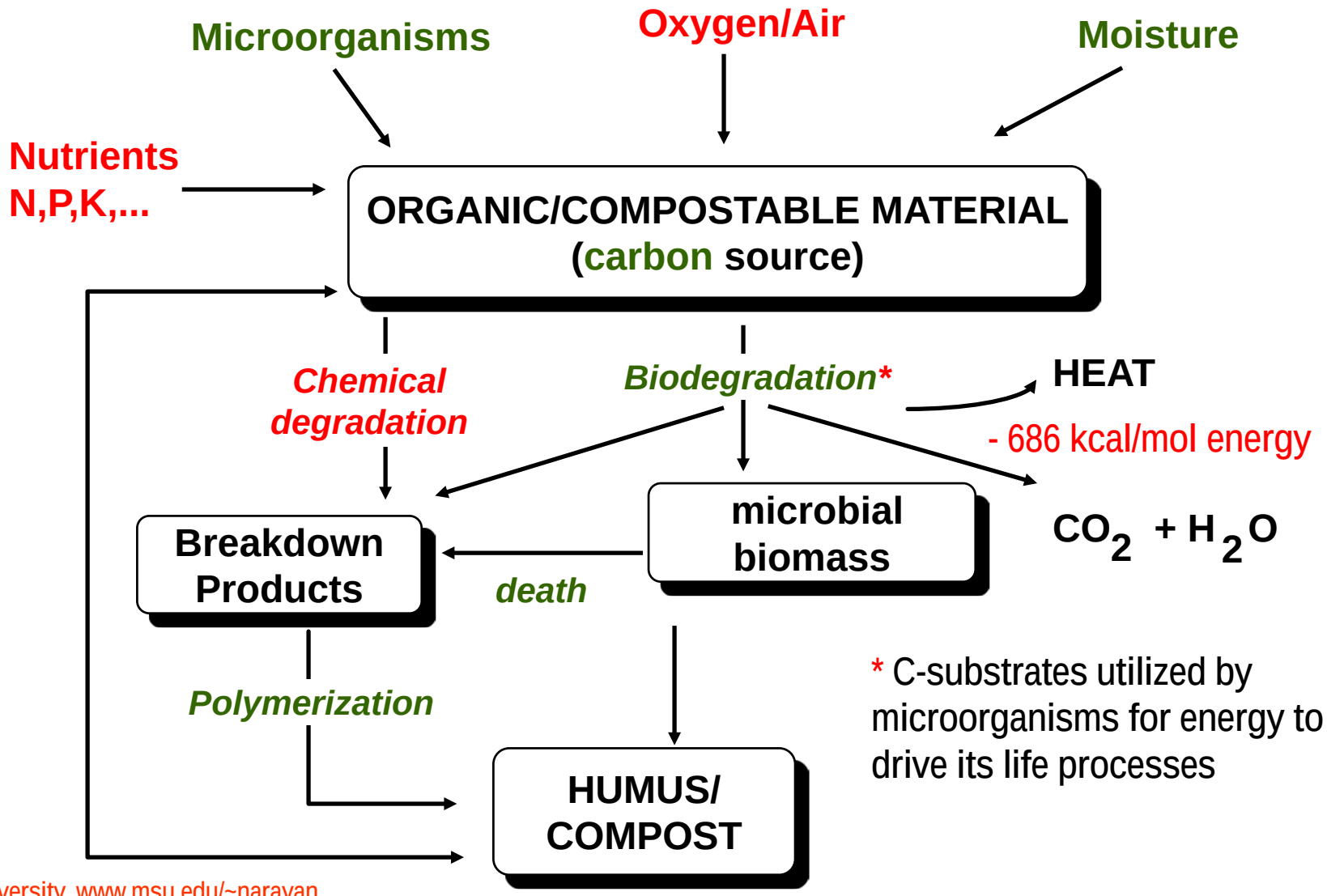
Value proposition for Compostable Plastic and hybrid Plastic-Paper products in Composting (Organics Recycling) Program

"Biodegradable-compostable plastics is the enabling technology for complete and efficient food waste diversions from landfill to composting"

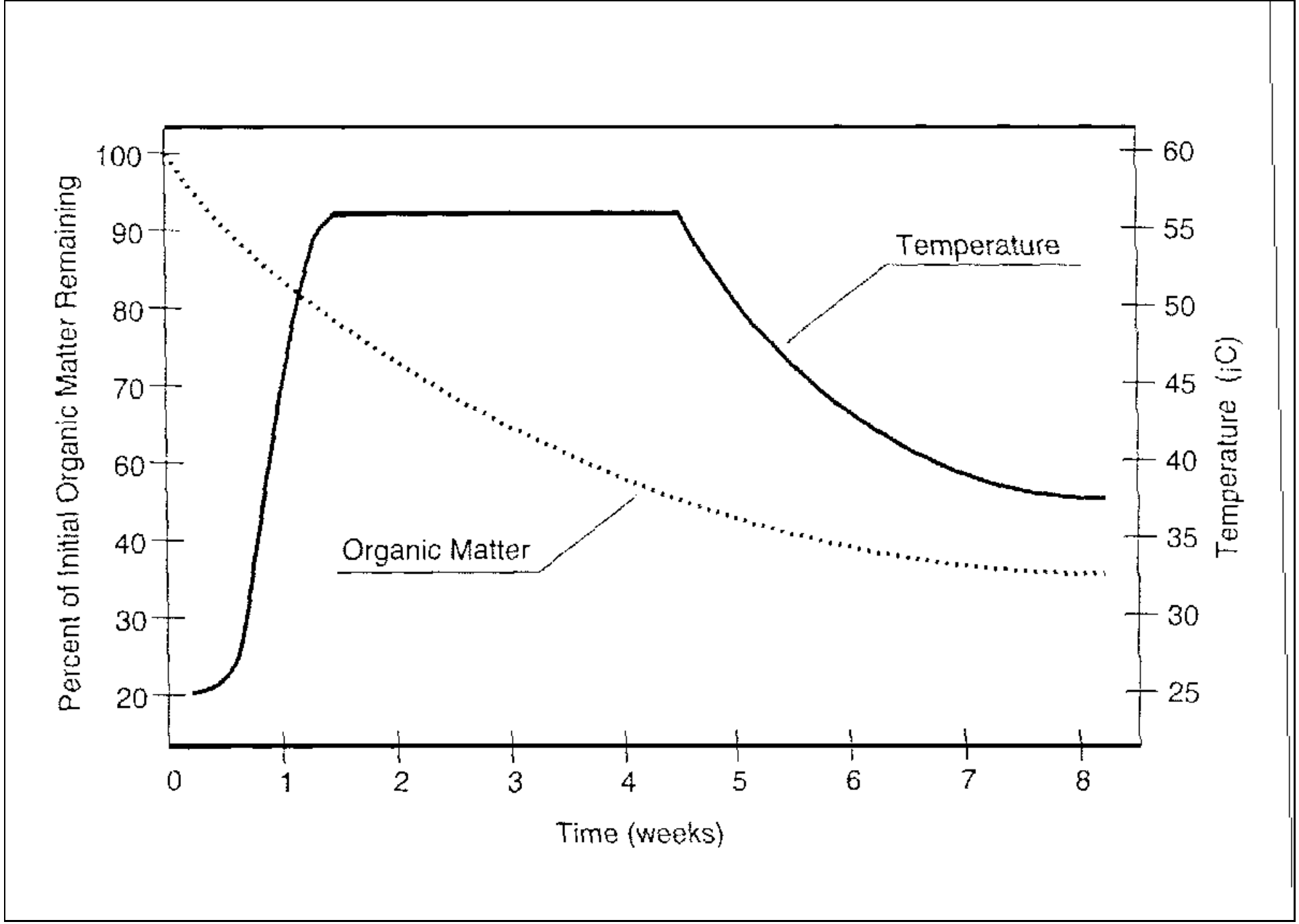
Ramani Narayan
University Distinguished Professor
narayan@msu.edu

Presentation at 35th Annual MRC conference – MI -- Compostable Plastics and their role in organics recycling programs, November 10 2016

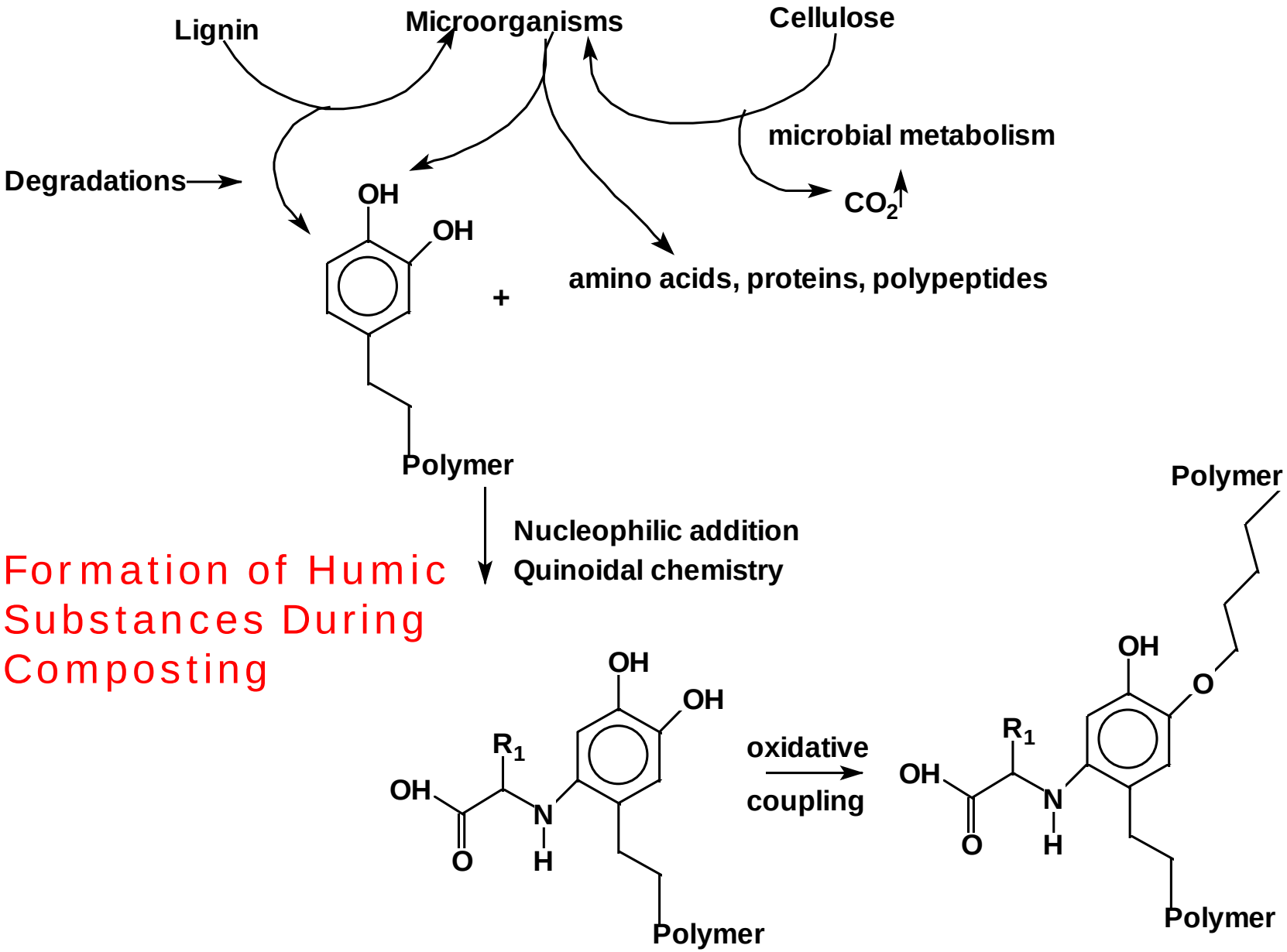
COMPOSTING PROCESS



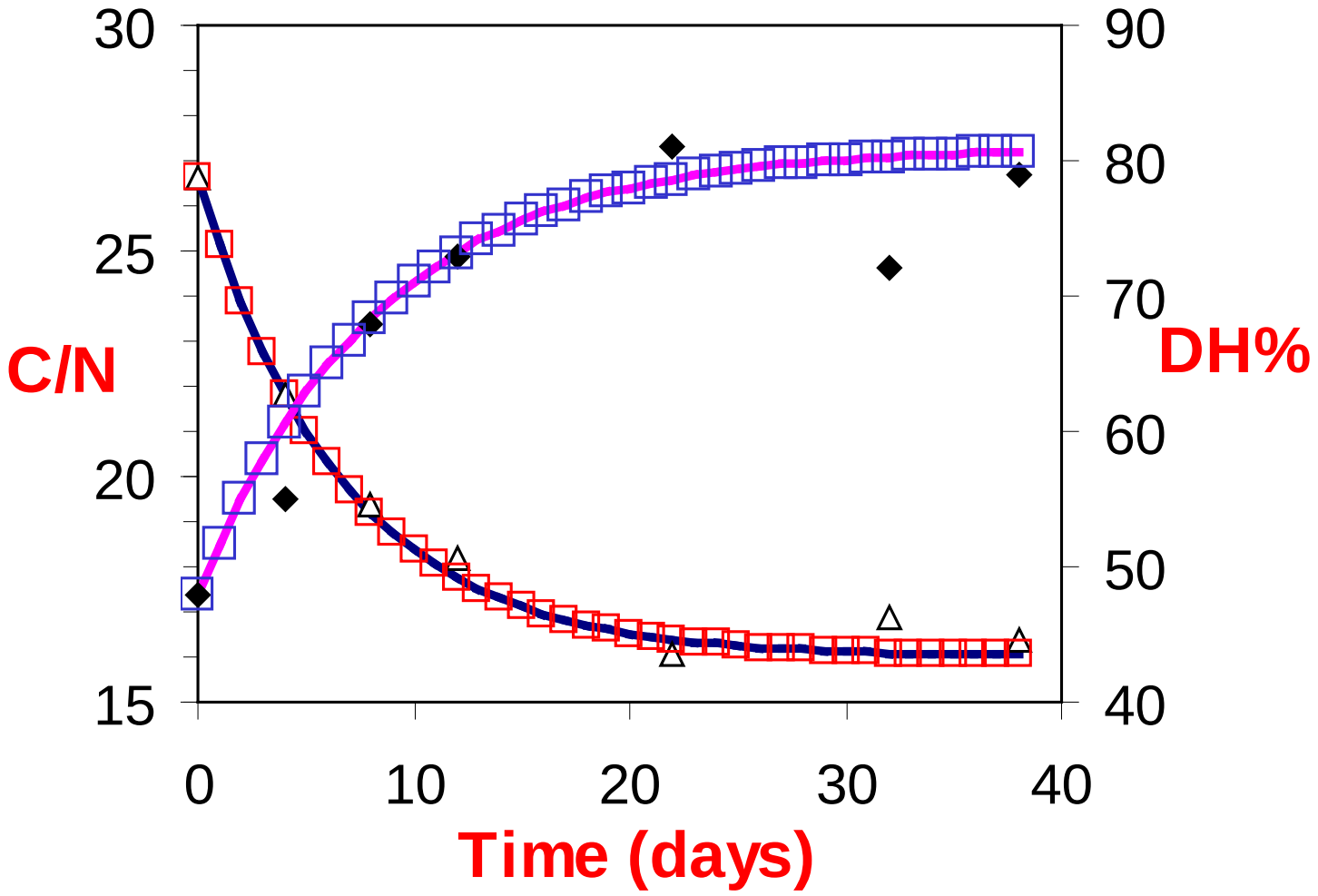
* C-substrates utilized by microorganisms for energy to drive its life processes


Percent of Initial Organic Matter Remaining
100
90
80
70
60
40
30
20
Temperature
Organic Matter
60
55
50
45
40
35
30
25
Temperature (iC)
0
1
2
3
4
5
6
7
8
Time (weeks)

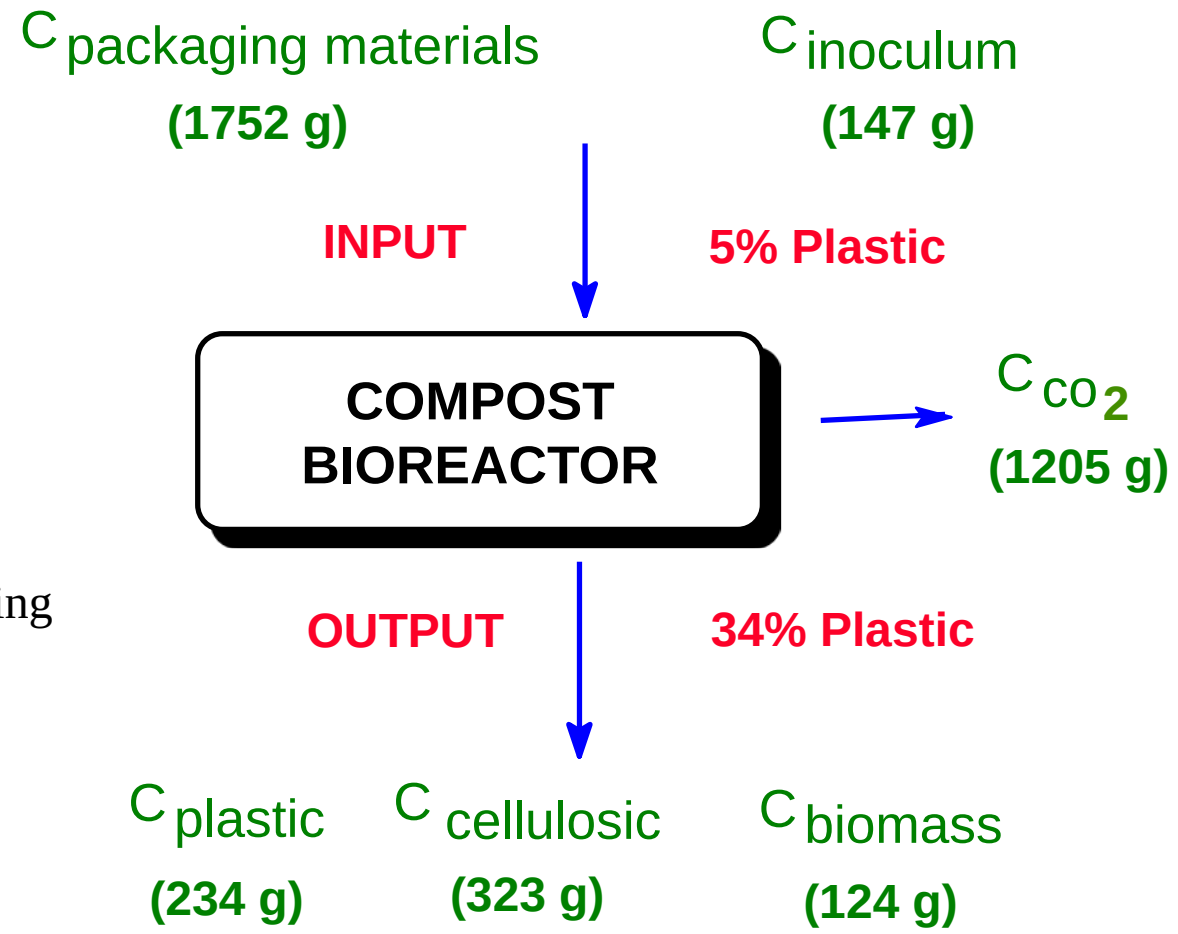
Formation of Humic Substances During Composting



Pilot Scale Composting of paper-yard waste



Pilot-Scale Composting of PE-Coated Packaging



Coatings, modifiers, adhesives need to demonstrate complete biodegradability under composting conditions

Use ASTM D6868!!!!

RECYCLING ORGANIC WASTES TO PRODUCE QUALITY COMPOST

- Yard Wastes
- Food & other biowastes
- Paper
- Compostable plastics
- paper-compostable plastic hybrids

COMPOSTING INFRASTRUCTURE

Quality Compost Product from a Semi-Segregated Waste Stream:

- Reduces chemical input requirements
- Increases soil water and nutrient retention
- Suppresses plant disease
- Augments organic matter

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

biodegradable-compostable plastics

biodegradable-compostable plastics can be a viable and responsible "end-of-life" solution in harmony with the "circular economy" concepts of closed loop systems

CAUTION: Unqualified use of the term "biodegradable" is wrong, misleading, and deceptive. It violates the law in California and U.S. FTC green guides.

Need to define disposal environment, time/rate and extent of biodegradation – qualified biodegradability claim

Needs to be complete in a safe, timely and efficacious manner

1. **Enables zero waste solutions – food and bio waste diversion from landfill**
   - **Closed venues/events**
2. **Useful in plasticulture e.g mulch film – soil biodegradability or composted**
3. **Unsubstantiated & non-verifiable claims – additives (oxo, organic, enzyme) added to PE, PP, PS, PET make it completely biodegradable anywhere from 9 months to 5 years**
4. **Not all biobased products are biodegradable-compostable; end-of-life is recycling**

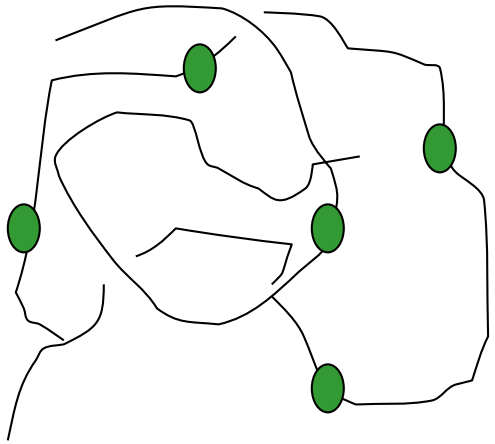
Biodegradability – A misused and abused term

QUESTION

- Can microorganisms present in the disposal environment utilize/assimilate the plastic carbon substrate – the biotic process
- **What extent and in what time frame?**
- 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?

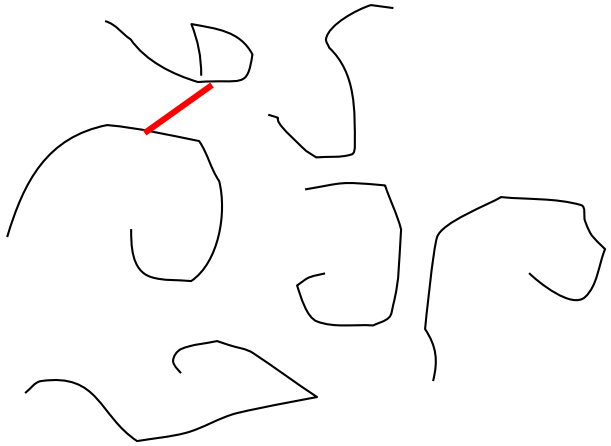


Polymer chains with susceptible linkages

Environment – soil, compost, waste water plant, marine

Hydrolytic
Oxidative
Enzymatic

STEP 1



Oligomers & polymer fragments

Complete microbial assimilation

defined time frame, no residues

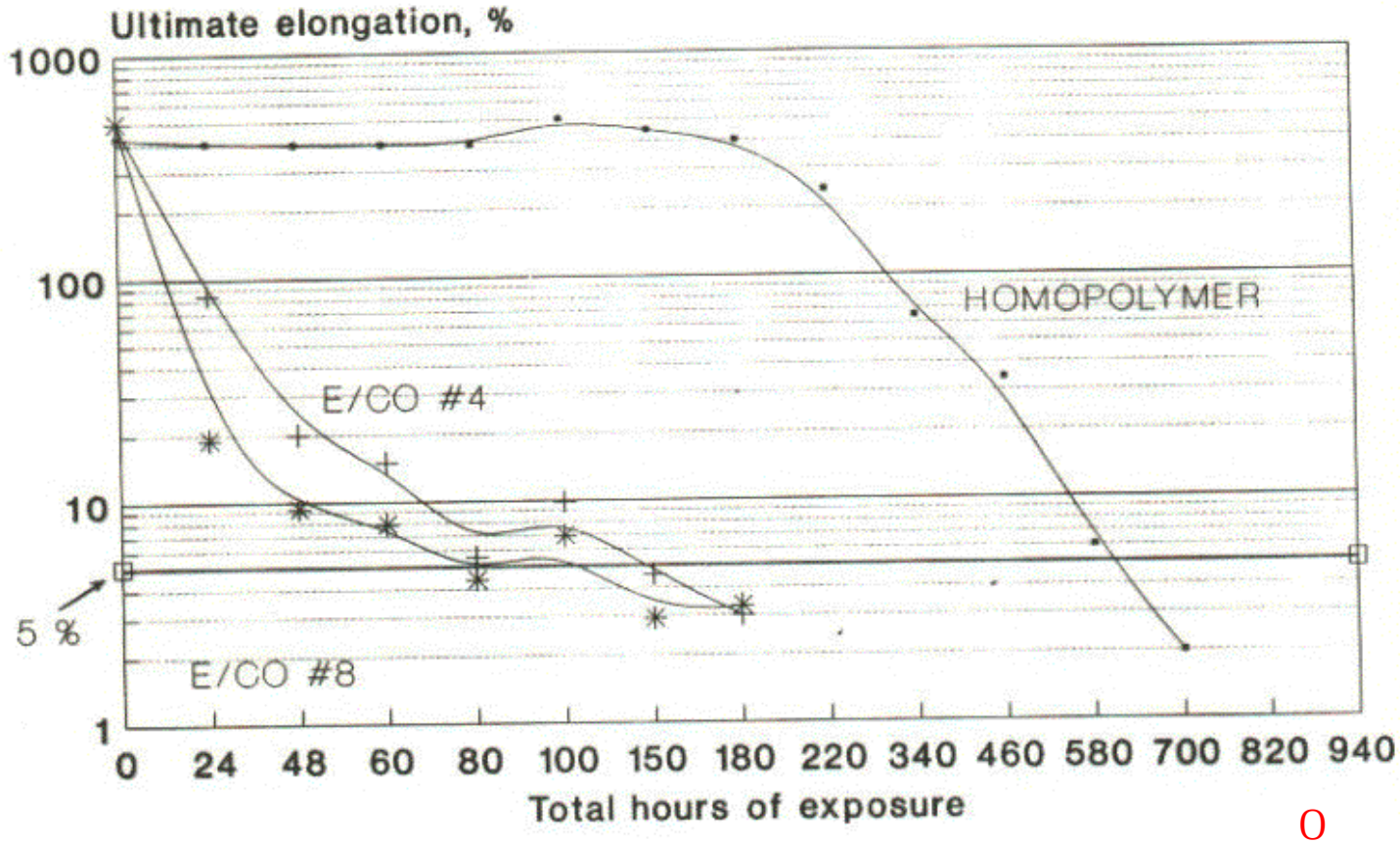
STEP 2

$CO_2 + H_2O +$ Cell biomass

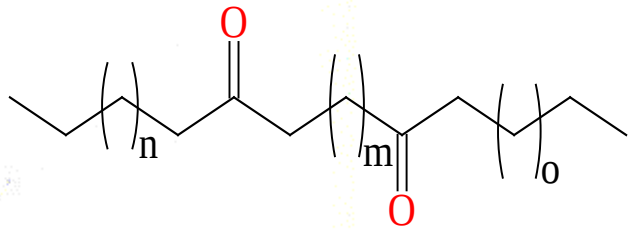
Biodegradation(Step 2): Only if all fragmented residues consumed by microorganisms as a food & energy source as measured by evolved CO_2 in defined time and disposal environment

VII. E/CO v. PE Homopolymer

Q-U-V 50 Degrees C LAB 1



astm4



ECO Copolymer

Degradable resin

Narayan

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**

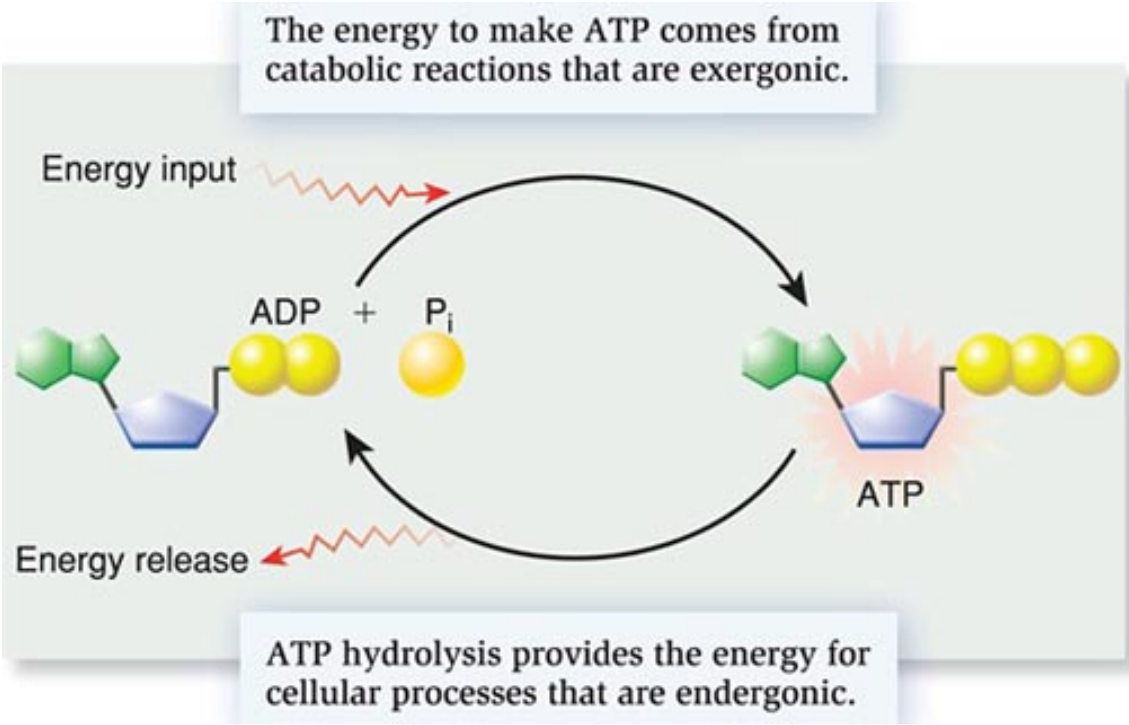
↳ **CO_2 + CH_4 ↑**

More Biodegradation/Bioassimilation Facts

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

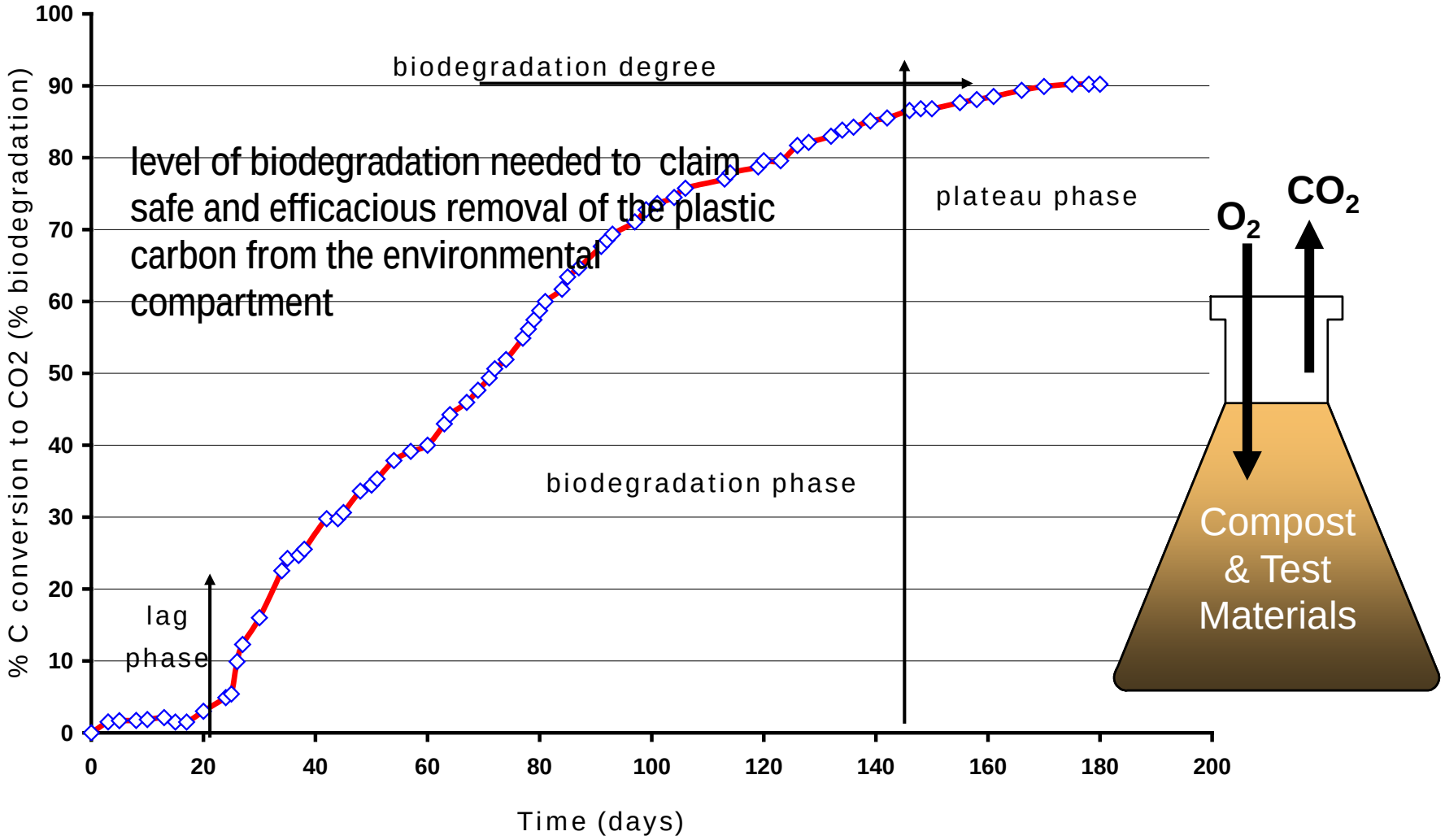
1. **Tricarboxylic acid cycle (TCA cycle)**
2. **Electron transport**
3. **Oxidative phosphorylation**

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

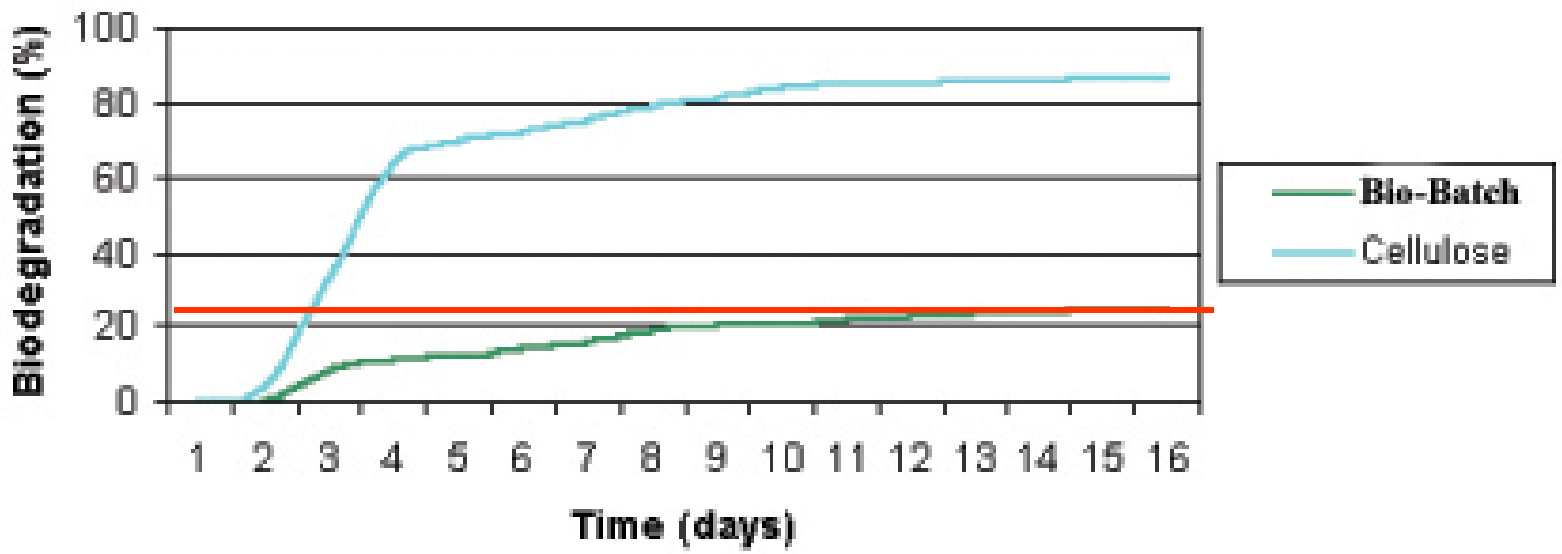
And so if you can show some colonization of microorganisms, biofilm formation or show some percent biodegradability (10 -20%) after which it levels off/plateaus; then a claim of biodegradability is made and an environmental value attribute claim is made

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

Green Washing Claims -- 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"***

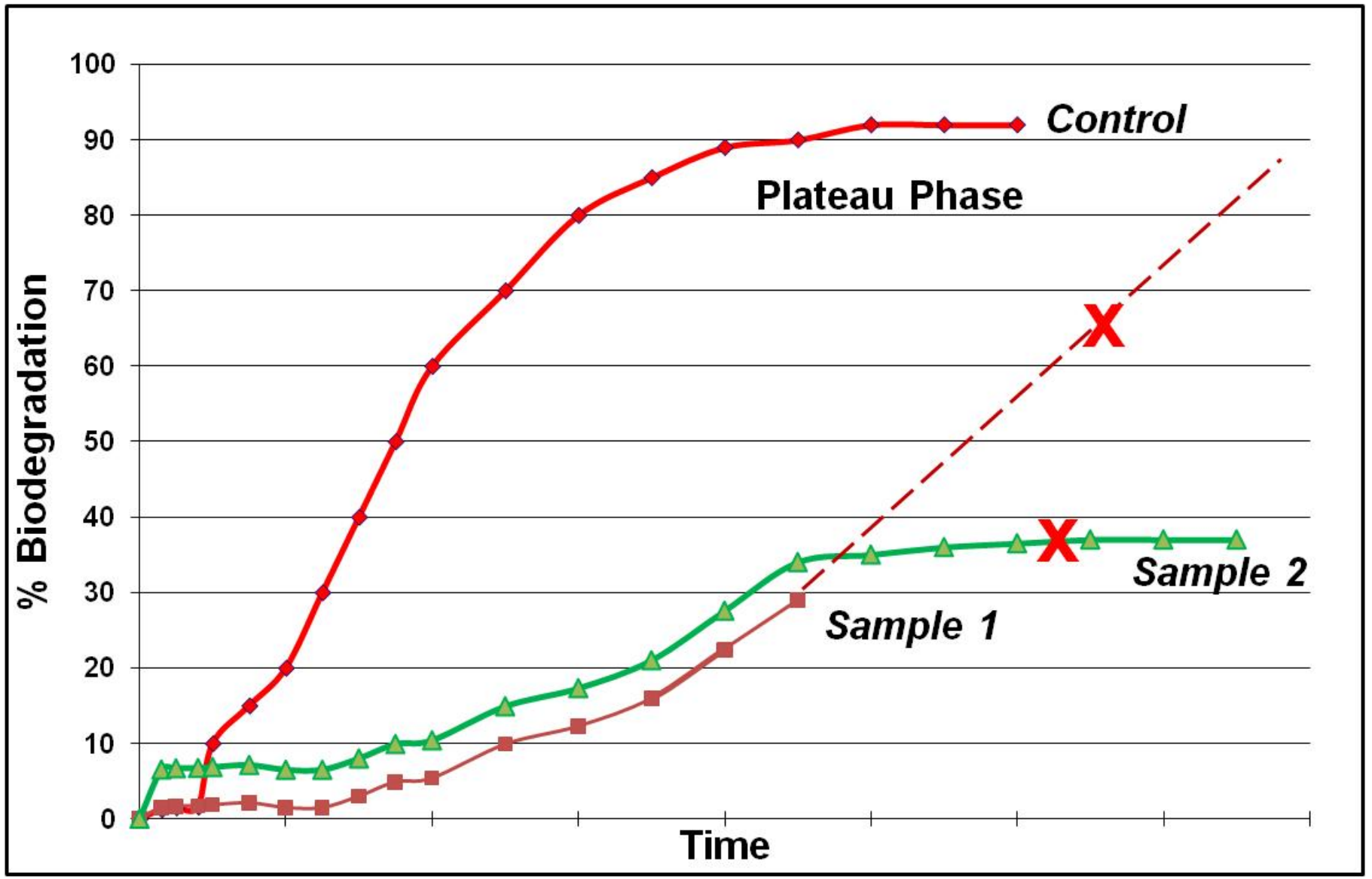


The 50% Bio-Batch film did not degrade as completely or as quickly as the cellulose. At the end of the test, 19% of the film had degraded.

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

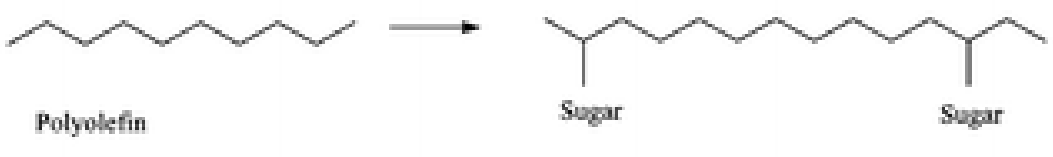
DATA DOES NOT SUPPORT THE CONCLUSIONS!

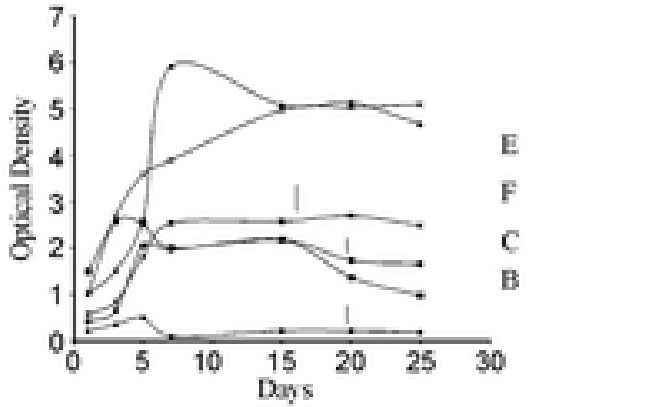
MISLEADING BIODEGRADABILITY CLAIMS



Caution -- BIODEGRADABILITY CLAIMS

- *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 only 2-12%,

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

POLYSTYRENE EATING MEALWORMS

PE EATING WAXWORMS

The gut bacteria in these worms can transform plastic into safe biodegradable waste (CNN)

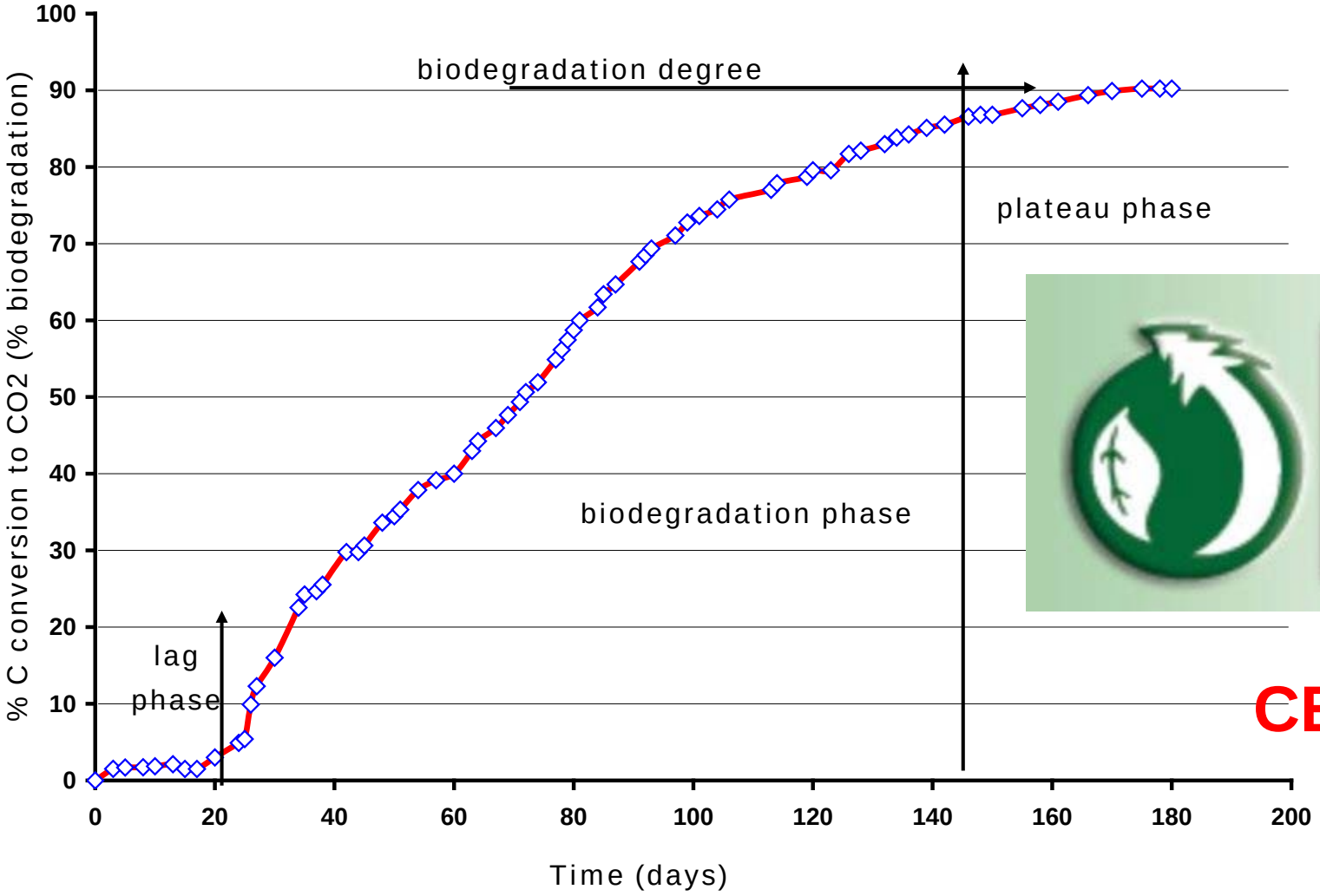
Remember, the Law of Nature, the first law of thermodynamics states that
"Matter can neither be created or destroyed" – polyethylene plastic cannot be magically destroyed/degraded into nothing.

Is it being stored in the gut of the wax moth to eventually starve – similar to documented reports of plastic found in birds and cows stomach?

Is it excreted unchanged as fecal matter to build up and dispersed into the environment causing negative environmental and health impacts?

TAKE HOME MESSAGE

- ***"Biodegradation" is not a magical solution to plastics waste management.***
- ***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.***
- ***Complete biodegradation of single use disposable plastics along with food and other biowastes in managed, closed loop disposal systems like composting and anaerobic digestion coupled to composting is environmentally responsible. This helps divert food and other biowastes from landfills and oceans.***
- ***State of California prohibits the unqualified use of "biodegradable" and only certified fully biodegradable-compostable plastics going into industrial composting systems are allowed. The U.S. Federal Trade Commission (U.S. FTC) has similar guidance on the use of terms like biodegradable and compostable.***



BPI

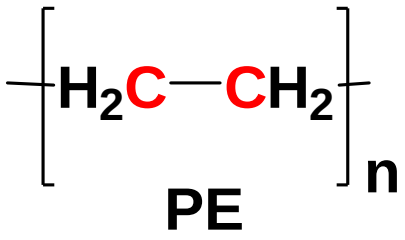
CERTIFICATION

ASTM D5338; ISO 14855; ISO 18606; EN 13432

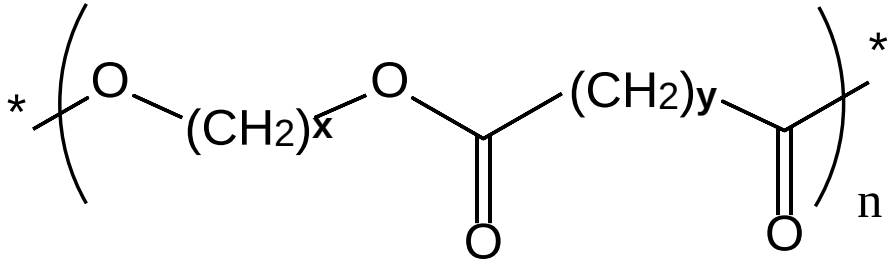
WHAT ARE BIOBASED PLASTICS

Biobased plastics and products refers to:

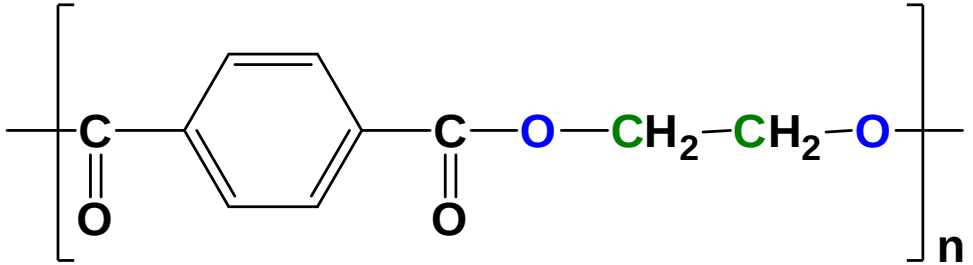
- **Origins of the carbon in the polymer**
- **Plant-biomass feedstock (biobased) vs petro-fossil feedstock**
- **The "beginning of life" and does not address end-of-life**
- **Biobased products are not necessarily and automatically biodegradable-compostable**



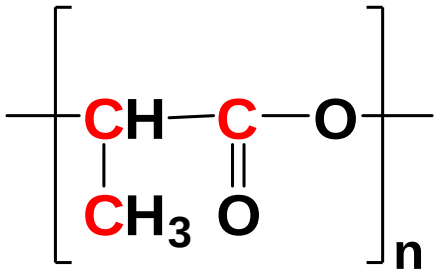
PE



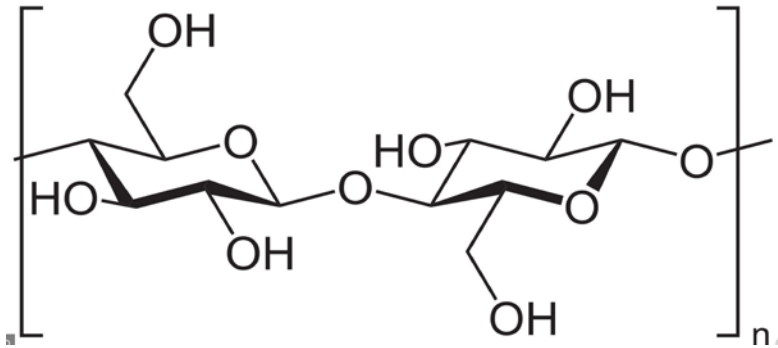
Biobased polyester



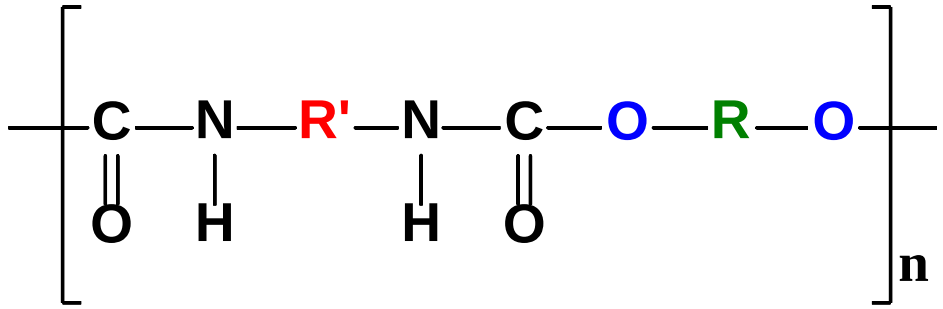
PET



PLA



Cellulose



Biobased polyurethane

Narayan

Exemplar: PLA

$$6nCO_2 + 6nH_2O \xrightarrow{\text{photosynthesis}} nC_6H_{12}O_6 + 6nO_2\uparrow$$

$$nC_6H_{12}O_6 \xrightarrow{\text{fermentation}} 2nCH_3CH(OH)COOH$$

$$2nCH_3CH(OH)COOH \longrightarrow nC_6H_8O_4(\text{Lactide}) + 2H_2O$$

$$nC_6H_8O_4 \xrightarrow{\text{polymerization}} 2\left[-O-\underset{\displaystyle CH_3}{\overset{\displaystyle H}{C}}-\overset{\displaystyle O}{\overset{\displaystyle \|}{C}}-\right]_n$$

(PLA)

NET $6nCO_2 + 4nH_2O \longrightarrow 2[C_3H_4O_2]_n\ (PLA) + 6nO_2\uparrow$

264 Kg 144 Kg

1.83 Kg of CO_2 removed from the environment to manufacture 1 Kg of PLA