On the subject of Biobased, Biodegradable & Compostable Materials/Plastics



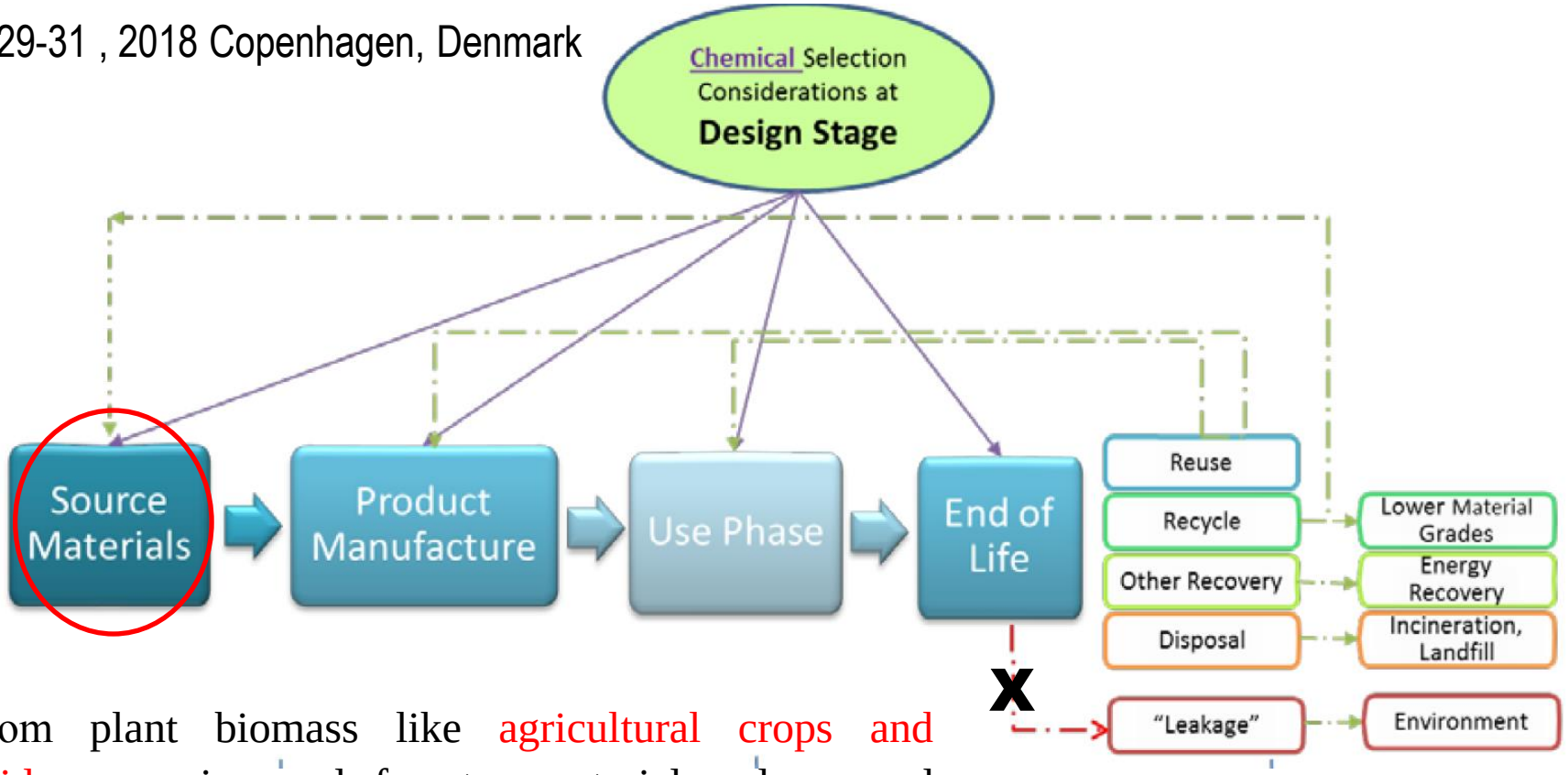
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OECD Global Conference on Environment

Plastics in a Circular Economy - Design of Sustainable Plastics from a Chemicals Perspective

May 29-31 , 2018 Copenhagen, Denmark



"from plant biomass like agricultural crops and residues, marine and forestry materials, algae, and fungi **living in a natural environment in equilibrium with the atmosphere**" – **BIOBASED PLASTICS**

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

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

Narayan

WHY BIOBASED??

What is the value proposition for replacing petro/fossil carbon with biocarbon?

- **Reduced carbon footprint**
- **Food security and creating value for rural agrarian economy**
- **Create "wealth" in rural agriculture through value-added industrial products**

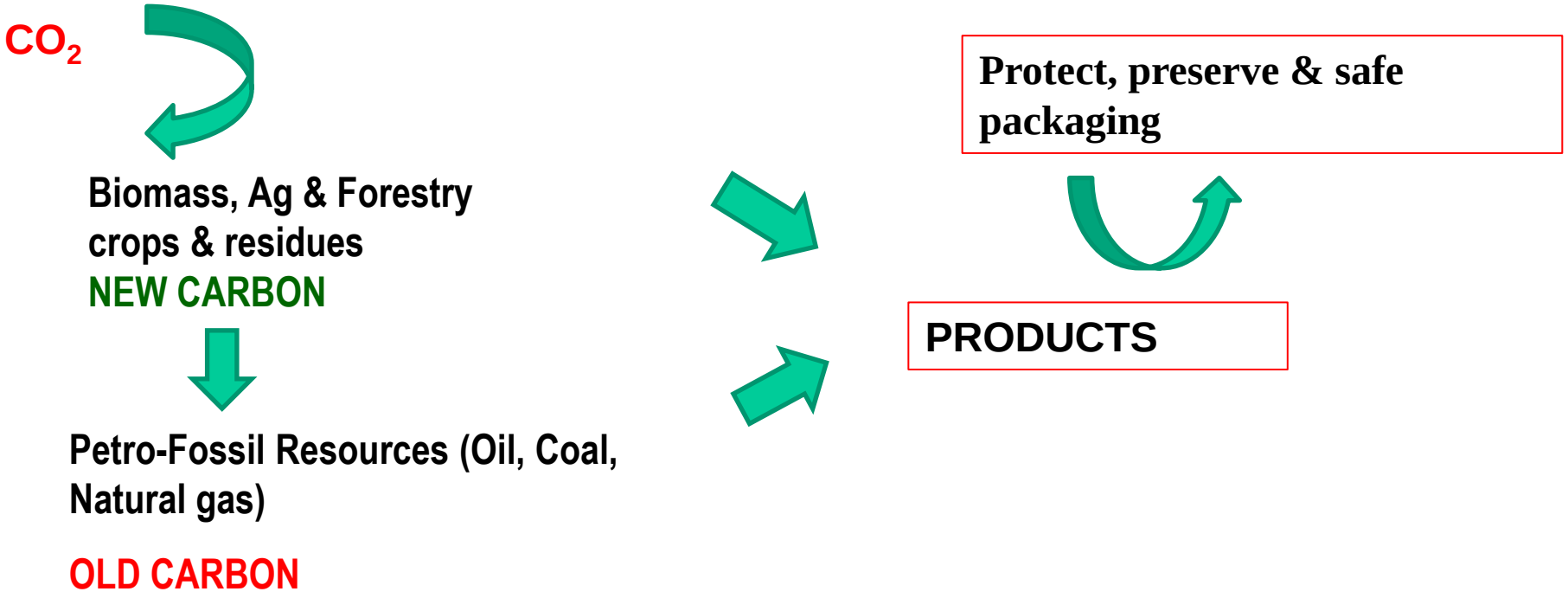
CAUTION:

Not all biobased plastics/materials are "Compostable Organic Recyclable"

Certified Compostable BioPlastics/Materials Are "Organic Recyclable"

Understanding the Value Proposition for biobased vs petro/fossil carbon

Biological Carbon Cycle – the material carbon footprint



^{12}C (98.89%); ^{13}C (1.1%); ^{14}C ($1x10^{-10}$)

$^{14}C/^{12}C$ = ~ 10^{-12} in the atmosphere in equilibrium with plant-biomass living systems

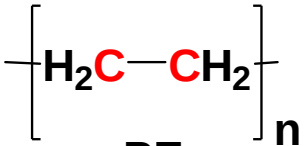
ASTM D6866

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

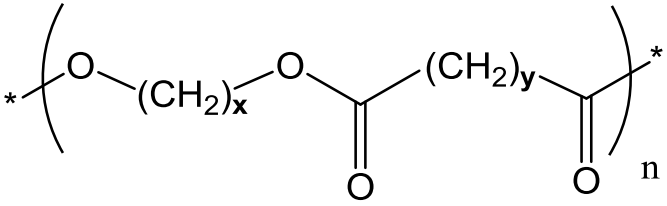
BASICS -- TERMINOLOGY

Biobased plastics and products refers to:

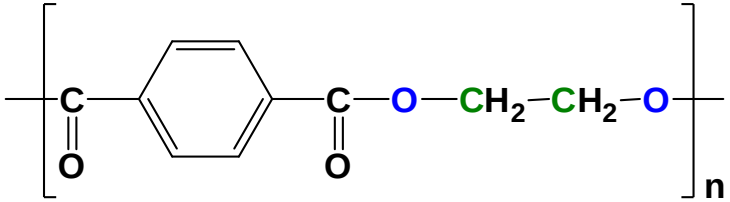
- **Origins of the carbon in the polymer**
- **Plant-biomass feedstock (biobased/renewable) vs petro-fossil feedstock**
- **The "beginning of life" and does not address end-of-life**
- **Biobased products are not necessarily and automatically biodegradable-compostable or recyclable**



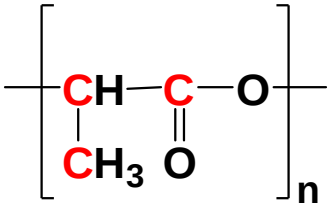
PE



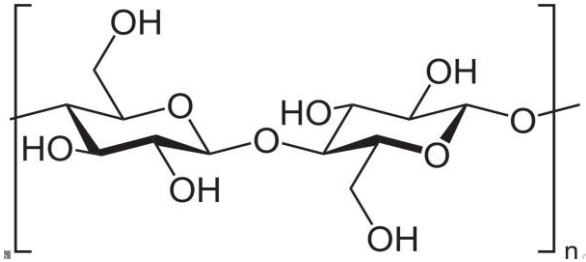
Biobased polyester



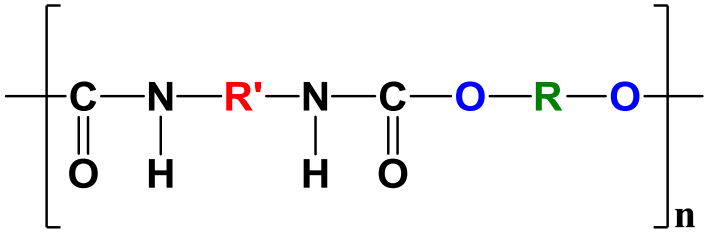
PET



PLA

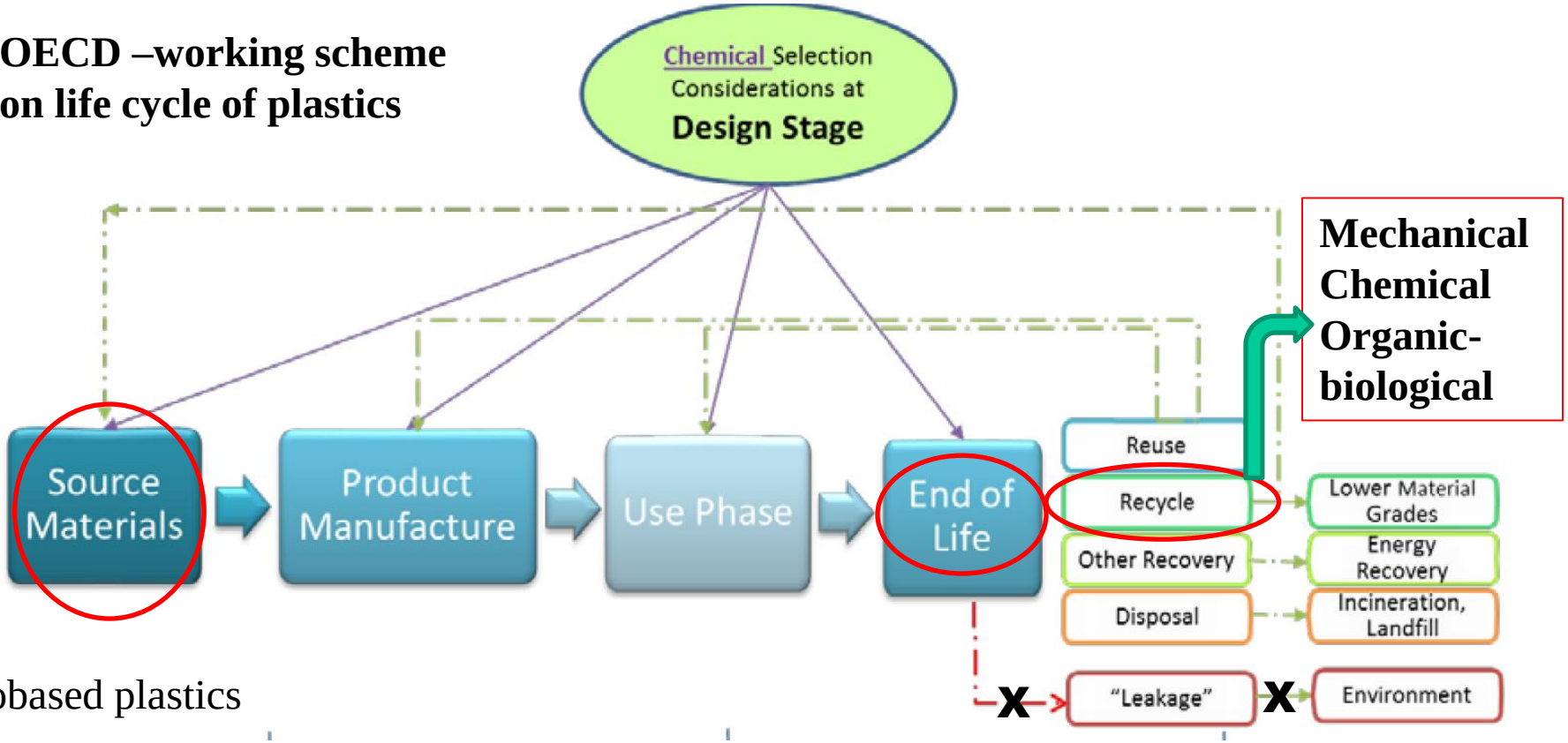


Cellulose



Biobased polyurethane

OECD –working scheme on life cycle of plastics



Biobased plastics

Land, oceans,

biodegradable-compostable plastic representing the "end-of-life".
"Certified Compostable BioPlastic"
ISO series standards – ISO TC61/SC14

ISO 18600 SERIES STANDARDS – ISO TC122 ON PACKAGING

ISO 18606 -- Packaging and the environment — Organic recycling
Emballage et environnement — Récyclage organique

Narayan

Question:

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

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

Biodegradability is a solution to Ocean plastics pollution

Yes

NO

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”

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





What about the Marine/ocean environment?

1. **Marine environment – IS NOT A DISPOSAL ENVIRONMENT and therefore designing for biodegradability in a marine environment IS NOT A SOLUTION**

2. **There may be value(?) to have the property of "biodegrability" engineered into products used in marine environments – in case they are "inadvertently" lost. However, even these biodegradable plastics can persist over a long period of time in many ocean environments and could have negative environmental impacts – SO BIODEGRADABILITY IS NOT A SOLUTION**

What about biodegradability in LANDFILLS & LITTER

--Uncontrolled disposal environments and no closing of the loop is possible – not compatible with the "Circularity Model"

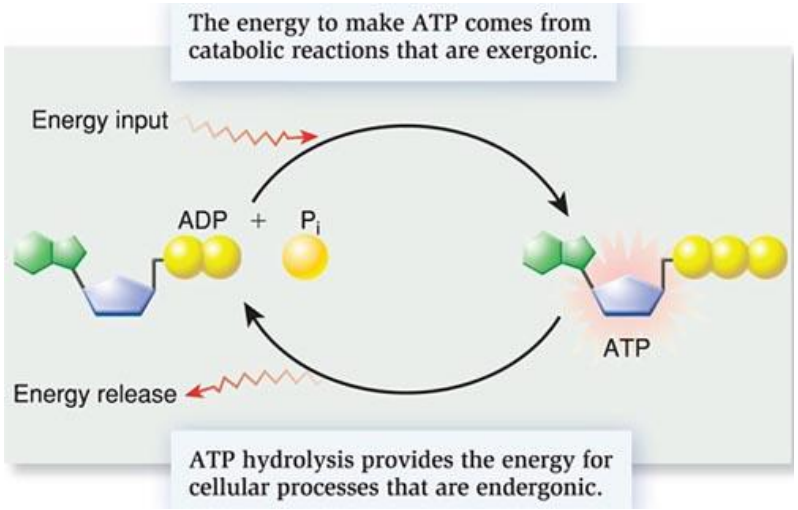
Basics of microbial utilization -- biodegradability

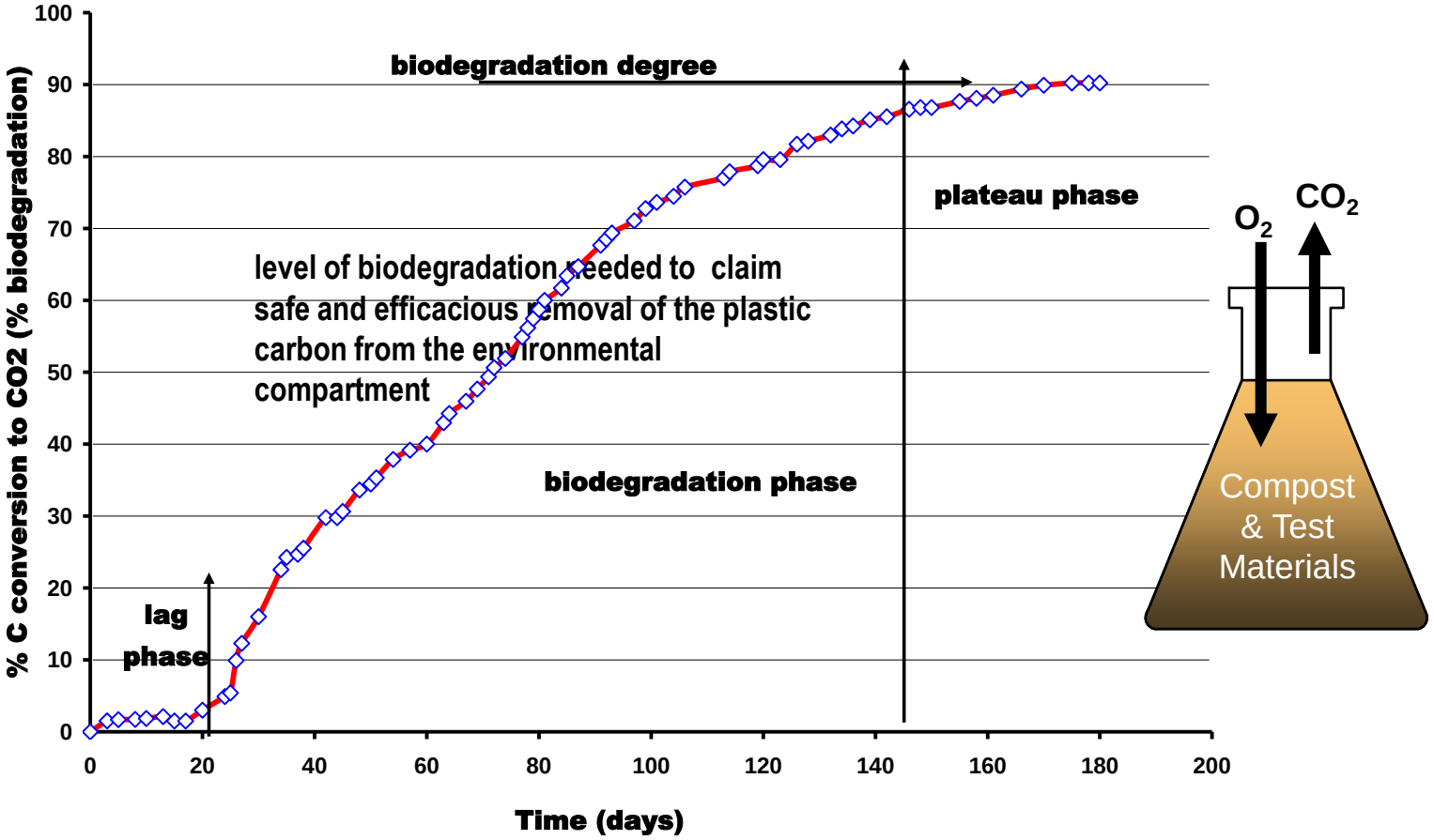
- Microorganisms utilize carbon substrates as “food” to extract chemical energy for their life processes.
- They do so by transporting to the C-substrate inside their cells and:
- Under aerobic conditions, the carbon is biologically oxidized to CO_2 releasing energy that is harnessed by the microorganisms 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

2 lactate ⟶ **CO_2 + CH_4↑**





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

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

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**

http://cen.acs.org/articles/93/web/2015/09/Mealworms-Munch-Polystyrene-Foam.html



Polystyrene—most familiarly produced as foams, including Styrofoam—has given the world cheap, lightweight insulation and containers for taking food to go. But the material biodegrades so slowly that it can sit in a landfill for hundreds of years.

A new finding points to a potential solution: Mealworms will dine on polystyrene foam when they can't get a better meal, converting up to 48% of what they eat into carbon dioxide (*Environ. Sci. Technol.* 2015, DOI: 10.1021/acs.est.5b02661).

Ramani Narayan, an expert in plastic biodegradation at Michigan State University **notes that about half of the polystyrene the mealworms eat is excreted back into the environment in fragments that may not be biodegradable and could carry toxins up the food chain – there is no change in MW as well!!!!**

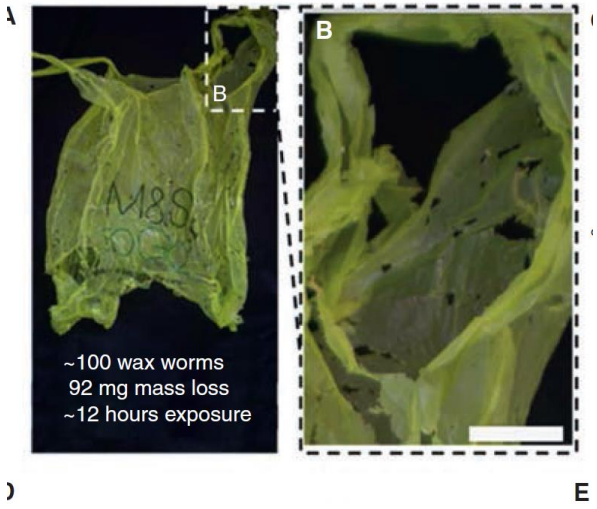
A solution to PS waste????

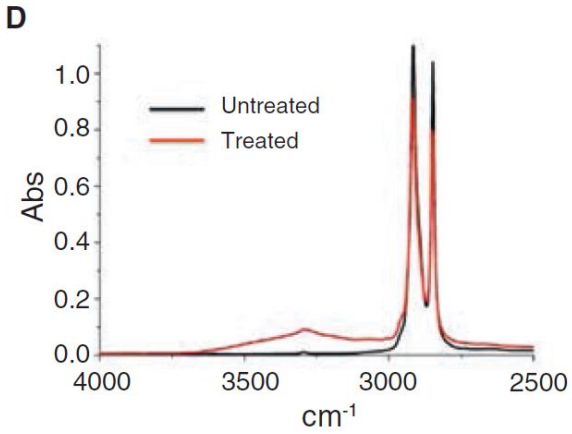
Polyethylene bio-degradation by caterpillars of the wax moth Galleria mellonella

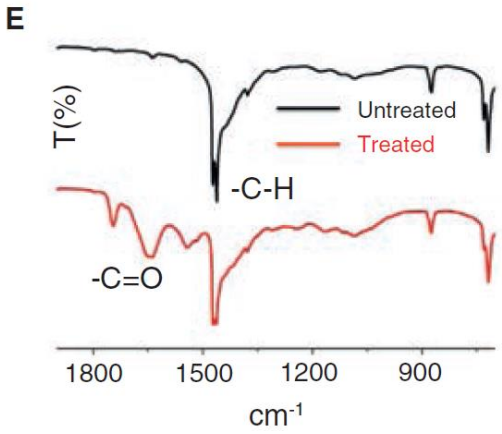
Current Biology *27*, R1–R3, April 3, 2017

"……..Therefore, new solutions for plastic degradation are urgently needed. We report the fast biodegradation of PE by larvae of the wax moth *Galleria mellonella*, producing ethylene glycol.

Beeswax (secreted by the worker honeybees) contains C-C bonds similar to PE, and so breaks it down ???????







Narayan

Biofilm formation and partial **biodegradation** of polystyrene by the actinomycete Rhodococcus ruber -- Biodegradation of polystyrene; Biodegradation (2008) 19:851–858

[Colonization, biofilm formation and **biodegradation** of polyethylene by a strain of Rhodoccocus ruber. Appl Microbiol Biotechnol (2004) 65: 97–104]

This study shows the colonization, biofilm formation and, **presumably, partial biodegradation** of polystyrene by R. ruber (C208)

(about 0.8% weight loss) of the polymer. Alternatively, the limited growth together with the low degradation rate could have resulted from consumption of low molecular impurities of the polymer surface. Similarly, the capacity of R. ruber C208, to form and maintain a stable and biologically active biofilm, for 11 days, on polystyrene may also be due to utilization of low molecular substances in the polymer

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

- Recycling – Depolymerization of PET wastes to TPA & EG using water and inexpensive (safe) catalyst is a economically viable and scalable process as opposed to the hyped up enzyme/microorganisms based schemes