Overview of Standards and Regulations in the Biobased Plastics Space & discussions around biobased value attributes and value proposition.

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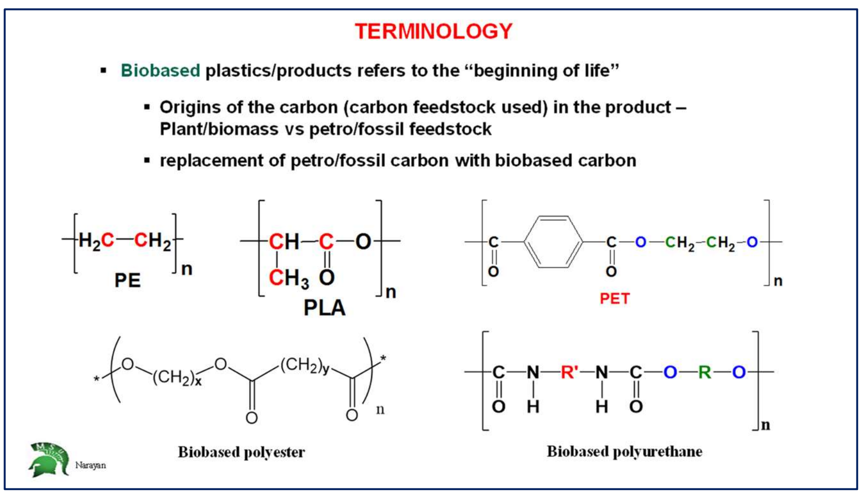
Biobased plastics are "plastics in which the (organic) carbon (of the polymer molecule) in part or whole comes from plant biomass like agricultural crops and residues, marine and forestry materials, algae, and fungi **living in a natural environment in equilibrium with the atmosphere**"

Note: Plastics in which the (organic) carbon comes from petroleum, natural gas, and other fossil resources are not biobased.

Plastics – Material which contains as an essential ingredient a carbon based high polymer and which at some stage in its processing into finishes product can be shaped by flow

biobased –containing organic carbon of renewable origin like (from) agricultural, plant, animal, fungi, microorganisms, marine or forestry materials living in a natural environment in equilibrium with the atmosphere – ASTM D6866

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



ASTM D6866-16 -- Standard Test Methods for Determining the Biobased Content of Solid, Liquid, and Gaseous Samples Using Radiocarbon Analysis

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

biobased carbon content—the amount of biobased carbon in the material or product as a percent of the total organic carbon (TOC) in the product

biobased carbon content on mass basis – amount of biobased carbon in the material or product as a percent of the total mass of product *biogenic*- containing carbon (organic & inorganic) of renewable origin like agricultural, plant, animal, fungi, microorganisms, macroorganisms, marine, or forestry materials

biogenic carbon content – the amount of biobased carbon in the material or product as a percent of the total carbon (TC) in the product

biogenic carbon content on mass basis – amount of biogenic carbon in the material or product as a percent of the total mass of product.

Complex assemblies (D6866)

Measure the % biobased carbon content of each organic constituent, then using the known % carbon content and proportion of each constituent within the assembly, formulate the % biobased carbon content for the assembly.

For an assembly containing "n" organic components, this can be achieved using formula

$$\text{Biobased Content of Product} = \sum_{i=1}^{n} M_i * BCC_i * OCC_i \; / \; \sum_{i=1}^{n} M_i * OCC_i$$

Where:

Mi = mass of the nth component present in the assembly

BCCi - % biobased carbon content of the nth component

OCCi = % organic carbon content of the nth component

EU-ASTM definitions

- Bio-based carbon content (CEN/TS 16640) – ratio between the total bio-based carbon and total carbon content of a product. This is mentioned biogenic carbon content in ASTM D6866.
- Bio-based carbon content (ASTM D6866) – ratio between the total bio-based carbon and total organic carbon content of a product.
- Bio-based content (EN 16785-1) – ratio between the total bio-based mass (carbon, oxygen, nitrogen and hydrogen) and the total mass of a product.

Application

USDA biopreferred program & EPA Greenhouse gas reporting requirements (D7459) use ASTM D6866 as does Japan EcoMark (http://www.ecomark.jp program. The EU-CEN standards are in harmony with ASTM and ISO standards and uses the same basic principles of radiocarbon analysis enunciated in ASTM D6866. European certification organizations are Vincotte, Belgium (OK biobased), DIN-CERTCO (Germany)

ISO standards – TC61/SC5/WG23 on Biobased Plastics

ISO 1660 series standards Parts 1 through 5

- Plastics – Biobased content – Part 1: General Principles
- Plastics – Biobased content – Part 2: Determination of biobased carbon content
- Plastics – Biobased content – Part 3: Determination of biobased synthetic polymer content

The above standards are approved International Standards

- Plastics – Biobased content – Part 4: Determination of the total biobased mass content
- Plastics -- Biobased content – Part 5: Declarations of the biobased carbon content, biobased synthetic polymer content, and biobased mass content

The above standards are at the DIS (Draft International Standard) stage. Part 4 is being harmonized with CEN TC 411 activity.

New Standards in development

WD (working draft) proposals for Carbon and environmental value proposition – general principles (Pt 1); material carbon footprint (Pt 2) Process carbon footprint (Pt 3); Total environmental footprint (Pt 4); Use, Reporting, Declaration, and Claims (Pt 5)

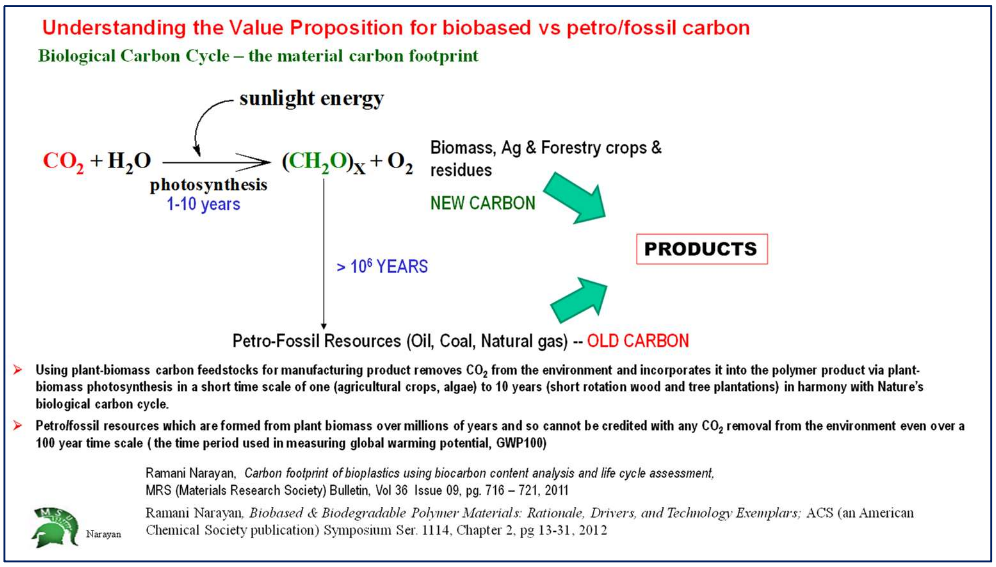
The rationale and guiding principles used to develop this set of standards will be described in Part 1 (described in later section on biobased value proposition). This set of standards would provide the tools and methodology to communicate clearly and transparently the value proposition of biobased plastics in terms of material and process carbon footprint, and total environmental footprint using the biobased content data from ISO 1660 series standards. It will be guided by the principles and practices in ISO 14040 LCA series standards. This series of standards are under the jurisdiction of TC 207 on Environmental Management Standards. The biobased plastics carbon value proposition standards in development under TC61/SC5/WG23 needs to be in line with ISO 14067 – Greenhouse gases -- Carbon footprint of products -- Requirements and guidelines for quantification and communication. This standard is under the jurisdiction of ISO/TC207/SC7.

ISO/TS 14067:2013 specifies principles, requirements and guidelines for the quantification and communication of the carbon footprint of a product (CFP), based on International Standards on life cycle assessment (ISO 14040 and ISO 14044) for quantification and on environmental labels and declarations (ISO 14020, ISO 14024 and ISO 14025) for communication. Requirements and guidelines for the quantification and communication of a partial carbon footprint of a product (partial CFP) are also provided.

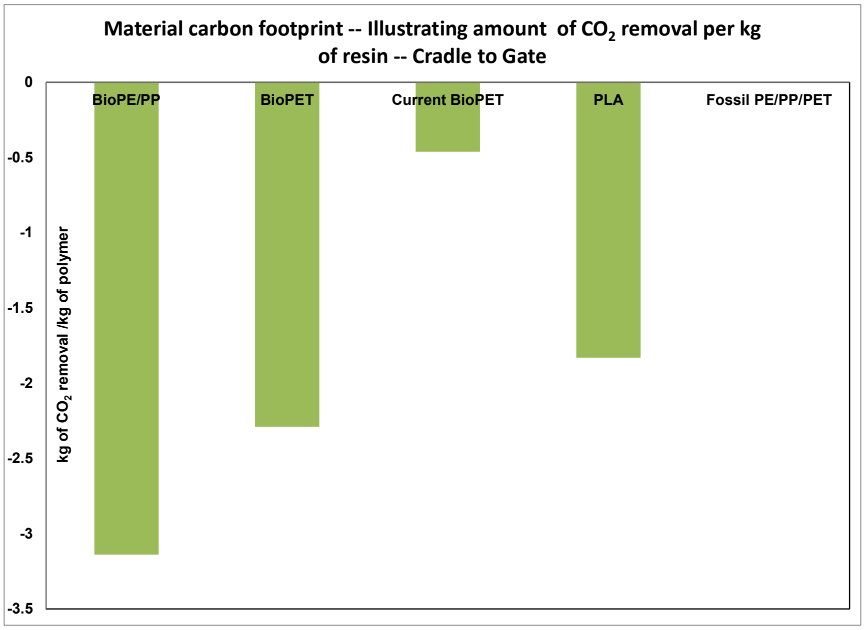
ISO/TS 14067:2013 is applicable to CFP studies and different options for CFP communication based on the results of such studies. Where the results of a CFP study are reported according to ISO/TS 14067:2013, procedures are provided to support both transparency and credibility and also to allow for informed choices.

Discussion around “biobased” value attributes and value proposition

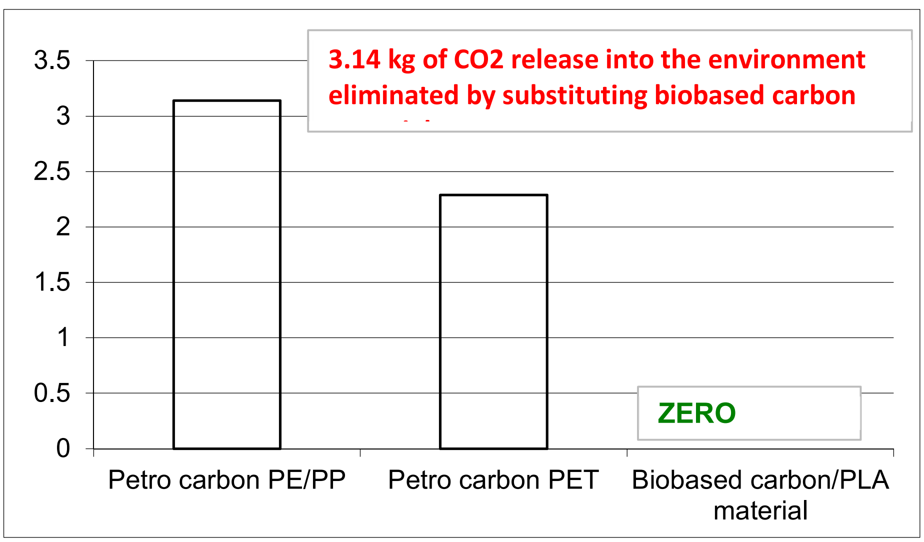
Replacing petro/fossil carbon with biobased carbon (from plant-biomass feedstocks) in plastics and industrial products offers the value proposition of removing carbon present as CO_2 in the environment and incorporating it into a polymer molecule via plant-biomass photosynthesis in a short time scale of one (agricultural crops, algae) to 10 years (short rotation wood and tree plantations) in harmony with Nature’s biological carbon cycle. Plastics made from petro/fossil resources (like Oil, Coal, Natural gas) which are formed from plant biomass over millions of years and so cannot be credited with any CO_2 removal from the environment even over a hundred-year time scale (the time period used in measuring global warming potential, GWP100). Process carbon and environmental footprint (arising from the process of converting the feedstock to product) are also improved. This concept is shown in the attached figure.



The biobased carbon content of products is determined independently and unequivocally using radio carbon analysis as codified in International Standards – the primary one is the ASTM D6866 (Standard Test Method for determining biobased (carbon) content of solids, liquids, and gaseous samples using radiocarbon analysis). Using experimentally determined biobased carbon content and applying fundamental stoichiometric calculations, one can readily calculate the amount of CO_2 removed from the environment by**1 kg of material**. For example: 1 kg of biobased polyethylene (PE) containing 100% biobased carbon content would result in removing 3.14 kg of CO_2 from the environment. 1 kg of PLA (100% biobased carbon content) would remove 1.83 kg of CO_2 from the environment. 1 kg of the current bio PET (20% biobased carbon content – only the glycol carbons come from plant-biomass) results in 0.46 kg of CO_2 removal from the environment. 1 kg of the 100% biobased carbon content PET results in 2.29 kg of CO_2 removal. See Appendix 1 for details of the stoichiometric calculations. In contrast, the petro-fossil carbon based products results in zero CO_2 removal from the environment. These results are graphically shown in the figure below.



Eventually, at the end-of-life of these plastics, the carbon will be released back into the environment as CO_2 through waste-to-energy systems or incineration or through composting or anaerobic digestion (if it has biodegradability-compostability feature built into it. However, the CO_2 released will be captured by the next season's crop or biomass plantation resulting in a **net zero** material carbon footprint, in harmony with Nature's carbon cycle. In contrast, the non-



biobased PE or PP will contribute a net 3.14 kg of CO_2 into the environment for every 1 kg of PE used. 1 kg of PET will contribute 2.29 kg of CO_2 to the environment.

In summary, the replacement of petro-fossil carbon in whole or part by biobased carbon (derived from plant biomass resources) offers the value proposition of reduced carbon footprint and the enabling technology to move towards the closed loop "circular economy" model that is being advocated and adopted by many nations and major industrial organizations and brand owners.

Biobased carbon content requirement

There is much misperception on the question of the amount of biobased carbon content necessary to claim environmental and sustainability values. Some have suggested that only 100% biobased plastic is acceptable – an all or nothing option. This is based on the analogous requirement of "complete biodegradability in targeted disposal environment in a short defined time period" for biodegradable-compostable plastics. However, this requirement is necessitated by the fact that many literature studies have shown that "degraded" or partial biodegraded fragments left in the environment could have environmental consequences (see discussion on biodegradability in later section). This thought process is not applicable for biobased carbon content requirements. Even partial substitution of the petro-fossil carbon by biobased carbon results in a positive good environmental value attribute -- removing CO_2 from the environment (as discussed earlier). In the bio PET example discussed earlier replacing only two of the ten carbons in the PET molecule with biocarbons (20% biobased carbon content) results in removing 0.46 kg of CO_2 per kg of PET. About 37.5 million tons of PET resin is used for manufacture of beverage bottles and a 20% biobased carbon content results in removing 17.2 million tons of CO_2 from the environment with an equivalency of 40 million barrels of oil.

The above thinking is reflected in the USDA biopreferred program, the EU bioeconomy programs, and the Japan Ecomark programs – the minimum biobased carbon content requirement is set around 25%. The USDA biopreferred program permits lower biobased carbon content than 25% on a case-by-case basis based on the size of the market – 100% biobased carbon content product with a thousand-ton market will remove much less CO_2 from the environment compared to a 20% biobased carbon content product with a 40 million ton market. In the durable goods, automotive sector even a 5% biobased content provides a value attribute and opens the door for incorporating more biobased components.

Biodegradability-Compostability – End-of-Life scenario

The biobased carbon value proposition for plastics articulated below does not address its end-of-life – the question of what happens to product after use when it enters the disposal environment. Biobased plastics are not necessarily biodegradable-compostable and all biodegradable-compostable plastics are not automatically biobased. The biobased carbon content has zero impact on the end-of-life of the biodegradable plastics. The molecular structure of the plastic and the availability of its carbon for transport into the microbial cell and subsequent utilization for energy drives the microbial assimilation (percent biodegradability) of carbon substrates like plastics -- the availability of carbon in a molecule to the microbes and not the source of the carbon is the key learning.

APPENDIX 1: Stoichiometric Calculations for CO_2 removal from the environment

$$6nCO_2 + 5nH_2O \xrightarrow{\text{photosynthesis}} \left(\!-C_6H_{10}O_5-\!\right)_n + 6nO_2$$

Starch/Cellulose

$$\left(\!-C_6H_{10}O_5-\!\right)_n + nH_2O \xrightarrow{\text{hydrolysis}} nC_6H_{12}O_6$$

$$nC_6H_{12}O_6 \xrightarrow{\text{fermentation}} 2nC_2H_5OH + 2nCO2$$

$$2nC_2H_5OH \xrightarrow{\text{dehydration}} 2nC_2H_4 + 2nH_2O$$

$$2nC_2H_4 \xrightarrow{\text{polymerization}} 2\left[-CH_2-CH_2-\right]_n$$

$$\boxed{\text{NET}}\ \underset{(88\text{ kg})}{4nCO_2 + 4nH_2O} \longrightarrow \underset{(28\text{ kg})}{2\left[-CH_2-CH_2-\right]_n} + 6nO_2$$

Stochiometric equation showing CO_2 "removal" from the environment and incorporation the carbon into biobased polyethylene molecule

For every kg of bio-PE manufactured there is 3.14 kg of CO2 removed from the environment.

$$6nCO_2 + 6nH_2O \xrightarrow{\text{photosynthesis}} nC_6H_{12}O_6 + 6nO_2\uparrow$$

$$nC_6H_{12}O_6 \xrightarrow{\text{fermentation}} 2nCH_3CH(OH)COOH$$

$$2nCH_3CH(OH)COOH \longrightarrow nC_6H_8O_4\text{(Lactide)} + 2H_2O$$

$$nC_6H_8O_4 \xrightarrow{\text{polymerization}} 2\left[-O-\underset{CH_3}{\overset{H}{C}}-\underset{\parallel\atop O}{C}-\right]_n$$

(PLA)

$$\text{NET}\quad \underset{264\text{ Kg}}{6nCO_2 + 4nH_2O} \longrightarrow \underset{144\text{ Kg}}{2[C_3H_4O_2]_n}\ \text{(PLA)} + 6nO_2\uparrow$$

1.83 Kg of CO_2 removed from the environment to manufacture 1 Kg of PLA

$$6nCO_2 + 6nH_2O \xrightarrow{\text{photosynthesis}} nC_6H_{12}O_6 + 6nO_2$$

$$nC_6H_{12}O_6 \xrightarrow{\text{fermentation}} 2nC_2H_5OH + 2nCO2$$

$$2nC_2H_5OH \xrightarrow{\text{dehydration}} 2nC_2H_4 + 2nH_2O$$

$$2nC_2H_4 + O_2 \xrightarrow{\text{oxidation}} 2n\ C_2H_4O$$

$$2n\ C_2H_4O + 2nH_2O \xrightarrow{\text{hydrolysis}} 2n\ HO\text{-}CH_2\text{-}CH_2\text{-}OH$$

$$\boxed{\text{NET}}\ \underset{(176\text{ kg})}{4nCO_2 + 6nH_2O} \longrightarrow \underset{(124\text{ kg})}{2n\ HO\text{-}CH_2\text{-}CH_2\text{-}OH} + 5nO_2$$

1.42 kg of CO_2 removal from the environment for every kg of b-MEG

0.46 kg of CO2 is removed from the environment per kg of bio-PET