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Standard Guide for Characterizing Environmental Aspects of Manufacturing Processes[1]

This standard is issued under the fixed designation E3012; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide provides manufacturers an approach to characterize any category of manufacturing process and to systematically capture and describe relevant environmental information.

1.2 This guide defines a Process Characterization Methodology that uses graphical and formal representations to support the construction of unit manufacturing process (UMP) information models for characterizing the environmental aspects of manufacturing processes.

1.3 This guide defines the graphical UMP information model as being comprised of four elements (input, output, product and process information, and resources) that supports manufacturers in systematically identifying, collecting, structuring, and visualizing manufacturing information.

1.4 This guide defines the formal representation of the UMP information model through the use of a modeling method and language that can effectively convey the meaning and intent of processes they characterize.

1.5 This guide provides the necessary structure and formality for identifying and capturing key information needs to assess manufacturing performance, yet provides no details about an actual assessment of the process performance.

1.6 This guide provides an approach to link individual UMP information models together to create a network or system of UMP models that extends the characterization of environmental aspects beyond an individual process to a production system or the product itself.

1.7 This guide may be used to complement other standards that address sustainability and the product life cycle. This guide most closely relates to the inventory component as discussed in the ISO 14040 series (ISO 14044) standards, and resource management as discussed in the ISO 55000 series (ISO 55001) standards.

1.8 *This guide does not purport to address all of the security issues and the risks associated with manufacturing information. It is the responsibility of the user of this standard to follow practices and establish appropriate information technology related security measures.*

1.9 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E2114 Terminology for Sustainability Relative to the Performance of Buildings

E2986 Guide for Evaluation of Environmental Aspects of Sustainability of Manufacturing Processes

2.2 *ISO Standards:*[3]

ISO 22400-1:2014 Automation systems and integration—Key Performance Indicators (KPIs) for manufacturing operations management; Part 1: Overview, concepts, and terminology

ISO 14040 Environmental management—Life cycle assessment—Principles and framework

ISO 14044 Environmental management—Life cycle assessment—Requirements and guidelines

ISO 55000:2014 Asset management—Overview, principles and terminology

ISO 55001:2014 Asset management—Management systems—Requirements

2.3 *UL Standard:*[4]

ULE 880 Sustainability for Manufacturing Organizations

[1] This guide is under the jurisdiction of ASTM Committee E60 on Sustainability and is the direct responsibility of Subcommittee E60.13 on Sustainable Manufacturing.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from International Organization for Standardization (ISO), ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.

[4] Available from Underwriters Laboratories (UL), 2600 N.W. Lake Rd., Camas, WA 98607-8542, http://www.ul.com.

2.4 *World Wide Web Consortium (W3C):*
eXtensible Markup Language (XML) 1.0 Recommendation [5]
W3C XML Schema Definition Language (XSD) 1.1 [6]

3. Terminology

3.1 Definitions of terms shall be in accordance with Terminology E2114.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *composability, n*—the ability to link individual unit manufacturing processes together to create a network or system of UMPs that can characterize the environmental aspects of a production system or product.

3.2.2 *key performance indicator (KPI), n*—a quantifiable measure or a set of quantifiable measures that a company or industry uses to gauge or compare performance in terms of meeting their operational and strategic goals.

ISO 22400-1:2014

3.2.3 *unit manufacturing process (UMP), n*—the smallest element or sub-process in manufacturing that adds value through the modification or transformation of shape, structure, or property of input material or workpiece.

3.2.3.1 *Discussion*—The UMP is a clearly-scoped and well-defined manufacturing process that produces a component, assembly, or product.

4. Significance and Use

4.1 This guide provides manufacturers a systematic approach for characterizing the environmental aspects of manufacturing processes utilizing formal representations.

NOTE 1—A UMP is formally represented using languages such as eXtensible Markup Language (XML), Unified Modeling Language (UML), or Systems Modeling Language (SysML) to facilitate data exchange, computability, sharing, and communication with other manufacturing and analysis applications. These capabilities support manufacturers in evaluating, documenting, and improving performance.

4.2 This guide provides the required structure and formalism to ensure consistency in characterizing manufacturing processes in a computer-interpretable way enabling effective communication, computational analytics, and exchange of performance information.

NOTE 2—This guide will promote new tool development that can link manufacturing information and analytics for calculating the desired environmental performance measures.

4.3 The guide supports the development of tools to improve decision support capabilities while facilitating the development and extension of standardized data and information bases such as Life Cycle Inventory (LCI) (ISO 14040 series).

NOTE 3—Data collected within manufacturing enterprises can be used to build enterprise-or-sector-specific databases that complement or extend LCI databases (ULE 880). This approach will improve the relevancy and completeness of the data while retaining key links to Life Cycle Assessment (LCA) methods.

[5] http://www.w3.org/TR/xml.
[6] http://www.w3.org/XML/Schema.

5. Unit Manufacturing Process Representation

5.1 The UMP representation utilizes graphical and formal methods in constructing UMP information models for characterizing the environmental aspects of manufacturing processes. Formal methods for acquiring and exchanging information will lead to better consistency in these characterizations and help establish a consolidated database of environmental measurements. Consistency of the characterizations will ensure effective communication of computational analytics and sharing of sustainability data.

5.2 The graphical representation (Fig. 1) is comprised of four elements (inputs, outputs, product and process information, and resources) to systematically identify, collect, structure, and visualize manufacturing information. Structured information of manufacturing processes facilitates data exchange, sharing, and communication with other manufacturing applications such as modeling, simulation, and analysis tools. It can provide process specific information to LCI databases that will support a more detailed and accurate LCA.

5.3 To achieve formal representations of manufacturing processes, UMPs require the adoption of a formal modeling method or language to effectively convey the meaning and intent of processes they characterize. The complete XSD schema [XML Schema Definition Language] intended for an XML [XML 1.0] implementation of UMPs is presented in Appendix X1.

5.4 The basic building blocks of XML Schemas consists of elements and attributes. Elements can also contain other elements, that is, child elements. A data type defines the valid content that child elements and attributes contain.

5.5 Table 1 presents the basic elements used in creating a UMP. Fig. 1 presents the relationships between these basic elements. Besides the attributes, *name*, *description*, and *type* of the UMP, the remaining part of the graphical representation (Fig. 1) is captured in the schema as child elements and includes input (see 5.5.1), output (5.5.2), feedback (5.5.3), product and process information (5.5.4), resource information (5.5.5), and transformation (5.5.6 and 6.5). The UMP Name must be unique among the UMP child elements.

5.5.1 *Input*—Includes all inputs that enter the UMP such as material (for example, raw materials or work-in-progress), consumables (for example, lubrication or forced air), energy and external factors (such as temperature, humidity, particulates, vibration, and shocks) that occur during the manufacture of a product. In the schema, Inputs are described with attributes *name*, *type*, *description*, *category*, and *unit*. *Type* defines the material or energy used as input; it can also be "feedback" which implies that a feedback can be connected. *Description* is a free text explanation. *Category* classifies the input and can be Energy, Material, Consumables, or other external factors. *Unit* quantifies the input to enable conversions, for example, energy, material, or water use.

5.5.2 *Output*—Includes all outputs that exit the UMP model such as products, by-products, waste, and emissions. Output of one UMP model can be an input to another UMP model. In the schema, Outputs are described with attributes *name*, *type*, *category*, and *unit*. *Type* defines the output such as material or

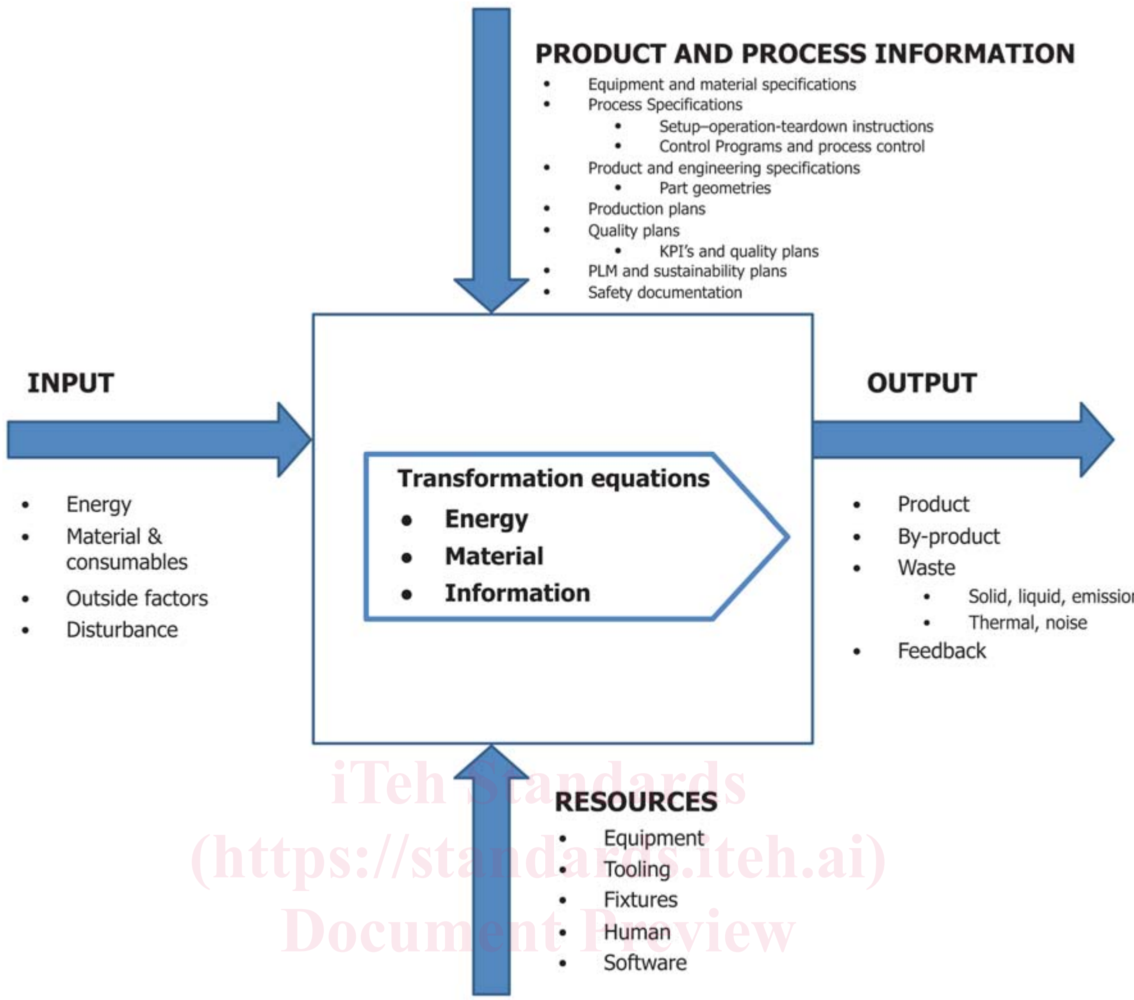


FIG. 1 Graphical Representation of UMP Information

TABLE 1 Element Description for UMP

Attribute	Datatype	Description
name	String	A unique name to identify the UMP
description	String	A freetext description of the UMP
type	String	A specific UMP type, for example, machining, casting, molding
Child Elements		
Input	Element	See Table 2
Output	Element	See Table 3
Feedback	Element	See Table 4
ProductProcessInformation	Element	See Table 5
ResourceInformation	Element	See Table 6
Transformation	Element	See Table 7

TABLE 2 Element Description for Input

Attribute	Datatype	Description
name	String	A unique name to identify the Child within the UMP model
description	String	A freetext description of the Input
type	String	The type of Input, for example, electricity, steelbar, oxygen, or feedback
category	String	Energy, Material, Consumables, or Disturbances
value	Decimal	Numeric value
unit	String	The unit of Input

energy. *Category* classifies the output and can be Product, By-product, Waste, or Emission. *Unit* quantifies the output to enable conversions, for example, energy, material, or water use.

5.5.3 *Feedback*—A feedback is a specific Output of the current process status. Feedback can be used as input back to the current UMP, to another UMP, or to other sets of UMPs models. The element is defined using a *name* and a unit. *Unit* quantifies the value to enable conversions, for example, energy, material, or water use.

5.5.4 *Product and Process Information*—Includes relevant information to enable the transformation (5.5.6) calculations of material, energy, and information. This includes items such as part geometry, material properties, control programs, and process plans. The schema ProductProcessInformation describes attributes *name*, *category*, *description*, *value*, and *unit*. *Category* classifies the Product and Process Information and is user defined. *Value* defines a number. *Unit* quantifies the value unit to enable conversions.

5.5.5 *Manufacturing Resource*—Includes process resources such as equipment, fixtures, tooling, and inspection gauges. The schema element ResourceInformation describes attributes

TABLE 3 Element Description for Output

Attribute	Datatype	Description
name	String	A unique name to identify the Child within the UMP model's Child Elements
description	String	A freetext description of the Output
type	String	The type of Output, for example, information on energy and waste
category	String	Product, By-product, Wastes, Emissions
value	Decimal	Numeric Value
unit	String	The unit of Output

TABLE 4 Element Description for Feedback

Attribute	Datatype	Description
name	String	A unique name to identify the Child within the UMP model
description	String	A freetext description of the Feedback
value	Decimal	Numeric value
unit	String	The unit of the Feedback

TABLE 5 Element Description for ProductProcessInformation

Attribute	Datatype	Description
name	String	A unique name to identify the Child within the UMP model
category	String	A name of a custom category
description	String	A freetext description of the ProductProcessInformation
value	Decimal	Numerical value
unit	String	The unit of the Product Process Information constant

TABLE 6 Element Description for ResourceInformation

Attribute	Datatype	Description
name	String	A unique name to identify the Child within the UMP model
category	String	A name of a custom category
description	String	A freetext description of the ResourceInformation
value	Decimal	The value of the constant
unit	String	The unit of the Resource Information

TABLE 7 Element Description for Transformation

Child	Datatype	Description
Equation	Element	Equation enables transformation

TABLE 8 Element Description for Equation

Attribute	Datatype	Description
category	String	Material Transformation, Energy Transformation, or Information Transformation
set	String	A unique name for a set of equations used by many UMP models. One set of equations should use or calculate Inputs and Outputs of the UMP model. Calculated Inputs and Outputs are dependent.
description	String	A freetext description of the Equation
Child Element		
Content	String	The equations modeling the transformation. References names to child of the UMP model, calculating Inputs or Outputs, or both. For example, Output1 = Input1 * ResourceParameter1; Output2 = Input1 * ResourceParameter2

name, *description*, *category*, *value*, and *unit*. *Category* classifies the manufacturing resource and is user defined. *Value* defines the constant using a decimal number. *Unit* quantifies the value unit to enable conversions.

5.5.6 *Transformation*—Describes the relations between inputs and outputs. Transformation currently includes the element equation as shown in schema (Appendix X1). However, the schema can be extended with other types of transformations, for example, code for simulation or complex functions (6.5). An Equation element calculates inputs, outputs, and feedbacks, using linear equations, with operators such as *, /, +, -, ^, ( ). The attribute set for equations defines a collection of equations. The *Category* of equation calculates material, energy, or information transformations

6. Process Characterization Methodology

6.1 The UMP graphical representation is illustrated in Fig. 1. This is the first step in the Process Characterization Methodology. Section 7 defines composability, the essential capability required for creating a network of linked UMP models through which specific production plans for a part, assembly, or a product (Fig. 2) can be defined.

6.2 The Process Characterization Methodology supports manufacturers in deriving specific UMP models for characterizing the environmental aspects of manufacturing processes. The Process Characterization Methodology is comprised of the steps described in 6.3 through 6.5.

6.3 *Identify UMPs and KPIs:*

6.3.1 Select appropriate UMP/s to be characterized (for example, Fig. 2).

6.3.2 Specify the boundary (Guide E2986) that encompasses one or multiple UMPs to enable the identification and selection of UMP specific elements (5.5).

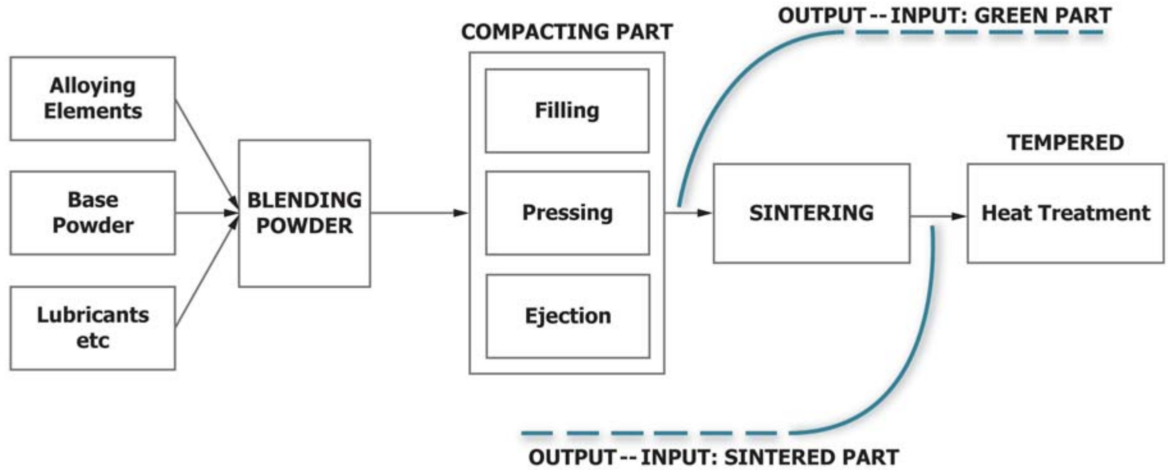
6.3.3 Product and process information can be common to a number of UMPs such as material feed-rate or unique to certain UMPs such as injection molding material injection temperature. Further, additional injection molding information such as part geometry, engineering specifications, number of mold cavities, and material selection provide important information on selecting the appropriate equipment, tooling, and fixtures.

6.3.4 Select the appropriate KPIs ensuring process control and product conformance.

6.4 *Identify UMP Specific Elements:*

6.4.1 Using the graphical and formal representation, one can identify and capture the essential information required to develop the specific UMP models (Fig. 3, for example). This includes the specific inputs, manufacturing resources, product and process information, and outputs for chosen UMP/s.

(a) Identify the Inputs—The inputs that enter the UMP can include intermediate products, work-in-progress (WIP), raw materials, lubrication, energy, and external factors (such as temperature, humidity, particulates, vibration, and shocks) that



The example shows how the output material information of one UMP model becomes the input material information of another UMP model.

FIG. 2 Example of Linkable UMP Models to Compose Powder Metallurgy Production Line

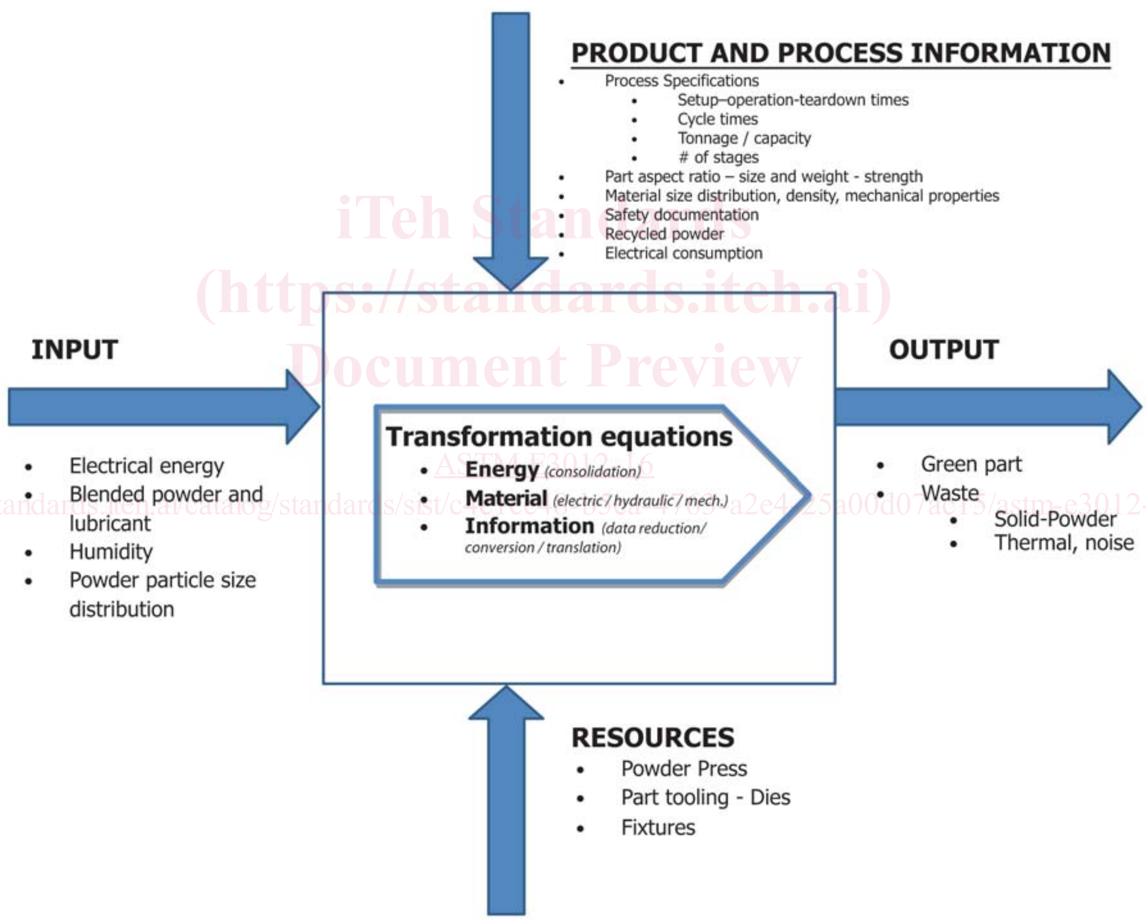


FIG. 3 Graphical Representation of Compacting Process Illustrated in Fig. 2

occur during the manufacture of a product. For the compacting process as shown in Fig. 3, the inputs include the energy, the blended powder, and the lubricant.

(b) Identify the Outputs—The outputs of the UMP include products, by-products, emissions, and waste. For the compacting process example the outputs include the compacted part, generally called the green part and the waste. Wastes for the compacting process are the part rejects and excess powder lubricant mix.

(c) Identify the Product and Process Information—The product and process information includes all relevant information to setup or control the process, or both. Items such as part

geometry, KPIs, material properties, setup and operating instructions, quality plans and charting, and control programs. Fig. 3 shows the candidate product and process information for the compacting process.

(d) Identify the Manufacturing Resources—This includes all process resources such as equipment, fixtures, tooling, and inspection gauges. For the compacting process this would include the presses and the appropriate tooling.

6.5 *Identify the Transformation Functions:*

6.5.1 *Material Transformation*—The UMP material-specific information such as mass change, phase change, structure change, deformation, and consolidation needs to be identified. For the compacting UMP (Fig. 3) the material transformation is 'consolidation.'

6.5.2 *Energy Transformation*—This can include chemical, electrical, thermal, mechanical, and electromagnetic. For compacting UMP, the energy transformation is from electrical to hydraulic to mechanical and thermal.

6.5.3 *Information Transformation*—Information transformations include items such as production metrics (for example, through-put and Overall Equipment Effectiveness - OEE) and environmental metrics (for example, energy, material, water, emissions, and waste). Document the information transformations and the mechanisms for converting the information.

7. Composability of Unit Manufacturing Processes

7.1 To realize the utility of the UMP models, most manufacturers will link a number of UMP models together to describe specific production plans for a part, assembly, or a product (see Fig. 4). This approach will enable manufacturers to extend the measurement of sustainable performance beyond an individual process to a production system or the product itself. This supports the evaluation of alternative methods to produce a part or product.

7.2 Composability will support the construction of a network of unit manufacturing processes, that is, a clearly-scoped and well-defined network or system of UMPs that defines a higher-level UMP or manufacturing system.

7.3 Linking variables are used to define a composed system (Fig. 5). A linking variable is defined by references to source and target UMP name and a name reference to the output and input element within those UMPs. To define such a link the type attributes must match. For example, the representation restricts a link between an output with *type* gas, to an input with the *type* electricity. The unit for the linked input and output is used to convert the actual value.

7.4 The composed system can be computed when all links have been defined by assigning values to the undefined inputs and outputs in UMPs in the composed system. Undefined outputs and inputs are those that are not calculated within the UMP, nor are linked to other UMPs.

7.5 To enable composability, manufacturers should consider the use of a common naming convention or classifiers for the UMP model parameters that facilitates the connection of outputs to inputs and outputs to other outputs, for example, type or ontology matching.

8. Keywords

8.1 characterization; composability; sustainability; transformation; unit manufacturing processes; XSD schema

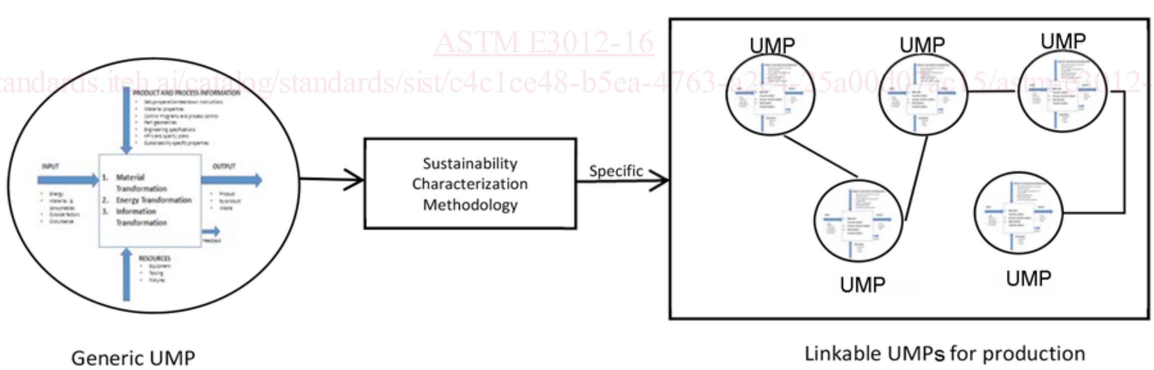


FIG. 4 Overall Schematic Showing Use of Generic Representation to Develop Specific UMPs and Supporting Linkage of Multiple UMPs