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Carbon foot print assessment,
a workable model for environmental improvement

MICHIGAN STATE UNIVERSITY

January 5, 2010

Workable model for environmental assessment of "biopreferred" products

RN

- **Using bio (carbon) content analysis for reporting carbon footprint reductions**
- **End-of-life strategies -- complete biodegradability within the context of a disposal system (composting, anaerobic digestion); recycling energy recovery**

Presentation at the USDA Biopreferred Public meeting, Washington DC, January 5, 2010

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MEETING GOAL & AGENDA

- Focus on the life cycle assessment (LCA) of BioPreferred designated items. Input from this meeting will provide valuable insights and direction as USDA's BioPreferred program works to **assess new procedures and guidelines for evaluating the sustainability of biobased products**
- The need for supplementary information about a product's environmental aspects (attributes) under the pending "USDA Certified Biobased Product" labeling program

Question being addressed is:

- **What is the environmental "value proposition" for biobased products and how does one calculate and report on it?**
  - **Using bio (carbon) content analysis (ASTM D6866) to document verifiable CO_2 reductions**
  - **End-of-life strategies -- complete biodegradability within the context of disposal system (composting, anaerobic digestion); chemical recycling, energy recovery**
  - **LCA is a valuable tool but can be abused and misused to derail biopreferred products**

Framing the question – What is this all about?

- **Managing Carbon is the burning issue of the day!**
  - **What are you doing to reduce your products (company's) carbon footprint?**
  - **What are you doing to reduce your products environmental footprint?**

Carbon footprint reductions = CO_2 reductions = global warming/climate change issues

CARBON FOOTPRINT VALUE PROPOSITION

Value proposition for biobased products

Using bio/renewable feedstock (as opposed to petro/fossil feedstock) to manufacture plastics and other products reduces product's carbon footprint by:

- **Reducing heat trapping CO_2 emissions**
- **Minimizing global warming/climate change problems**

Value proposition for biodegradable products

- **Using biodegradability as an end-of-life option to remove single use short life disposable plastics/products from the environmental compartment completely and in a safe and efficacious manner via microbial assimilation (microbial food chain)**
  - **Disposal environment (like composting, anaerobic digestor, marine**
  - **Time to complete biodegradation**
    - **90%+ of the carbon substrate should be completely assimilated by the microorganisms present in the disposal within a short time period (one year or less)**
  - **Degradable, partial biodegradable not acceptable – serious health and environmental consequences**

Terminology:

BIOBASED (BIOMASS OR RENEWABLE BASED)

Biobased (Biomass or Renewable) based Materials **– Organic material/s containing in whole or part biogenic carbon (carbon from biological sources)**

- **Refers to using biomass or crop feedstock (New carbon) vs petroleum or fossil feedstock (Old carbon)**
- **Reducing carbon footprint**

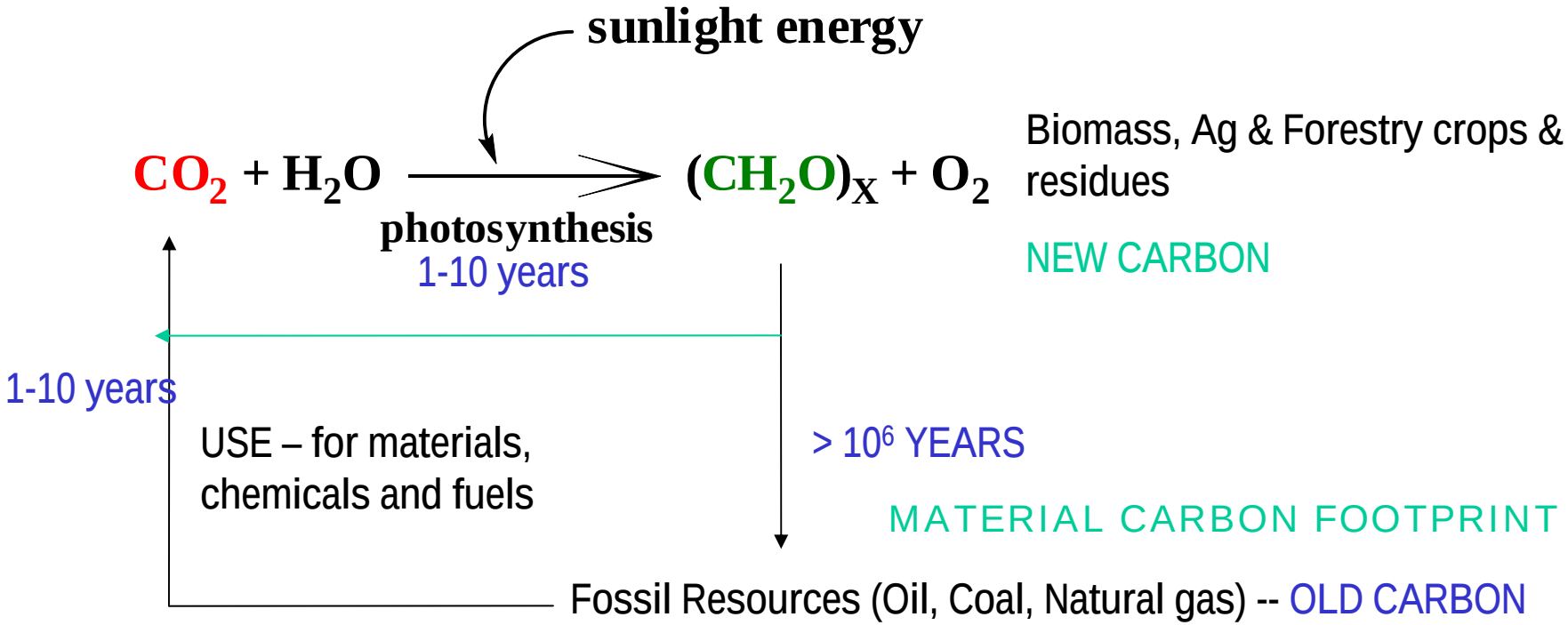
Organic Material/s **-- material(s) containing carbon based compound(s) in which the carbon is attached to other carbon atom(s), hydrogen, oxygen, or other elements in a chain, ring, or three dimensional structures (IUPAC nomenclature)**

Bio(carbon) Content **-- The bio content is based on the amount of biogenic carbon present, and defined as the amount of bio *carbon* in the plastic as fraction weight (mass) or percent weight (mass) of the total organic carbon in the plastic. (ASTM D6866)**

% bio or biobased content = Bio (organic) carbon/total (organic carbon) * 100

ASTM D6866 – Standard Test Methods for Determining the Biobased Content of Solid, Liquid, and Gaseous Samples Using Radiocarbon Analysis

Terminology: Fundamentals, & Rationale



Rate and time scales of CO_2 utilization is in balance using bio/renewable feedstocks (1-10 years) as opposed to using fossil feedstocks

CO_2 sequestration

Sunlight energy

$$CO_2 + H_2O \longrightarrow (CH_2O)_x + O_2$$

photoautotrophs -- algae, plants, and some bacteria fix inorganic carbon to **organic matter** (carbohydrates) using sunlight as the energy

Oceans

$$2CO_2 + H_2O \longrightarrow 2HCO_3^- \xrightarrow{Ca^{2+}} 2CaCO3\downarrow$$

Produce shells and other body parts by organisms such as coral, clams, oysters, some protozoa, some algae – when they die, they become carbonate rich deposits and over very long period of time physically and chemically altered into sedimentary rocks

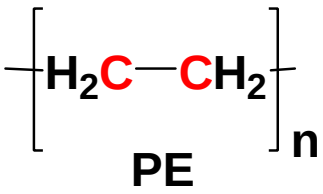
Chemoautotrophs – uses energy from oxidizing some inorganic substances in their surroundings – certain bacteria and archae

Carbon footprint classification – global warming potential (GWP) impact category

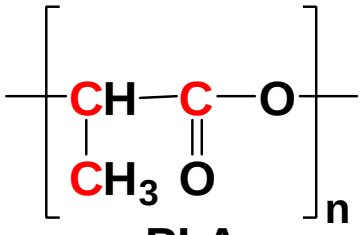
- **MATERIAL CARBON FOOTPRINT**
  - Document using biobased carbon content analysis ASTM D6866
- **PROCESS CARBON FOOTPRINT**
  - Document using LCA methodology – ASTM 7075 or ISO 1440 standards
- Environmental Footprint
  - All impact categories not just carbon/global warming category

Carbon footprint contributions divided into:

- **MATERIAL/PRODUCT CARBON FOOTPRINT – Impact of replacing the petro/fossil carbon with bio carbon – the origins of the carbon**



PE



PLA

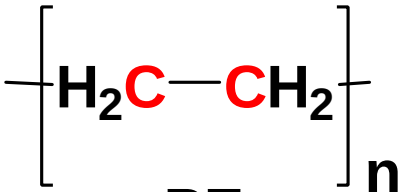
- **PROCESS CARBON FOOTPRINT – Impact of converting feedstock to product**
  - **Carbon emissions from all stages of unit operations to convert the selected C-feedstock (petro or bio/renewable) to product**
  - **Material (Carbon) balance – life cycle inventory analysis (LCI)**
  - **Impact on the environment of the carbon emissions – global warming potential (GWP)**

- **Environmental Footprint (LCA methodology)**
  - **Carbon footprint + other impact footprint categories like human health, ozone depletion, eutrophication, acidification, photochemical smog, etc**

Material Carbon Footprint

What is the impact of the material/product's carbon footprint on the environment ?

- **100 Kg of polyethylene will result in net ?? Kg of CO_2 released into the atmosphere**
- **100 Kg of bio polyethylene will result in net ?? Kg of CO_2 released into the atmosphere**
- **100 Kg of polyester (PET – assume C2 glycol and C8 terephthalic acid will results in net ?? Kg CO_2 release into the atmosphere**
- **100 Kg of 100% biobased PET will result in net ?? Kg release into the atmosphere**



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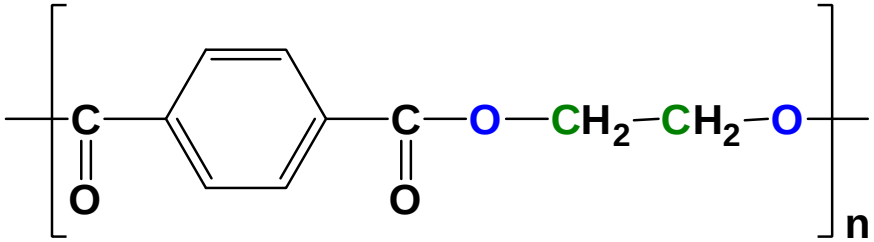
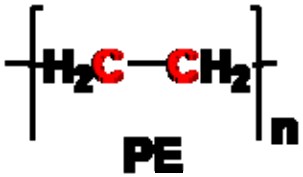
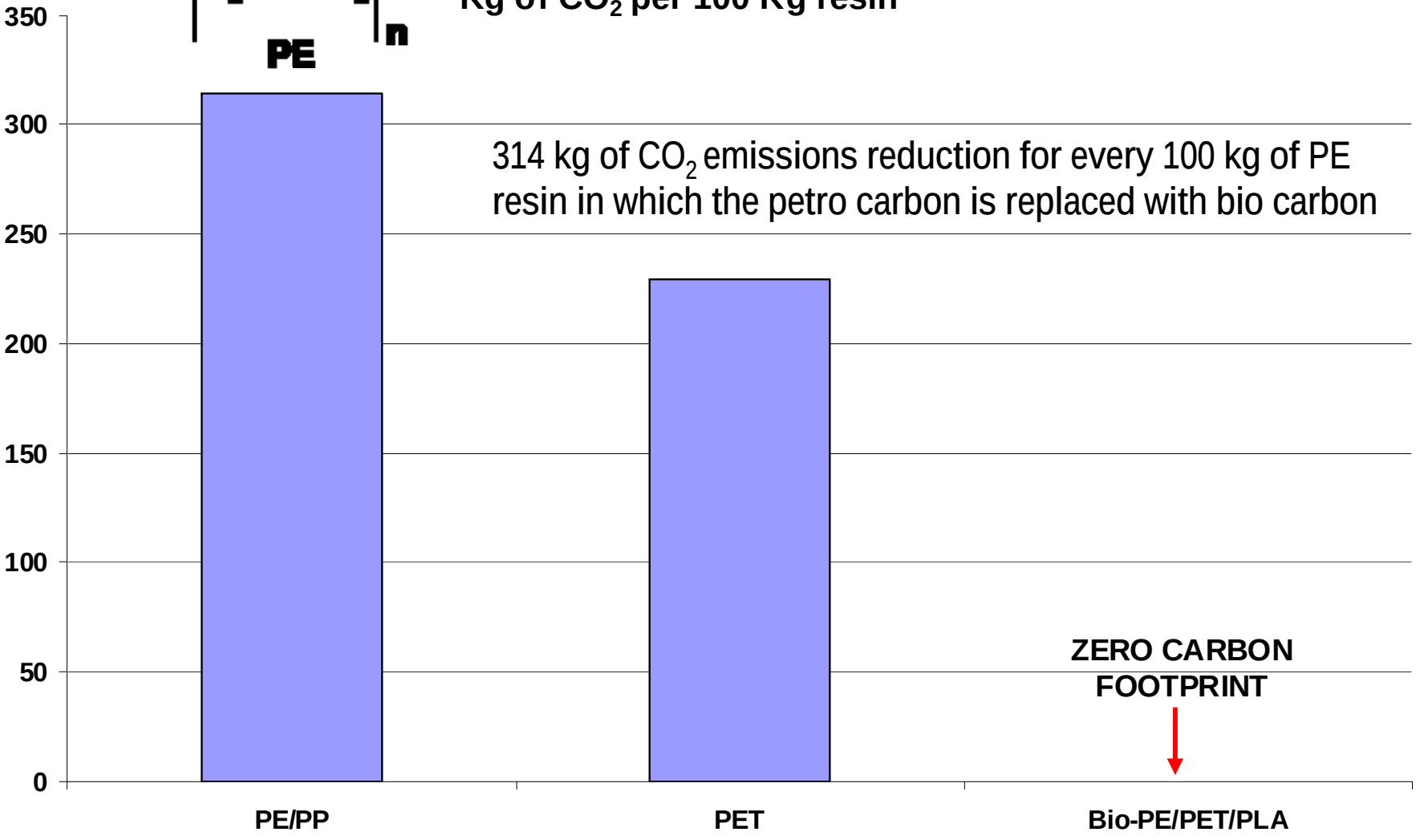


PET

Material Carbon Footprint



Kg of CO_2 per 100 Kg resin



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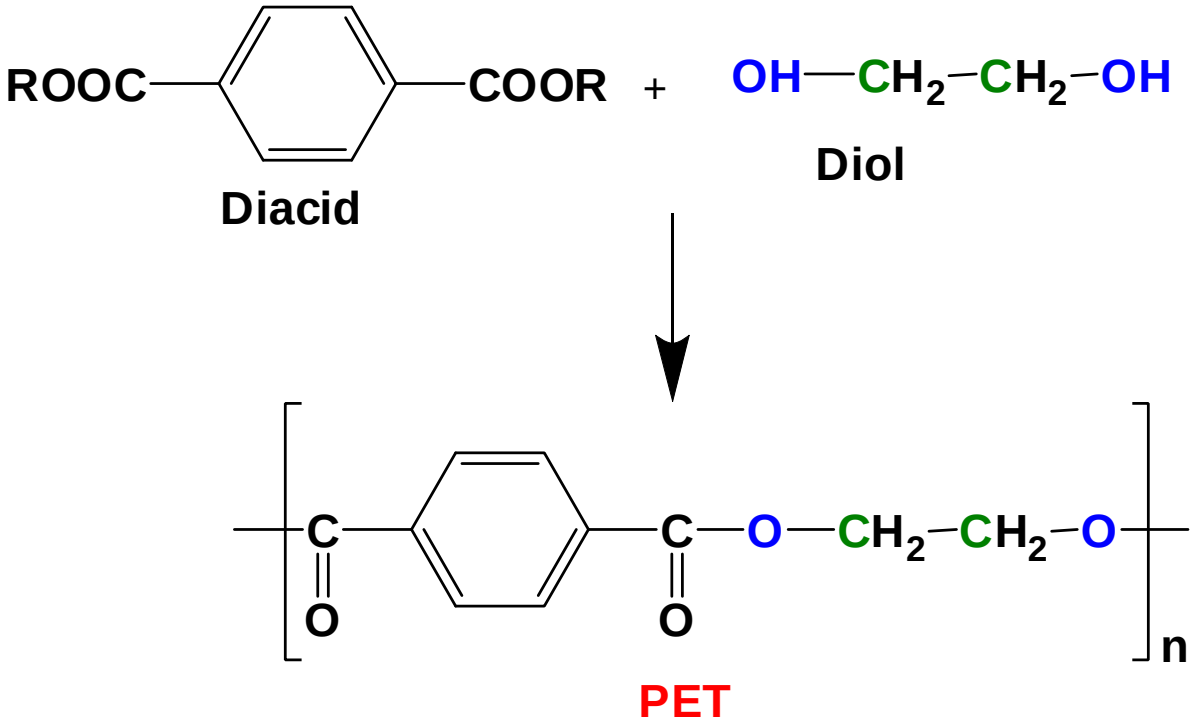
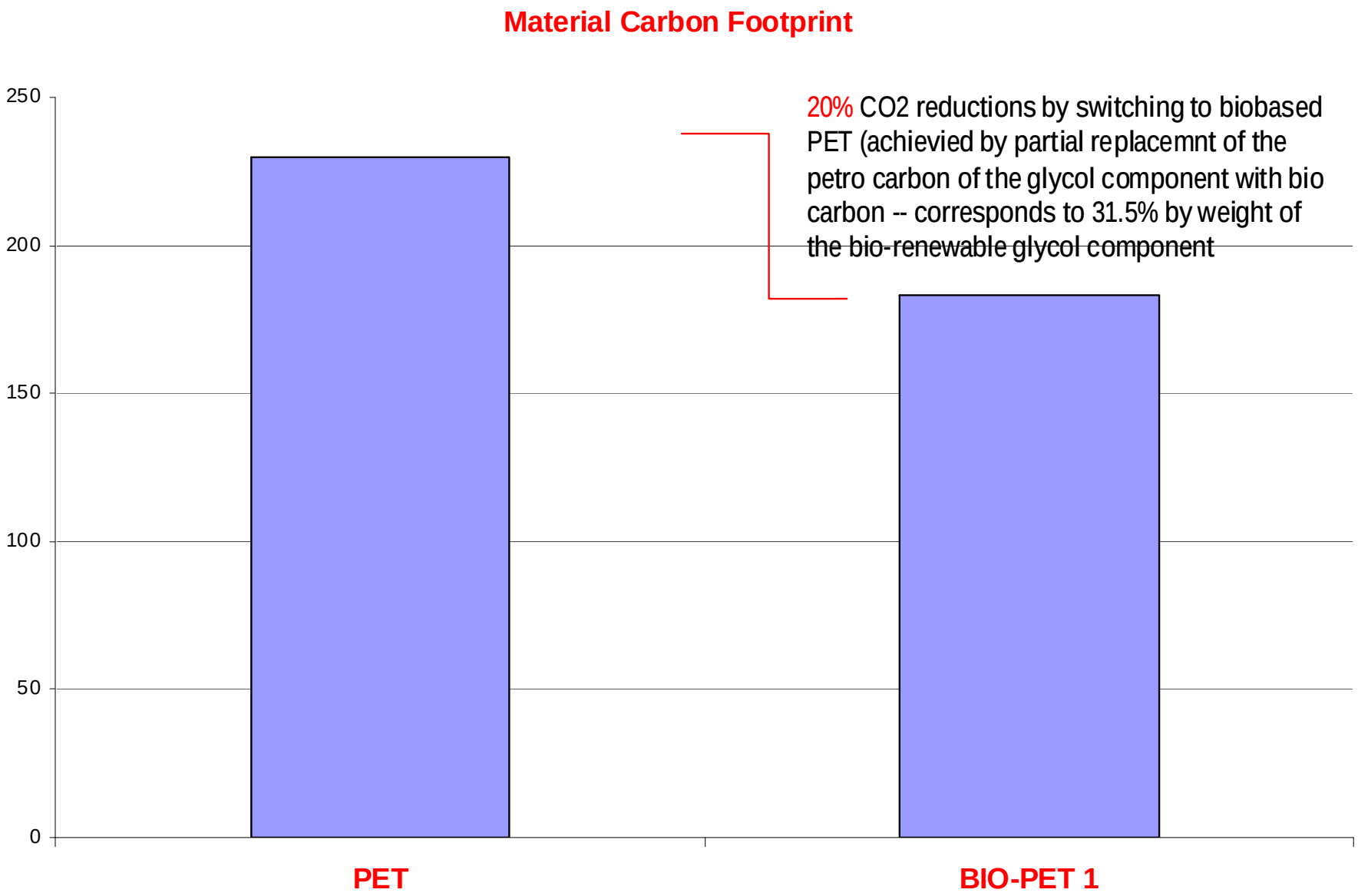
Material carbon footprint calculations – PET exemplar



Acid component = 8C; glycol component = 2C;
Acid component = 68.75%; glycol component = 31.25% on mass basis

Bio (carbon) content is 20% if two petro carbons substituted by bio carbons – by using the glycol (diol) component from bio(plant sources)

Material carbon footprint calculations – PET exemplar



Communicating and presenting CO_2 emissions reduction data – "material carbon" footprint

Considering that the world wide use of PET resin for bottles and fiber is 37.5 million metric tons, this first step of replacing the glycol petro carbon with bio carbon offers an annual CO2 reduction of 17.19 million metric tons. To visualize this CO2 reduction in practical ready-to-understand terms the following equivalency applies (equivalency calculator):

- Eliminate CO2 emissions from driving 3 million passenger vehicles each year
- Eliminate CO2 emissions from consuming 1,951,191,82 gallons of gasoline each year
- Eliminate CO2 emissions from consuming 40 million barrels of oil each year
- Eliminate CO2 emissions from using electricity in 2,384,189 homes each year

GHG, equivalency calculator; www.epa.gov

Biobased Carbon Content Determination

Amount of biobased *carbon* in the material or product as fraction weight (mass) or percent weight (mass) of the total organic carbon in the material or product.

$$\% \text{ BIO or BIOBASED CONTENT} = \frac{\text{BIO (Organic) CARBON}}{\text{TOTAL (Organic) CARBON}} * 100$$

- **On a carbon basis, not weight or mole or any other measure.**
- **Reducing carbon foot print is the driver for using a bio/renewable feedstock (new carbon) -- not oxygen or nitrogen or anything else**
- **So biocarbon content is the correct measurement metric**

Measurement of bio (carbon) content – the Principle

$^{14}CO_2$ – Solar radiation

$^{12}CO_2$

Biomass/Bio-organics

$(^{12}CH_2O)_x \longleftrightarrow (^{14}CH_2O)_x$

NEW CARBON

> 10^6 years

Fossil Resources
(petroleum, natural gas, coal)

$(^{12}CH_2)_n$ $(^{12}CHO)_x$

OLD CARBON

C-14 signature forms the basis of Standard test method to quantify biobased content (ASTM D6866)

Cosmic radiation

$^{14}N \rightarrow {}^{14}C \rightarrow {}^{14}CO_2$

$^{12}CO_2$

Narayan, *ACS (an American Chemical Society publication) Symposium Ser.939, Chapter 18, pg 282, 2006*

Measurement of bio (carbon) content – ASTM D6866

C-product combusted to CO_2

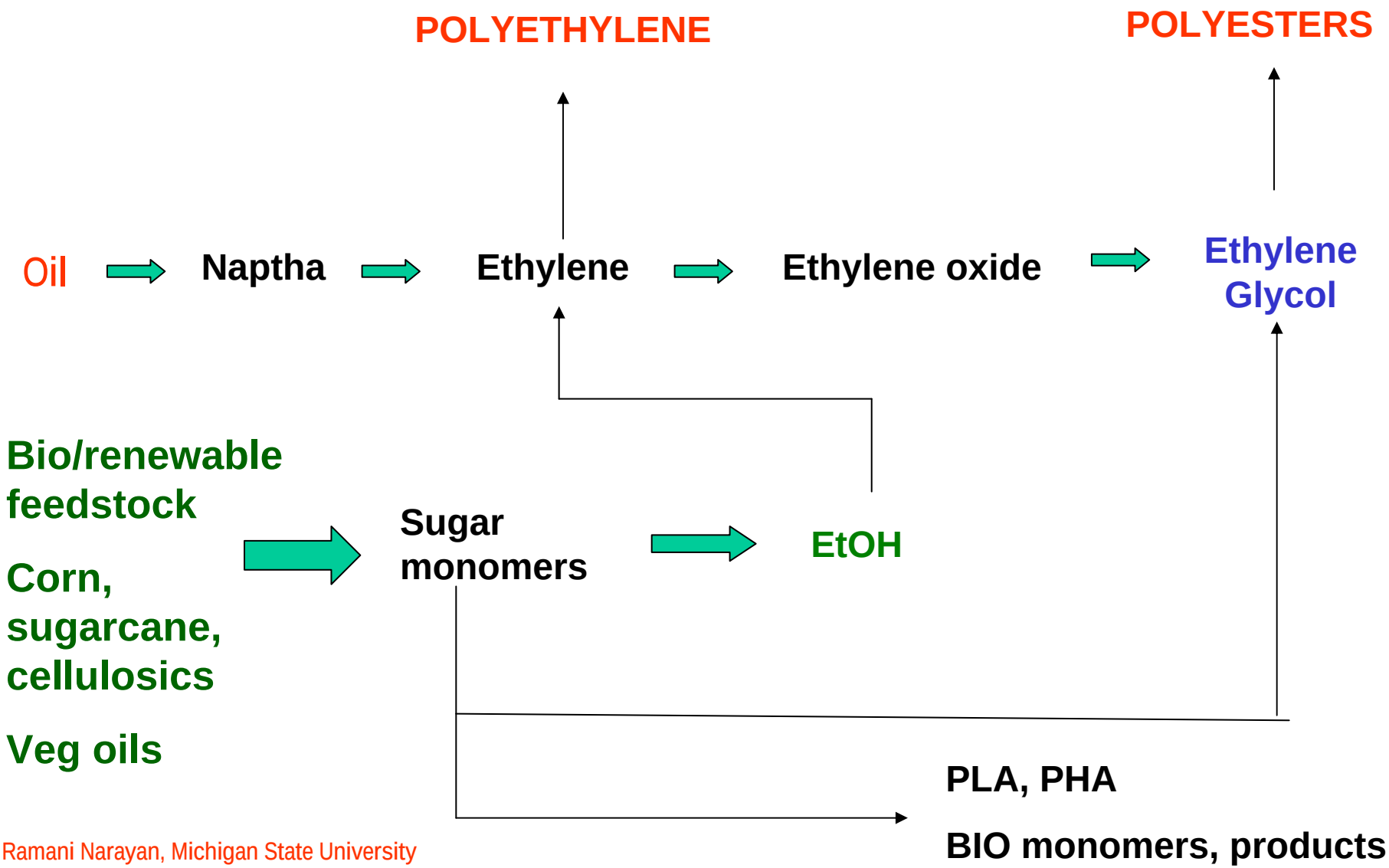
$^{14}C/^{12}C$ ratio is compared directly with a oxalic acid radiocarbon standard reference material (SRM 4990c) that is 100% new (bio) carbon – actually 0.93 of the reference material to correct for the post 1950 ^{14}C injection into the atmosphere.

14.27 dpm/g is the absolute value of the primary oxalic acid standard (SRM 4990b)

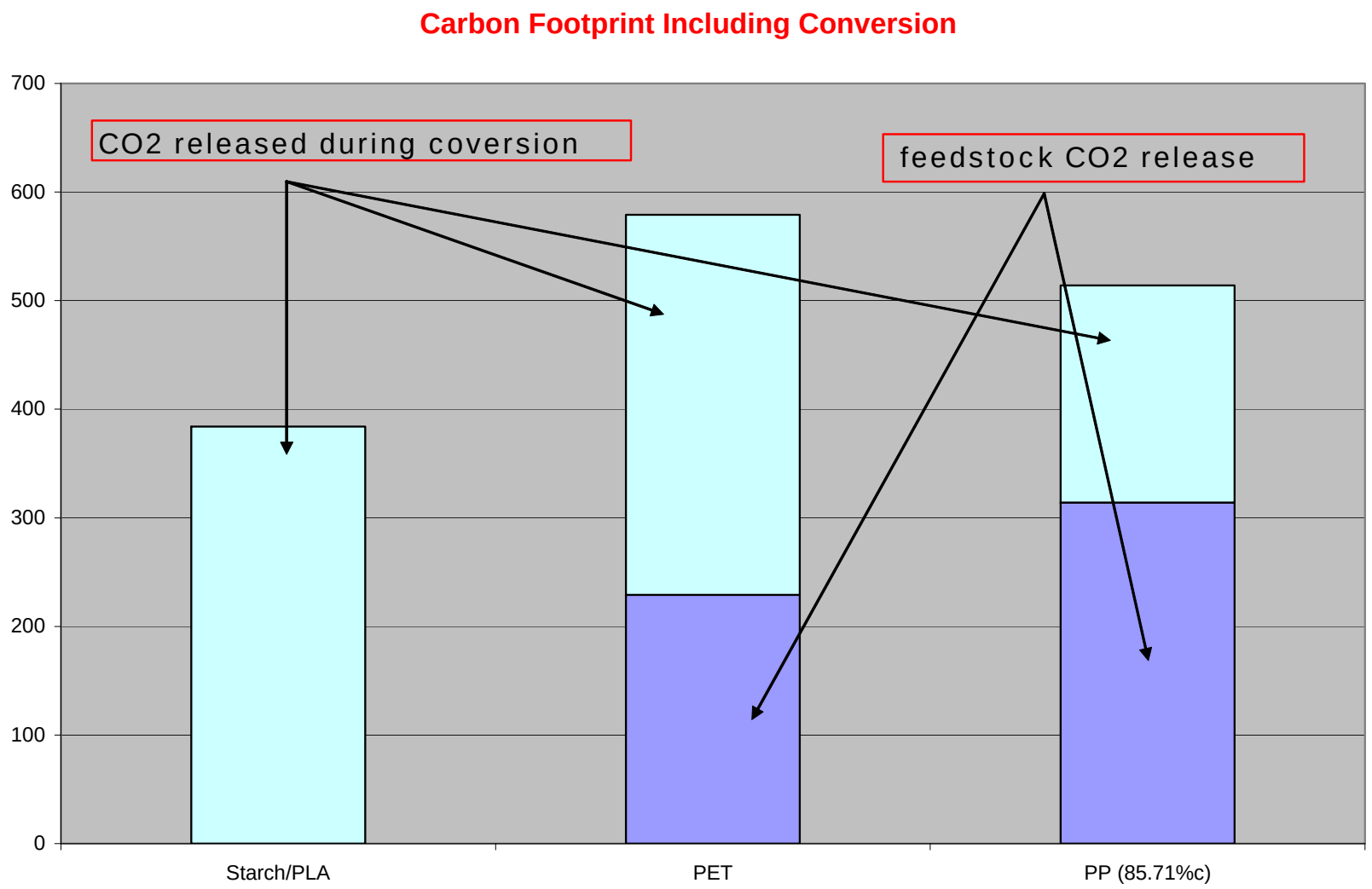
Process Carbon Footprint

- **Intrinsic "Material Carbon" footprint established for switching from petro carbon feedstock to biocarbon feedstock – the reduction achieved is equal to the percent biocarbon content incorporated**
  - **ASTM D6866**
- **Carbon footprint from the conversion of feedstock to product – cradle to factory gate scenario and total environmental footprint to be calculated using LCA methodology ASTM D7075 or ISO 1440**
- **End of life scenarios – disposal system can give skewed/misused LCA's**
- **Transport (of product from factory/production point to customer) and disposal can be considered to have the same footprint for petro and bio feedstock derived products**
  - **B2B value chain analysis OR carbon to factory gate analysis**

ORIGINS OF CARBON IN PRODUCT



Process Carbon Footprint – the LCA trap



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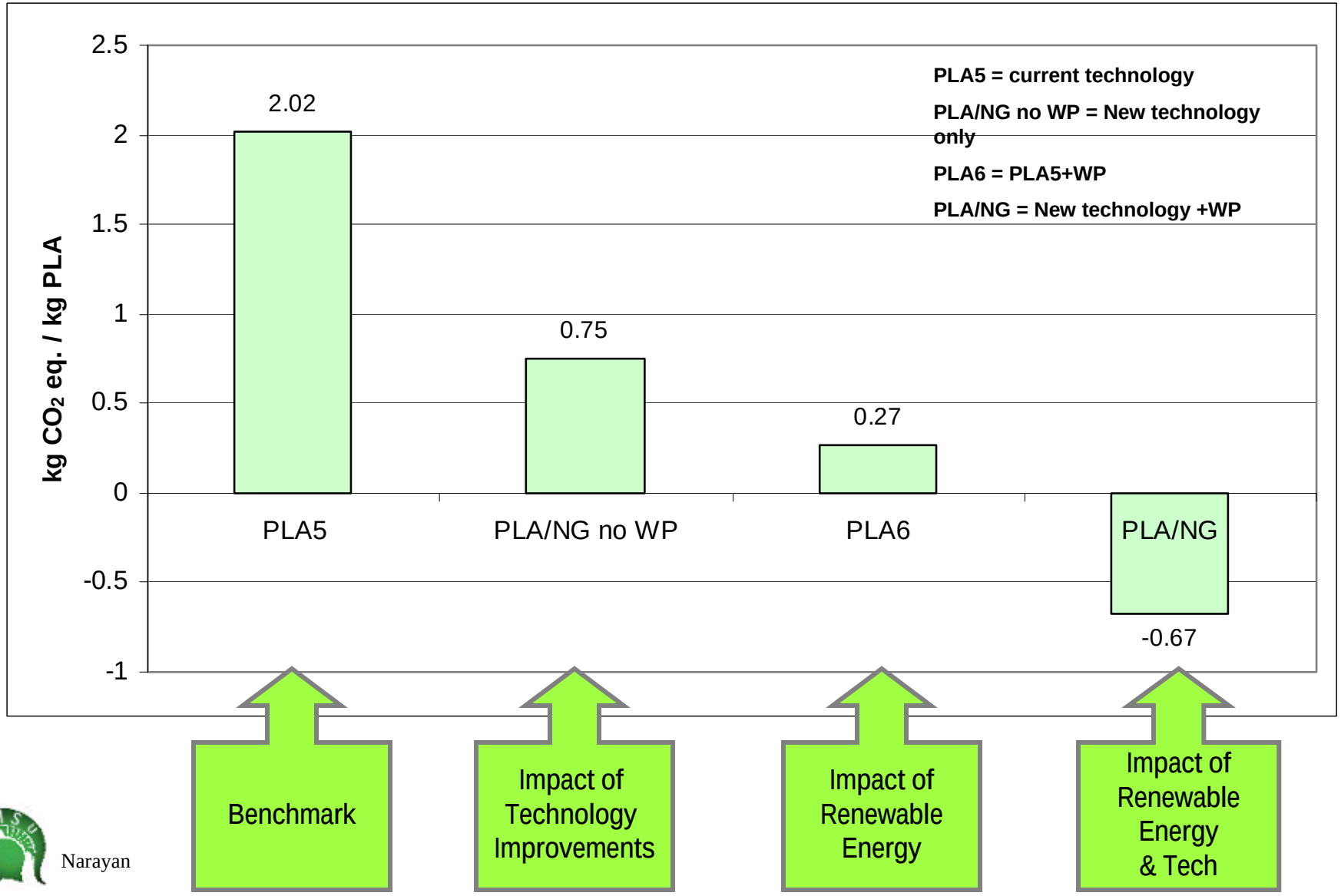
Results of the utilization of renewable energy and new technology on GHG

Vink et al, www.natureworksllc.com



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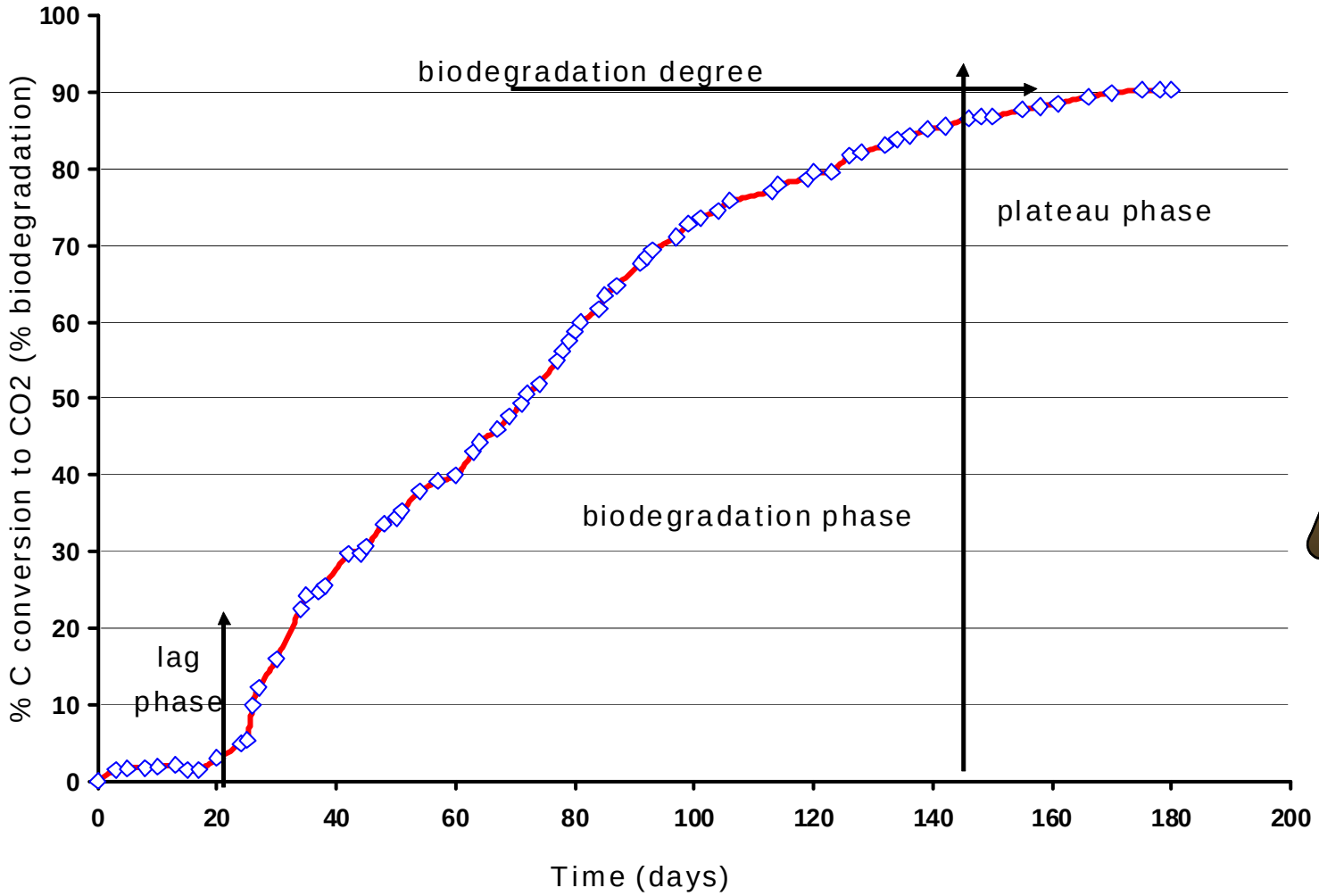
LCA and bio carbon content summary

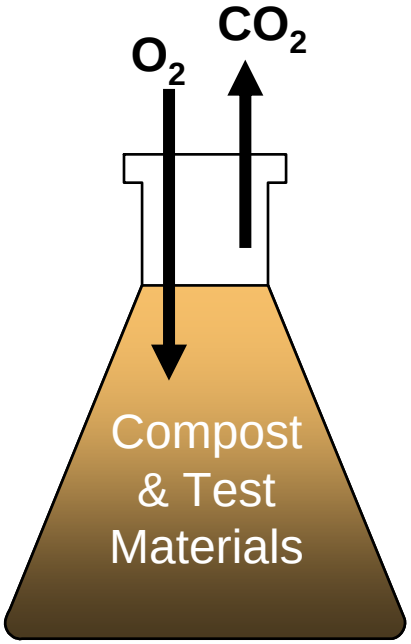
- **Life Cycle Assessment is a useful and important tool to compute and report on the environmental footprint of product, process, or service offering**
- **LCA provides for continual improvement, new options, new material choices for reducing the environmental impact of your product**
- **Practitioners and users of LCA need to be careful in comparative analysis of products because of the data used, the boundary conditions**
- **Remember – LCA methodology provides the process carbon and environmental footprint not material carbon replacement footprint**
- **Beware of skewed/misused LCAs because of data quality or imposed boundary conditions, specifically end-of-life options**
- **B2B (cradle –to-factory gate)carbon and environmental footprinting is an important and viable methodology to compute and report on the value proposition for bioplastic/products**
- **The material carbon footprint reductions value proposition of "BIO" -- providing for a reduced carbon footprint is given by biocarbon content analysis**

Biodegradability

- Using biodegradability as an end-of-life option to completely remove single use short life disposable products from the environmental compartment in a safe and efficacious manner via microbial assimilation (microbial food chain)
  - Disposal environment (like composting, anaerobic digestor, marine
  - Time to complete biodegradation
    - 90%+ of the carbon substrate should be completely assimilated by the microorganisms present in the disposal within a short time period (one year or less)
  - Degradable, partial biodegradable not acceptable – serious health and environmental consequences
  - Specification Standards ASTM D6400, D6868, D7021
  - Specification Standards EN 13432 (European Norm)
  - Specification Standards ISO 17088 (International Standard)

Measuring biodegradability





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Problems with incomplete and partial biodegradation

- plastic pieces can attract and hold hydrophobic elements like PCB and DDT up to one million times background levels. As a result, floating plastic is like a poison pill
    - From Algalita Marine Research Foundation – www.algalita.org/pelagic_plastic.html
- PCBs, DDE, and nonylphenols (NP) were detected in high concentrations in degraded polypropylene (PP) resin pellets collected from four Japanese coasts.
- Plastic residues function as a transport medium for toxic chemicals in the marine environment.
    - Takada et al Environ. Sci. Technol. 2001, 35, 318-324
    - Blight, L.K. & A.E. Burger. 1997. Occurrence of plastic particles in seabirds from the Eastern North Pacific. Mar. Poll. Bull. 34:323-325

Summary

- To clearly communicate and articulate the environmental value proposition or attributes of biobased products and send a clear message, the USDA biopreferred program should focus on the reporting requirement of :
  - material carbon footprint reductions using bio (carbon) content analysis (ASTM D6866) – addresses the global warming potential impact category
  - End-of-life options like biodegradability in a defined disposal environment (like composting, anaerobic digestion) using ASTM standards – addresses several environmental impact categories
- LCA is a useful tool that helps define the environmental impact for the process of converting the bio or petro feedstock into product. However, it is just a process carbon footprint, and has a number of constraints and issues. It should not be a "requirement" in the biopreferred program.
- The fundamental driver or switch to biobased products is the material carbon footprint reductions arising from the "short-term" biogenic carbon cycle – the rate and time scales of CO_2 sequestration is in balance with the use and release resulting in a carbon neutral footprint.
- In contrast to the "long-term" carbon cycle for petro/fossil feedstocks - the rate and time scale of CO_2 sequestration is in millions of years and the rate and time scales of use and release in a 10 year time frame