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Standard Guide for
Alternative Allocation Approaches to Modeling Input and Output Flows of Secondary Materials and Related Recycling Scenarios in Life Cycle Assessment[1]

This standard is issued under the fixed designation E3199; 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 illustrates alternative allocation approaches that provide options for modeling secondary material flows and related recycling scenarios within a life cycle assessment (LCA) study. It helps practitioners characterize and understand materials recycling across industries; provides the available methodologies for consideration of the environmental impacts that are attributed to material and product flows in LCA; aids in assessment of the overall life cycle of systems and understanding of materials; and supports life cycle management.

1.2 The guide is not intended to contradict or circumvent the LCA provisions of ISO 14025, ISO 14040, ISO 14044, ISO 14067, ISO/TR 14049, or ISO 21930. When conflicts arise related to LCA, the guidance of those ISO standards takes precedence.

1.3 The following seven material-specific appendixes are included:

Title	Appendix
Recycling of Copper	Appendix X1
Recycling of Flue Gas Desulfurization (FGD) Gypsum	Appendix X2
Recycling of Glass	Appendix X3
Recycling of Plastics	Appendix X4
Recycling of Post-consumer (PC) Gypsum	Appendix X5
Recycling of Stainless Steel	Appendix X6
Recycling of Supplementary Cementitious Materials	Appendix X7

1.4 The values stated in SI units are to be regarded as standard. The values given in parentheses after SI units are provided for information only and are not considered standard.

1.5 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

A941 Terminology Relating to Steel, Stainless Steel, Related Alloys, and Ferroalloys

E2114 Terminology for Sustainability Relative to the Performance of Buildings

2.2 *ISO Standards:*[3]

ISO 14001 Environmental management systems — Requirements with guidance for use

ISO 14025 Environmental labels and declarations — Type III environmental declarations — Principles and procedures

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

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

ISO/TR 14049 Environmental management — Life cycle assessment — Illustrative examples on how to apply ISO 14044 to goal and scope definition and inventory analysis

ISO 14067 Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification

ISO 15270 Plastics — Guidelines for the recovery and recycling of plastics waste

ISO 21930 Sustainability in buildings and civil engineering works — Core rules for environmental product declarations of construction products and services

3. Terminology

3.1 *Definitions*—For definitions of general terms used in this guide, refer to Terminology E2114. For general terminology related to life cycle assessment, refer to ISO 14040.

[1] This guide is under the jurisdiction of ASTM Committee E60 on Sustainability and is the direct responsibility of Subcommittee E60.80 on General Sustainability Standards.

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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 American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

3.1.1 *post-consumer, n*—descriptive term covering material, generated by the end-users of products, that has fulfilled its intended purpose or can no longer be used (including material returned from within the distribution chain). **ISO 15270**

3.1.2 *secondary materials, n*—material recovered from previous use or recovered from waste derived from another product system and used as an input in another product system.

3.1.2.1 *Discussion*—Example: recycled scrap metal, crushed concrete, glass cullet, recycled wood chips, recycled plastic granulate.

3.1.2.2 *Discussion*—Secondary material is measured at the point (that is, system boundary) where the secondary material enters the product system from another product system. **ISO 21930**

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *environmental impact, n*—change to the environment, whether adverse or beneficial, wholly or partially resulting from an organization's activity.

3.2.1.1 *Discussion*—Modified from ISO 14001.

3.3 *Acronym:*

3.3.1 *ISO*—International Organization for Standardization

4. Significance and Use

4.1 LCAs can help to identify some of the potential environmental impacts of products or services throughout the entire life cycle. In a life cycle inventory analysis, emissions into the air; discharges into the water and soil; and product, material, and energy flows at all stages of a product's life cycle are compiled and quantified. The resulting life cycle impact assessment (LCIA) converts the quantified parameters into environmental impact categories.

4.2 Options for managing products at their end of life (EOL) can include, but are not limited to, re-using, recycling, recovering, remanufacturing, converting to energy, incinerating, composting, combustion, digestion/respiration, or discarding as waste. Materials enter subsequent life cycle(s), either in the same or in other applications, reducing the input of primary raw material and impacting the amount of waste. LCA will be required to determine if environmental impact reductions are expected to be realized and to what extent for each specific application. The end-of-life management can impact the overall life cycle assessment.

4.3 The application of an allocation method for recycling in life cycle assessments is useful in assessing potential environmental impacts, which may be either beneficial or adverse.

4.4 As part of good LCA practice, practitioners should consider recycling in the sensitivity analysis.

4.5 LCA practitioners are expected to ensure consistency and conformance with the relevant provisions of ISO standards.

4.6 Allocation for recycling can split the flows and impacts between two different product systems.

5. Summary of Guide (LCA)

5.1 While existing guidelines and standards (for example, ISO 14040 and ISO 14044) consistently recommend allocation to account for the environmental impacts of recycling in LCA, there is no further guidance on the recommended methodologies that apply across industries and sectors outside the building and construction sector (ISO 21930). Due to the variety of products that are recycled and the differences of their life cycles, several allocation methodologies have been developed and are currently applied globally. There is no one approach that can be consistently recommended for all materials and products. ISO has standardized its rules for allocation regarding Environmental Product Declarations (EPD) for Building and Construction Products in ISO 21930 and ISO 14025, the general EPD standard. This guide does not override these rules.

5.2 Appendix X1 to Appendix X7 provide examples of existing methodologies applied in different industries for different recycled raw materials and products. These examples complement specific guidance and case studies for recycling in LCA as provided in ISO/TR 14049 and go beyond the specific focus of ISO 14067 on carbon footprinting.

6. Summary of Methods

6.1 There are three primary frameworks for modeling end-of-life recycling in LCA, which are used most commonly by practitioners globally. For all these frameworks, the guidelines for setting system boundaries should be in line with the ISO 14040 series standards. The selection of a modeling approach for secondary materials and recycling scenarios should reflect the goal and scope of the LCA study.

6.1.1 The Recycled content/"cutoff" approach has been utilized in LCA for many years due to its simplicity and modeling ease. The practitioner essentially places no beneficial environmental impact on the recycled content in the production phase of the life cycle of the product being studied, and recycled materials collected at the end of life are sent to the next product system with no environmental impact (beneficial or adverse). The end-of-life collection remains in product system A. The impacts arising from the end-of-life collection processes/activities remain within and are attributed to the primary product system.

NOTE 1—This approach is mandated in ISO 21930.

6.1.2 The end-of-life recycling approach is based on the concept in ISO 14040 of system expansion. Essentially, the practitioner expands the product system A boundary in order to give credit to the first life cycle for the beneficial impact of utilizing a material that is recyclable in its initial use. The material for recycling is a beneficial impact given to product system A. The end-of life approach covers end-of-life material for recycling. It potentially acknowledges recycling that has not yet taken place. The end-of-life approach is often applied to open-loop product systems where materials are recycled and enter into subsequent product systems. When this approach is used, it should not circumvent other relevant ISO 14000 series standards.

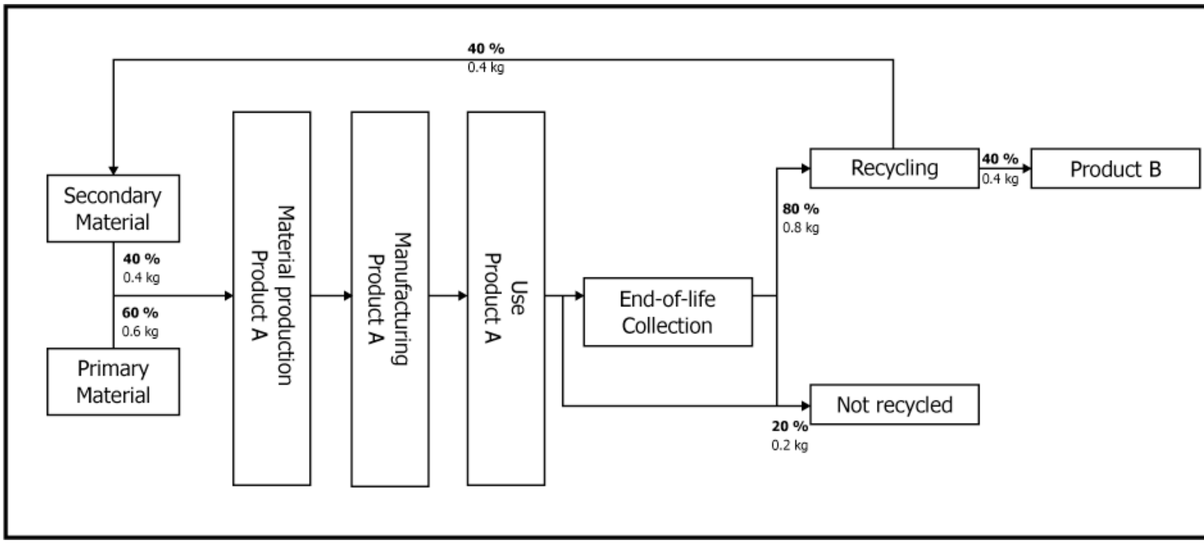

FIG. 1 Material Flows in Common, Idealized Product System

6.1.3 The 50/50 (hybrid) approach uses a combined approach to distribute environmental impacts between product systems. It takes the environmental impacts from end-of-life recycling and collection/sorting, and the environmental impact for the material recycling is divided equally between product system A and product system B. Other splits (for example, 20/80 or 60/40) can also be used and depend on the specific product system and use/recycling patterns.

6.1.4 There are also other approaches available including the waste valuation approach, which accounts for the value of the material at the end of life (**1**).[4]

6.1.5 More detailed guidance on the methodological aspects of the modeling of reuse, recycling, and recovery of energy are provided by the International Reference Life Cycle Data System (ILCD) Handbook of the European Commission (**2**).

7. Synthesis

7.1 The following section demonstrates how the approaches described in Section 6 include recycling in LCAs and how impacts associated with recycling are distributed over the product systems involved. The approaches for including recycling in LCAs are applied to a generic production system. When changes in the inherent properties of materials occur, LCA practitioners should take those into account in accordance with the guidance provided in the 2013 PEF Guidance document of the European Commission (**3**). Product system A is described in Fig. 1. This product system consists of 60 % primary material and 40 % recycled material inputs. Eighty percent of the material from the product system is collected at its end of life and recycled, 20 % is not recycled. Half of the recycled material goes into the same product system A, whereas the other half goes into another product system B. Environmental impacts can occur. There are different approaches on how to allocate/distribute the environmental impacts related to the material recycling between the product systems A and B.

7.2 The recycled content approach (6.1.1 and Fig. 2) builds on the assumption that the secondary material input used in product system A is free of environmental impacts except those that are related to required activities such as collection, sorting, processing, and transport of the materials. In consequence, there are no environmental impacts from recycling the materials after use that can be allocated to product system A. The recycled content approach instead acknowledges the recycling that has taken place.

7.3 The end-of-life approach (6.1.2) assumes that the secondary material input has the same environmental impacts as the primary raw materials. It is therefore modeled as though 100 % of the input is from primary raw materials. The environmental impacts associated with collection, sorting, transport, and processing are considered, as well as the environmental impacts related to the replacement of primary raw materials with recycled materials. All impacts related to recycling are allocated to product system A, as shown in Fig. 3. The end-of-life approach is often used for raw materials and product systems where recycling is significant but does not necessarily take place in the same product system ("open-loop recycling"), which is different than "closed-loop recycling" where recycling takes place in the same product system. For products with an extended lifetime, the end-of-life approach acknowledges the potential environmental impacts from future recycling.

7.4 The 50/50 approach (6.1.3) describes a distribution of environmental impacts over two product systems A and B. The environmental impacts resulting from recycling, preparatory activities (for example, sorting, collection), and the recycling processes (processing) are distributed equally over both the product systems. It also is possible to adjust the environmental

[4] The boldface numbers in parentheses refer to a list of references at the end of this standard.

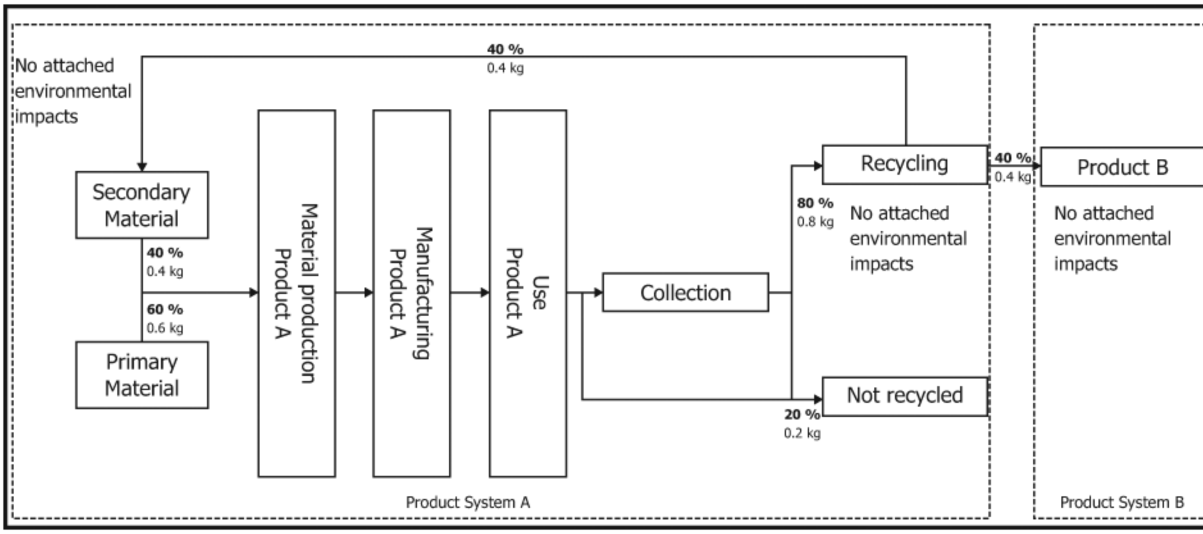

FIG. 2 Recycled Content Approach

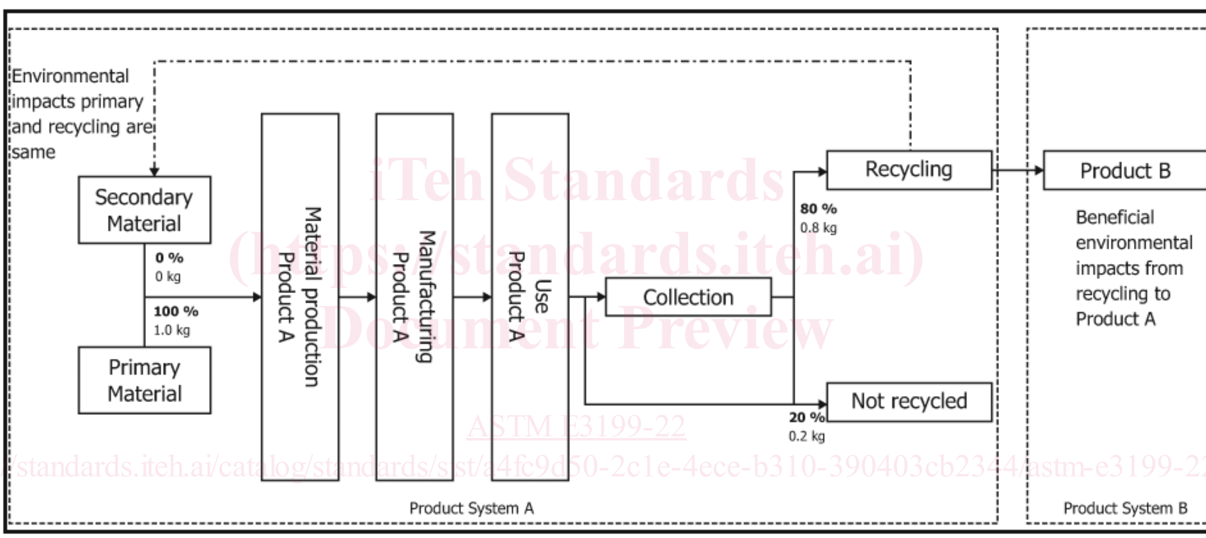

FIG. 3 End-of-life Approach

impacts distribution (for example, 20/80 or 40/60) with appropriate justification. A 50/50 approach is shown in Fig. 4.

8. Appendix Preparation

8.1 This section provides the expected format and content for appendixes and the order in which each section should appear. All appendix examples are expected to be consistent in structure and provide practitioners with concise information. They should not exceed two pages in length.

8.2 Provide a description of the industry or the material discussed in the appendix.

8.3 Explain the implications for LCA studies including the standard recycling practices and relevant parameters influencing the modeling approach, such as:

8.3.1 Supply and demand of the material.

8.3.2 Specific properties and use patterns.

8.3.3 Condition of material, whether a physical or chemical separation from other materials is required for recycling.

8.3.3.1 Feasibility and practicality of the separation process for recycling.

8.3.4 Typical product service life.

8.3.5 Potential changes in material properties during use and recycling.

8.3.6 Collection practices and the recycling process.

8.4 A simplified flow chart as illustrated in Section 7.

8.5 Some of the parameters mentioned above influence the choice of methodology. The approach for including recycling into LCA should be stated and justified. The examples in 8.5.1 show how these parameters help to identify the appropriate approach.

8.5.1 *Supply and Demand Examples:*

8.5.1.1 The end-of life approach can promote increased collection and recycling efficiencies for materials when general demand is steadily growing but the supply of recycled raw materials is more limited relative to that rate of growth due to a long product life, as stated in Bergsma et al (**4**).

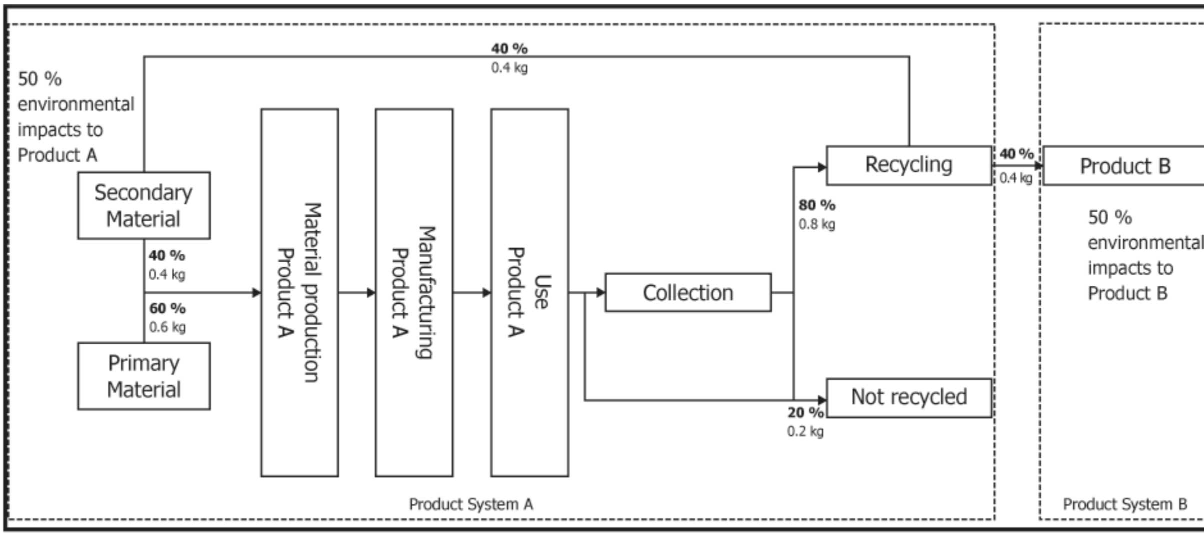

FIG. 4 50/50 Approach

8.5.1.2 The recycled content approach is often applied for those products where supply and demand are in balance or where supply exceeds demand.

8.5.2 *Lifetime of Products Examples:*

8.5.2.1 For products with an extended lifetime, the end-of-life approach acknowledges the potential beneficial environmental impacts from future recycling.

8.5.2.2 The recycled content approach instead acknowledges the recycling that has taken place.

8.6 Third-party documentation or references such as Product Category Rules or journal articles should be provided when available to support inclusion of the appendix and provide practitioners with additional background information.

NOTE 2—All references that are not standards are listed at the end of the standard guide in accordance with ASTM format. Copies of the referenced documents should be supplied with the appendix submission. The referenced document list is not considered part of the appendix length.

9. Keywords

9.1 50/50 (hybrid); allocation; cutoff approach; end-of-life; environmental impacts, life cycle assessment (LCA); recycled; recycled content; recycling; sustainability

APPENDIXES

(Nonmandatory Information)

X1. RECYCLING OF COPPER: METHODOLOGICAL APPROACHES IN LIFE CYCLE ASSESSMENT

X1.1 Copper Use

X1.1.1 Copper is used in many applications, including electricity generation and transmission, electrical and transport devices, and construction materials. Copper use is increasing on a global scale, and recycling plays an important role in meeting this demand. On average, copper contains 30 % recycled content globally (**5**).

X1.1.2 It is estimated that two-thirds of the 550 million tons of copper produced since 1900 are still in productive use (**5**). Of this amount, approximately 70 % is used for electrical applications and 30 % for nonelectrical applications. Around 45 % is used in power generation and transmission, 20 % in construction, 12.5 % in appliances and electronics, 12.5 % in transport, and 10 % in other applications.

X1.1.3 A large percentage (approximately 50 %) of copper is used in a near pure form (>99.9 % copper content). This includes copper products such as copper wire for electrical conductors and sheet for roofing applications. The remainder is mainly used in the form of alloys, where it is mixed with other metals like zinc for brass and tin for bronze.

X1.2 Copper Recycling Pathways

X1.2.1 High copper content products can be recycled directly into new products by direct melting and reshaping, without the need to be re-refined to copper cathode first. This is also valid for end-of-life materials for recycling made from alloys like brass or bronze, when collected and sorted in mono-fraction. As a result, copper and its alloys belong to a group of metals where effective recycling of scrap directly into new products is well established. In addition, even scrap with less than 1 % copper content can be used as a replacement for primary copper sources (ore and concentrate). The potential for copper to be removed from copper-containing scrap is not dependent on the concentration of copper in the mix (Fig. X1.1).

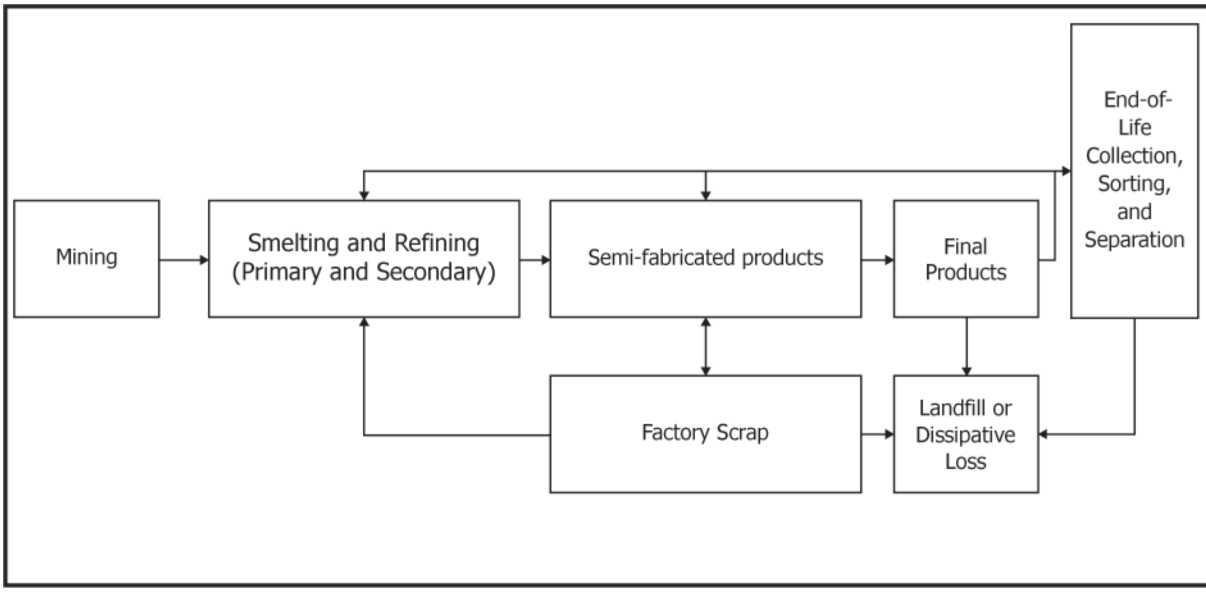

FIG. X1.1 Recycling Paths of End-of-life Products Made from Copper Materials

X1.3 Modeling Recycling of Copper in LCA

X1.3.1 The EOL materials for recycling from copper product systems are almost always fed back into the metal production cycle, be it in the primary plants, secondary plants, or semi-fabrication, such as rod, tube, or wire. This is due both to its recyclability as well as its value. The final product of copper recycling is identical to primary copper (for both the primary and secondary smelter routes) when refined into purified copper. Similarly, copper will be similar in its properties to the original scrap material entering the fabrication process for semi-fabrication. In addition, the copper scrap market has been historically not in oversupply, thus EOL materials for recycling from each product will substitute for primary material and not compete with other EOL materials for recycling. This is likely to remain the case for many years to come, as demonstrated by copper demand projections linked to the growing electric vehicle and electrification trends. Therefore, the end-of-life modeling approach is typically used for copper (**6**). However, the practitioner should take into account market growth and scrap demand and ensure alignment with ISO 14040 series standards when undertaking a study, in order to confirm this approach and ensure justification.

X1.3.2 As shown in Fig. X1.1, recycling is part of both the primary and secondary production of copper cathode. As losses are dependent on technological production processes, a certain amount of primary material (for example, cathode) will still be necessary in fabrication processes of products made from copper materials.

X2. RECYCLING OF FGD GYPSUM: METHODOLOGICAL APPROACHES IN LIFE CYCLE ASSESSMENT

X2.1 FGD Gypsum Overview

X2.1.1 Flue gas desulfurization (FGD) gypsum ($CaSO_4 \cdot 2H_2O$) is used as a raw material for the production of gypsum panel products in place of mined natural gypsum. As a co-product of electricity generation in coal-fired power plants, FGD gypsum is produced in the SO_2 scrubbing operations associated with stack emissions. FGD gypsum is substituted on an equal molar basis with natural gypsum in gypsum panel production. For FGD gypsum to be used in the production of gypsum board, it should be dewatered prior to shipment to the gypsum board manufacturing plant. FGD gypsum typically arrives at the gypsum board manufacturing plant with a higher moisture content than natural gypsum requiring additional drying energy prior to calcination to produce stucco suitable for producing gypsum board.

X2.2 Implications for Life Cycle Assessment

X2.2.1 LCA studies incorporating FGD gypsum use the recycled content approach applying no environmental impacts to the FGD material. This approach is appropriate for a material that is essentially the byproduct of a pollution-control system and for which significant portions of the material have no commercial use and are currently sent to landfill. The approach applied in the LCA modeling of FGD gypsum in LCA is shown in Fig. X2.1. The modeling of FGD gypsum should include environmental impacts of de-watering at the electrical facility and transportation of the FGD gypsum to the gypsum board or manufacturing site (**7**).

X2.2.1.1 Some dewatering of the FGD gypsum occurs at the generation plant, and any energy associated with this should be taken into account (**8**).

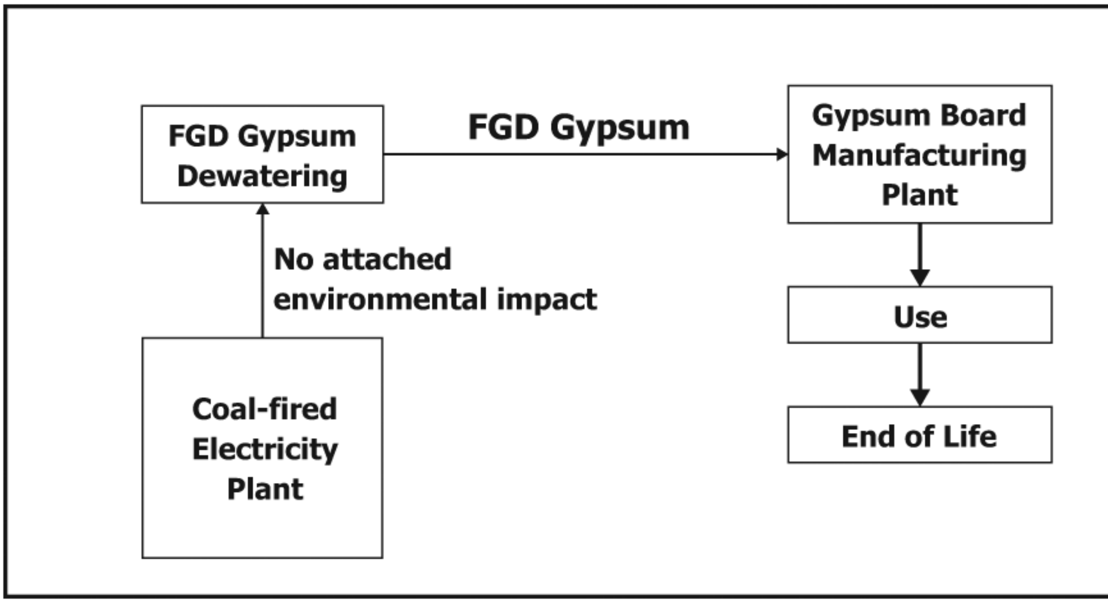

FIG. X2.1 Simplified Scheme for Recycling of FGD Gypsum

X3. RECYCLING OF GLASS: METHODOLOGICAL APPROACHES IN LIFE CYCLE ASSESSMENT

X3.1 Background

X3.1.1 Glass is used in many applications all around the world, the most common being for packaging of food and beverages, for fenestration, and for thermal insulation. Glass, which is not lost due to breakage and is in a form amenable to recycling, may be recycled many times for the same composition. In many cases, compared to raw mineral materials, recycled glass requires less energy to process into new glass products, yielding a net benefit in consumption of energy resources, lifetime of processing equipment, and reduction in greenhouse gases (**9-11**).

X3.1.2 Recycled glass or "cullet" is primarily used by the packaging and fiberglass industries. The glass packaging manufacturing industry requires color-sorted container glass. Fiberglass insulation industry can utilize mixed-colored container glass or flat glass.

X3.1.3 Some recycled glass is not able to be used in the manufacture of new glass bottles and jars or to make fiberglass. This can be because of excessive organic, metallic, or ceramic/stone contamination or because the recycled glass particles are too fine to be processed to meet manufacturing requirements.

X3.1.4 In some cases, there may not be a nearby market for bottle-to-manufacturing recycling. Some of this glass may be used in non-container or non-fiberglass products. These "secondary" uses for recycled container glass can include tile, filtration, sand blasting, concrete pavements, and parking lots.

X3.2 Glass Recycling Pathways

X3.2.1 Glass containers may be recycled at end of life after consumer use (post-consumer) or as part of the manufacturing of a glass item (post-industrial).

X3.2.2 The post-consumer recycling pathway consists of the following steps:

X3.2.2.1 Recyclable glass materials are collected at residential curbside bins, business recycling locations, or local recycling government drop-off centers. These may be sorted at the initial location (single stream) or may be mixed recycling.

X3.2.2.2 The mixed recyclables are collected by trucks and transported to a material recovery facility (MRF), where they are sorted by material type.

X3.2.2.3 The glass recyclables are sent to a glass recycling company. The single-stream glass recyclables may be delivered directly to a glass processing company from the point of collection.

X3.2.2.4 The glass recycling company removes contaminants, sorts the glass by color, and crushes it to the required uniform size (cullet).

X3.2.2.5 Glass cullet is delivered to manufacturers of glass containers and fiberglass insulation for processing into new glass goods.

X3.2.2.6 Contaminants from the MRF glass stream (plastics, ferrous metals, and nonferrous metals) may be recycled to other industries. Organic and ceramic contamination is sent to landfill.

X3.2.3 The post-industrial recycling pathway may consist of the following steps:

X3.2.3.1 Glass cullet may be reused within the manufacturing facility, or

X3.2.3.2 Broken or scrap glass from manufacturing may be sent to a glass recycling company as in step 3 (X3.2.2.3), followed by step 4 (X3.2.2.4) as before.