Degradation of Biodegradable UV-degradable and Oxodegradable Plastics in Composting, Landfill, and Marine Environments

Golden Gate SPE Technical Fair

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Topics

• Waste Management Issues
• Biodegradable, Oxodegradable, and UV-degradable Plastic Materials
• Biodegradation Testing Results
  – Compost Environment
    • Vacaville In-vessel Food Waste
    • Laboratory ASTM D-6400 Compost Anaerobic Digestion
  – Marine Water Environment
  – Landfill Environment
• Conclusions and Recommendations
• Questions
Waste Management Issues

• 2004 Waste Characterization Study*
  – Total waste in landfills for California was 40.2 million tons in 2003.
  • Plastic waste was 9.5% of the weight of the landfill and 17% of the volume of the landfill. (Approximately the same % over last 20 years)

* http://www.ciwmb.ca.gov/Publications/?pubid=1097

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<th>M Tons</th>
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*100.00%  40.20
Plastic Waste

Reference: http://www.algalita.org

- Land
  - LA River

- Ocean
  - Pacific Gyre
    - Dead zone off of CA has floating debris, the size of Texas. Floating plastic is in the debris.
    - 80% of ocean debris has a land source.
  - Debris is eaten by birds, mammals, and fish causing injury and death.

Dead Albatross

Photo courtesy of Ron Prendergast, Melbourne Zoo
Waste Management Options

• Incineration
  – Waste to energy conversion has advantages and disadvantages.
    • Potential air pollution is a major disadvantage.

• Landfill
  – Total waste in landfills for California increases 2 to 3% (or ~1.5 million tons) every year.
  – 50 to 60% of solid waste in California from 2003 is organic based and can be converted to compost.

• Composting
  – Aerobic windrow method is most common and yields compost from green yard waste in 90 – 120 days.
  – Aerobic in-vessel method yields compost in 60 – 90 days.

• Anaerobic digestion
  – Converts organic waste to methane gas
Sustainable Strategies

• Organizations can benefit by being more sustainable.
• Sustainability can be defined as
  – Reducing the amount of energy used,
  – Reducing the amount of petroleum products used, and
  – Reducing the amount of waste generated at a facility, including solid waste, liquid waste, CO₂ waste, etc.
• Waste can be diverted (reduced) by
  – Eliminating waste at its source.
  – Recycling materials
    • Metal, glass, paper, plastic
  – Composting organic-based materials
    • Food waste, wood products, biodegradable plastics
• Use of bio-based materials can reduce the dependency on petroleum, reduce the amount of energy used, and reduce the plastic waste.
Biobased and Biodegradable Plastics

• Biobased plastics are plastics made from natural materials
  – Some are biodegradable: PLA, PHA, Starch based plastics, Sugar cane, cellulose, some Cereplast products. ([http://bpiworld.org/](http://bpiworld.org/))
  – Some are not:
    • Polyethylene made from sugar cane,
    • Polyethylene with starch additives: 30% biobased,
    • Confusion exists on which plastic products are environmentally friendly and which plastic products are not good for the environment.

• CA Integrated Waste Management Board (CIWMB) initiated research funding to better explain the true biodegradability of most common biodegradable plastics.
  – Evaluate what happens to the biodegradable plastic products in commercial composting, in anaerobic landfill, and in marine environments.
  – Can biodegradable plastics solve the landfill and marine waste problems?
What does Biodegradable Mean?

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

Biodegradation: Only if all fragmented residues consumed by microorganisms as a food & energy source
Define time and environment (disposal system)

Reference: Dr. Ramani Narayan, Michigan State University, www.msu.edu/~narayan
Biodegradable versus Degradable Plastics

• Biodegradable and Compostable plastics are safe for the environment
  – Bio-degraded by microorganisms in soil, compost, or marine environments.
  – Made from corn, potato, polylactic acid, sugar cane, or polyester.
  – Compostable
    • Regulated by ASTM standards- will degrade in compost environment in less than 180-days.
    • Does not leave any fragments in residue, does not have any heavy metals or toxins, and will support plant life.

• Oxodegradable plastics are not biodegradable and may cause environmental problems
  – Fragmented into smaller pieces by sunlight, oxygen, or microbes.
    • Oxodegradable, photo-degradable, starch-polyethylene plastics.
  – Can cause environmental problems.
    • Results in small fragments that can pollute compost, landfill, marine.
    • Does not degrade as fast as compostable plastics, may leave small fragments in soil, may not have toxic residuals, may not support plant life.
Bio-based versus Petroleum-based Materials

• Bio-based plastics can be biodegradable or NOT.
  – Plastics produced from natural materials- Biodegradable- YES
    • Corn: Nature Works PLA for rigid products (similar to Polystyrene), PHA and corn starch flexible products (similar to LDPE)
    • Sugar Cane and Bamboo- Rigid products
    • Ecoflex trash bags are produced from petroleum materials and are Biodegradable- YES
  – Natural fibers- YES
    • Kenaf, Sisal, Jute, Hemp, Flax
  – Resins produced from natural and synthetic materials- NOT biodegradable.
    • Corn oil, soy protein, etc. replaces alcohol in polymerization.
      – Polyurethanes and polyesters

• Disposal plan for compostable plastics: should be composted and not sent to landfill and not recycled.
• Disposal plan for petroleum-based plastics: should be recycled or sent to landfill.
Truly Biodegradable Plastics

- Biodegradable Products certified by BPI World
  - Useful for food service items to help organizations be more sustainable and divert waste from landfill to composting.
  - PLA cups, salad containers, and utensils.
  - Plates
  - Trash bags

Reference: http://www.ecoproducts.com/
Products Tested

• Compostable (Certified by Biodegradable Polymers Institute- BPI)
  – PLA Cups, forks, spoons, knives, clamshell containers, lids, and straws
  – Biobag, Ecoflex, PHA Bags, Husky Eco Guard biodegradable trash bags
  – Sugar Cane Bagasse plates, bowls, and containers.

• Oxo-Degradable (NOT certified by Biodegradable Polymers Institute- BPI)
  – Natural Value Oxo-degradable Ecosafe Trash Bags
  – Oxo Biodegradable Eco-friendly plastic bag
  – UV-degradable plastic bags and soda can rings

• Control
  – LDPE plastic trash bag
  – Kraft paper
  – Cellulose filter paper

• Other Compostable plastics that are available that were not tested (http://www.bpiworld.org/)
  – Approved products: bags, food services, packaging, roll products
  – Approved resins: Biograde, Cereplast, Ecobras, Gracebio, Agroresins, Plastarch
Commercial Compost Environment

• What happens to plastics in compost facilities?
  – Site: Nor-Cal Vacaville In-vessel Food Waste
• Materials (Purchased at stores or on-line)
  – Compostable: PLA lids, Biobag trash bags, Ecoflex Polyester bags, PHA Bags, Husky Eco Guard biodegradable bags, Sugar Cane Bagasse lids.
  – Oxodegradable: Ecosafe Trash Bags, Eco-friendly plastic bag, UV-degradable plastic bags
  – Controls: LDPE plastic trash bag and Kraft paper
• Tests
  – Monitored visual disintegration and biodegradation of products after 30, 60, 90, and 180 day test intervals.
  – Monitored temperature of air and compost, moisture percentage, pH, compost maturity, and % solids.
NorCal Vacaville In-vessel Compost Pictures

In-vessel composting with polyethylene cover

Compost pile after 30 days
NorCal In-vessel Compost Pictures

1. Corn starch plastic bag
2. Mirel PHA plastic bag
3. Ecoflex plastic bag
4. Oxodegradable plastic bag
5. Oxodegradable plastic bag
6. UV-polyethylene plastic bag
NorCal Vacaville  In-vessel Compost Pictures

PLA lids  Sugar can lids  Kraft paper

Husky Eco-Guard plastic bag  LDPE plastic bags
NorCal Vacaville In-vessel Compost Pictures

Burlap sacks filled with samples

Compost pile after 30 days
NorCal Vacaville In-vessel Food Waste Compost

- Results

- 30 days (In-vessel) September to October 2006
  - Some degradation: Food waste and PLA cups, forks, spoons, knives, clamshell containers, lids, and straws, Sugar cane plates and lids, and Corn starch trash bags.
NorCal In-vessel Compost Pictures - 30 days

Corn starch plastic bag  Mirel PHA plastic bag  Ecoflex plastic bag

Oxodegradable plastic bag  Oxodegradable plastic bag  UV-polyethylene plastic bag
NorCal Vacaville after 30 days Pictures

PLA lids
Sugar can lids
Kraft paper
Husky Eco-Guard plastic bag
LDPE plastic bags
NorCal Vacaville Static Pile Compost

Compost temperature: 140 +/- 5°F  Moisture: 40-45%
NorCal Vacaville In-vessel Food Waste Compost

• Results

– 30 days (In-vessel)
  • Some degradation: Food waste and PLA cups, forks, spoons, knives, clamshell containers, lids, and straws, Sugar cane plates and lids, and Biobag trash bags.

– 180 days: (Windrow)
  • No degradation: Oxo-biodegradable and UV degradable plastic trash bags; LDPE control.
  • Some high degradation: Sugar cane lids and Kraft paper control
  • Full degradation: no visible fragments- PHA bag, Ecoflex bag, PLA lids, Husky Eco-Guard plastic trash bags.
NorCal Vacaville In-vessel Food Waste Compost Pictures (180 days)

(Note: Kraft paper fragments were wet and had low strength and obvious lignin degradation)

Static Compost pile

Kraft paper

Sugar cane lids

Compost temperature: 140 +/- 5°F  Moisture: 40-45%
Vacaville In-vessel Food Waste Compost Pictures (180 days)

Oxodegradable bag  UV-degradable

LDPE stretch film control
NorCal Vacaville In-vessel Compost and Vacaville Static Pile Compost (180 days)

Oxodegradable bags 180 days

Note: Oxo-degradable plastics are not designed to biodegrade in a compost environment.
Vacaville In-vessel Food Waste Compost

• Results
  – 30 days (In-vessel)
  – 60 days: (Windrow)
  – 180 days: (Windrow) March 2007

  • No degradation: Oxo-biodegradable and UV degradable plastic trash bags; LDPE control.
  • Some degradation: Sugar cane lids and Kraft paper control
  • Full degradation: no visible fragments- PHA bag, Ecoflex bag, PLA lids, Biobag trash bags.
Laboratory Biodegradation Compost

- **Materials**
  - Kraft paper, Cellulose filter paper and low density polyethylene controls
  - Oxo-biodegradable: Ecosafe and Eco-friendly plastic trash bags
  - Compostable biodegradable products, i.e., PLA straws, Biobag trash bags, PHA bags, Ecoflex bags
  - Biodegradable: Stalk Market sugarcane lids.

- **Method (Per ASTM D-5338)**
  - Redesigned of laboratory procedure with
    - Improve the accuracy of CO$_2$ measurement with LabView data acquisition system and computer control.
    - CO$_2$ scrubber, 50 psi pressure canister to supply moist air.
  - 45-day test interval

- **Tests**
  - Monitored carbon dioxide and oxygen levels for 45-days.
  - Phytoxicity tests with tomato seeds.
  - Regulated metals testing for Cd, Pb, and Co.
Specification Standard for Biodegradable/Compostable Plastics

• ASTM D6400 identified 3 criteria

Mineralization (D5338):
  • Conversion to carbon dioxide, water & biomass via microbial assimilation
  • 60% of carbon conversion to CO2 for homopolymer & 90% carbon conversion to CO2 for block, segmented copolymers, and blends, including addition of low MW additives
  • Same rate as natural materials Leaves, paper, grass & food scraps
  • Time -- 180 days or less; if radiolabeled polymer is used 365 days or less

Disintegration
  • <10% of test material on 2mm sieve

Safety
  • No impacts on plants, using OECD Guide 208
  • Regulated (heavy) metals less than 50% of EPA (USA, Canada) prescribed threshold

Reference: Dr. Ramani Narayan, Michigan State University, www.msu.edu/~narayan
% C conversion to CO2

biodegradation curve

biodegradation degree 65%

lag-phase
degradation phase
plateau phase

O2 → CO2

Compost & Test Materials

Reference: Dr. Ramani Narayan, Michigan State University, www.msu.edu/~narayan
Testing Methods

• Laboratory Environment
  – ASTM 5338 Standards

Sampling process schematic.

42 Jars at 50°C for 45 days

Wet air void of CO₂

Biogas

CO₂ or O₂ Detector

Computer
Laboratory Biodegradation Compost Pictures
## 45-day Degradation Results

<table>
<thead>
<tr>
<th>Material</th>
<th>Biodegradation Conversion %</th>
<th>Degradation rate g/day</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellulose positive control</td>
<td>71.99</td>
<td>0.016</td>
<td>Pass</td>
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<tr>
<td>Kraft paper positive control</td>
<td>61.91</td>
<td>0.014</td>
<td>Pass</td>
</tr>
<tr>
<td>PHA bag</td>
<td>64.03</td>
<td>0.014</td>
<td>Pass</td>
</tr>
<tr>
<td>PLA straws</td>
<td>61.22</td>
<td>0.014</td>
<td>Pass</td>
</tr>
<tr>
<td>Sugar cane plate</td>
<td>61.12</td>
<td>0.014</td>
<td>Pass</td>
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<tr>
<td>Biobag trash bag</td>
<td>60.47</td>
<td>0.013</td>
<td>Pass</td>
</tr>
<tr>
<td>Ecoflex bag</td>
<td>60.14</td>
<td>0.013</td>
<td>Pass</td>
</tr>
<tr>
<td>Blank compost control</td>
<td>1.69</td>
<td>0.000</td>
<td>----</td>
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<tr>
<td>Polyethylene negative control</td>
<td>1.70</td>
<td>0.000</td>
<td>Fail</td>
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<tr>
<td>Oxodegradable bag</td>
<td>2.19</td>
<td>0.000</td>
<td>Fail</td>
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</tbody>
</table>
Laboratory Marine Testing

- **Materials**
  - Kraft paper and low density polyethylene controls
  - Oxo-biodegradable: Ecosafe and Eco-friendly plastic trash bags
  - Biodegradable: Biodegradable products, i.e., PLA straws, Biobag trash bags, PHA bags, Ecoflex bags, and Stalk Market sugarcane lids.

- **Methods (Based on ASTM D-6692 standards)**
  - Place 30 mg of sample in jar with 100 ml of ocean water at 30°C.
    - Ocean water was retrieved in July 2007 from Big Sur beach in California.
    - Water was held at 5°C until testing.

- **Tests**
  - At 30 days weigh samples after 24 hours of drying in air and then replace water with fresh 100 ml and place in oven.
  - At 60 days weigh samples after 24 hours of drying in air and then add fresh 40 ml and place in oven.
  - At 90 days weigh samples after 24 hours of drying in air.
Laboratory Marine Testing Pictures

Experimental Set-up

Oxo-degradable 90 days

PHA 30 days

PHA 90 days
Laboratory Marine Testing

• Results
  – 30 days in water
    • No degradation: Oxo-biodegradable and UV degradable plastic trash bags; LDPE control, Kraft paper control; PLA lids; Sugar cane lids; Biobag trash bags; Ecoflex bag, UV degradable soda rings.
    • Some degradation: PHA bag - 36% disintegration
  – 60 days in water
    • No degradation: Oxo-biodegradable and UV degradable plastic trash bags; LDPE control, Kraft paper control; PLA lids; Sugar cane lids; Biobag trash bags; Ecoflex bag, UV degradable soda rings.
    • Some degradation: PHA bag - 60% disintegration
  – 90 days:
    • No degradation: Oxo-biodegradable and UV degradable plastic trash bags; LDPE control, Kraft paper control; PLA lids; Sugar cane lids; Biobag trash bags; Ecoflex bag, UV degradable soda rings.
    • Some degradation: PHA bag - 70% disintegration
Landfill Environment

• What happens to organic materials in landfill environment?

• Old Landfills: Inactive landfill- no oxygen and no water results in no organic microbes
  – Airless tomb for materials

• Results
  – Materials are not designed to biodegrade in landfill.
Waste Management Issues

- 2004 Waste Characterization Study*
  - Landfill is
    - 30% organic
    - 21% paper
    - 10% lumber
  - Landfill is not designed to biodegrade organic materials due to lack of oxygen and moisture and temperature.

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Description of Typical Inactive Landfill

• Dry tomb landfill approach per US EPA (1991)
  – Used to recover biogas (methane and carbon dioxide)
    • Liner- compacted clay underlayer with overlying flexible membrane liner (FML), or thin plastic sheeting.
    • Leachate collection and removal system (LCRS)
      – Drainage system located above the liner to collect and remove all leachate.
      – Leachate can contaminate groundwater.
    • Cover- low permeability covering placed over landfill once it is filled. Cover keeps atmospheric and run-off moisture out of landfill.
    • Groundwater monitoring wells- notifies leakages
  – Note produces very little methane or carbon dioxide due to lack of oxygen, low temperature, and lack of water. Thus, very little biodegradation.
Degradation in Typical Landfill

Reference: http://environment.about.com/od/recycling/a/biodegradable.htm

• Most landfills are totally anaerobic
  – Very little air due to compacted so tightly,
  – Very little biodegradation occurs.

• “Typically in landfills, there’s not much dirt, very little oxygen, and few if any microorganisms,” says green consumer advocate and author Debra Lynn Dadd.

• University of Arizona researchers uncovered
  – still-recognizable 25-year-old hot dogs, corncobs and grapes in landfills, as well as 50-year-old newspapers that were still readable.
Description of Typical Inactive Landfill

- Dry tomb landfill approach per US EPA (1991)
  - Used for Municipal solid waste (MSW) management
    - Liner- compacted clay underlayer with overlying flexible membrane liner (FML), or thin plastic sheeting.
    - Leachate collection and removal system (LCRS)
      - Drainage system located above the liner to collect and remove all leachate.
    - Cover- low permeability covering placed over landfill once it is filled. Cover keeps atmospheric and run-off moisture out of landfill.
    - Groundwater monitoring wells- notifies leakages
    - Other systems used to enhance ability to manage leachate.
Degradation in Typical Landfill


• Typical degradation time for materials

• Results:
  – Plastic bags, 10 – 20 years
  – Diapers 10 – 20 years
  – Plastic Bottles 70 - 450 years
  – Plastic six-pack holder rings, 450 years
  – Styrofoam cup, non-biodegradable
  – Leather shoes, 25 – 40 years
  – Nylon fabric, 30 – 40 years
  – Tin cans 50 - 100 years
  – Aluminum cans 200 - 500 years
Degradation in Active Landfill


• Typical degradation time for materials

• Results: note duration are estimates:
  – Banana peel, 2 – 10 days
  – Orange peels, 1 month
  – Sugarcane Pulp Products, 1 - 2 months
  – Cotton rags, 1 – 5 months
  – Paper, 2 – 5 months
  – Rope, 3 – 14 months
  – Wool socks, 1 – 5 years
  – Cigarette filters, 1 – 12 years
  – Tetrapaks (plastic composite milk cartons), 5 years
Active Landfill Environment

- New Landfill methods: Active management by adding oxygen, moisture, and microbes to enhance waste degradation and control leachate.
- Biodegradation is increased with new system.
- Biogas is removed as used as a fuel source.
- Not very common due to high costs.
- Degradation of organics in anaerobic landfills creates carbon dioxide, methane and other organic compounds. (Very little information is available)
  - Carbon dioxide and methane are recovered and sold
  - Methane is 22 times more dangerous to ozone create than carbon dioxide.
Conclusions

• Compostable materials degrade under commercial compost environments.
  – PLA container, Sugar cane lids, PHA bag, Ecoflex bag, and Husky Eco-Guard plastic bag completely degraded in commercial
    • Green yard waste,
    • In-vessel compost systems, and
    • Laboratory conditions
• Oxodegradable and UV-degradable plastics do NOT biodegrade in compost environments.
• Oxodegradable and UV-degradable plastics may fragment into smaller pieces compost environments, but may also create more SEVERE environmental consequences.
Conclusions

• PHA degraded significantly in marine environment.
• Sugar cane degraded slightly in marine environment.
• PLA straws, Ecoflex bag, and Biobag did not disintegrate in marine environment.
• Oxodegradable and UV-degradable plastics do NOT biodegrade in marine environment.
• Biodegradable plastics may biodegrade slightly in landfill environments, but may not biodegrade.
• Oxodegradable and UV-degradable plastics will NOT biodegrade in landfill environment.
Recommendations

• The research work will help the expanded use of compostable plastic materials for selected applications.

• The compostable materials should be certified as compostable by BPI and included in procurement standards.

• The compostable plastic materials should perform well in simple applications, e.g., food service ware, lawn and leaf refuse bags that have dry contents, grocery bags, department store bags, and pet bag products.
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• The
Questions?