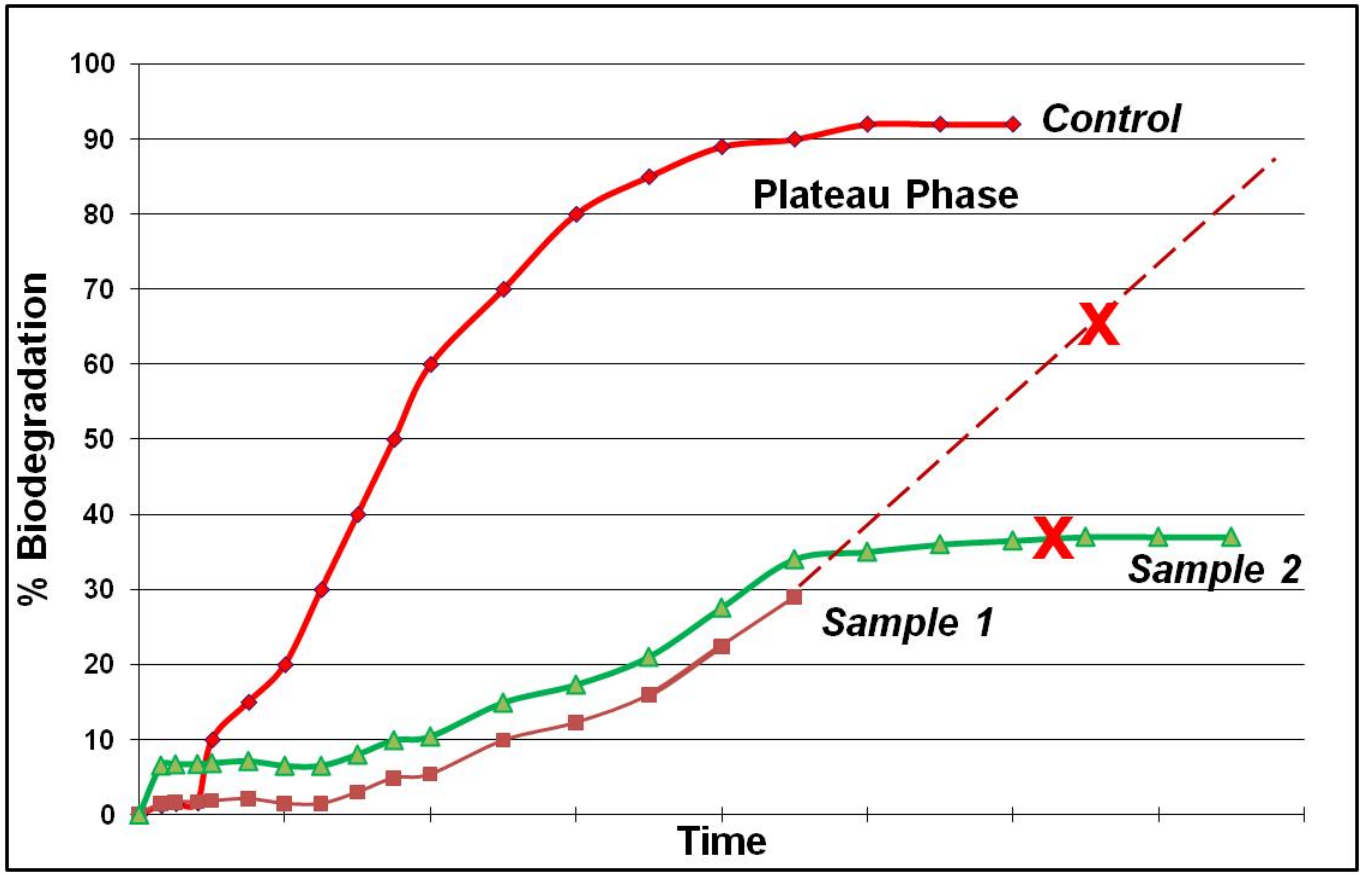



**The 50% Bio-Batch film did not degrade as completely or as quickly as the cellulose. At the end of the test, 19% of the film had degraded.**

**The results of the aerobic degradation tests indicate that, in time, plastics produced using Bio-Batch pellets will biodegrade in aerobic conditions.**

**DATA DOES NOT SUPPORT THE CONCLUSIONS!**

# MISLEADING BIODEGRADABILITY CLAIMS



## U.S. Sixth Court of Appleals – U.S. FTC vs additive company claiming biodegradability in landfill

Further, through a facial analysis of the advertising in question, we reject company's argument that the word "biodegradable" means, in the context of consumer advertising, *only* that
the product is "intrinsically" biodegradable, with no time element.

Such an interpretation would render the term meaningless. This is because nearly all substances, including conventional plastics, will biodegrade if given enough time – even if that time period might be thousands or millions of years

**ASTM STANDARDS REQUIREMENTS**

*Claims of performance shall be limited to the numerical result obtained in the test and not be used for unqualified "biodegradable" claims. Reports shall clearly state the percentage of net gaseous carbon generation for both the test and reference samples at the completion of the test. Furthermore results shall not be extrapolated past the actual duration of the test.*

Additional Slides on microplastics ocean pollution
&
Composting of compostable plastics at MSU

**In 2010 about 5.0 to 12.7 million tons of "mismanaged" land based plastic waste entered into the oceans from 192 costal countries within 50 km of the coast – Science , Vol 347, Issue 6223 pg 768, 2015**

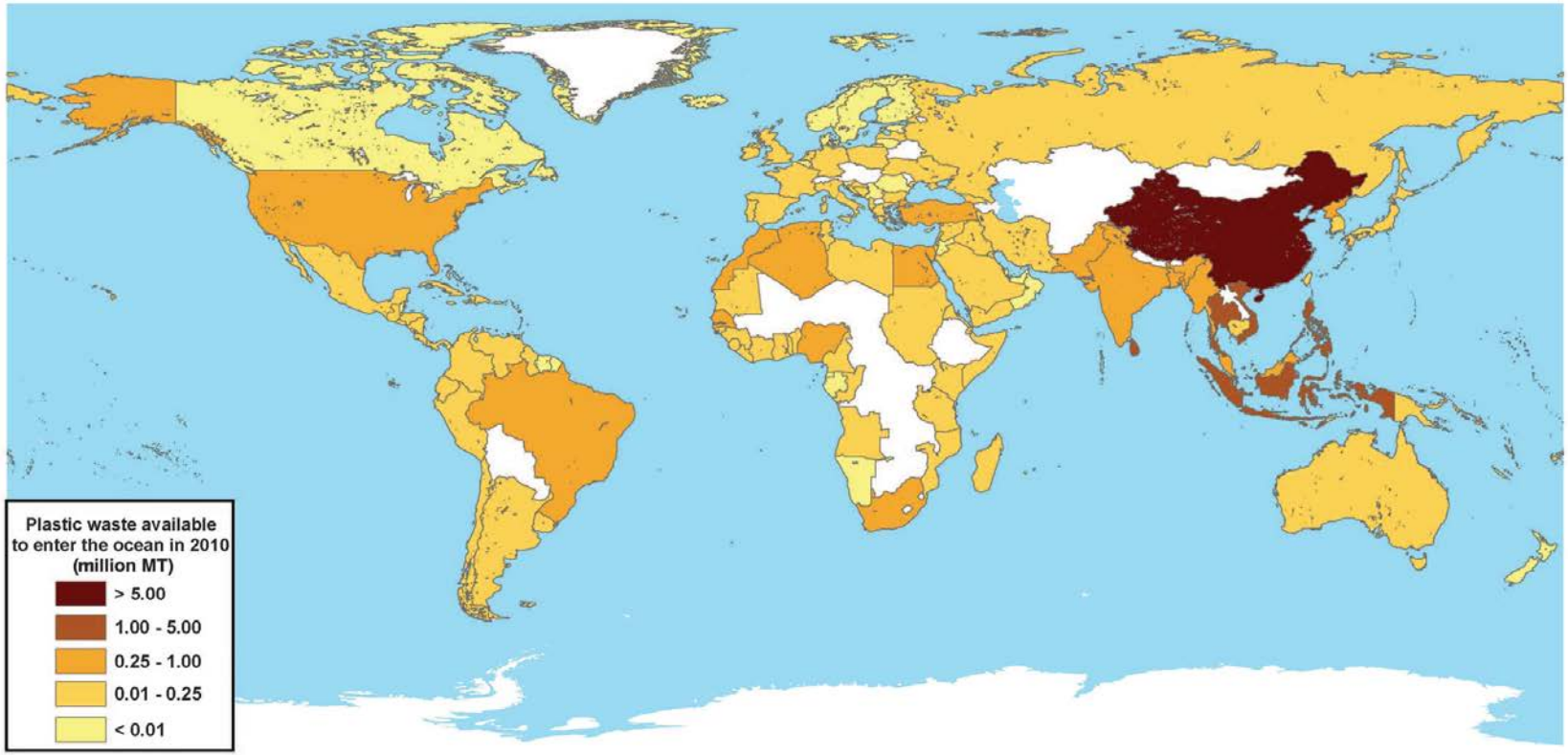



**Fig. 1. Global map with each country shaded according to the estimated mass of mismanaged plastic waste [millions of metric tons (MT)] generated in 2010 by populations living within 50 km of the coast.** We considered 192 countries. Countries not included in the study are shaded white.

**By 2025**

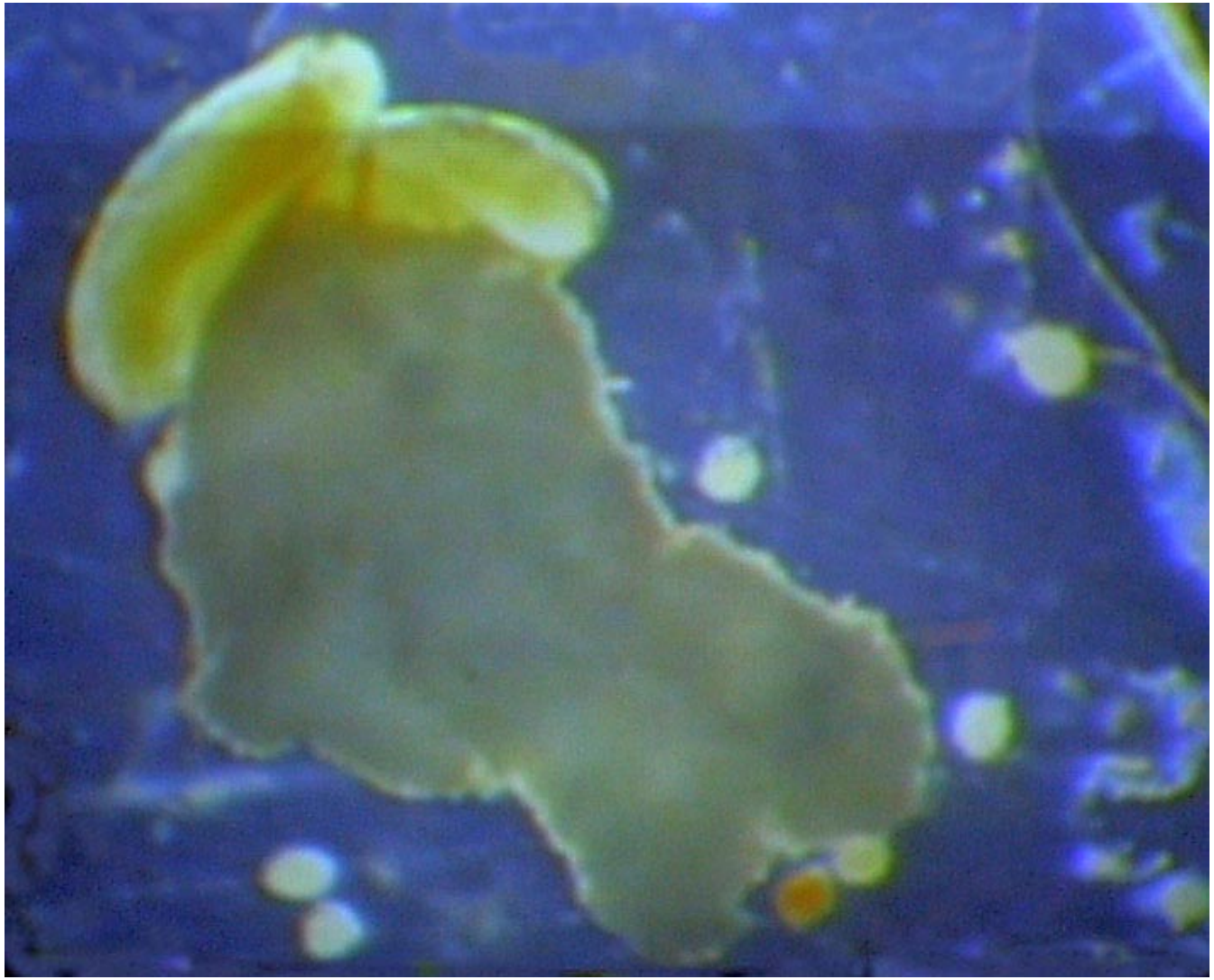
**618.7 million tons mismanaged waste**

**About 200 million tons leaks into the oceans**

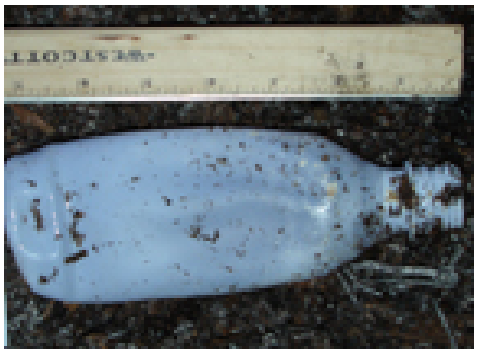
**More plastics in the oceans than plankton**

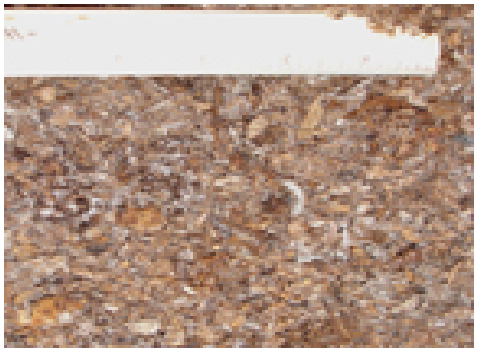
**Colonization of microplastics loaded with toxins**

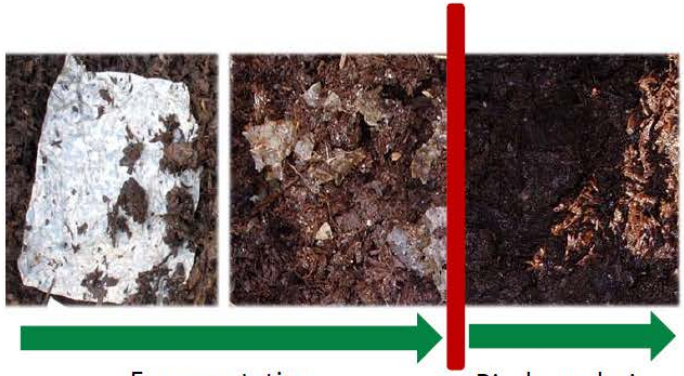
**Guess where this ends up???**



MSU COMPOST PILE – Sample boxes with biodegradable material








## Natur-Ware in a Composting Environment