Addition of End-of-Life Recycling Methodology to GREET® 2022 for Steel and Aluminum

by

J.C. Kelly and C.P. Kolodziej

Systems Assessment Center

Energy Systems and Infrastructure Analysis Division

Argonne National Laboratory

October 2022

CONTENTS

1. Introduction 1
2. Comparison of the End-of-Life Recycling and Recycled Content Methods.......................... 2
3. End-of-Life Recycling Rates 3
4. Implementation in GREET 4
REFERENCES 5

TABLES

Table 1. End-of-life recycling rates for select materials and applications..................................... 4

ACRONYMS

EOLR	End-of-Life Recycling
GREET®	Greenhouse gases Regulated Emissions and Energy use in Technologies
LCA	Life Cycle Analysis
RC	Recycled Content

This page intentionally left blank.

Addition of End-of-Life Recycling Methodology to GREET® 2022 for Steel and Aluminum

Jarod C. Kelly and &

Systems Assessment Group

Energy Systems and Infrastructure Analysis Division

Argonne National Laboratory

October 2022

This memo documents the addition of the End-of-Life Recycling Method for select materials in the GREET® (Greenhouse gases Regulated Emissions and Energy use in Technologies) model for an additional perspective on the life cycle burdens of those materials. The methodological addition is applied to steel, wrought aluminum, and cast aluminum. This allows users to see how end-of-life "credit" from material recycling can impact life cycle burdens. This is in addition to the Recycled Content Method, which has been in the GREET model since it began covering the vehicle material life cycle.

1. Introduction

The GREET® model has historically utilized the Recycled Content (RC) Method (often also called the Cutoff Approach) when determining the embodied environmental burdens of a material. However, in life cycle analysis (LCA), there are other approaches for evaluating and allocating the burdens associated with the production of primary (or virgin) materials and of secondary (recycled) materials. In addition to the Recycled Content Method, is the End-of-Life Recycling (EOLR) Method (also called the Avoided Burden Approach). Both approaches are ISO-compliant and frequently applied to LCA. There are additional methodologies for determining how the burden of primary and secondary materials can be allocated to a product or a suite of products during the course of a material's operational life. However, the two methods discussed here are the most widely used, and thus the addition of the End-of-Life Recycling Method is an important augmentation of the GREET model that allows LCA practitioners to consider two different perspectives on how material lifetimes and recycling can be treated, and they can thus evaluate the differences between these two perspectives.

2. Comparison of the End-of-Life Recycling and Recycled Content Methods

This document is not a comprehensive comparison of the RC and EOLR methods. Interested readers should examine the work of Frischknecht (2010) and Johnson et al.(2013), which both provide detailed perspectives on each, as well as additional context for further allocation approaches. Briefly, Frischknecht identifies that the RC method "*accounts for environmental impacts at the time they occur"* (2010), whereas the EOLR method operates under the basic assumption that the material will likely be recycled in the future and thereby avoid significant resource consumption and pollutant emissions at that time. Thus, the RC method may be thought of as characterizing the system as it currently is (i.e., it identifies how much recycled material goes into the product today) while the EOLR method may be considered prospective (i.e., it identifies the likely recycled material derived from the product in the future). Both offer important perspectives in the LCA space and Frischknecht notes that each is considered ISO compliant (2010).

Mathematically, the RC method can be described as follows. The basic construct to determine the environmental burden of a product composed of primary and secondary material is:

$$m_p b_p + m_s b_s$$

where m is mass, b is an environmental burden, p stands for primary material, while s stands for secondary material. Note that we can reduce this equation with the knowledge that the sum of m_p and m_s is equal to the total mass, or m_t. In this case, we can identify that:

$$m_t = m_p + m_s$$

$$m_p b_p + m_s b_s = (1-\alpha) m_t b_p + m_t \alpha b_s = m_t((1-\alpha) b_p + \alpha b_s)$$

where α is the recycled content of the product. At the limit, we can observe that when α is equal to zero the equation reduces to yield and environmental burden of $m_t b_p$, or exclusively primary material production burdens. But, when α is set to unity, it reduces to $m_t b_s$, or exclusively secondary material production burdens.

We can similarly describe the EOLR method in the following way. The EOLR method assigns full primary burden to the product and the method then credits it for the quantity that can be recycled using a net avoided burden approach (i.e., it includes the difference in burden between primary and secondary production). Mathematically, the environmental burden of a product using the EOLR method is described as:

$$m_t b_p - \beta m_t (b_p - b_s)$$

where the nomenclature used is the same, with the exception that β is the end-of-life recycling rate of this material within the product. We can again reduce this equation, finding that:

$$m_t b_p - \beta m_t(b_p - b_s) = m_t\big(b_p - \beta(b_p - b_s)\big) = m_t((1-\beta)b_p + \beta b_s)$$

Again, at the limit, we can observe that when β is equal to zero the equation reduces to yield an environmental burden of $m_t b_p$, or exclusively primary material production burdens. But, when β is set to unity, it reduces to $m_t b_s$, or exclusively secondary material production burdens. Thus, we can further conclude that if $\alpha = \beta$, then the two equations are equal if the burdens of producing primary and secondary materials are internally equal between the EOLR and RC methods (i.e., b_p for the RC method equals b_p for the EOLR method, and b_s for the RC method equals b_s for the EOLR method).

Note, that this equivalence of b_p and b_s across the two formulations is not necessarily a given. Johnson et al. (2013) highlight this in their work, assuming temporal variance in these values. In this present expansion of the GREET model, we do not assume such temporal variance and assume that the burdens of production for both primary and secondary materials, as applied to the RC and EOLR methods, occur in the same year. This is a simplification of the true situation, but not one that invalidates the approach.

3. End-of-Life Recycling Rates

A review of the literature has identified appropriate rates of recycling for automotive materials at their end-of-life that can be used in the EOLR method. A report from the American Iron and Steel Institute and the Steel Manufacturers Association outlined several end-of-life recycling rates associated with steel from multiple sectors (2021). While the main interest in the present implementation is for automotive steel, we present the others for future consideration in Table 1. For aluminum, the end-of-life recycling rate is described in Kelly and Apelian's analysis of the automotive aluminum sector's recycling (2016). While GREET delineates between wrought and cast aluminum, Kelly and Apelian do not. However, they report that between 80 and 98% of automotive aluminum is recycled at the end of its life, with a weighted average recycling rate of 91%. Since we cannot distinguish between wrought and cast aluminum from the data, we apply the same rate of recycling to both categories in our GREET implementation at this time.

Table 1. End-of-life recycling rates for select materials and applications

Material	Application	End-of-life recycling rate	Source
Steel	Automotive	96%	(American Iron and Steel Institute and Steel Manufacturers Association 2021)
	Construction, structural sections	97%	(American Iron and Steel Institute and Steel Manufacturers Association 2021)
	Construction, rebar	59%	(American Iron and Steel Institute and Steel Manufacturers Association 2021)
	Construction, other	68%	(American Iron and Steel Institute and Steel Manufacturers Association 2021)
	Appliances	78%	(American Iron and Steel Institute and Steel Manufacturers Association 2021)
	Containers	62%	(American Iron and Steel Institute and Steel Manufacturers Association 2021)
	Misc./Other	46%	(American Iron and Steel Institute and Steel Manufacturers Association 2021)
Aluminum	Automotive - Wrought	91%	(Kelly and Apelian 2016)
	Automotive - Cast	91%	(Kelly and Apelian 2016)

4. Implementation in GREET

The 2022 version of the GREET model will include the EOLR methodology in addition to the RC methodology that had previously been the only option. The default settings for methodology will apply the RC method, but users will be able to toggle the EOLR method. The control settings for this will be available in the Mat_Inputs tab, Section 4 of GREET 2. Note that users can select to toggle on steel, wrought aluminum, and/or cast aluminum in any combination. No other materials have EOLR methods applied at this time. Results throughout the GREET 2 model now include an EOL credits section that reports how much credit is obtained for end-of-life recycling.

ACKNOWLEDGEMENTS

This activity was supported by the Vehicle Technologies Office, Office of Energy Efficiency and Renewable Energy, United States Department of Energy under Contract Number DE-AC02-06CH11357. The authors would like to thank Jerry Gibbs of that Office for their guidance and support. The views and opinions of the authors expressed herein do not necessarily state or reflect those of the U.S. Government or any agency thereof. Neither the U.S. Government nor any agency thereof, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights.

REFERENCES

American Iron and Steel Institute and Steel Manufacturers Association. 2021. “Determination of Steel Recycling Rates in the United States.” https://www.steel.org/aisi-and-sma-steel-recycling-rates-report-final-07-27-2021.

Frischknecht, Rolf. 2010. “LCI Modelling Approaches Applied on Recycling of Materials in View of Environmental Sustainability, Risk Perception and Eco-Efficiency.” *The International Journal of Life Cycle Assessment* 15 (7): 666–71.

Johnson, Jeremiah X., Colin A. McMillan, and Gregory A. Keoleian. 2013. “Evaluation of Life Cycle Assessment Recycling Allocation Methods: The Case Study of Aluminum.” *Journal of Industrial Ecology* 17 (5): 700–711.

Kelly, Sean, and Diran Apelian. 2016. “Automotive Aluminum Recycling at End of Life: A Grave-to-Gate Analysis.” *Rep. Cent. Resour. Recovery Recycl. CR3 Met. Process. Inst. Worcest. Polytech. Inst*.