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Standard Guide for Determination of Biobased Content, Resources Consumption, and Environmental Profile of Materials and Products[1]

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INTRODUCTION

There is an increasing desire in United States and other parts of the world to use materials and products derived from biobased or renewable resources as a means of reducing dependency on fossil based resources and decreasing their environmental profile. Central to the determination of biobased content, resource consumption and environmental profile of materials and products is the origin and fate of the carbon contained in or released during their production, use, and disposal.

Both biobased and fossil materials have carbon as a common foundation. The amount of renewably fixed carbon utilized is a measure of the biobased resource content of a product. Carbon also represents a large part of a product's environmental profile. It is thus reasonable to use carbon and carbon equivalent to combine and track raw materials and energy consumption in the creation of a product.

It is very useful to know the biobased content of a material or product. However, knowledge of all the resources consumed and byproduct materials and energy released allows determination of its environmental impact and thus materially raise the understanding of the consequences of the creation of the product.

1. Scope

1.1 This guide covers a process to determine (*1*) biobased content of materials and products, (*2*) total resource consumption, both biobased and nonrenewable, in the form of raw materials and energy, and (*3*) an environmental profile, which would also include emissions and waste generated.

1.2 Reference to the use of factors to convert materials and energy to carbon equivalents are provided **(1-6)**[2]. In addition, the use of ISO standards to determine the material and energy inventories and an environmental profile of the products and materials is discussed. It is outside the scope of this guide to provide a detailed description of the use and application of life cycle assessment tools and conversion factors for the determination of a biobased material's environmental profile. Future ASTM International standards are being prepared to cover these subjects.

1.3 In the application of this guide, the protection of business confidential information is an important consideration. In general, the level of detail required to evaluate material and energy inputs and outputs can be reported without revealing proprietary unit process information. Unit processes can be treated as black boxes with inputs and outputs. If business confidentiality is still a concern, unit processes can be further combined or the final LCA (Life Cycle Assessment) results can be reviewed and certified by an external, independent expert with which the vendor will have the appropriate secrecy agreement.

2. Referenced Documents

2.1 *ISO Standards:*[3]

ISO 14040 Environmental Management-Life Cycle Assessment-Principles and framework

ISO 14041 Environmental Management-Life Cycle Assessment-Goal and scope definition and inventory analysis

ISO 14042 Environmental Management-Life Cycle Assessment-Life cycle impact assessment

ISO 14043 Environmental Management-Life Cycle Assessment-Life cycle interpretation

[1] This guide is under the jurisdiction of ASTM Committee D20 on Plastics and is the direct responsibility of Subcommittee D20.96 on Environmentally Degradable Plastics.

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[2] The boldface numbers in parentheses refer to the list of references appended to this guide.

[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

2.2 *Presidential Orders:*[4]

13101: 9/16/1998 Greening the Government through Waste Prevention, Recycling, and Federal Requisition

13123: 6/3/1999 Greening the Government through Efficient Energy Management

2.3 *Legislative Act:*[4]

Farm Security and Rural Investment Act of 2002 (P. L. 107-171), Title IX Energy, Section 9002.

3. Terminology

3.1 *Definitions:*

3.1.1 *biobased carbon equivalent, B*—total biobased carbon used in the creation of the materials, including raw materials and biobased energy, where energy has been converted to carbon equivalent using well documented methods and conversion factors. *B* is thus the total biobased resource equivalent used in creation of the material.

3.1.1.1 *Discussion*—Examples of factors to convert a unit of energy into carbon equivalent are referenced in this guide. However, it is outside the scope of this guide to describe their use and application. This will be the subject of future ASTM International standards.

3.1.2 *biobased content, W(b)*—amount of biobased material as fraction weight or percent weight of the total material.

3.1.3 *biobased material*—organic material in which carbon is derived from a renewable resource via biological processes. Biobased materials include all plant and animal mass derived from CO_2 recently fixed via photosynthesis, per definition of a renewable resource.

3.1.4 *biobased product*—product generated by blending or assembling of biobased materials, either exclusively or in combination with non-biobased materials, in which the biobased material is present as a quantifiable portion of the total mass of the product. Biobased material in a multicomponent product should be measured on a component basis rather than on the whole product.

3.1.5 *environmental profile or environmental footprint*—environmental consequences of the creation of a material, measured in terms of impact indicators such as the generation or recapture of CO_2, biodegradability, recycling, and so forth.

3.1.5.1 *Discussion*—References are provided to international ISO standards for conducting life cycle inventories and environmental impact analysis. The specific applications of these ISO standards for determining an environmental profile of biobased products are outside the scope of this guide. This will be the subject of future ASTM International standards.

3.1.6 *fossil carbon*—carbon contained in materials presumed to represent remnants from prehistoric life, and thus representing nonrenewable resources, such as oil, gas, coal, and kerogen in oil shale. Fossil carbon age since fixation is measured in thousands and usually millions of years.

3.1.6.1 *Discussion*—Peat moss is not fossil carbon, but is usually considered nonrenewable.

3.1.7 *fossil carbon equivalent, F*—total of fossil carbon equivalent used in creation of the material, including raw materials and energy, where energy has been converted to carbon equivalents. *F* is thus the total fossil resource equivalent used in creation of the material.

3.1.8 *fraction biobased carbon equivalent or biobased resource content, E(B)*—fraction of total carbon equivalent attributable to biobased origin. $E(B) = B/(F+B)$, as fraction or percent.

3.1.9 *life cycle assessment (LCA)*—the collection and assembly of materials and energy input and output data including an evaluation of the potential environmental impacts of a specified product system. The categories of environmental impacts that should be considered include resource use, human health and environmental emissions, and ecological consequences.

3.1.10 *life cycle impact assessment (LCIA)*—the assessment of a product system's environmental profile through identification and evaluation of relevant impact categories.

3.1.11 *life cycle inventory (LCI)*—the collection and assembly of materials and energy input and output data for a specified product system. LCI is only one of the phases in conducting an LCA and is not an assessment of the environmental impacts associated with the product system.

3.1.12 *net biobased carbon equivalent, E(NB)*—amount of biobased carbon equivalent, less fossil carbon equivalent, used in the creation or manufacture of a material.

3.1.12.1 *Discussion*—Net biobased carbon equivalent is a measure of the relative consumption of biobased and fossil resources associated with creation of a material.

3.1.13 *product system*—for the purposes of this standard, the product system is the energy and material inputs and outputs from raw material acquisition through production of the biobased material or product. This phase in a product's life cycle is commonly referred to as "cradle-to-gate." "Cradle-to-grave" LCI and LCA, while important, are not being prescribed in this guide because the ultimate function unit or use of the biobased material could take many forms and have many different fates.

3.1.14 *renewable carbon equivalent*—carbon contained in material created from recently fixed CO_2 that qualifies as a renewable resource.

3.1.15 *renewable resource*—resource that replenishes or can be made to replenish on an essentially predictable time schedule, such as farm and forestry products and abundant wildlife. Old growth forests, rare species and all fauna and flora not regenerated on an essentially predictable time scale are not considered renewable resource. Generally the renewal cycle time is less than human life span (<100 years).

3.1.16 *total carbon equivalent or total resource consumption, E(T) = F + B*—*E(T)* represents the total resources required to create or manufacture a material, and is thus a measure of total resource demand. *E(T)* is expressed as weight of carbon per unit weight of finished material, since there is no defined molecular weight associated with the carbon equivalent of energy.

3.1.16.1 *Discussion*—Other sources of energy, such as wind, solar, hydroelectric, nuclear, and so forth, are reflected as reduction in the magnitude of *F* through appropriate changes in conversion factors for energy to carbon equivalent.

[4] Available from U.S. Government Printing Office Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401.

3.2 *Abbreviations:*

B'	=	weight of biobased carbon in finished material
F'	=	weight of fossil carbon in finished material

4. Significance and Use

4.1 Biobased materials are considered a means to reduce the consumption of nonrenewable resources and reduce the environmental impact associated with the creation of materials and products, such as increased CO_2 emissions and so forth. The U.S. Government has expressed the desire to use its buying power to promote usage of biobased materials, as evidenced in Presidential Orders 13101 and 13123 and the recently passed Farm Security and Rural Investment Act of 2002 (P.O. 107 - 171.).

4.2 This guide provides a vendor with a standardized process to develop and compile information on the total resources consumed in creation of a product, define what fraction of the resources are biobased, and transmit the information in a clear and logical way. Carbon is the foundation of both biobased and fossil (nonrenewable) resources. Carbon also represents a large fraction of the environmental profile considerations of a product. Therefore carbon is used in this guide to combine and track energy and raw materials resources consumption involved in creation of a product.

4.3 This guide provides a way to determine and report weight fraction of biobased material in a product, or its biobased content, *W(b)*.

4.4 This guide also provides for verification and validation of the information supplied by vendors to support their product claims.

4.5 This guide provides a way to determine the biobased and nonrenewable (fossil) resource consumption, both as raw materials and as energy, involved in creation of a product and to combine the biobased and nonrenewable resources into total resource consumption on a consistent basis.

4.6 A companion standard[5] provides a test method for authentication of the origin of carbon claimed to be derived from renewable resources.

5. Procedure

5.1 Fig. 1 shows the main steps or elements in the process to identify and determine biobased content and resource consumption of materials and products. Note that the determination of biobased content, *W(b)* is concerned only with composition of finished material. In contrast, the total resources consumption includes the feedstock materials as well as process energy involved in manufacture of the final product. Both materials and energy are expressed as carbon equivalents.

5.2 The biobased content will be determined on homogenous materials or the simplest subunits into which the object can be divided. Fig. 2 describes separation of products into component materials. A product will be identified either as a homogenous material, a blend or an assembly of components. If an assembly, each component will be examined separately and biobased components identified for further examination as materials. Identification by components versus an assembly has two significant merits: (*1*) the materials are amenable to testing via isotope analysis and (*2*) a rational determination of proper amount of biobased material must start with the homogenous subunits and then progress to the whole assembly.

5.3 The compilation and verification of biobased content and resource consumption data are shown in Fig. 3 and Fig. 4. The vendor is requested to supply a life cycle inventory (LCI) for the material, which will include all raw materials and energy flows. Only a portion of the LCI data, namely the origin and quantity of biobased components contained in the finished material, is used to calculate biobased content, *W(b)*. LCI information on total feedstock and process energy is used to determine biobased and total resource consumption, *E(B)* and *E(T)*. Energy is converted to carbon consumption equivalent via accepted conversion factors. Alternately, the vendor may develop conversion factors and documentation for a nonstandard process, for example, one using large amounts of biobased or other forms of renewable energy.

5.4 Materials that can be created via synthesis from fossil carbon sources as well as via biobased routes (for example, ethanol) will be given particular attention. If the origin of the carbon in the material requires validation, it can be subjected to carbon isotope analysis, per Fig. 3.

5.5 Vendor-supplied documentation is used to substantiate claims regarding the biobased content of materials or products or both. In most cases, vendors should already have or should be able to obtain data on raw materials and resources and a high level description of the production processes sufficient to demonstrate its biobased content. Vendors are encouraged to organize and present this information in the form of a LCI per ISO 14041 for two reasons. First, the LCI should satisfy the basic requirement to document biobased content. Second, the LCI should establish a baseline for developing an environmental profile by quantifying the use of energy and raw materials and their associated emissions to air, water, and land.

5.5.1 The completeness of the vendor-supplied documentation and the nature/type of biobased material can be used to determine if an audit step is necessary. By using an external, independent expert to audit the vendor documentation, any concerns regarding the disclosure of business confidential information can be addressed.

5.6 Based on the LCI, the following quantities are determined as shown in Fig. 4:

W(b)	=	fraction of biobased material in finished product, that is, its biobased content
B	=	total weight of biobased carbon equivalent used in the manufacture of the material
F	=	total weight of fossil carbon equivalent used in the manufacture of the material
B'	=	weight of biobased carbon in finished material
F'	=	weight of fossil carbon in finished material

5.6.1 Thus quantities *B* and *F* include energy and raw materials and represent the total resource demands for the

[5] Test Method D 6866, to Determine the Biobased Content of Natural Range Materials Using Radiocarbon and Isotope Ratio Mass Spectrometry Analysis, is a newly designated standard that is, at the time of this guide's publication, awaiting final approval.

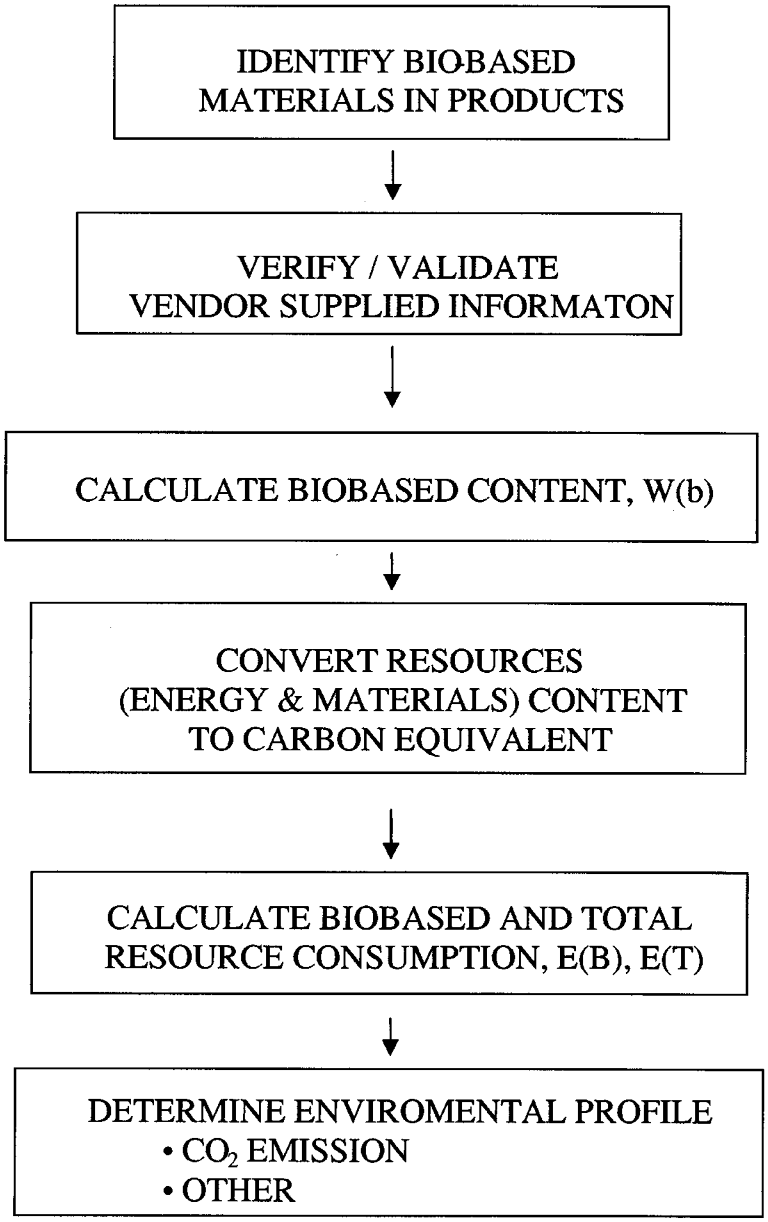

FIG. 1 Overview Process to Determine Biobased Content, Resource Consumption and Environmental Profile of Materials and Products

manufacture or creation of the material. The quantities *B'* and *F'* refer to the finished material and are useful in authentication of the origin of carbon. The emphasis is thus on total amounts and nature of carbon used, not whether the carbon appears in the finished material or is used as a source of energy. Within the scope of this guide *F* and *B* should be the focus of environmental impact of the material.

5.7 There are several quantities that are useful in the description of the biobased content of the material and should be available either to the audit agency or the purchaser or both.

5.7.1 *W(b), Biobased Content*—*W(b)* is defined above and is usually expressed as % wt. It is an easily calculated measure, but does not reflect the total resources consumed in the creation of the material.

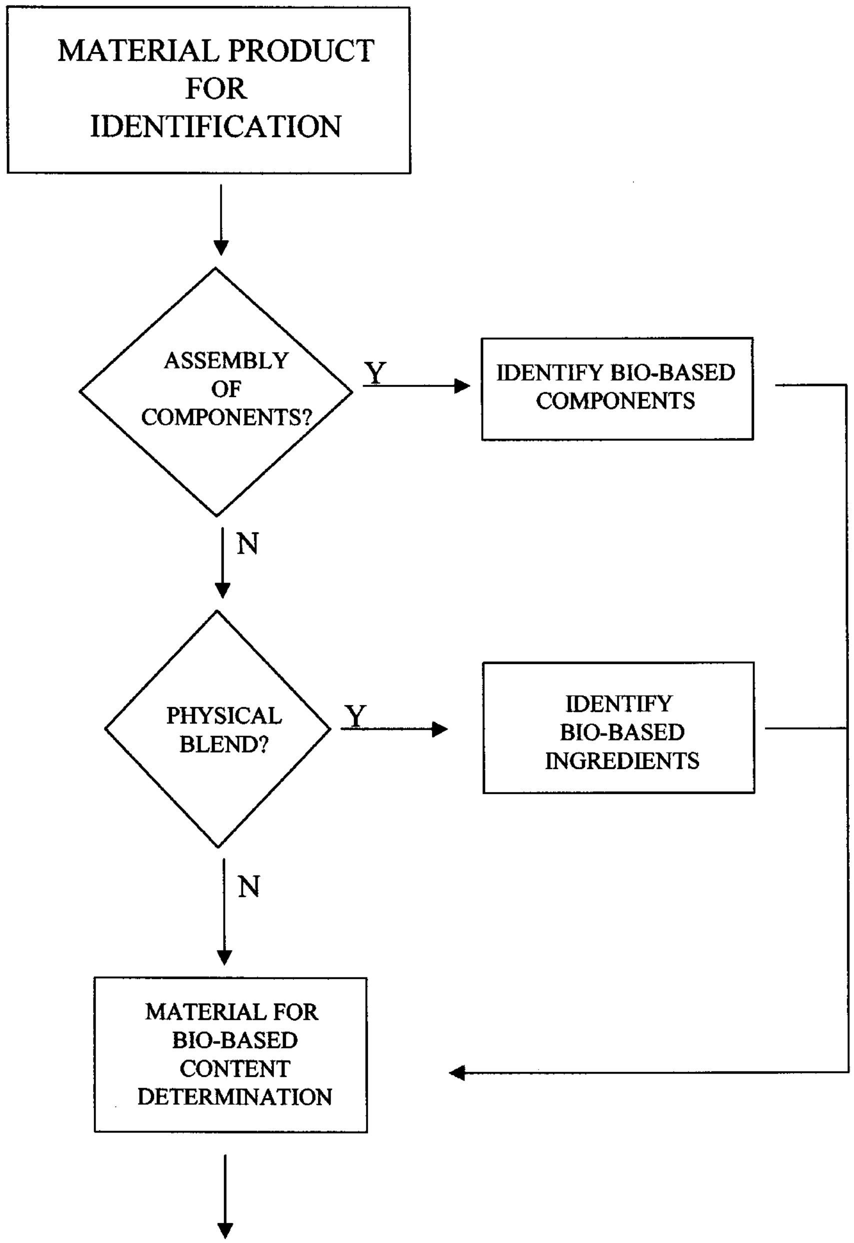

FIG. 2 Process for Separation of Products into Their Biobased Material Components

5.7.2 *B, Biobased Carbon Content Equivalent—B* includes all carbon from biobased sources, including raw materials and energy. Energy from biobased sources is converted to equivalent carbon via conversion factors. *B* is expressed as weight of biobased carbon per unit weight finished material since there is no specific weight of biobased material associated with the energy component.

5.7.3 *F, Fossil Carbon Content Equivalent—F* includes all carbon from fossil sources, that is, both raw materials and process energy. It is thus analogous to *B* for the biobased component and is expressed as weight fossil carbon per unit weight finished material. Again, the energy component does not represent a specific molecular structure or material weight, and *F* is expressed in carbon equivalent weight.

5.8 There are several expressions derivable from *B* and *F*.

$$E(B) = \frac{B}{B + F}\text{, biobased carbon content equivalent.} \quad (1)$$

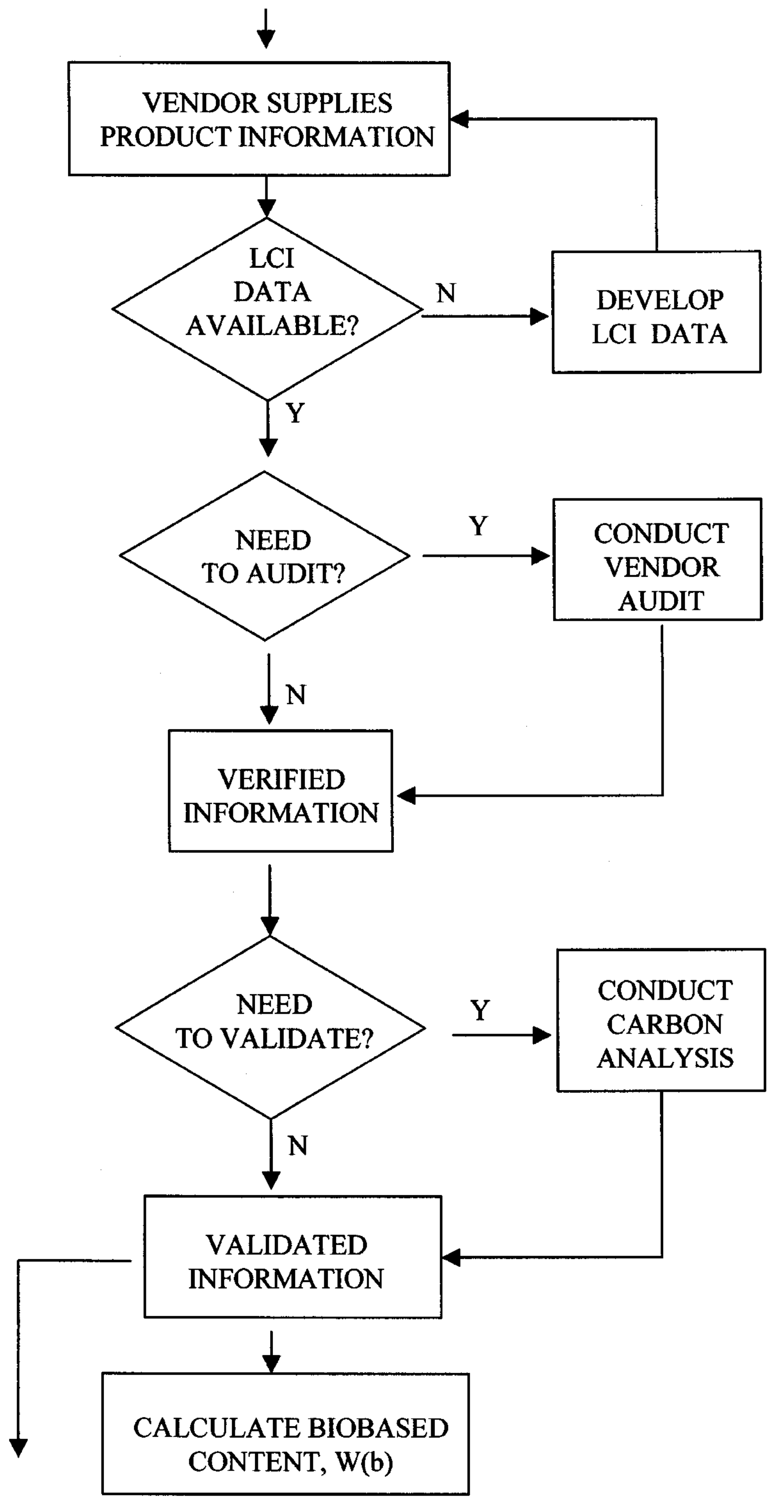

FIG. 3 Process to Determine and Verify Biobased Content

Where: *E(B)* represents the fraction of biobased resources among the total resource consumption in the creation of a product. *E(b)* should thus be the quantity used in assessment of biobased content of a product in the environmental sense.

$$E(T) = B + F, \text{ total carbon content equivalent} \quad (2)$$

Where: *E(T)* represents the total expenditure of resources in carbon or carbon equivalent attendant to creation of a material, both from renewable and nonrenewable resources.

$$E(NB) = B - F, \text{ net biobased carbon content equivalent} \quad (3)$$

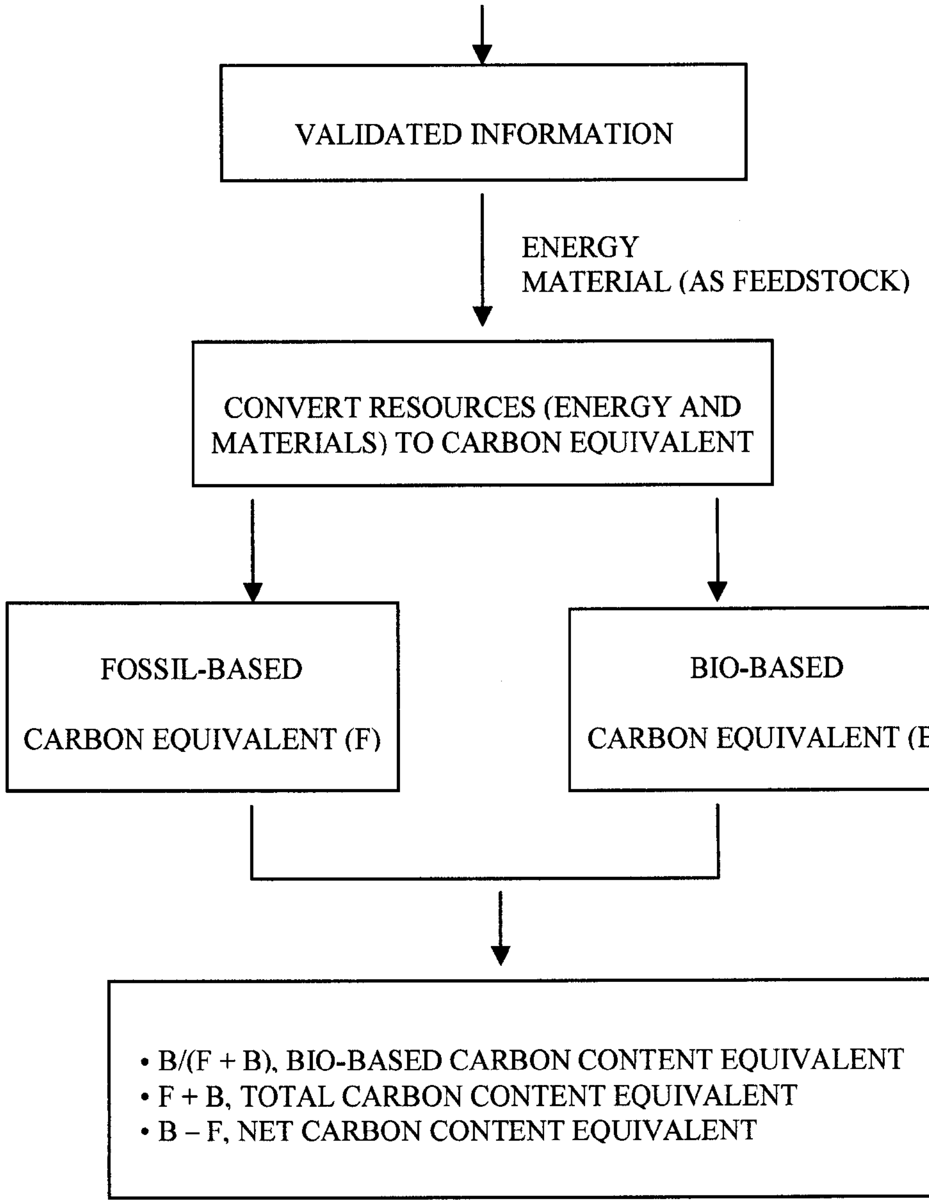

FIG. 4 Determination of Biobased and Total Resources Consumption

E(NB) is the difference between the renewable carbon and the nonrenewable or fossil carbon resources and represents thus the net "gain" or "loss" of recently fixed carbon. Since the terms contain both energy and material, *B* and *F* must be expressed in terms of carbon. *E(NB)* can assume values from <0 to $+1$, if unit weight of carbon is used in definition of *B* and *F*.

A material with $E(NB) = 1$ denotes a pure biobased carbon material manufactured without the use of fossil carbon.

5.9 *F'* and *B'* are quantities needed in authentication of claims in regard to biobased content of materials by means of carbon isotope analysis.

6. Numerical Examples

6.1 Assume that a hypothetical biobased material contains 0.4-kg biobased carbon per kilogram of material (approximately equivalent to starch) and no fossil carbon. Let the total process energy consumption be equivalent to 0.6-kg carbon/kg material. All process energy is assumed to be derived from fossil carbon. Process yield is assumed to be 100 %, so that $B = B'$. Thus:

$$B = 0.4$$
$$F = 0.6$$
$$B' = \mathrm{B}$$
$$F' = 0$$

Hence:

$$W(b) = \text{biobased content} = 1.0 \text{ or } 100\ \%$$

$E(B)$ = 0.4/(0.4 + 0.6) = 0.4 or 40 %
$E(T)$ = 0.4 + 0.6 = 1.0
$E(NB)$ = 0.4 - 0.6 = -0.2

6.2 The net equivalent biobased carbon content shows that the fossil carbon use slightly outweighs the renewable carbon use. The example illustrates the potential significance of the energy component in manufacturing.

6.3 Most manufacturing represents negative net biobased carbon flow on the basis of $E(NB)$. Agriculture, which usually shows a positive $E(NB)$, can also show a significant F value because of the energy component.

6.3.1 Consider the above case, with 50 % of the energy derived from biobased fuels (for example, bagasse or residue from saw mill).

B = 0.4 + 0.3 = 0.7
F = 0.3
B' = 0.4
F' = 0

Thus

$W(b)$ = 1.0
$E(B)$ = 0.7
$E(T)$ = 0.7 + 0.3 = 1.0
$E(NB)$ = 0.7 - 0.3 = 0.4

6.4 Thus use of biobased material as a source of energy can have a significant effect on $E(NB)$.

6.5 Assume a hypothetical synthetic material contains 0.85-kg carbon/kg finished material (similar to polyolefins) and the manufacture requires 0.4-kg carbon equivalent, all from fossil resources. Thus

B = 0
F = 0.85 + 0.4 = 1.25
$W(b)$ = $E(B)$ = 0
B' = 0
F' = 0.85
$E(T)$ = 0.85 + 0.4 = 1.25
$E(NB)$ = 0 – 1.25 = –1.25

7. Summary of Environmental Profile Determination

7.1 A process for determination of a material's environmental profile is shown in Fig. 5. Life cycle assessment (LCA), while still at an early stage of development, is recognized globally as an important tool in documenting material and energy inputs and outputs for a given product system and for assessing possible environmental impacts. The International Organization of Standardization (ISO) has developed a series of recognized practices for conducting the various stages of life cycle assessments (ISO 14040, 14041, 14042, and 14043). It is outside the scope of this test method to prescribe methods for conducting LCA. However, the use and application of LCA tools for the determination of an environmental profile of biobased materials and products will be the subject of future ASTM International standards.

Within the context of this test method, LCA as a technology will be referred to and used in two ways. The first is called life cycle inventory analysis (LCI). The second is called a life cycle impact assessment (LCIA), which, in addition to the inventory, includes the development of an environmental profile for the biobased material or product or both. By their nature, aspects of LCI and the more inclusive LCIA may be subjective, and therefore, the scope, boundary conditions, and assumptions used must be clearly specified. ISO 14040 describes the uses and limitations of the LCA technology.

7.2 *Use and Limitations*

7.2.1 The purpose of the LCIA is to develop an environmental profile of a product system's energy and raw materials inputs and outputs as determined in the LCI. ISO 14042 specifies a process for selecting environmental impact categories and their associated environmental indicators that can then be used to quantify the environmental issue of concern. For example, the environmental indicator for the climate change impact category could be greenhouse gas emissions. It is outside the scope of this guide to specify a particular set of impact categories for developing an environmental profile. The primary reason for this is that the selection of relevant environmental impact categories is highly product system specific. Details for conducting the LCIA can be found in ISO 14042.

7.2.2 Results of the LCIA form the basis of an environmental profile. No attempt is made in this guide to provide an interpretation or make a recommendation. The intent behind the development of an environmental profile is to provide consumers and users of the biobased material or product with information so that they can make more informed purchasing decisions.

8. Keywords

8.1 biobased content; carbon; renewable resource

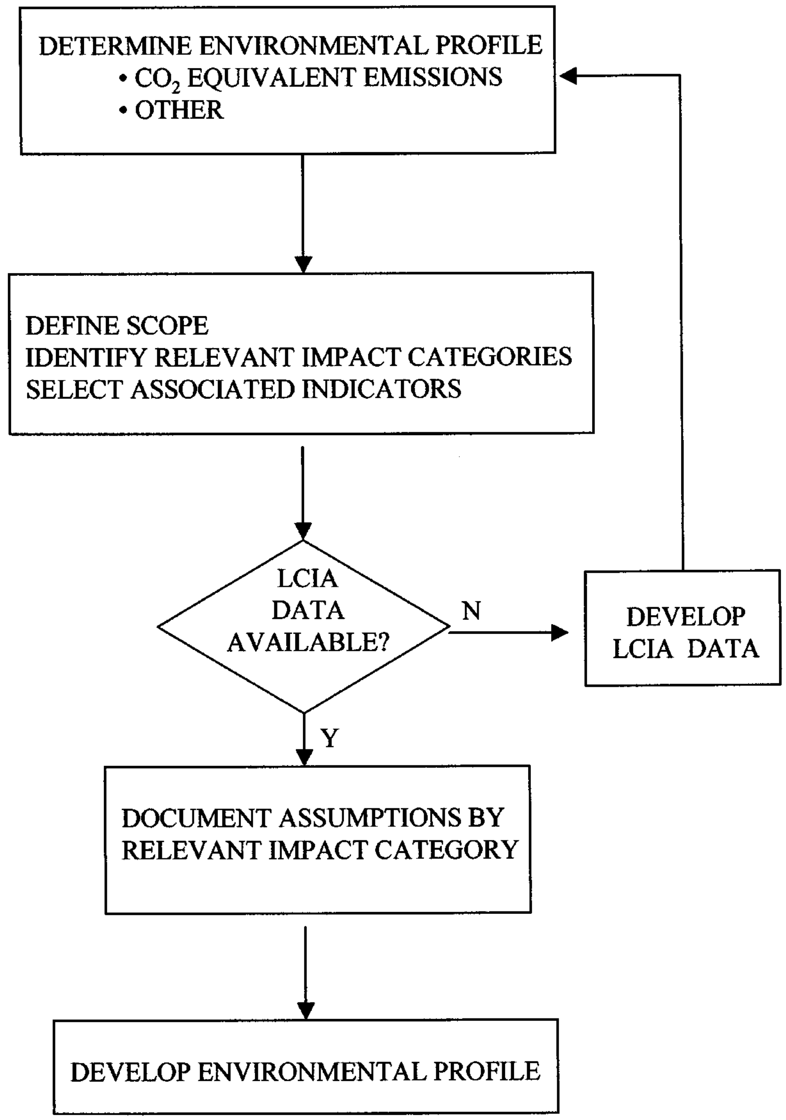

FIG. 5 Determination of Environmental Profile of Materials and Products

REFERENCES

(**1**) *Annual Energy Review 1996*, Energy Information Administration, U.S. Department of Energy, July 1997.

(**2**) *Electric Power Annual 1996*,Vol I, EIA, Office of Coal, Nuclear, Electric, and Alternate Fuels, August 1997.

(**3**) *Electricity Supply and Demand 1994 - 2004*, North American Electric Reliability Council, June 1995.

(**4**) *Monthly Energy Review*, Energy Information Administration, U.S. Department of Energy, December 1997.

(**5**) *Renewable Energy Annual 1996*, E.I.A, Office of Coal, Nuclear, and Alternate Fuels, December 1997.

(**6**) *Renewable Resources in the U.S. Electric Supply*, E.I.A, Office of Coal, Nuclear, Electric, and Alternate Fuels, February 1993.