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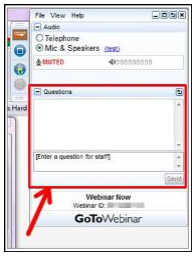

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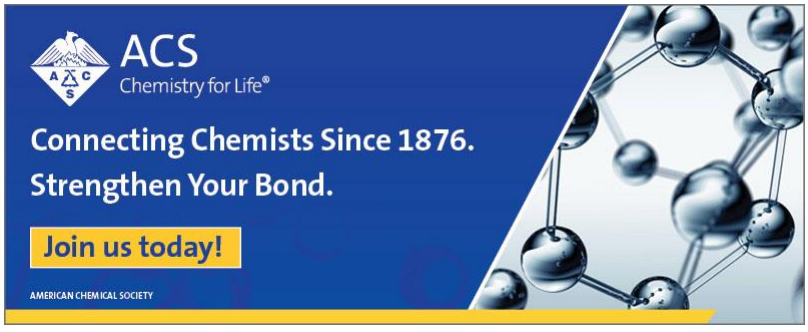

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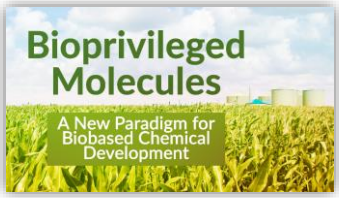
"Excellent presentation with great visuals that explained foundational aspects of petrochemical and biobased processes."

Fan of the Week

Jelte Lanting, Sr. Corporate Scientist,
ACS member for 35 years strong!



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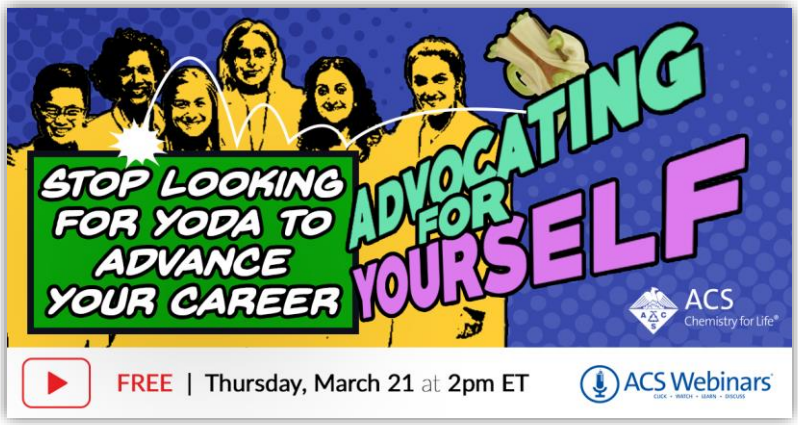

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IS BIODEGRADABILITY A SOLUTION TO PLASTIC WASTE POLLUTION IN OCEAN AND ON LAND?

THIS ACS WEBINAR WILL BEGIN SHORTLY...

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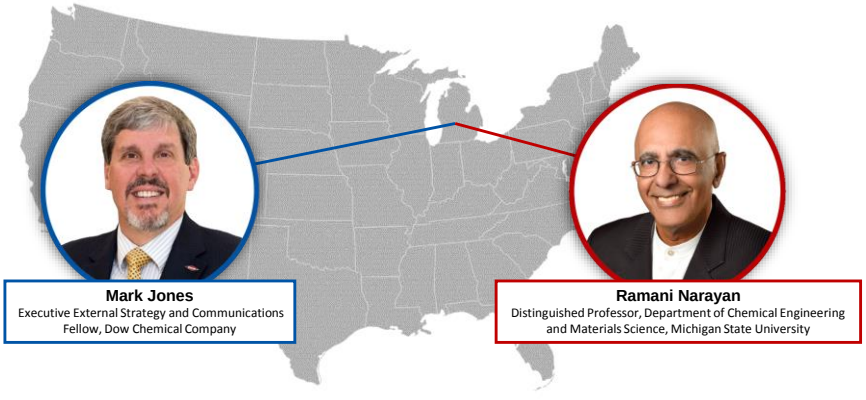
Is Biodegradability a Solution to Plastic Waste Pollution in the Ocean and on Land?



Mark Jones
Executive External Strategy and Communications Fellow, Dow Chemical Company

Ramani Narayan
Distinguished Professor, Department of Chemical Engineering and Materials Science, Michigan State University

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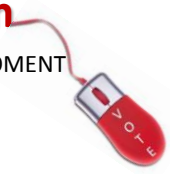
Audience Survey Question

ANSWER THE QUESTION ON BLUE SCREEN IN ONE MOMENT



When you see the term **"biodegradable"** on a plastic product – is your immediate reaction, good…the product will biodegrade / disappear in:

- About a 1 year
- About 2 years
- About 5 years
- Less than 100 years
- Need more information

** If your answer differs from the choices above…tell us in the chat!*

Basics: Terminology

Bioplastics represents two separate and independent concepts:

1. **biobased plastics addresses the "beginning of life" of the plastic**
   - Origins of the carbon in the polymer molecule
   - petro/fossil vs. plant-biomass derived carbon

2. **biodegradable-compostable plastic addresses the "end-of-life".**

   (a) provides for environmentally responsible removal from disposal environment by microorganisms present
   - biological/organic recycling

   (b) Concept of "Certified Compostable BioPlastic"

Biobased Plastics *are* ***NOT*** *necessarily biodegradable/compostable*

Biodegradable-Compostable Plastics *are* ***NOT*** *necessarily Biobased*

BMRG Biobased Material Research Group MICHIGAN STATE UNIVERSITY

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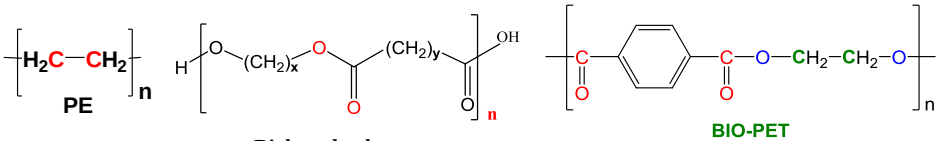
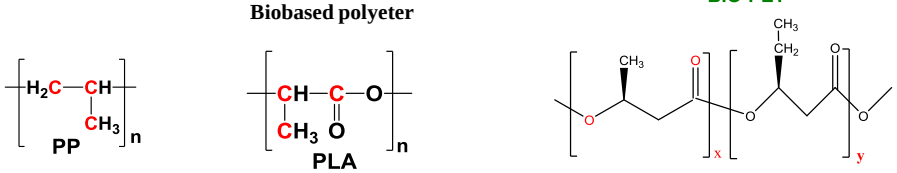
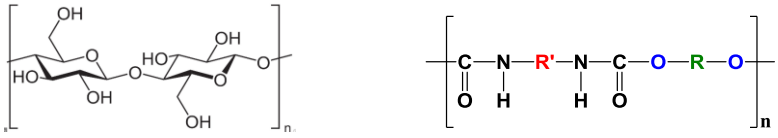
Understanding "Biobased & Biodegradability" at Molecular level







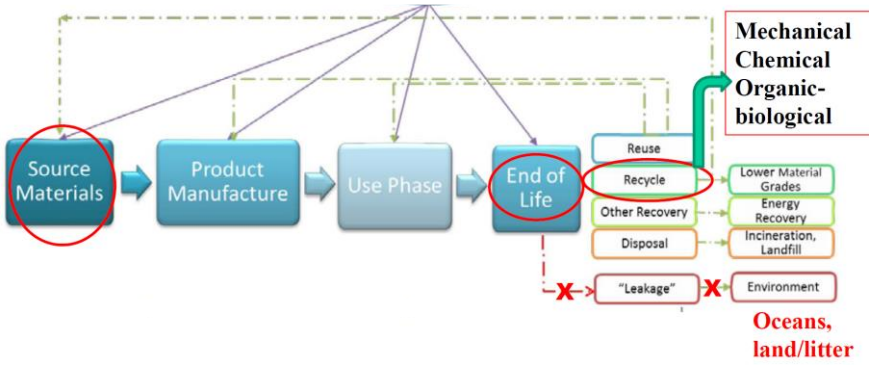
Why Biobased?

What are the benefits of 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: ***Need to still address the issue of end-of-life mechanical, chemical, biological/organic recycling***

Design for End-of-Life Strategy

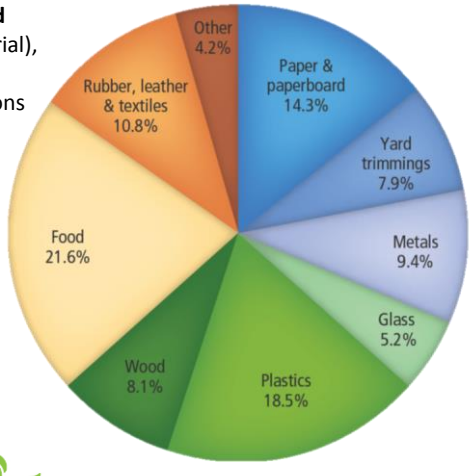


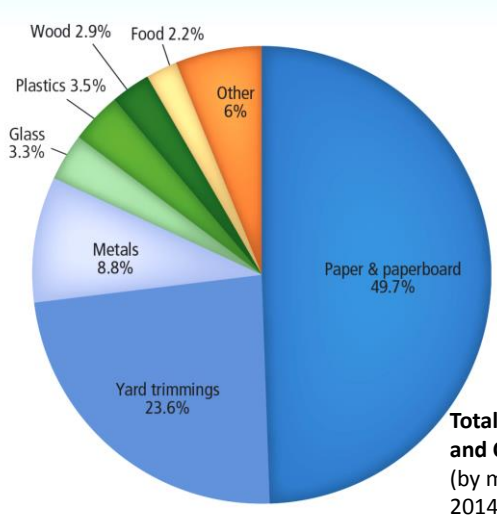
ISO series standards on biodegradability in target disposal systems like composting, AD, soil (mulch film not litter), ocean? **– ISO TC61/SC14 "Certified Compostable BioPlastic"**

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

MSW Numbers (U.S. EPA; 2014 Fact Sheet, November 2016)

Total MSW Landfilled (by material), 2014 136 Million Tons





Total MSW Recycling and Composting (by material), 2014 89 Million Tons

EPA, MSW: Food Waste 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

Other Wastes	Weight recovered million tons	GHG benefits (MMT CO2-eq)
Food, other	1.84	**1.7**
Yard trimmings	20.6	1.04

Recovered through composting EPA warm model , 2013

258.46 million tons waste generated & 52.6% landfilled

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Organic / Bio Waste Management in Emerging Economies

- **Uncontrolled open dumps in the emerging economies of the world**
- **Pockets of anaerobic environments leads to methane generation – 25X GWP**
- **Managed closed loop waste management infrastructures for organic / biowaste will reduce the country's GHG emissions**

At least 80 percent of ocean plastic comes from land-based sources, but the actual number is probably much higher.

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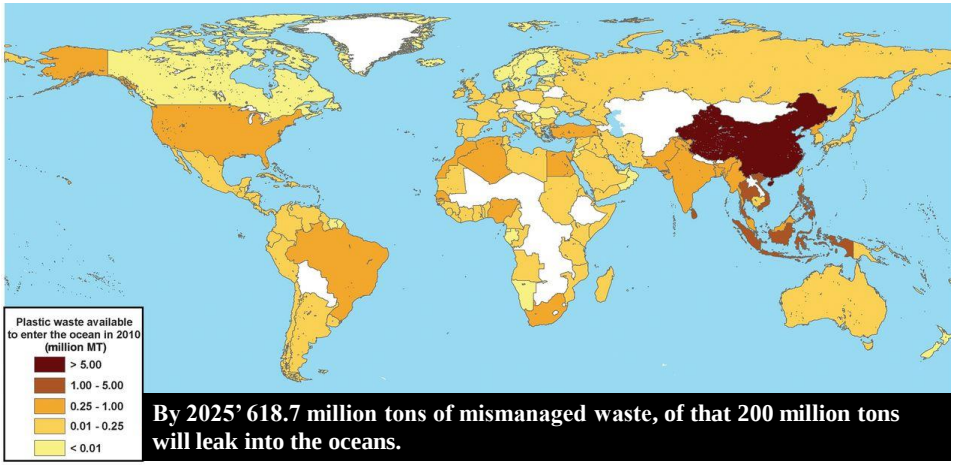
Plastics Ocean Pollution

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.



By 2025' 618.7 million tons of mismanaged waste, of that 200 million tons will leak into the oceans.

Science , Vol 347, Issue 6223 pg. 768, 2015

Rank by mass of mismanaged waste and ocean leakage (25%) – based on population living within 50 km of the coast

		Million Metric Tons	
		Mismanaged waste	Ocean Leakage
1	China	17.81	4.45
2	Indonesia	7.42	1.85
3	Philippines	5.09	1.27
4	Vietnam	4.17	1.04
5	India	2.88	0.72
6	Nigeria	2.48	0.62
7	Bangladesh	2.21	0.55
8	Thailand	2.18	0.54
9	Egypt	1.94	0.48
10	Sri Lanka	1.92	0.48
11	Malaysia	1.77	0.44
12	Pakistan	1.22	0.31

Divert mismanaged waste to collection & recycling

Organics including compostable plastics for recovery by composting, anaerobic digestion

Durable Plastics recovery through mechanical and chemical recycling

Science , Vol 347, Issue 6223 pg. 768, 2015

Certified / Verified Compostable Plastics

Certified/ Verified Compostable Plastics is the **"enabling technology"** to efficiently and efficaciously divert food and other organic wastes from landfills (NA) & open dumps (mismanaged wastes, emerging economies) 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

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Certified / Verified Compostable Plastics

- **Eliminate** problematic or unnecessary plastic packaging and move from single-use to reuse packaging models
- **Innovate** to ensure 100% of plastic packaging can be easily and safely reused, recycled, or composted by 2025
- **Circulate** the plastic produced, by significantly increasing the amounts of plastics reused or recycled and made into packaging or products

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India – Solid Waste Management Rules, 2016

Excerpts:
Schedule II (Rule 16(1), (b), (c), 16(4)

Standards for Composting. The waste processing facilities shall include composting as one of the technologies for processing of biodegradable (organic) waste. In order to prevent pollution from compost plant, the following shall be complied with namely: xxxxxxxxx

Plastics Waste Management (Amendment) Rules, 2018

Each carry bag made from compostable plastics shall bear a label "compostable" and shall conform to the Indian Standard: IS or ISO 17088:2008 titled as Specification for "Compostable Plastics"

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Audience Survey Question

ANSWER THE QUESTION ON BLUE SCREEN IN ONE MOMENT

Is biodegradability a solution to plastics end-of-life…**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 completely
- (D) The product is utilized / assimilated by the microorganisms partially – for example 50% is utilized and the remaining 50% nothing happens or breaks down into small visible (or not) molecules

** If your answer differs from the choices above…tell us in the chat!*

Question

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

Biodegradability in concert with 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."

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Important Lesson

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

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Example: A False and Misleading "Biodegradable" Claim

- BIODEGRADABLE: Yet tough enough to handle kitchen waste, yard trash, lawn clippings and much more. Use our eco-friendly trash bag and help contribute to plastic waste management & environmental conservation.

"Small Garbage Bags, 4 Gallon kitchen trash Bags, Wastebasket Liners Bags **biodegradable trash bags** For Office, Home, Bathroom, Kitchen, 90 counts drawstring trash bags. (Grey)"

https://www.amazon.com/Freedom-Living-Biodegradable-Contractor-Janitorial/dp/B079K8QW3P/ref=sr_1_9?ie=UTF8&qid=1534520822&sr=8-9&keywords=biodegradable+trash+bags

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Example: A False and Misleading "Biodegradable" Claim

P-Life.com.hk

"P-Life Oxo-Biodegradable Plastic Technology"

"The First and Only Oxo-Biodegradable Plastic Additive in the World Certified in SPCR141, Appendix4 in accordance with ASTM D6954."

Chemical Evolution and Research Institute, Japan

5. Results

Samples	Amount of evolved carbon dioxide (g)				Biodegradability (%)				Test periods (Days)
	n-1	n-2	n-3	Mean	n-1	n-2	n-3	Mean	
P-Life dosed LDPE Film	32.2	33.7	32.7	33	27.2	32.5	28.8	29	144
Cellulose	28.0	29.9	28.6	29	78.2	90.2	81.9	83	55

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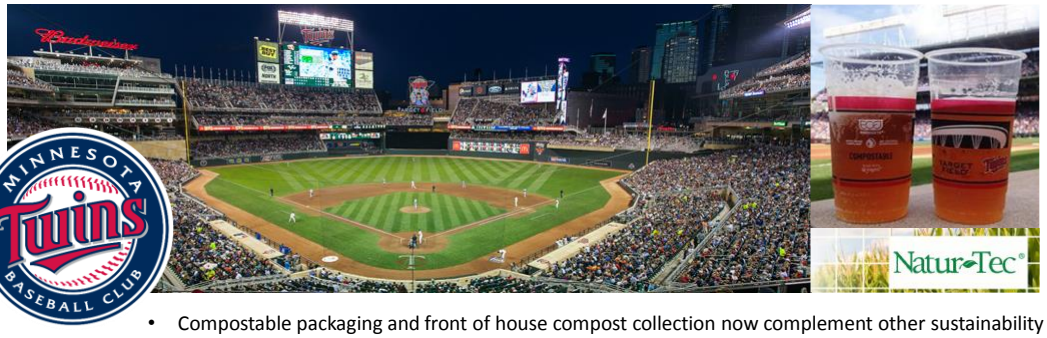
Certified Compostable Waste Bags

- THREE GALLON SIZE: Each of our compost bags has a capacity of 3 gallons!
- 100% COMPOSTABLE: The food waste bags are fully compostable.
- BPI-CERTIFIED: Our compostable bags meet BPI requirements for safety standards.

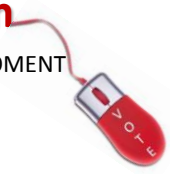
Major League Baseball Park: Systems Approach to Waste Diversion



- 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 always compostable, contamination is kept to a minimum and a **diversion rate of over 90% is within reach**
- Organic stream is sent to a country transfer station that sends material to The Mulch Store and A Full Circle Organics compost facilities.

Audience Survey Question

ANSWER THE QUESTION ON BLUE SCREEN IN ONE MOMENT



Biodegradability is a solution to:

- Ocean plastics pollution
- Litter
- Both
- None

** If your answer differs from the choices above…tell us in the chat!*

What about the Ocean Environment?

1. The 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"**

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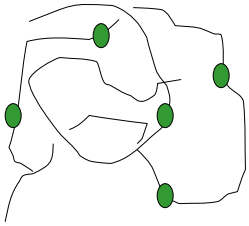
What does Biodegradable Mean?

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?

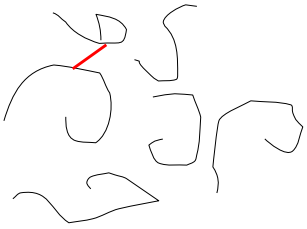


Polymer chains with susceptible linkages

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

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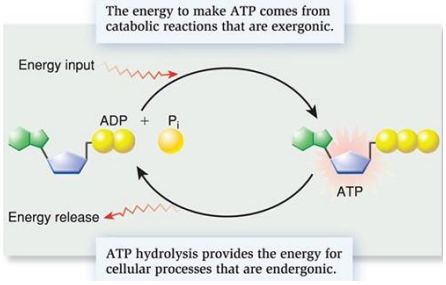
Basics of Microbial Utilization: Biodegradability

- 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↑**



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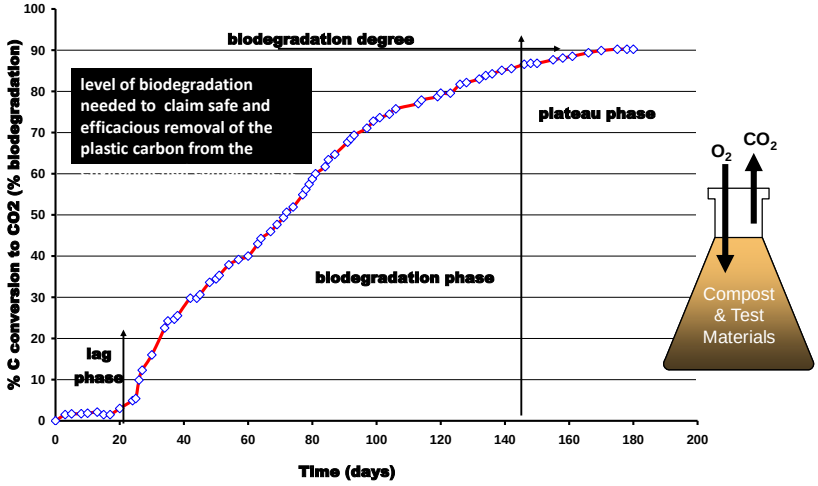
Measuring rate and extent of biodegradability using test plastic as the sole carbon source



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

Compostability Certification and ASTM Specifications

Context

- ASTM (American Society of the International Association for Testing and Materials), founded in 1898, develops voluntary consensus technical standards
- For compostable products: ASTM **D6400** and **D6868** are pass/fail, and have three basic components:

1. **Biodegradation/Mineralization** — In no more than 180 days, 90% of the organic carbon must be utilized by the natural compost microorganisms as measured by the evolution of CO2 from the microbial metabolism when compared to the positive cellulose control.
2. **Disintegration** — After 12 weeks, no more than 10% of a product's original dry weight may remain after sieving on a 2.0-mm sieve.
3. **No adverse impacts** on ability of compost to support plant growth — Heavy metals in the product must be less than 50% of those prescribed for composts; germination rate and plant biomass of the sample composts shall be no less than 90% of the blank composts for 2 different planet species.

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".***

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

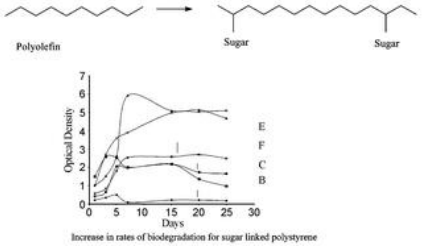
Misuse of Biodegradability Claims

- ***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.



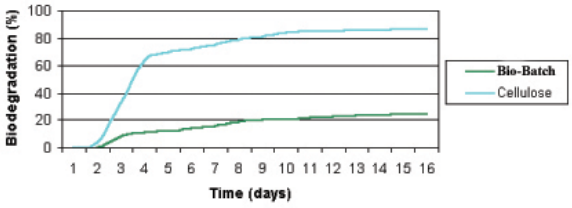
Increase in rates of biodegradation for sugar linked polystyrene

weight loss of only 2-12%,

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

Misleading (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!

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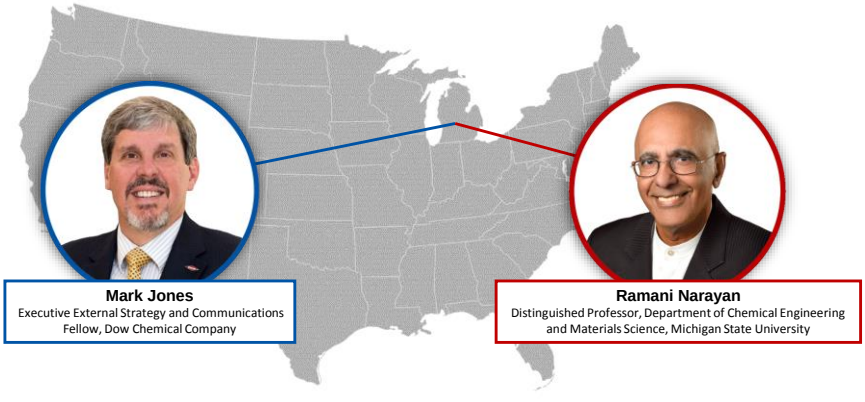

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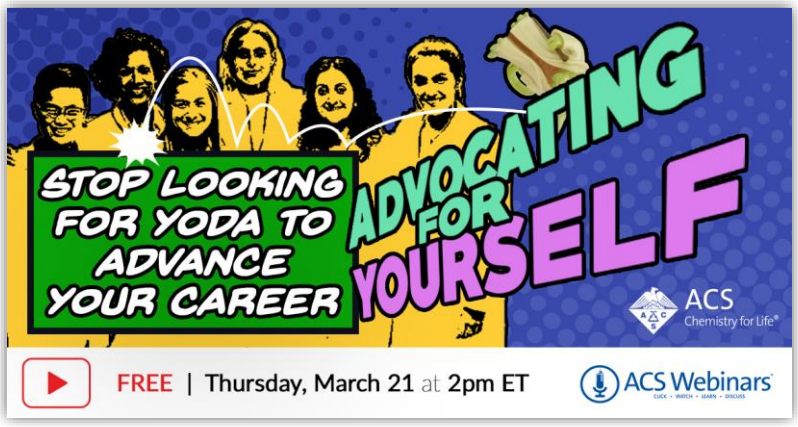

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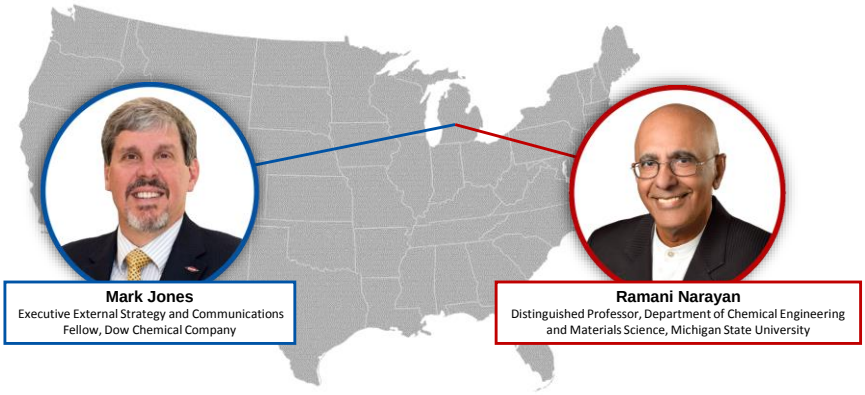

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Final Thoughts

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- 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.**
- 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
- Complete soil biodegradability for agricultural products like mulch films is beneficial and environmentally responsible
- 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.
- Biobased plastics offers the value proposition of carbon footprint reductions, supports rural agrarian economy and in harmony with EMFs **"Circular Economy"** model. **Caution** – need to address "end-of-life"

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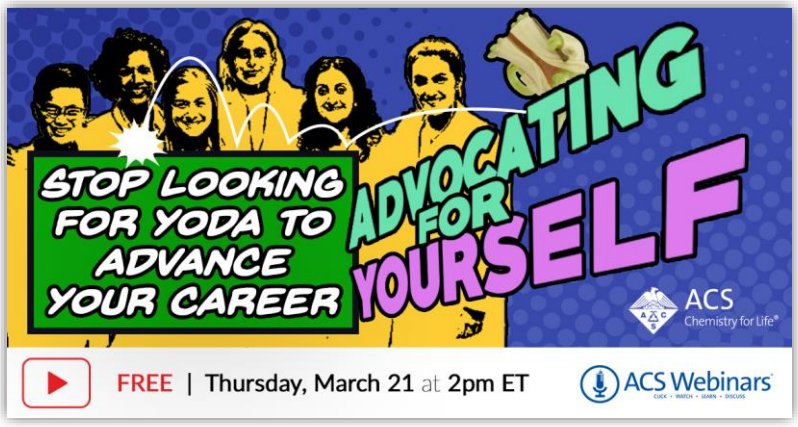

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