CATRA 2021 Scrap Tire Life Cycle Assessment

Annex II - Circularity Study

1. Circularity Framework
2. Results by Pathway
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Scope 3 Consulting, LLC
scope3@scope3consulting.com

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1 Circularity Framework

The UN Sustainable Development framework recognizes a transition from a “linear economy” to a “circular economy” as a pivotal element of reaching sustainability (United Nations, 2023). A linear economy is one in which materials are extracted from nature, used for one productive purpose, and thereafter disposed of in a landfill or other final disposal. In contrast, a circular economy is one in which resources and materials are systematically recovered at the end of one useful life and somehow made useful for another.

The term “Circularity” was introduced to describe quantitative measurement of the degree to which a production system supports Circular Economy principles. Circularity is promoted by diversion of materials from landfill, by reuse and recycling, and may also be promoted by the use of products with a lower material intensity.

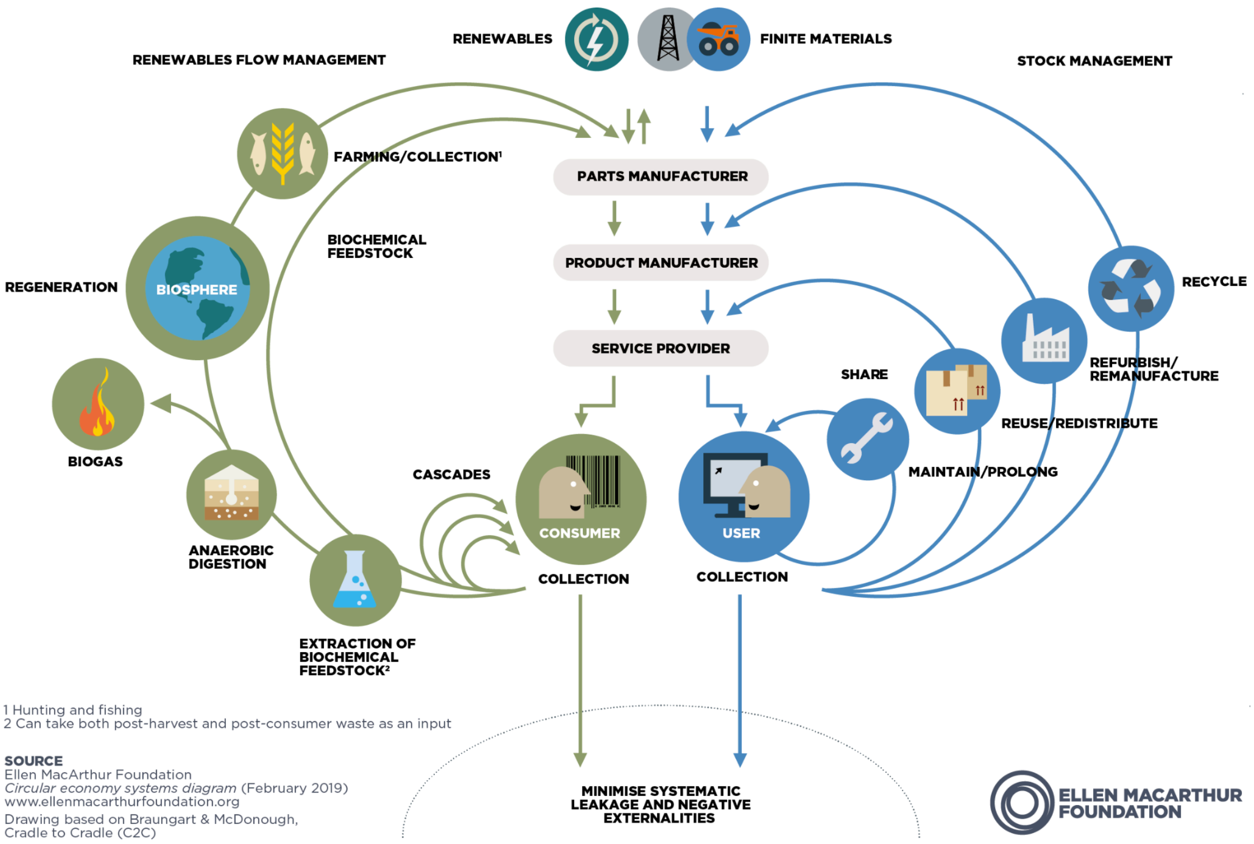
The scrap tire management system in Canada is inherently part of the circular economy because it recovers end-of-life tires and returns them to the economy. The purpose of this study is to evaluate the different tire-derived products that result from scrap tire management with regard to their contribution to a circular economy.

1.1 Circular Economy Concepts

Circularity metrics are useful for assigning a numerical value that represents many qualitative aspects of supply chains and material management. Traditional LCA models and LCA mid-point metrics certainly account for differences in material sourcing and end-of-life. However, it is often difficult to quickly understand how the results are influenced by circularity.

There are many factors that go into defining a measure of circularity. Obvious properties like recycled content and recycling rate are important. But there are other factors that can also be included in a circularity measure. These include: material efficiency in supply chains (beyond simply ‘recycled content’); allocating impacts between material generators and users; defining benchmarks for product lifetime. Because circularity measures aspects of a system that may extend beyond a single product, assessing circularity is not necessarily within the scope of life cycle assessment. For instance, products that are recycled once may not promote circularity to the same extent as products recycled multiple times.

As its name implies, circularity involves the flow of industrial materials through various circular patterns or cycles. These include both technical cycles (products and materials moving through different kinds of industrial activities within the economy) and biological cycles (products and materials moving between the economy and regenerative natural systems). Figure 1 shows a depiction of these two kinds of cycles in relation to the industrial economy.



1 Hunting and fishing
2 Can take both post-harvest and post-consumer waste as an input

SOURCE
Ellen MacArthur Foundation
Circular economy systems diagram (February 2019)
www.ellenmacarthurfoundation.org
Drawing based on Braungart & McDonough,
Cradle to Cradle (C2C)

Figure 1 Biological and technical cycles in the circular economy. From Ellen MacArthur Foundation (2019).

1.2 Methodology

[The Material Circularity Index (MCI) developed by the Ellen MacArthur Foundation is the most commonly used circularity metric, and it is the methodology we adopt. We believe that a circularity measure should, at minimum, consider these key aspects of circularity:

- Primary (virgin) material mass flow: How much a product system depends on the extraction of new resources
- Waste generation: How much of a product's mass is disposed, with the attendant loss of the potential for re-use.
- Biological cycling: If a material is sourced from a sustainable or regenerative biological system, this could have a different circularity score than virgin mineral resources.
- Lifetime and utility: If there are two products, made with the same material, with the same mass, and one product lasts, on average, twice as long as the other, the more durable product should be considered more circular than the other.

The MCI meets these requirements (EMF, 2019), and has the benefit of being relatively simple, and completely transparent. The MCI ranges from zero (not circular) to one (most circular).

Many other methodologies have been introduced for measuring circularity. Some of these methods expand the scope of circularity to include energy and other resource use in the material supply chains of products. We deem this unnecessary, since these resource use metrics are often included in LCA studies. Other methods are more narrowly focused on recycled content and recycling, and so do not account for differences in durability or re-use (D'Adamo et al., 2024; Palomero et al., 2024; Saidani et al., 2019).

The MCI takes a reasonably nuanced, but transparent approach to deal with the perpetual question of how to quantify chained loops (material is looping, but there are many individual market participants along the path). The functional approach provides a linkage between two types of system attributes that affect circularity. Specifically, the methodology provides that reducing linear material flow by some factor (*k*) should have the same effect on the circularity score as changing the lifetime by the same factor (*k*).

Furthermore, the function of utility provides that a fully linear product does not receive a score of zero. This allows for a product to be 'worse' than the fully linear case, for example, for a product with fully linear material flows (i.e. no recycled content used, no recycling or recovery at end of life), but with a lifetime that is worse than the industry average. Finally, for products that would otherwise get a negative MCI score (e.g. because of poor lifetime or utility), these are truncated so all final scores are between zero and 1 (inclusive).

Figure 2 illustrates how the MCI is computed for products with different circularity characteristics.

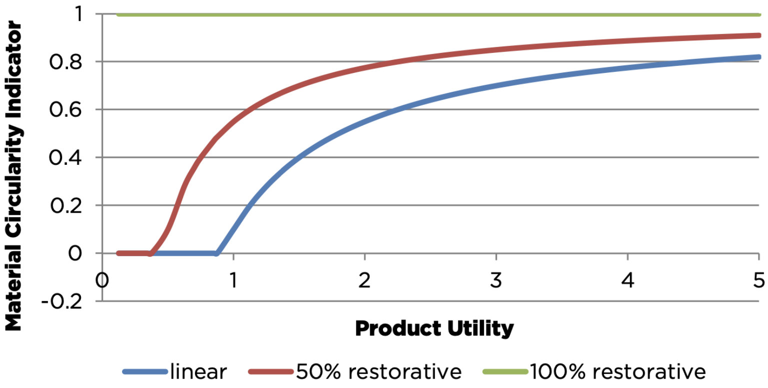


Figure 2 The MCI for different hypothetical product systems having different types of circularity.

1.3 Calculating the MCI for Scrap Tire Products

The MCI is calculated using a mathematical equation based on approximately 20 parameters describing different aspects of the product system, including its mass, reuse/recycled content, likelihood of downstream reuse and recycling, utility compared to similar products, and other aspects.

The following are particularly important for the tire recycling system:

M	Total mass of the product
F_R	Fraction of mass of a product's feedstock from recycled sources
E_F	Efficiency of the recycling process used to produce recycled feedstock for a product
C_R	Fraction of a product being collected to go into a recycling process (downstream)
L	Normalized average lifetime of a product (as a multiple of industry average)

Determining the MCI for each tire-derived product requires specifying these (and other) parameters and then applying the methodology.

For this study, all the products are normalized to 1000 kg of tires, except asphalt modification, which was represented as 1000 kg of modified asphalt product.

The recycled content fraction (F_R) accounted for the presence of non-tire-derived materials such as new retread rubber, binder material, dyes and paints, and steel linkages in blasting mats.

Efficiency of the recycling process (E_F) indicates waste lost during collection and recycling. For the tire recycling system, this factor was taken to be 94% for manufactured products, and 99% for TDA. The recycling efficiency includes recovery of steel and tire-derived fuel.

The collection rate (C_R) indicates the likelihood that the present product is collected for recycling at the end of its *next* life.

The normalized product lifetime (L) does not report actual life in years, but instead reports the multiple of the alternative product’s life.

Table 1 shows the parameters used to describe tire-derived products in the top-half, and comparable displaced products in the bottom half. Below we discuss each class of product briefly.

Tire-derived Products

Both new tires and retreaded tires have the feature of a high collection recovery rate of $C_R = 0.85$ because of scrap tire management. Additionally, the efficiency of collection E_F was taken to be 0.8 because approximately 15% of the weight of each tire is lost during use, leaving 85% to be recovered. This combines with the recycling recovery rate of 94% to give a parameter value of 0.8.

Crumb, mulch, TDA, and molded products are assumed to be made almost entirely of recycled rubber, while steel and fiber are also assumed to be recovered. In the case of molded products, 4% of the weight is taken to be binder; for mulch, 2% is taken to be coatings.

Table 1 Circularity parameters for tire-derived products.

	M (kg)	F_R	E_F	C_R	L
Tire-Derived Products					
Retreaded Tire	1000	80%	80%	85%	0.8
Crumb, infill	1000	100%	94%	20%	1
Molded product	1000	96%	94%	20%	1
Molded product, recovered	1000	96%	94%	80%	1
TDA (geotech)	1000	100%	99%	10%	1
TDA (alternative daily cover)	1000	100%	99%	0%	1
Blast Mat, Tire derived, 5.1 sq.m	1000	90%	94%	10%	1.5
Tire-derived mulch	1000	98%	94%	0%	2.5
Fiber, TDF, 35 GJ	1000	100%	94%	0%	1
1.2 meters of roadway (RMA)	1000	12%	94%	20%	1.2
Displaced Products					
(new tire)	1000	0%	80%	85%	1
(Acrylic coated sand infill)	1000	0%	80%	0%	1
(Rubber product)	1000	0%	95%	20%	1
(Concrete)	1800	10%	95%	10%	1
(Gravel)	1700	0%	1%	0%	1
(blast mat, steel, 5.1 sq.m)	410	40%	95%	75%	1
(wood chips, certified, recovered)	920	0%	90%	40%	1
(wood chips, certified)	920	0%	90%	0%	1
(wood chips)	920	0%	90%	0%	1
(conventional fuel, mix, 35 GJ)	1100	0%	100%	0%	1
1.2 meters of roadway (conventional)	1000	10%	100%	20%	1

For Molded products, we include two alternatives for the collection rate (C_R) parameter– ordinary molded products are assumed to be collected for recycling at a low rate (20%) while the “Molded product, recovered” is given a collection rate of 80%, comparable to tires themselves. Tire derived mulch is assumed to have 2.5 times the lifetime of conventional mulch.

Blasting mats are expressed in terms of the expected surface area from 1,000 kg of tire, according to the parameters developed for the study. This value is equal to 5.1 square meters. The same value is used to model conventional steel blasting mats. Tire-based blasting mats are assumed to have 1.5 times the lifetime of steel blasting mats.

TDA used in geotech applications is given a low but non-zero likelihood of being collected and reused (10%). Likewise, roadway use is given a low likelihood of collection (20%) and use as Recycled Asphalt Pavement (RAP).

For the Roadway use case, the recycled content of 12% indicates an assumption that RAP makes up 10% of the roadway, while the recycled crumb rubber makes up an additional 2%.

Tire-derived fuel is modeled as recovered fiber, having a high energy intensity of 35 GJ/tonne.

Displaced Products

Many of the assumptions around displaced products mirror those of the conventional products, except they are made up of minimal or no recycled content (F_R). Exceptions include concrete and roadway, each of which is assumed to have some recycled aggregate or asphalt, and blast mats, which are assumed to be made of conventional steel which contains recycled content.

Several displaced products require a larger mass to meet the equivalent functionality of 1,000 kg of tires. Gravel, concrete, and conventional fuels all require more material, whereas wood-chip mulch requires slightly less and steel blast mats require substantially less material. In both cases, the tire-derived alternatives make up for their higher mass by having a longer lifetime (L).

Wood chips are described as three different possibilities indicating different levels of circularity. The most highly-circular wood chips (“wood chips, certified, recovered”) are assumed to be generated from sustainably managed forests, and are also assumed to be recovered at end of life. The intermediate tier, “wood chips, certified”, are generated from sustainable forestry but are not recovered. Finally, conventional “wood chips” have neither sustainable production nor recovery. 40% of wood chips are assumed to be dissipated into the environment and to decay naturally.

2 Circularity Results by Pathway

We assessed the MCI score for nine different tire-derived products and ten different displaced products. The results are shown in Table 2, and graphically in Figure 3. The results show that tire-derived products almost universally have higher MCI scores than their conventional counterparts.

The highest-scoring tire derived product is “molded product, recovered,” which is a molded product that is itself collected for recycling at the end of life. Retreaded tires, mulch, and blasting mats round out the top four tire-derived products. These high scores are generally driven by the tire-derived products’ relatively longer lifetimes compared to the conventional counterparts.

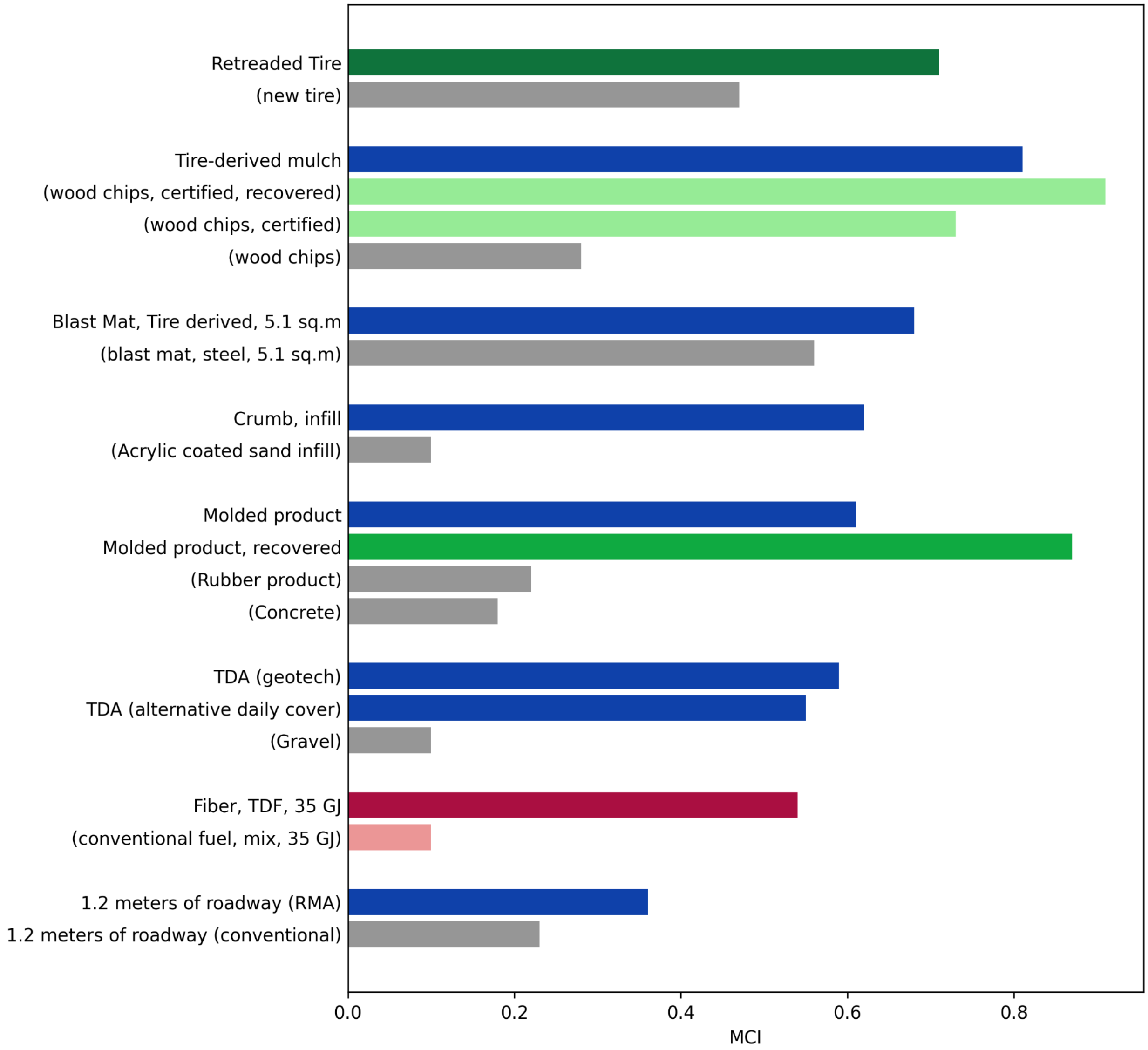


Figure 3 Material Circularity Indicator (MCI) for various tire-derived products and their displaced analogues. Entries are ordered by decreasing circularity.

Table 2 Circularity indicator results for tire-derived and displaced products. *V* indicates the amount of virgin material extracted; *W* indicates the amount of final waste disposed.

	V (kg)	W (kg)	**MCI score**
Tire-Derived Products			
Retreaded Tire	200	271	**0.75**
Crumb, infill	0	852	**0.62**
Molded product	40	836	**0.61**
Molded product, recovered	40	251	**0.87**
TDA (geotech)	0	906	**0.59**
TDA (alternative daily cover)	0	1005	**0.55**
Blast Mat, Tire derived, 5.1 sq.m	100	954	**0.68**
Tire-derived mulch	20	1031	**0.81**
Fiber, TDF, 35 GJ	0	1032	**0.54**
1.2 meters of roadway (RMA)	882	814	**0.36**
Displaced Products			
(new tire)	1000	171	**0.47**
(Acrylic coated sand infill)	1000	1000	**0.10**
(Rubber product)	900	820	**0.22**
(Concrete)	1620	1643	**0.18**
(Gravel)	1700	1700	**0.10**
(blast mat, steel, 5.1 sq.m)	246	138	**0.56**
(wood chips, certified, recovered)	0	184	**0.91**
(wood chips, certified)	0	552	**0.73**
(wood chips)	920	552	**0.28**
(conventional fuel, mix, 35 GJ)	1100	1100	**0.10**
1.2 meters of roadway (conventional)	900	810	**0.23**

In contrast, the otherwise highly-circular “retreaded tire” route has a somewhat lower than expected circularity score, in part because of the assumption that it has a shorter service life.

Tire-derived fuel is seen to be considerably higher-scoring (0.54) than its linear counterpart, which scores 0.1. Even though combustion is a final use, with no possibility of further cycling, the use of recycled material as fuel has a higher score because it reduces resource extraction.

The use of crumb rubber in rubber-modified asphalt is perhaps the most surprising, resulting in the lowest circularity score for any tire-derived product, at 0.36. This result is due to the way the indicator is designed, focusing on the overall product and not only the tire-derived portion. The presence of crumb rubber both increases the fraction of material that is recycled and also increases its service life. Thus the RMA roadway has a considerably higher score than the conventional roadway (which scores only 0.23) - but it is still lower than other tire-derived products.

Among the conventional products, wood chips from sustainable forestry have the highest circularity score and are the only product that has a higher score than any tire-derived product. Non-sustainable-forestry wood chips, by contrast, have an unremarkable score.

Tires themselves have the next highest score, owing to their high likelihood of collection. Steel blasting mats are the next-highest because they both contain recycled content and are likely to be recycled. Most other conventional products score very low (around the minimum score of 0.1 for fully linear products).

3 Provincial Circularity Indicator

The tire-derived products resulting from each province's management of scrap tires can be combined together to form a Provincial Circularity Indicator PCI. The indicator is a weighted sum of the circularity scores of each individual tire-derived product:

$$PCI = MCI_1 \cdot s_1 + MCI_2 \cdot s_2 + \ldots$$

$$\text{where } s_1 + s_2 + \ldots = 100\%$$

This enables a cumulative MCI indicator to be computed over the entire provincial output. This metric can be computed for each study year or other period. This provides another view of the results of scrap tire management efforts.

Table 3 shows a summary of the tire-derived products generated by all of the study's 2024 participants, along with their MCI score and their share of total production. The cumulative MCI score is shown in the bottom row. Provincial reports include province-specific versions of this chart.

Table 3 Tire-derived products, their MCI scores, their shares of total production by participating provinces, and cumulative MCI scores for each year.

	MCI	2019	2020	2021	2022	2023
Crumb rubber, tire-derived	0.62	40 %	40 %	44 %	46 %	48 %
Molded Product	0.61	21 %	16 %	20 %	20 %	20 %
Heat from combustion, tire-derived fuel	0.54	9 %	9 %	7 %	6 %	5 %
Retreaded tire	0.71	7 %	1 %	2 %	1 %	1 %
Shred, tire-derived	0.59	6 %	18 %	8 %	10 %	8 %
Blast Mat, Tire derived	0.68	5 %	4 %	5 %	4 %	5 %
Processing waste	0.54	5 %	4 %	5 %	5 %	6 %
Mulch, tire-derived	0.81	3 %	3 %	4 %	2 %	2 %
Sidewalls, Tubes, other	0.55	0.0 %	0.0 %	0.0 %	0.0 %	1 %
Cumulative MCI Score		**0.62**	**0.61**	**0.62**	**0.61**	**0.61**

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