Global trends and driver of advanced bio-based chemicals and materials

Biobased (Beginning of life) and Biodegradable-Compostable (End-of-life) Plastics

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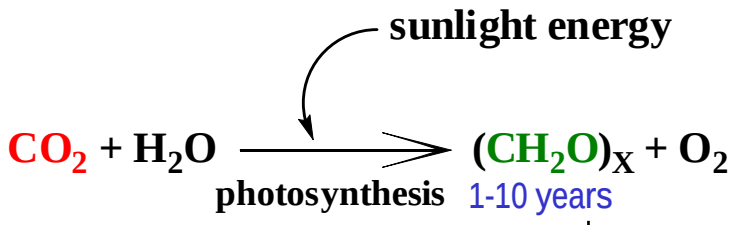
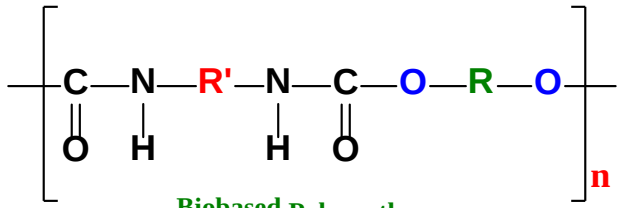
BIOBASED -- ASTM D6868; ISO 16620 (Pt 2)

– containing organic carbon of renewable origin from agricultural, plant, animal, fungi, microorganisms, marine or forestry materials living in a natural environment in equilibrium with the atmosphere.



Plant-Biomass, Ag & Forestry crops & residues

NEW CARBON

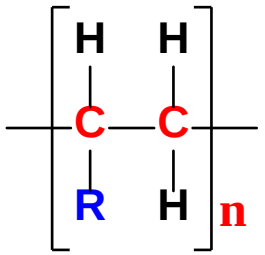


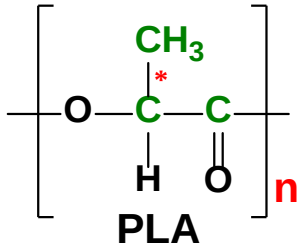
Biobased Polyurethane

> 10^6 YEARS

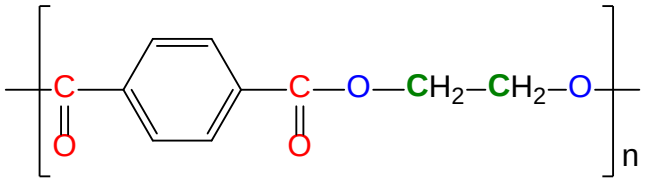
Petro-Fossil Resources (Oil, Coal, Natural gas) -- OLD CARBON

PRODUCTS

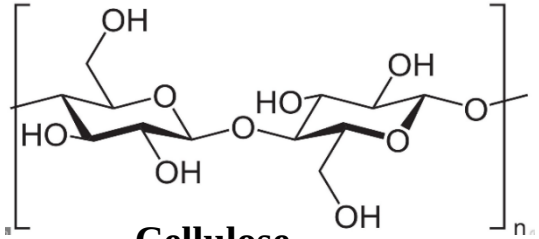




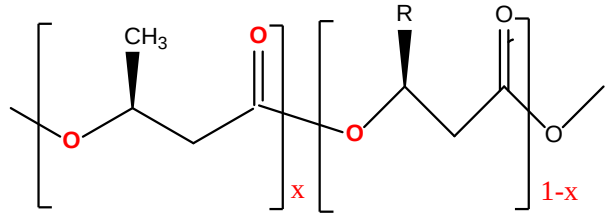
PLA



BIO-PET



Cellulose



PHBV -- R = $-(CH_2)_2-$ PHBH -- R = $-(CH_2)_3-$

PHAs -- Polyhydroxy alkanoates

Narayan

Biobased (Carbon) Content -- Standards

ISO 1660 series standards –Plastics Biobased content Parts 1 through 5

ASTM D6866 Determining the Biobased Content of Solid, Liquid, and Gaseous Samples Using Radiocarbon Analysis

ISO DIS 22526 Carbon and environmental value proposition – general principles (Pt 1); material carbon footprint (Pt 2); Process carbon footprint (Pt 3); Total Environmental footprint (Pt 4)

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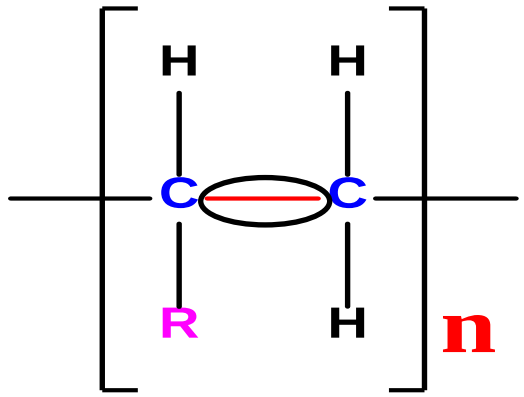
END-OF-LIFE; Plastics waste (non-durable packaging & consumer products) management



Carbon-Carbon backbone

R = -H; Polyethylenes (HDPE, LDPE, LLDPE)

R = $-CH_3$; Polypropylenes (PPs)

R= $-CH_2-C_6H_5$; Polystyrene (PS)

R = -Cl; Poly(vinyl chloride) : PVC

49.3% (of 358 million tons; 2018)

ubiquitous, light weight, persistent (non-biodegradable) plastics are everywhere, polluting the land and the oceans – mismanaged plastic wastes

- Thermal cracking, including pyrolysis requires high temperatures (400C+) and gives a mixture of products – gases, liquid products, waxes and tar residue – chemical recycling?
- **Claims around oxo; chemical or biological additives; enzymes/microbes break down – C-C- bonds to small molecules around ambient temperatures that is BIODEGRADED!**

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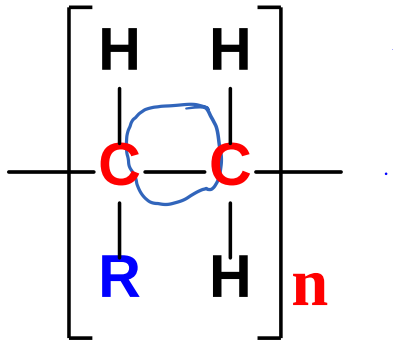
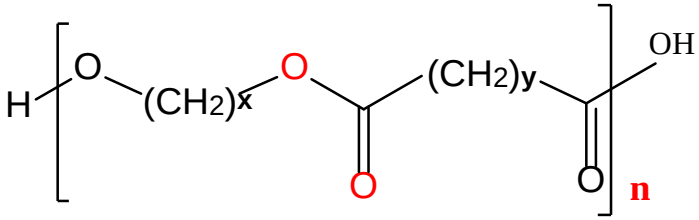
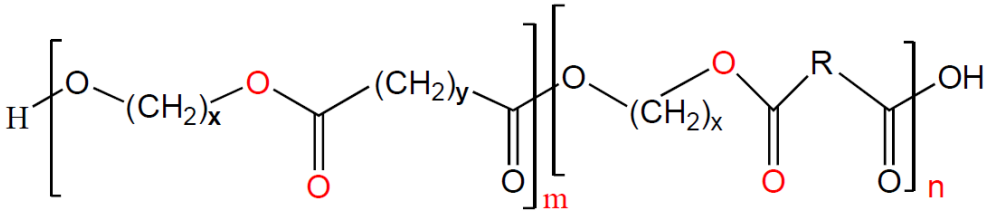
Innovation in Polymer Materials

Ester backbone vs carbon-carbon backbone polymers

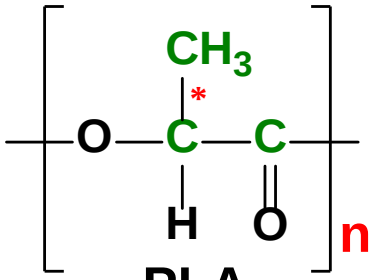




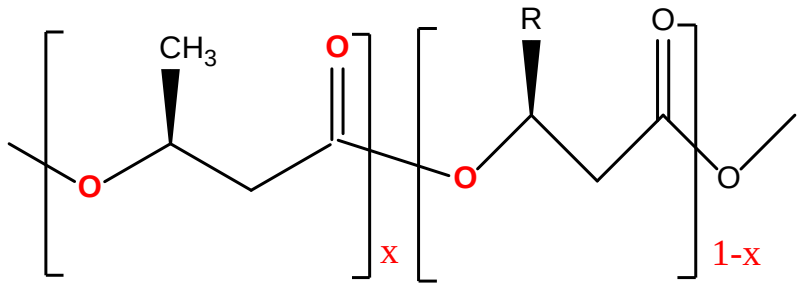
Biobased polyester



Compostable random copolyester



PLA



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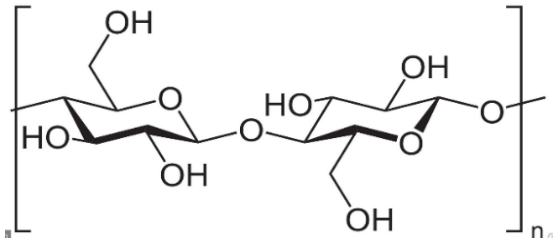
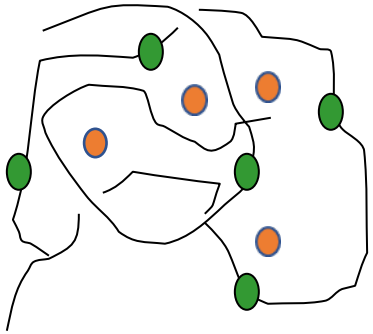


Cellulose

-C-C- backbone polymers contribute to microplastics on leakage to ocean & land

What does “Biodegradable” Mean?

Can microorganisms in the disposal environment (composting, soil, anaerobic digestor) assimilate/utilize the carbon substrate as food source and completely remove it from the environment in a short measurable time?

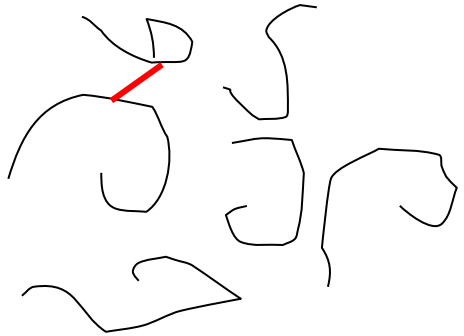


Polymer chains with susceptible linkages

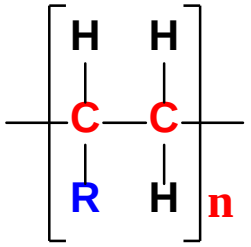
Environment – soil, compost, waste water plant, marine

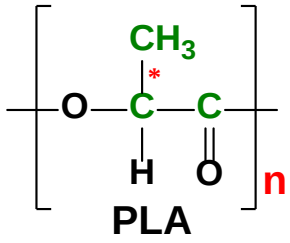
Hydrolytic
Oxidative
Enzymatic

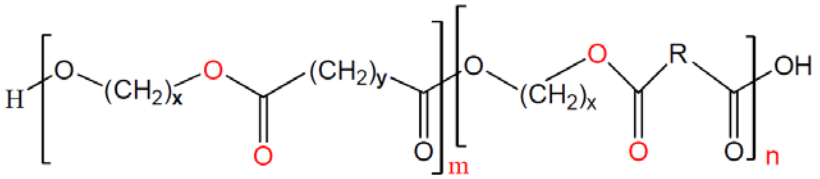
STEP 1



Oligomers & polymer fragments







Compostable random copolyester

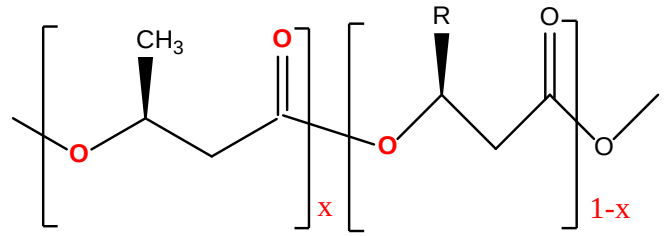
STEP 2

Complete microbial assimilaton

defined time frame, no residu

$CO_2 + H_2O$ + 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



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Additives

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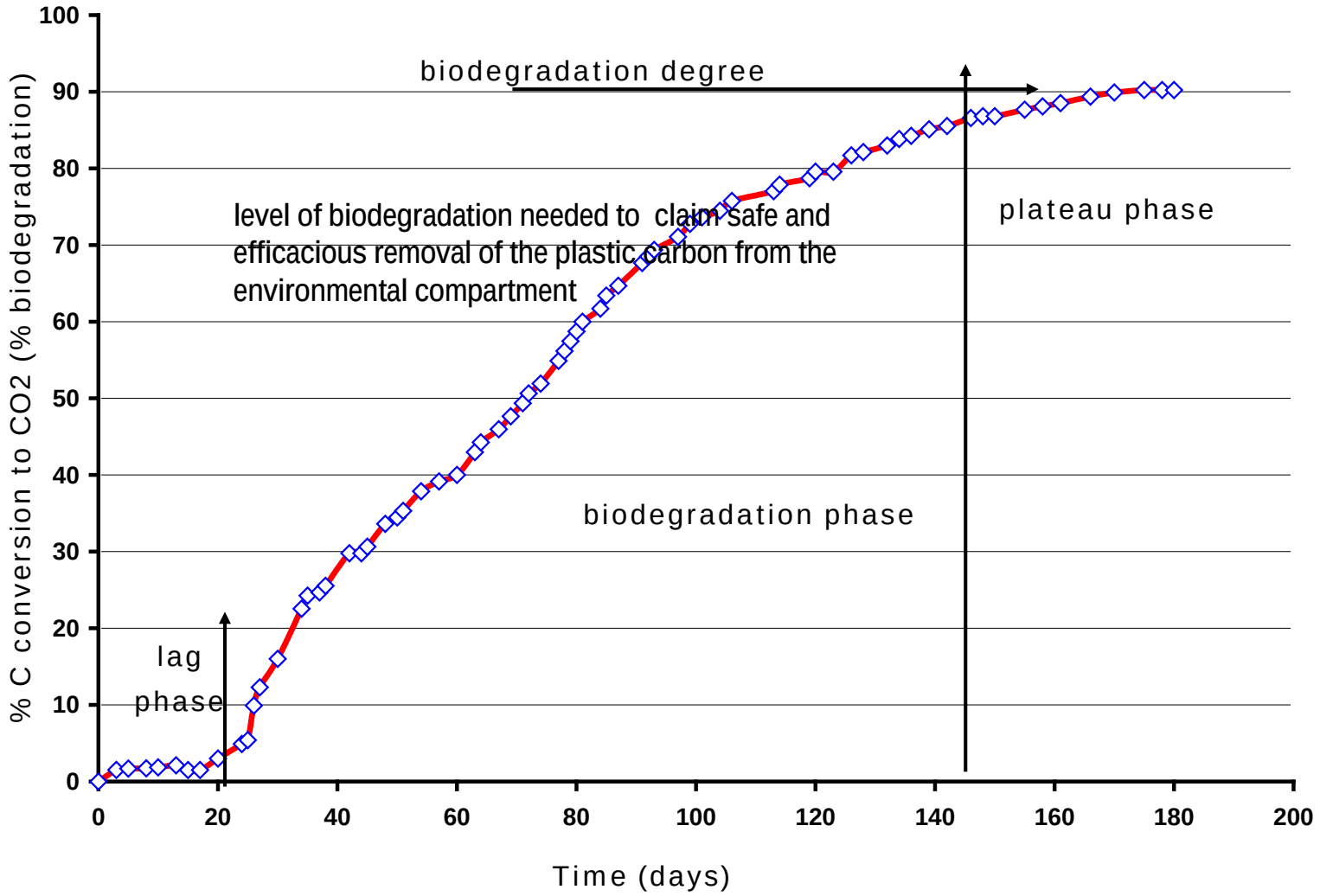

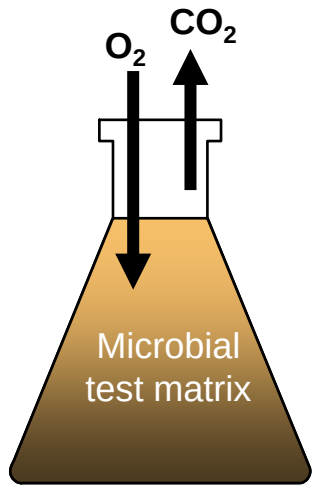

ASTM D5988; ISO 17556 -- Soil biodegradability test method

EN 17033 – soil biodegradability specifications for biodegradable mulch film

COMPOST -- ASTM D5338; ISO 14855; ISO 18606; EN 13432 AS 4736 & 5810

Specification – ASTM D6400, 6868 ; ISO 17088; EN13432

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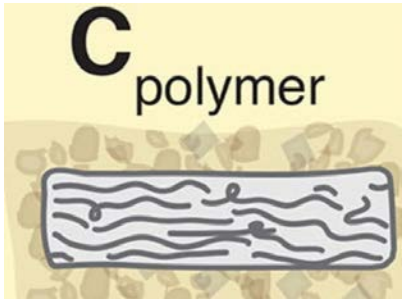
Dos and Do Nots When Assessing the Biodegradation of Plastics

Environ. Sci. Technol.2019, 53, 17, 9967-9969



Molecular structure
polymer backbone linkage
Crystallinity, morphology

+

Characteristics of the receiving biological system/environment

- Moisture content
- **Temperature (depends on the biological environment)**
- **Compost, AD,** soil, land, ocean,
- Defined time

C_{CO_2} **90% +**
$+ C_{microbial\ biomass}$
$(+ C_{remnant\ polymer})$

Lab scale Standard for **complete** biodegradability

ASTM/ISO/EN test methods & **Specifications**

Respirometry analyses may be complemented by tracing the plastic's carbon into microbial biomass through the use of isotopically labeled plastics

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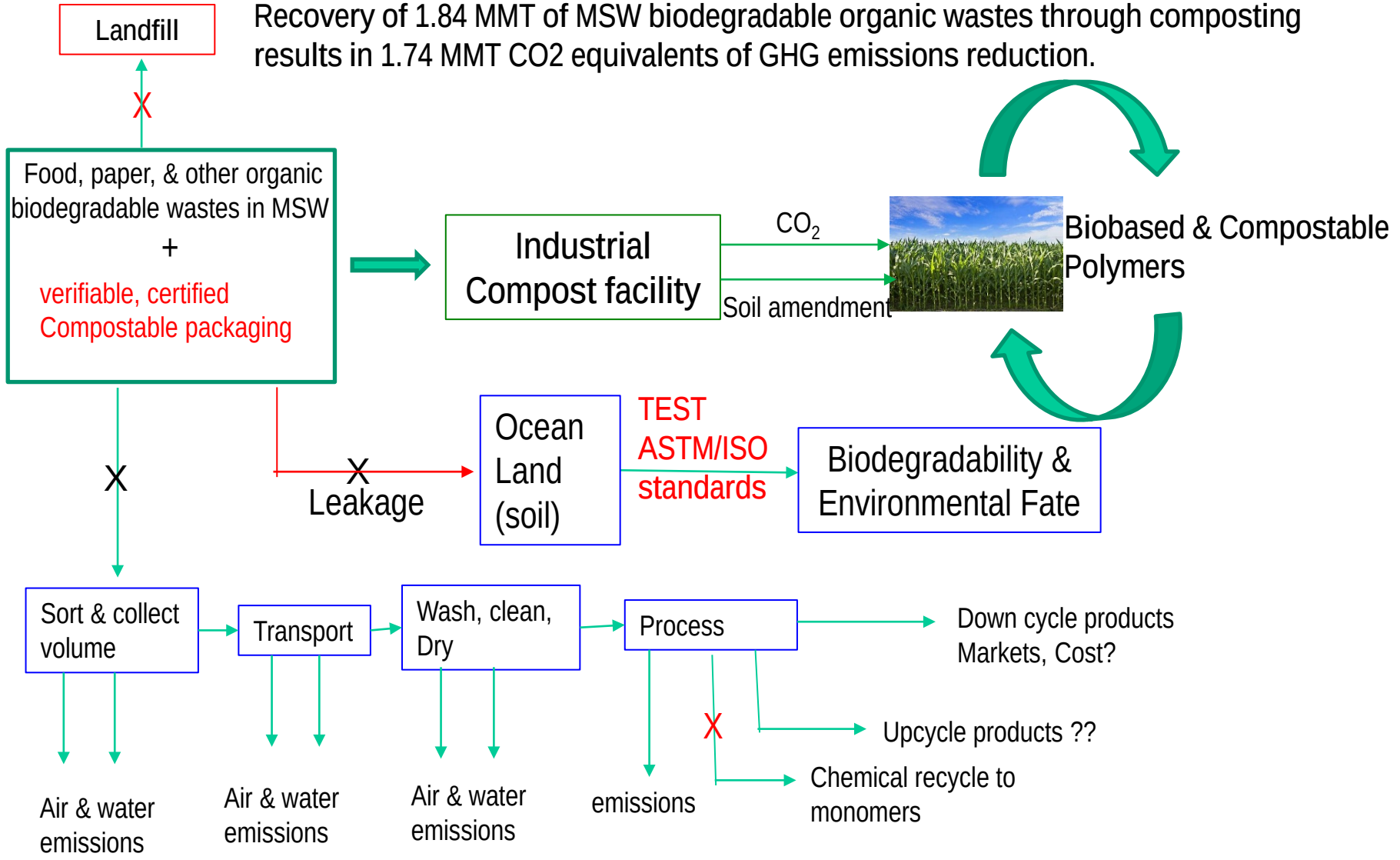
THE MISUSE OF BIODEGRADABILITY AS AN EOL OPTION

- Oxo-biodegradable catalysts and organic/enzyme additives render C-C backbone polymers like PE, PP, PS completely biodegradable or biodegradable in landfills -- abound in the marketplace and press
- 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 Indian meal-moth, can degrade polyethylene”.

Caterpillars & mealworms are NOT the^ next new biodegradable magical solution to plastic waste management? Nor are the oxo-biodegradable or enzyme additives to hydrocarbon plastics

50% + of organic biodegradable wastes goes to landfills or dumps
leads to methane generation – 25X GWP

Recovery of 1.84 MMT of MSW biodegradable organic wastes through composting results in 1.74 MMT CO2 equivalents of GHG emissions reduction.



Recycling vs Composting (Biological/Organic Recycling)

Thank you

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Ramani Narayan, Michigan State University, 2021 – It will be much appreciated