Scrap Tire Recovery and Recycling in British Columbia, 2017–2020

CATRA 2021 Scrap Tire Life Cycle Assessment

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for CATRA / TSBC

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Version 2.2

July 6, 2022

Contents

This report has been updated:

2.1 – April 13, 2022 – Release to province

2.2 – July 6, 2022– Incorporate final critical review comments

Executive Summary

This report presents estimates of the environmental performance of scrap tire management in British Columbia. Scrap tire flows are described over the full study period (2017 through 2020), and environmental performance is reported for 2020. A summary is shown in Figure ES.1.

The report compares impacts resulting from program activity ("incurred") against the impacts of competing products that may be avoided through the use of tire-derived materials ("displaced"). The net comparison between these two amounts represents an estimate for the potential environmental benefits of scrap tire management.

Findings:

- 205.4 kt (kilotonnes) of scrap tires were managed in British Columbia over the study period (2017 through 2020).
- During 2020, 51.7 kt of scrap tires were recycled to produce Crumb (55.0%), Mulch (21.4%), TDF fibre (14.8%), and TDF whole tires (8.8%).
- During 2020, scrap tire management and production of tire-derived products resulted in a global warming impact of 37.0 kt CO_2-eq. Potentially avoided impacts of the displaced products are 77.6 kt CO_2-eq. This results in a net savings of 40.6 kt CO_2-eq, equivalent to 178 million kilometers of vehicle travel[1].
- Five out of six impact categories showed a potential net improvement during 2020.
- Out of 21 routes for used tire processing, 16 showed the potential for a net reduction in GHG emissions.

[1] Assuming a fuel economy of 8.1 liter/100km

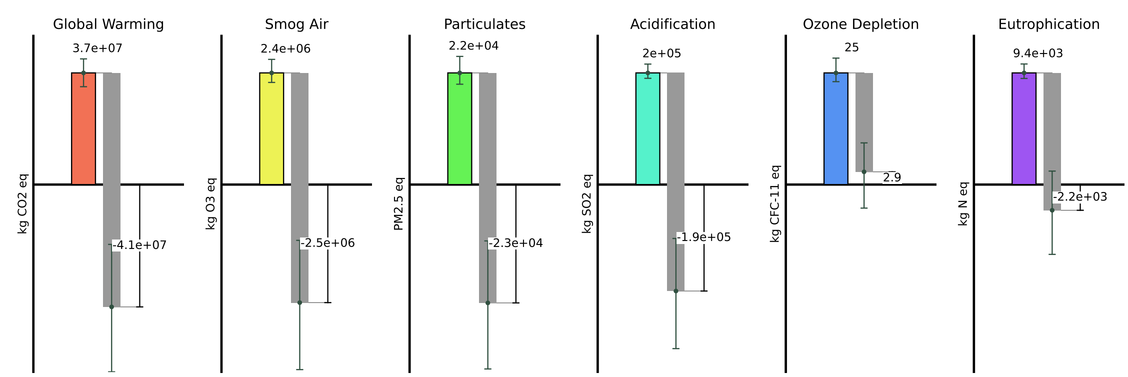

Figure ES.1: Environmental impacts of managing 51.7 kt of scrap tires in BC during 2020. Incurred impacts are shown in the colored bar; potentially avoided impacts due to tire recycling, are shown in gray. The net total is indicated on each panel.

Life Cycle Modeling:

The results depend on primary data collected during the study, values reported in literature, widely used life cycle databases, and modeling assumptions. Displacement relationships are the linchpin of any calculation of a "net" benefit (incurred minus displaced impacts), and are based on physical relationships, as well as assumptions regarding economic interactions. Displacement factors are shown in Table B-1, and more details are available in the full "CATRA 2021 Scrap Tire Life Cycle Assessment" ISO report.

Provincial Summary:

- Tires were collected from cities throughout the province and delivered to processors in the Vancouver area.
- Almost all tires were converted to crumb and mulch by Delta-based Western Rubber Products inc, which is a division of US-based Liberty Tire Recycling. About 7–10% of collected tires, as well as all tire-derived fiber, were combusted for fuel at in a cement kiln operated by Lehigh Northwest Cement.
- BC was the only province in the study that did not report any tire-derived aggregate production.
- The end-use of tire-derived crumb was determined based on a nation-wide market model to include primarily molded rubber products, followed by pour-in-place surfaces, displaced primary rubber, turf infill, and rubberized asphalt.
- TDF combustion was the largest contributor to environmental impacts in the province, followed by reverse logistics.
- Both the Delta and Chemainus facilities provided high-quality data sets to the facility inventory survey.
- The overall quality of the tire collection and processing data from British Columbia was high. The biggest gaps had to do with matching collection records to tire types, and to determining the end-uses of tire-derived crumb.
- A summary of the performance of all 21 different modeled end-uses for tires in BC is shown in Section 4.5 and in tabular format (Table A-2).
- For processors that produce molded and pour-in-place products, the selection of binder used in the product is the most influential factor on the environmental performance of the tire-derived molded product. A follow-up LCA study on the tradeoffs of different molded product formulations could be valuable.

1 Introduction

This report presents estimates of the environmental performance of scrap tire management in British Columbia for 2017 through 2020. The intended audience of this report is Tire Stewardship BC. This provincial report was produced as part of the Scrap Tire Life Cycle Assessment project commissioned by the Canadian Association of Tire Recycling Agencies (CATRA). The study was conducted by Scope 3 Consulting LLC, based in Santa Barbara, CA, USA.

About 420,000 tonnes of scrap tires were managed in Canada in 2020 (Table 1). British Columbia accounts for about 12% of that total, making it the fourth largest provincial tire flow, after Alberta.

Table 1: Total scrap tire collections per year by province (tonnes). Phase 1 includes a mix of fiscal and calendar year periods (2017). Note that primary Ontario data were not available for 2020, and the value shown here is from the CATRA website.

	Phase 1	2018	2019	2020
Ontario	141,738	163,503	145,924	*159,325**
Quebec	92,504	94,485	102,976	93,980
Alberta	64,459	68,730	70,463	69,655
BC	49,650	51,419	52,622	51,738
Manitoba	19,186	18,838	17,662	18,638
Newfoundland	5,996	6,255	6,366	6,382
Saskatchewan	NA	18,002	20,593	20,509
Total (t)	373,533	421,232	416,606	420,227

* Estimated Ontario collections as reported on the CATRA website

1.1 Scrap Tire Management in British Columbia

Since 2007, scrap tires in BC are managed through an industry-led Product Stewardship system. Tire Stewardship BC holds the responsibility for the operation of the scrap tire recycling program, in accordance with its Extended Producer Responsibility Plan, approved by the BC Ministry of Environment. TSBC collects an Advance Disposal Fee (eco-fee) on every new "regulated" tire sold in BC (or on a vehicle imported from the U.S.). The fees are applied to the operation of the program, including transportation, processing, and manufacturing incentives. Eco-fees are set by TSBC on the following types of tires:

- Passenger and light-truck tires (PLT) include tires designed for use on automobiles and pickup trucks, smaller trailers and RVs, and motorcycles;
- Medium truck tires (MT) are commonly known as Commercial Truck Tires and include tires for trucks, buses, and larger RVs not marked "P" or "LT";
- Agricultural tires (AG) include smaller drive and rolling tires up to 16", in addition to drive wheel tires between 16.5" and 25.5";

- Logger Skidder tires (LS) incldue forklift tires, bobcat/skid steer tires over 16.5" and Agricultural Drive tires 26" and over.

Small tires that are not included in the scrap tire program include those from cycles, wheelchairs, and wheelbarrows. Aircraft, Construction equipment, and Industrial tires are also not included.

Tires collected in British Columbia are processed in-province at three facilities. Western Rubber Products Ltd. produces tire-derived crumb and mulch products in its processing facility in Delta. The crumb rubber is used to manufacture products such as playground surfaces, rubber flooring tiles, and agricultural mats. Western also operates a marshalling and shredding facility in Chemainus which collects tires from Vancouver Island and transfers shredded tires to the mainland. Lehigh Northwest Cement consumes whole tires, as well as tire-derived fuels, for use as TDF in a cement kiln.

2 Goal and Scope

This is version 2.2 of the Scrap Tire Life Cycle Assessment (LCA) study for British Columbia. Version 1 was delivered in spring of 2020 to participating provinces. Version 2.0 was submitted for critical review in October, 2021. This is the final version, incoporating two rounds of critical review comments.

- Study Commissioner: Canadian Association of Tire Recycling Agencies (CATRA), on behalf of its participating members
- Study Practitioner: Scope 3 Consulting LLC; Brandon Kuczenski and Kyle Meisterling, directors
- Target Audience: Each provincial report is targeted to the provincial organization staff and board of directors.

The report includes comparative assertions:

- about the relative significance of impacts from recycling activities compared with the potential benefits of avoided activities;
- about the relative impacts of different displaced material systems (wood chips, mined aggregate, molded rubber, etc.)

ISO 14044 requires that LCA results be critically reviewed before they are used to support comparative assertions disclosed to the general public. This provincial report is based on a critically reviewed study. For further details on the review, please see Section 2.2.3.

2.1 Goal of the Study

The goal of the study is to estimate the relative environmental impacts and benefits of various options for responsible management of scrap tires in participating provinces throughout Canada. The study is designed so that the national results, as well as the provincial-scale results are calculated using a consistent methodology and data collection. The study results are meant to provide information to provincial management associations and boards of directors about the relative magnitudes of environmental impacts and benefits that may arise as a consequence of scrap tire management activities.

2.2 Study Design and Methodology

This provincial report is prepared using the same methodology as the national-scale CATRA report, which is undergoing critical review for compliance with ISO standards. These provincial results are calaculated using province-specific scrap tire volumes, processing routes, and energy mixes. In this report, the specific circumstances of British Columbia are reported in detail, along with province-specific results. The methods, assumptions, and background data are fully described in the “CATRA 2021 Scrap Tire Life Cycle Assessment”, which was preparted according to ISO 14044 and is currently undergoing critical review. The complete ISO report with critical review is available from CATRA and the study authors. The overall study spans seven Canadian provinces (BC, AB, SK, MB, ON, QC, NL).

2.2.1 Material Flow Basis

Each provincial study is based on information describing hauling and processing of scrap tires provided by the provincial organization or its constituent processors. The synthesis and modeling based on that data is known as a material flow analysis (MFA). The material flow data is used to estimate the transportation requirements and tire-derived products specific to each province’s situation and to the time period of interest.

2.2.2 Facility Surveys

The energy and resource requirements of scrap tire processing were determined through a confidential survey that was distributed to processing facilities throughout Canada. Data from 19 facilities, covering a total of 421,000 tonnes of scrap tire processing, were used to build the resource requirement invenotry of scrap tire processing. More information about the methods and results of the facility survey and resulting inventory are available in the main report.

2.2.3 Critical Review

This report is based on an LCA study that underwent critical panel review in accordance with ISO standards. The purpose of critical review is to ensure that the study was performed in a manner consistent with ISO methodology and best practices, and that the conclusions of the report are supported by the data presented.

The review found that the study was in conformance with ISO standards, the methods used to carry out the LCA are scientifically valid, and the findings are supported by the information presented. The ISO report, as well as the reviewers' comments, are available upon request from CATRA as well as from Scope 3 Consulting. Please note that although the provincial model and findings for British Columbia were included in the scope of the review, this provincial report itself was *not* reviewed.

2.2.4 Changes After Critical Review

There were four significant changes between Versions 2.1 and 2.2:

1. For the **TDF-coal** route, the reviewers identified that there was a mismatch between the thermal efficiency assumed for TDF combustion and the thermal efficiency of coal combustion, resulting in an incorrect comparison between TDF combustion and displaced coal combustion. After the correction, the performance of the TDF-coal route has become *less favorable*.

2. Small adjustments were made to the model used for the combustion of tire-derived fiber. The model had formerly included some aspects of incinerator operation that were not consistent with the operation of a cement kiln. After the correction, *no significant differences* are visible in the results.

3. The physical displacement factor between tire-derived molded rubber products and concrete products was corrected, resulting in a *more favorable* outcome for this comparison with respect to all indicators, including a sign reversal (net-unfavorable becoming net-favorable) for global warming. Note: this change was not a result of critical review.

4. The comparison between avoided CO_2 emissions and vehicle kilometers included in the Executive Summary has been updated. In version 2.1, the comparison was based on an unduly high fuel-efficiency assumption (6.3 liter/100km or about 34 miles per gallon), resulting in an inflated estimate for the number of vehicle kilometers avoided. After the correction, a more reasonable value of 8.1 liter/100km or about 26 miles per gallon is used. Note: this change was not a result of critical review.

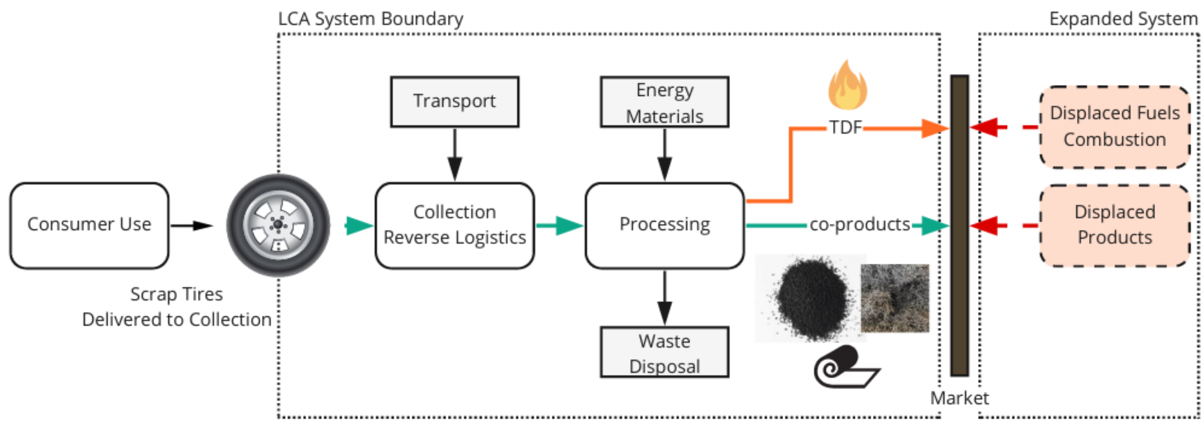

Figure 1: Basic system boundary diagram. The LCA system boundary includes activities related to scrap tire management, while the expanded system boundary includes activities displaced by the products of scrap tire management.

2.3 Scope of the Study

2.3.1 Function of the System under Consideration

The primary function of the system under consideration is to provide responsible management of the scrap tires generated within province of British Columbia during 2017 through 2020. The focus year is 2020.

2.3.2 System Boundary

The systems modeled in the study include the handling of tires that have been returned to a designated collection point, their delivery to a processing facility, the production of tire-derived products, and the downstream effects of tire-derived products and materials on other markets. The production of scrap-tire-derived products is assumed to "displace" the production of alternative products, as detailed in the Inventory Modeling section in the Background Report. Figure 1 depicts two distinct systems that interact: the scrap tire management activities (LCA System Boundary) and potentially displaced products (Expanded System). A list of all tire recycling routes included in the study is shown in Table B-1.

Figure 2 shows an illustration of the parts of the study, highlighting the processes that were active in British Columbia. Red outlines indicate activities displaced by tire-derived products, due to scrap tire processing in British Columbia during 2020.

2.4 Life Cycle Impact Indicators

This study presents impact scores for six life cycle impact indicators drawn from the TRACI 2.1 LCIA methodology.

- **Climate Change** (kg CO_2-equivalent) indicates the radiative forcing potential of greenhouse gas emissions on a 100-year timescale.
- **Smog Formation** (kg O_3-equivalent) indicates the potential creation of ground-level ozone from emissions of volatile compounds.
- **Human Health-Particulates** (kg PM2.5-equivalent) indicates the quantity of particulate matter released into the air, adjusted for severity by comparison to 2.5-micron dust.
- **Acidification** (kg SO_2-equivalent) reports emission of compounds that contribute to increased acidity in the air.
- **Ozone Depletion** (kg CFC11-equivalent) describes the destruction of ozone in the stratosphere by highly persistent halogenated chemicals.
- **Eutrophication** (kg N-equivalent) reports environmental emissions of compounds containing nitrogen and phosphorus, which can destabilize aquatic ecosystems.

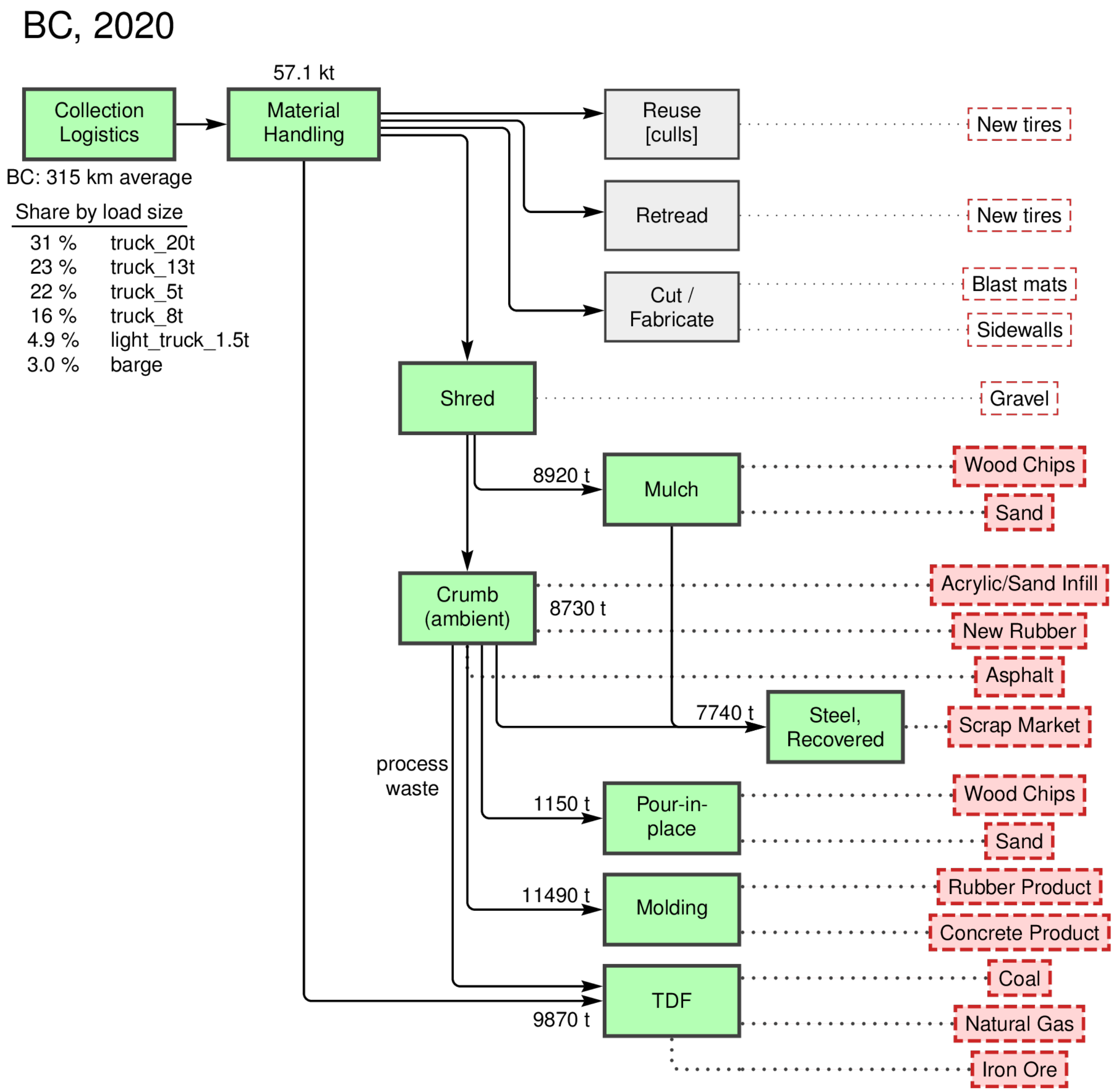

Figure 2: Diagram of the system modeled in the study. The green boxes show processes that are included in the British Columbia 2020 provincial case. Red boxes represent the production of goods and materials that are avoided by using tire-derived products ("displaced" processes). Processes shown in the grey boxes are included in the per-tonne models, but were not used in British Columbia during 2020. Flows to landfill are modeled, but not shown in the figure. The Material handling amount includes multiple-counting of tires that were handled by more than one facility.

3 Scrap Tire Management in British Columbia: Material Flows

We obtained detailed data about the collection and processing of scrap tires from TSBC, which we used to calculate the flow of scrap tires and tire-derived materials from the points of collection, through processing, to final products. A Sankey diagram showing the flow of scrap tires through the province throughout the study period is shown in Figure 3.

Our analysis is based on two data sources provided by TSBC on an annual basis. The first was a transportation detail, which provided a list of tire shipments, including counts and weights, by generator city and date. This table includes the destination processor and distance estimate. However, it does not specify the count of tires by type. This table was used to compute logistics requirements and shipment load sizes for tire collection modeling.

The second data set was an annual table of processor products delivered to market, grouped by state/province and country of the consumer. This table was used to determine the makeup of tire-derived products for the study, and was also helpful in estimating the locations of end-use markets for tire-derived crumb for the nationwide study. No information was available on the actual end-uses for tire-derived crumb in the study.

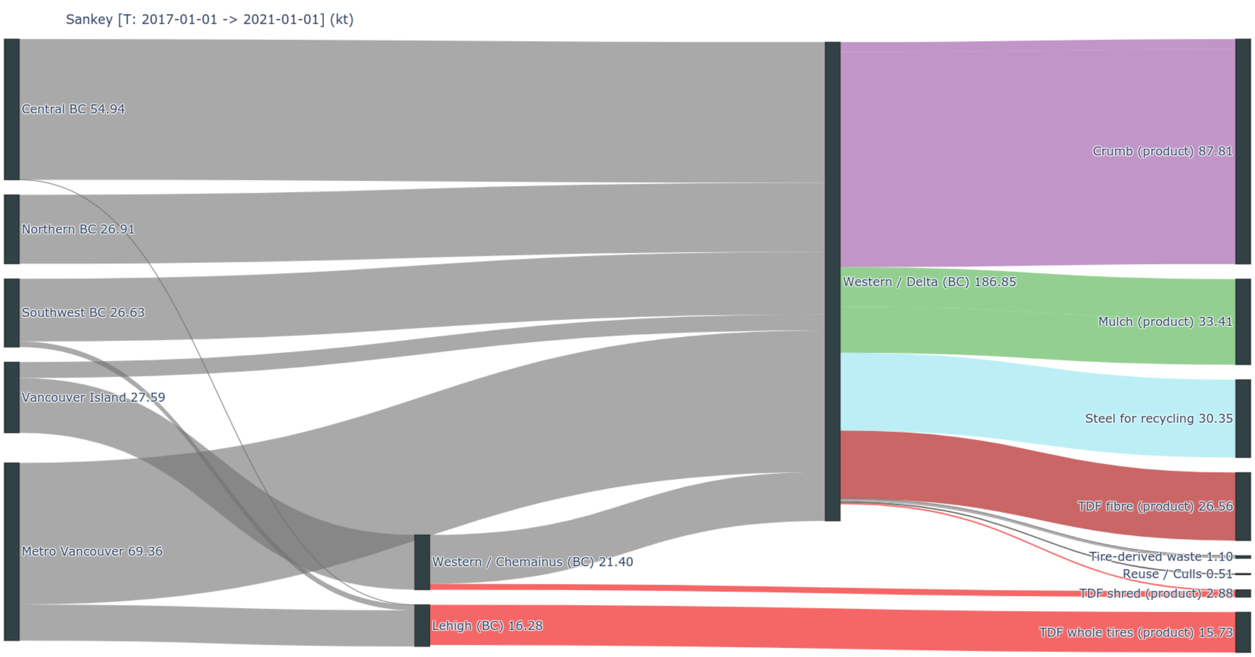

Figure 3: Sankey diagram showing the material flow of scrap tires and tire-derived materials in the province of British Columbia (2017 through 2020).

3.1 Collection and Freight

Estimated freight requirements for scrap tire collections by year are shown in Table 2. The average shipping distance for each tire is also reported, and is calculated by dividing total freight requirements by total collections. Barge transport indicates the transfer of shredded tires from Chemainus to the mainland. The freight requirements are fairly consistent year-over-year.

Table 2: Logistics requirements for scrap tire collection in British Columbia (million tonne*km).

	Phase 1	2018	2019	2020
Transport truck_20t	4.603	5.670	5.574	5.091
Transport truck_5t	3.790	3.451	3.891	3.670
Transport truck_13t	2.906	3.237	3.588	3.696
Transport truck_8t	2.511	2.621	2.796	2.571
Transport light_truck_1.5t	0.648	0.697	0.826	0.805
Transport barge	0.357	0.469	0.411	0.482
Total	14.816	16.145	17.086	16.315
Average Distance (km)	298.	314.	325.	315.

Figure 4 shows a time-series plot comparing scrap tire collections to tire-derived products for each month of the study period. Collections show a clear seasonal pattern, and do not show any notable disruption due to the Coronoavirus pandemic. Processor output data was provided only on an annualized basis, so products in this chart are allocated equally across each day of the year.

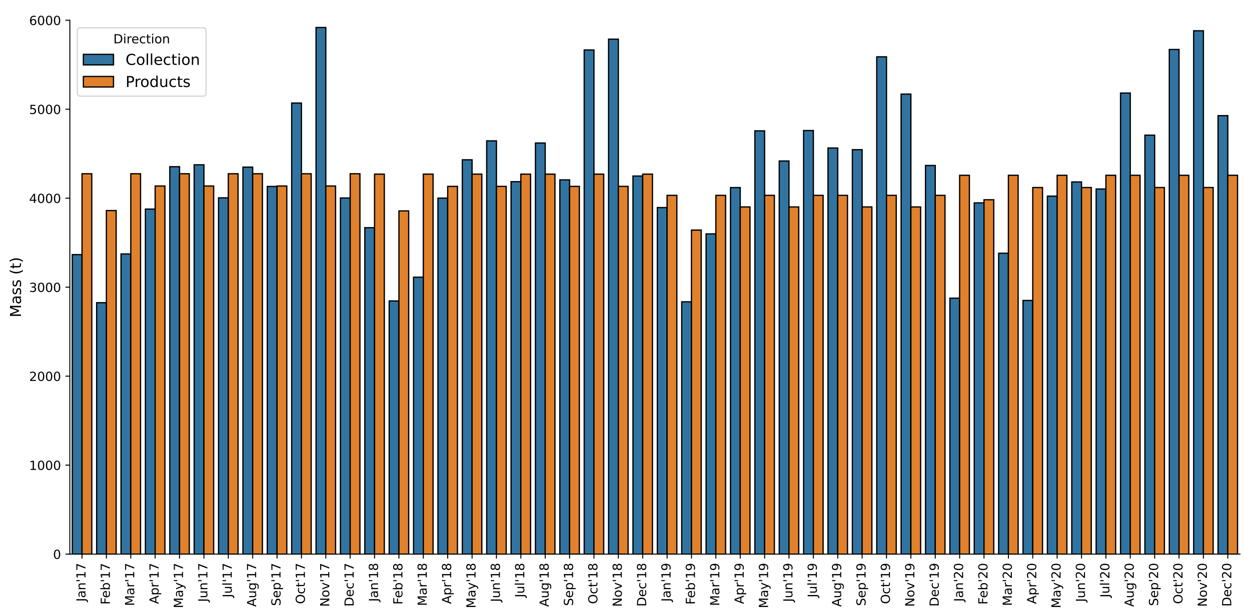

Figure 4: Collection and products by month in British Columbia.

3.2 Tire-Derived Products

Tire-derived products produced in British Columbia from all processing sites are shown in Table 3, and compared to total collections. Any tire-derived wastes reported are shown as well. Differences between tires collected and products generated are assumed to reflect changes in stock-on-hand at the processors. Tire-derived products were mainly crumb and mulch. Collections exceeded products in every year except 2017 (Phase 1). Unaccounted for products are reported as a change in stock but may also represent tires that were disposed and not reported to the program.

Table 3: Tire-derived products in British Columbia (tonnes).

	Phase 1	2018	2019	2020
Crumb (product)	21,533	22,816	20,477	22,984
Mulch (product)	7,789	8,968	7,735	8,921
Steel for recycling	7,300	7,653	7,666	7,736
TDF fibre (product)	8,303	7,292	7,645	6,197
TDF whole tires (product)	4,752	3,501	3,809	3,672
Tire-derived waste	145	53	143	756
Reuse / Culls	514	0	0	0
Total Products	50,335	50,283	47,474	50,265
Net Stock Change	-685	1,136	5,148	1,473
Total Collections	49,650	51,419	52,622	51,738

3.3 Displaced Products

The products potentially displaced by the tire-derived products are shown in Table 4 for the year 2020. The masses of potentially displaced products was calculated according to the technical and economic displacement factors described in Table B-1. Because no information was available on the end-uses of tire-derived crumb in BC, we used the market mix developed for the national report, in which about 60% of crumb rubber is used for molded products, and the remainder is split among displaced primary rubber, pour-in-place surface, turf infill, and rubber-modified asphalt.

Table 4: Primary products displaced by tire-derived products in British Columbia (2020).

Displaced Product	Amount	Units	Mass (kt)
Wood Chips, displaced	10.163	kt	10.163
Sand, displaced	21.611	kt	21.611
Acrylic coated sand, displaced	0.919	kt	0.919
Roadway mix and service lifetime	132.730	km	NaN
Primary rubber, in product, displaced	8.951	kt	8.951
Concrete product, displaced	3.559	kt	3.559
Primary rubber, polybutadiene	3.965	kt	3.965
Steel, displaced	5.802	kt	5.802
Heat, coal, in cement kiln, displaced	243.527	10^6 MJ	9.741
Iron ore, in cement kiln, displaced	0.884	kt	0.884

4 Results and Interpretation

In this section we present quantitative results of the life cycle impact assessment. Results have two types of contributions: positive-valued (incurred) contributions and negative-valued (displaced) contributions.

- Positive-valued contributions result from direct actions taken within the scrap tire management system that have environmental impacts. These include emissions from transportation of tires from collection centers to processors, direct emissions from facility operations, upstream emissions from materials used by processors, and emissions from electricity generation.
- Negative-valued contributions represent emissions associated with the production of products that compete with tire-derived products in the marketplace, and so are potentially avoided by the use of scrap tires.

The sum of these positive and negative impacts indicates the potential net environmental impacts that could occur if tire-derived products are displacing primary products.

4.1 Uncertainty

The LCA model includes uncertainty in the recycling process inventories, and in the market effects of tire-derived products. The charts in this section indicate uncertainty in the results by including error bars or “whiskers” that extend upward and downward from an indicated result or a net total. The size of the error bar indicates the uncertainty in the estimate.

Uncertainty is applied to the following parameters (please consult the ISO report for details):

- In the displacement relationship between tire-derived products and the products with which they compete, we apply uncertainty to the amount of displacement according to the type of product being displaced;
- Inventory parameters that describe scrap tire processing, such as electricity and diesel
- Freight requirements for scrap tire collection;
- Aspects of tire composition, including biogenic carbon and zinc content.

Each unit of tire-derived product is considered to replace anywhere between 0.2–1 equivalent unit of displaced product, depending on the nature of the product. This is called the displacement rate. Error bars on the negative-valued contributions reflect this uncertainty only, while error bars on net results reflect all uncertainties. Displacement relationships are reported in Appendix B.

4.2 Provincial-scale Results

The provincial scale results provide an estimate of the environmental implications of "management of all program tires" during a given time period. These results report aggregate emissions and potential benefits associated with the activity of the program over one year (2020). In addition, the potential environmental impacts of scrap tire managment can be compared year-over-year.

The aggregated total results for provincial activity during 2020 are presented in Figure 5 and Table 5. The results indicate that five out of six categores showed a potential net improvement during 2020, although for one of them the result is marginal. A net improvement occurs when incurred impacts are smaller than the impacts of potentially avoided impacts, in a given impact category.

Table 5: Total impacts incurred, total impacts avoided, and net total impacts due to tire recycling in British Columbia during 2020.

	Unit	Incurred Impacts	Avoided Impacts	Net Total
Global Warming Air	kg CO2 eq	3.7e+07	-7.8e+07	-4.1e+07
Smog Air	kg O3 eq	2.4e+06	-4.9e+06	-2.5e+06
Human Health Particulates Air	PM2.5 eq	2.2e+04	-4.5e+04	-2.3e+04
Acidification Air	kg SO2 eq	2e+05	-3.9e+05	-1.9e+05
Ozone Depletion Air	kg CFC-11 eq	25	-22	2.9
Eutrophication Air + Water	kg N eq	9.4e+03	-1.2e+04	-2.2e+03

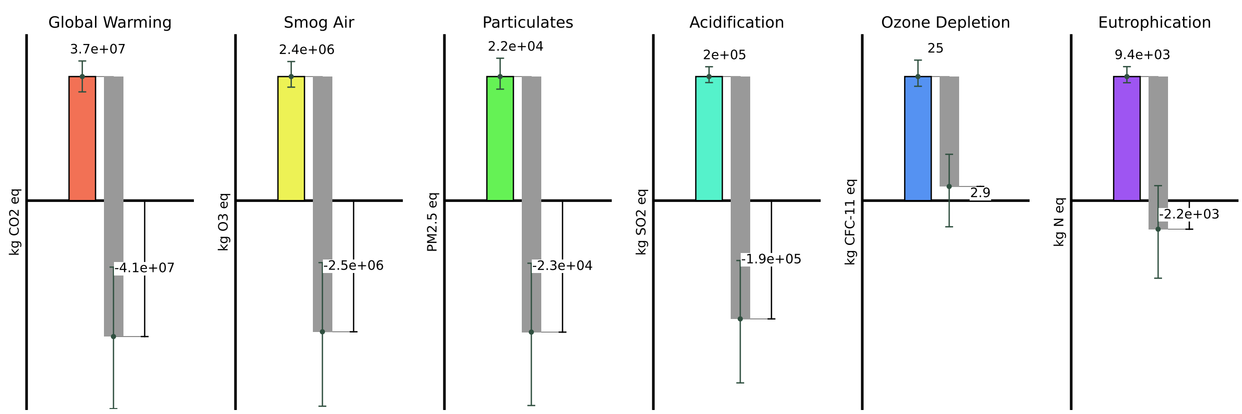

Figure 5: Total impacts incurred and avoided due to scrap tire management during 2020. The colored bar in each panel indicates incurred emissions in the named category, while the gray bar indicates potentially avoided emissions in that category.

We can observe that the results are not sensitive to changes in foreground parameters (whiskers on positive bars). The displacement rate assumptions, however, have a strong effect on magnitude of the avoided impact scores (whiskers on negative bars). The most-negative point on each bar indicates the most favorable displacement assumption (i.e. a tonne of tires displaces nearly a tonne of primary product).

In the global warming, smog, particulates, and acidification categories, the favorable result is robust to modeled variation in the displacement rate. This means that even if the least-favorable displacement assumption were applied, the results would still show a net improvement.

In the category of eutrophication, avoided impacts were slightly larger than incurred impacts, but the difference was within the margin of uncertainty. In the category of ozone depletion and eutrophicaion, incurred impacts were about the same size as potentially avoided impacts.

4.3 Stage Contribution Analysis

The emission totals above for 2020 are shown alongside other years, and disaggregated into different stages, in Figure 6. This chart enables a visual comparison of the relative contributions of different parts of the scrap tire management system, as well as a depiction of how the results changed over time. Full details by disaggregated stage for 2020 are available in Table A.1

Collection and material handling at processing facilities (including diesel and propane combustion) made generally small contributions to the impact indicator score, compared with processing activities. Likewise, transport of tire-derived products, and avoided transport of displaced products, were small in comparison to displaced production contributions. The largest impacts from collection and material handling were found in the smog indicator and can be traced to diesel combustion. Disposal of tire-derived waste made up a negligible share of impacts in all categories.

The most significant impact contribution during the processing stage was the production of binder used in molding and pour-in-place product systems. The binder was modeled as a mix of 95% polyurethane adhesive and 5% latex, so the polyurethane production dominates. The selection of binder(s) is a key area for facilities producing molded or poured products to consider when evaluating their environmental impacts.

British Columbia has relatively clean electricity grid in comparison to the national average. As a consequence, impacts from electricty production are visible but do not make a significant contribution to the results.

The results show that displaced impacts from tire-derived crumb and mulch are large enough to provide substantially negative impact scores in most categories. Using TDF produces a small net benefit when the displaced fuel is coal. In the categories of eutrophication and ozone depletion, the marginal results are driven by the production of polyurethane adhesive binder used in the molding process.

4.4 Greenhouse Gas Emissions

A detailed stage contribution analysis for GHG emissions during 2020 is shown in Figure 7 as a “waterfall” chart. In this chart, stages are ordered from top to bottom by the most-positive

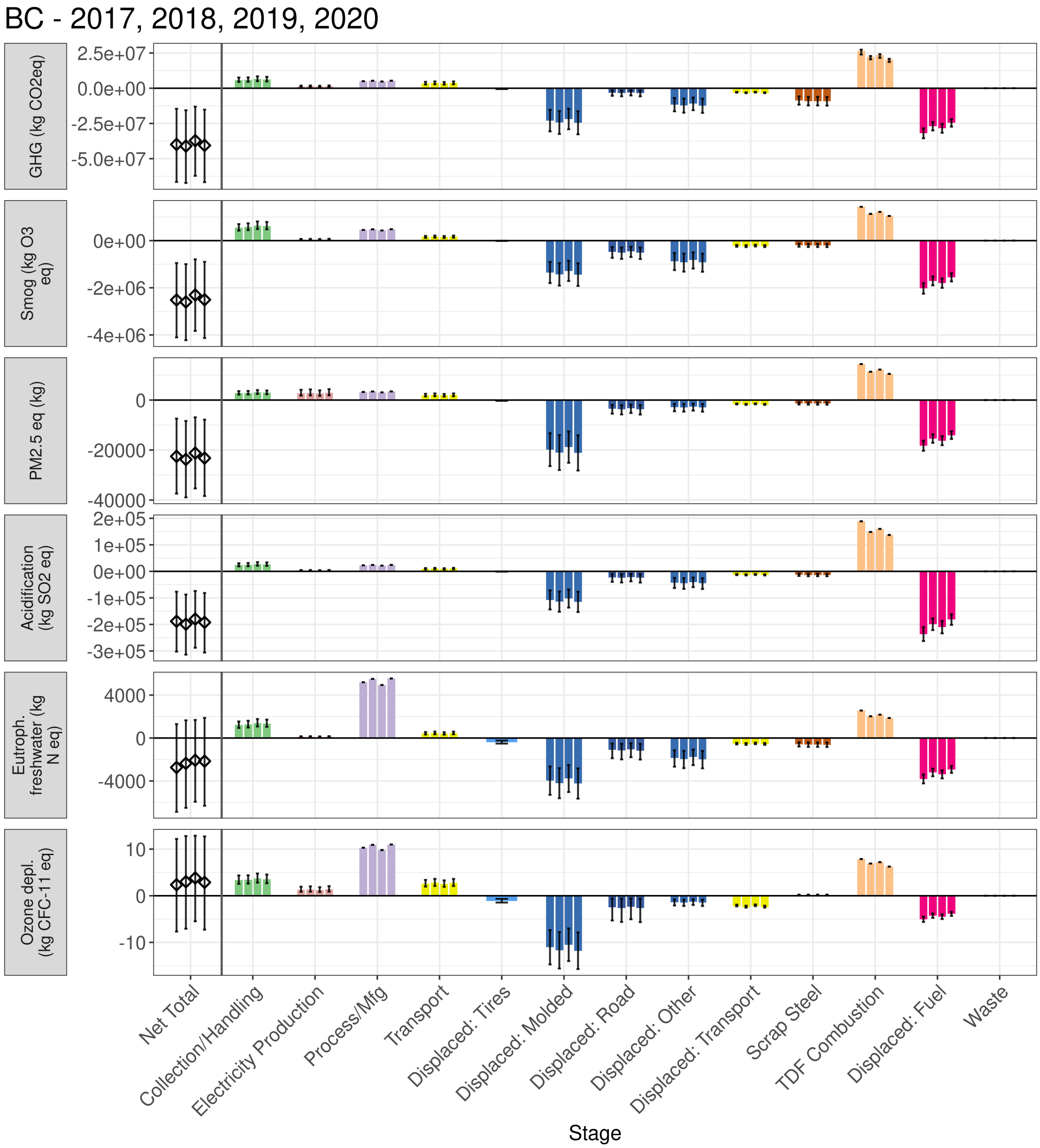

Figure 6: Province-wide environmental impacts of managing 205.4 kt of scrap tires in BC during 2017–2020, stage contribution analysis, by year. Net impacts, which take into account avoided production due to tire recycling, are indicated by the diamond symbol on the left. Colored bars show contributions by individual stages in the tire recycling system. Modeled uncertainty is indicated for each bar.

(impacts caused by recycling activities) to the most-negative contribution (impacts avoided because of recycled products). The total quantity of incurred emissions is shown at the right-hand edge of the chart, corresponding with Table 5. The median net result (excluding uncertainty) is indicated by the red triangle at the bottom of the figure.

The waterfall shows that a considerable portion of the GHG benefit is due to the displaced combustion of coal in cement production (bottom-most bar). If this fuel were changed to natural gas, the magnitude of this bar can be expected to be about half the size.

4.5 Results per Tonne of Tires Processed

Results are also presented on a tonne-of-tires basis for each of the various scrap tire use cases that are included in the model. Results at this scale can be compared directly to one another to evaluate the relative benefits and impacts of the end-uses and treatment options considered. The per-tonne results are provided for a full range of different end-products using logistics requirements and electricity grid specific to British Columbia.

The chart allows the reader to compare different options for tire recycling on a consistent basis– the treatment of a tonne of scrap tires. On this chart, the absolute height of each bar indicates emissions that are attributable to the selected processing route, and thus are expected to occur if a tire is processed using that route. The diamond indicates the "net effect", which is the processing emissions minus the potentially avoided emissions from displaced production. The error bars around the diamonds indicate the range of likely outcomes considering all sensitivity parameters in the model, but are dominated by the displacement rate. GHG emission impacts are shown in Figure 8, while all six indicators are shown in Figure 9.

Reuse (culls), displacing new tires: If culled tires are returned directly to use, then this route provides a very effective route to potential impact reductions because the burdens associated with new tire production are significant. However, the re-use of culled tires carries risks because the service history of the tire is not known. A culled tire is assumed to replace between 1/6 and 1/3 of a new tire.

Retread, displacing new tires: Displacement of new tire production leads to significant benefits for remanufactured (i.e. retreaded) tires. The most substantial incurred impact during retreading is the production of the replacement tread. The retread route shows net improvement in five of six categories (smog is essentially even), although the improvement in acidification is marginal.

Devulcanization, displacing primary rubber: The devulcanization process modeled here does not produce a perfect substitute for virgin rubber. However, the mechanical properties are such that it could replace up to 10% of the rubber in a product. One possible application would be use in tires.

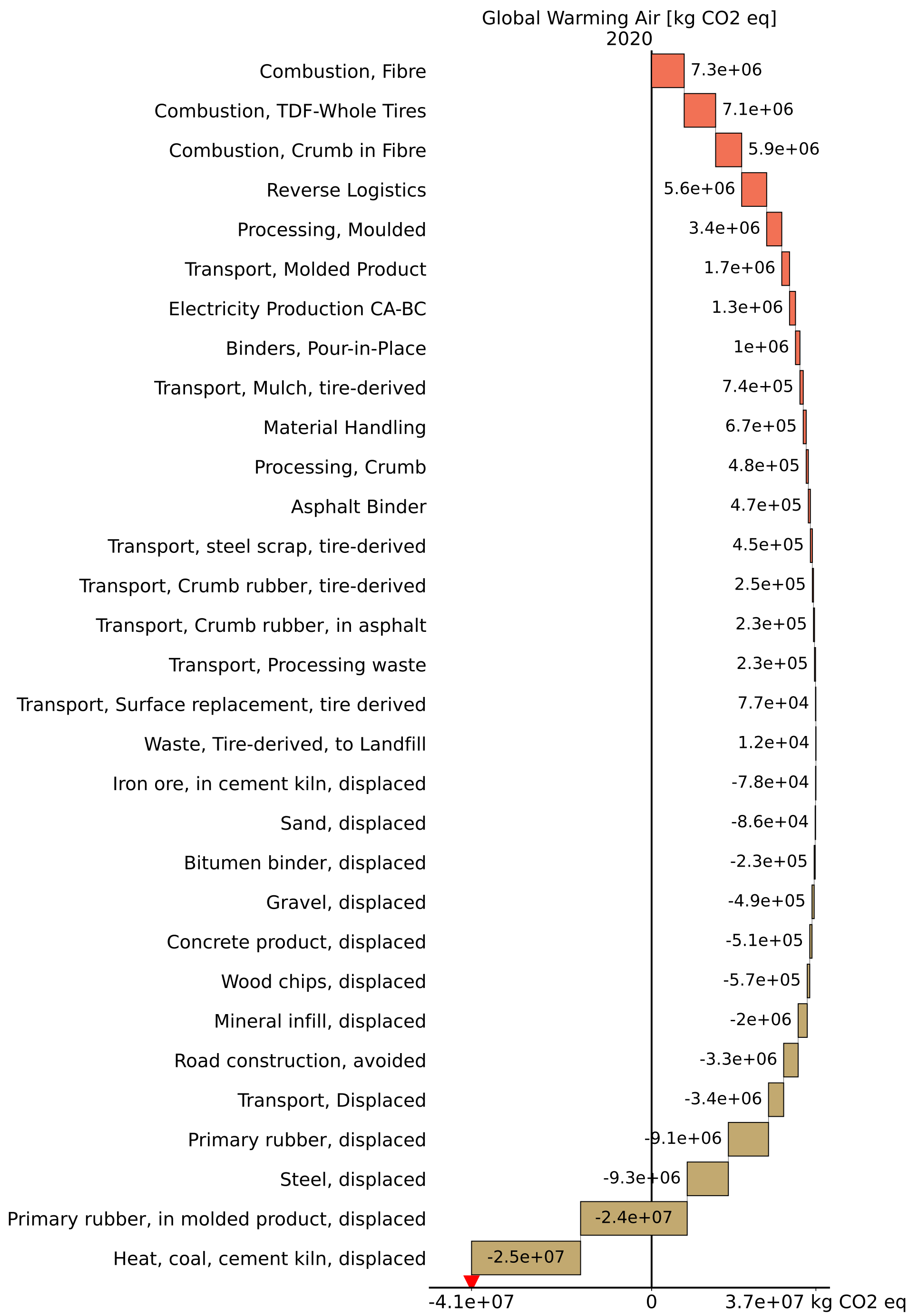

Figure 7: Greenhouse gas impact contribution by stage for British Columbia in 2020. The red triangle at the bottom shows the estimated net total GHG impact.

Assuming the devulcanized rubber displaces new polybutadiene rubber (BR), this route has net-negative impact scores in five of six categories. For ozone depletion, the displaced BR production process has nil impact, so there is no displacement benefit. For GHGs, Smog, and Acidification, devulcanization is among the best performing routes.

Molded rubber, displacing primary extruded rubber or concrete: This route represents the production of molded products from crumb rubber with binder and heat. Although this process has high energy requirements, their impacts are matched or exceeded by the impacts of producing the binder, which makes up less than 4% of the mass of the finished product. Still, molded tire-derived rubber shows a substantial net benefit across every category when compared to extruded primary EPDM rubber.

Concrete is made with cement, which has notably high emissions; however, the quantity of cement in the concrete mix modeled is low enough that the potentially avoided emissions are of the same order as the incurred process emissions, leading to a slight potential improvement on global warming, and increased impact scores in other categories.

Sidewalls, displacing gravel silage weights: Tire sidewalls are very inexpensive to produce; however, they must be shipped to a location where they are useful. This study assumes that tire-derived silage weights displace gravel bags, and that gravel is shipped a comparatively shorter distance. Consequently, this route has negligible benefits and results in a small net increase in all impact categories.

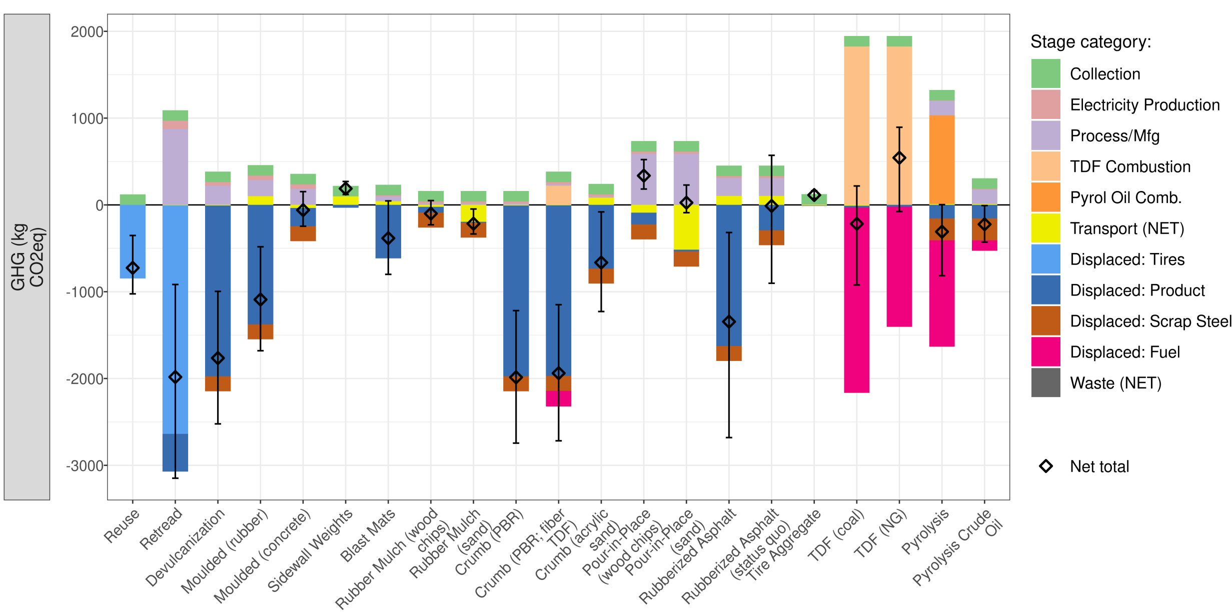

Figure 8: Net greenhouse gas impacts per tonne of scrap tires for different management routes, using BC conditions.

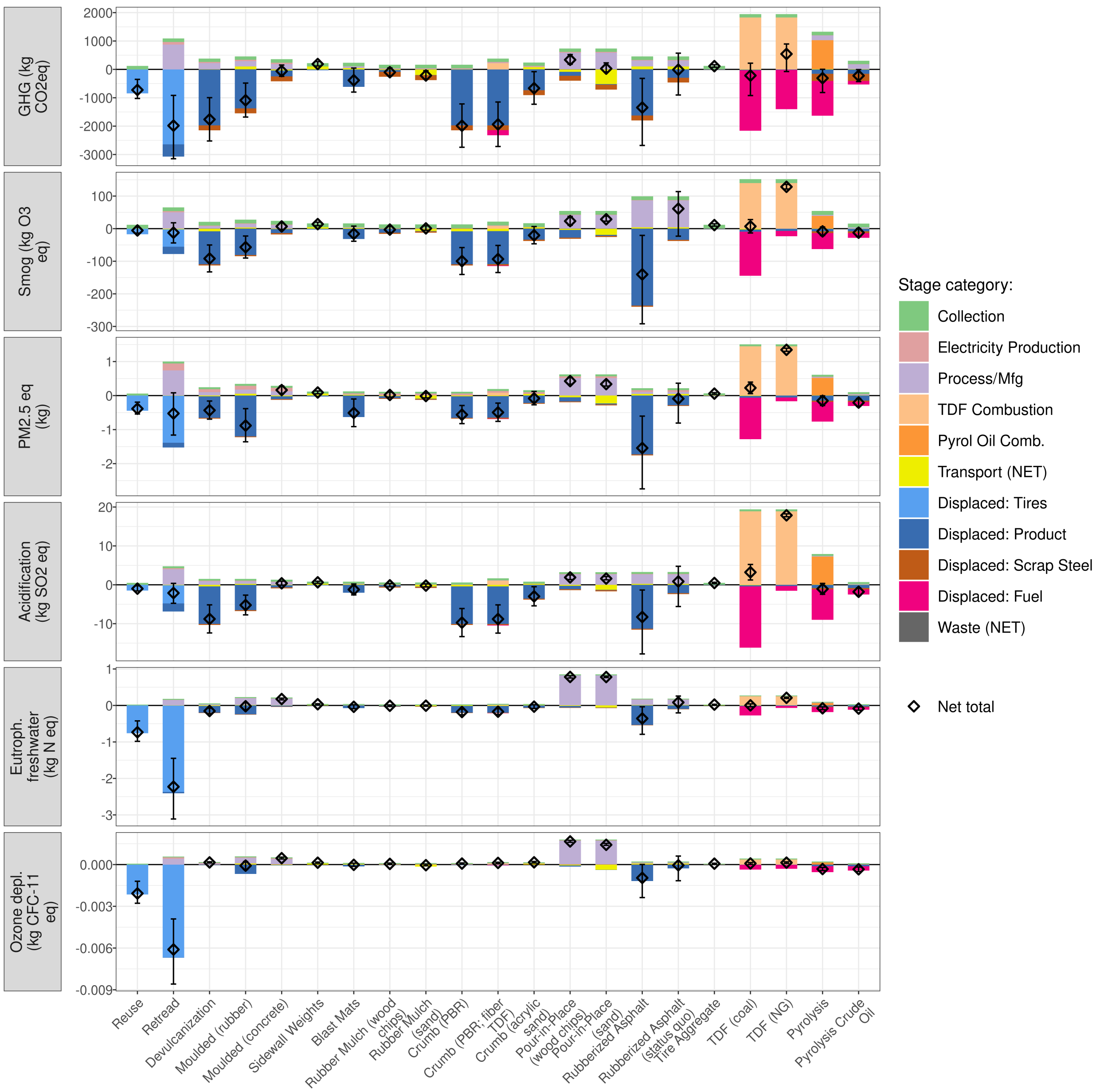

Figure 9: Stage contribution analysis of all processing routes considered in the study, using BC conditions (impacts per tonne of tires processed). Net results are indicated by a diamond on each stacked bar. Potentially avoided impacts (negative bars) due to displaced production vary strongly between different products.

Blast mats, displacing steel blast mats: Tire-derived blast mats are the conventional choice in many cases. The alternative system, steel wire blast mats, is lighter per area covered (and thus easier to handle) but has shorter longevity. In the comparison between tire-derived mats and steel mats, the tire-derived mats are beneficial in all six categories.

Mulch, displacing wood chips or sand: Rubber mulch used in land cover results in marginal improvements in all categories. This route reflects pessimistic assumptions about the impacts of production: mulch production is modeled as identical to crumb, due to a lack of facility data to disaggregate these two activities.

Crumb, displacing primary rubber: This route reflects the use of tire-derived crumb in products in place of primary rubber, including tire-derived crumb displacing virgin crumb for infill. The polybutadiene process selected for displacement has high impact scores, leading to a higher net benefit for this route. If crumb displaces a lower-intensity material, the benefits will be reduced.

Crumb, displacing acrylic-coated sand infill: Because the use of tire-derived crumb for turf infill is in fact "business as usual" for the market, we applied a weaker economic displacement assumption to this product case (20-80%, 50% median). Even with this assumption, tire-derived crumb rubber has lower impact scores than acrylic-coated sand because acrylic production has high impact intensity.

Pour-in-place, displacing wood chips or sand: Pour-in-place uses appear to be unfavorable in most or all impact categories, almost entirely driven by the impacts of binder production. The only marginal case is in the global warming indicator for the pour-in-place displacing sand route, where the emissions from binder production are balanced by significant avoided transportation of sand. In the case of pour-in-place displacement, the assumption that tire-derived products last longer than the displaced product is reasonable because the product is installed in a more permanent fashion.

Crumb in rubber-modified asphalt: Rubber-modified asphalt also shows significant advantages, but only under the assumption that roads produced with rubber-modified asphalt have longer service life. If road service life is assumed to stay the same ("status quo"), the advantage vanishes, and smog and eutrophication impacts are likely to increase. Smog impact scores from rubber-modified asphalt are attributable to our modeling assumptions regarding the use of a substantial amount of diesel fuel to heat the mixture of bitumen and crumb rubber (see Section 3.5.13 in the full ISO report). If this amount of fuel use is not required, or if cleaner fuels are used, the incurred burdens for rubber-modified asphalt would be reduced.

TDA, displacing gravel: Tire uses that displace gravel show negligible benefits and impacts. Shred requires minimal processing to produce but also has minimal potential benefits, because gravel also has relatively low impact scores.

TDF, displacing coal or natural gas: TDF combustion resulted in small improvements in global warming and net increases in the other five catgegories under the base case assumption of displacing 90% coal; zero out of six categories showed improvement if the TDF displaces natural gas (TDF (NG)). For global warming, the comparison is more favorable under the assumption of high biogenic carbon content. On balance, TDF appears to be only a marginally beneficial route for tire disposal.

Pyrolysis There are two routes modeled: In the “Pyrolysis” route, the pyrolysis oil is used as a fuel, and displaces combustion of fuel oil; in the “Pyrolysis Crude Oil” route, the pyrolysis oil is used as a refinery feedstock, and displaces production of crude oil. The two pyrolysis routes show modest net benefits in each of the 6 main impact categories. These benefits arise primarily because of the potentially avoided manufacture of carbon black (due to the recovered pyrolysis char), and the recovery of steel. For GHGs, the bioC content of tires also results in lower impact from combustion, compared to fuel oil. For Eutrophication and Ozone depletion, the net benefit is primarily due to the pyrolysis process having lower impact scores than fuel oil mining and refining.

5 Conclusions

We have completed an LCA of the scrap tire management system in Canada. The overall quality of the data used in the model is good, and the goal of the study was met. In general, the impact indicator scores from scrap tire recycling activities are small compared to the potentially avoided impacts of some primary products. If tire-derived materials displace primary materials in the market, then scrap tire management is ecologically beneficial.

- It is likely that tire-derived products from the scrap tire management system in British Columbia resulted in avoided emissions through displaced production of primary rubber. In five out of six impact category indicators, a net improvement was obtained, and in four of those categories the improvement was robust to sensitivity analysis regarding the displacement rate.
- For global warming, smog, particulates, and acidification, the magnitude of avoided impacts was probably at least twice the magnitude of incurred impacts. For eutrophication, the avoided impact was slightly more than the incurred impact. For ozone depletion, the magnitude of avoided impacts was smaller than magnitude of incurred impacts.
- The largest contributor to impact scores in the scrap tire management system was tdf combustion, followed by reverse logistics. BC had the longest mean transport distance of any province other than Newfoundland.
- Of the 21 options modeled, 16 result in net negative GHG impact indicator results, meaning scrap tire management potentially reduces emissions for these use options (See Table A.2).
- The five processing routes with the greatest potential for reducing GHG impacts included crumb rubber replacing PBR, retread, devulcanization replacing PBR, rubber-modified as-

phalt with roadway service life extension, and molded rubber replacing extruded EPDM.

- Rubber-modified asphalt without service life extension did not generate a net improvement.
- For TDA (replacing mined aggregate) and Sidewalls used as weights (displacing gravel-in-bag weights), the net result is very close to zero.
- For TDF displacing coal, the effects on global warming are slightly beneficial, while impacts are increased for other categories. For TDF with a high proportion of biogenic carbon, the global warming impact comparison is somewhat more favorable. For TDF displacing natural gas, no improvement is obtained.
- Both molded and pour-in-place processes require the use of a binder. Although the precise binder used may vary by manufacturer, this study used a polyurethane binder compound that was highly toxic and impact-intensive to produce. Molded and pour-in-place product manufacturers should assess their selection of binder.
- Devulcanization appears to show promise as a highly circular route to retain the value of tire-derived rubber. However, more study is needed to determine whether laboratory-scale parameters used in this study are an adequate proxy for commercial-scale devulcanzation.
- Pyrolysis performs better than conventional TDF in 4 of 6 impact categories when TDF displaces coal, and substantially better than TDF displacing natural gas (all categories). Pyrolysis of tires with a higher fraction of natural rubber (i.e. OTR tires) is likely to be moderately more beneficial than pyrolysis of PLT for the greenhouse gas indicator.

Appendices

Appendix A Tabular Results

A.1 Numerical Results, Provincial Activity 2020

See figure 6.

Table A-1: Total Incurred and avoided impacts by stage during the period of 2020.

	Global Warming kg CO2 eq	Smog Air kg O3 eq	Particulates PM2.5 eq	Acidification kg SO2 eq	Ozone Depletion kg CFC-11 eq	Eutrophication kg N eq
Combustion, Fibre	7.34e+06	4.09e+04	2.42e+01	1.17e+03	3.80e+00	7.36e+01
Combustion, TDF-Whole Tires	7.09e+06	5.45e+05	5.64e+03	7.35e+04	1.44e+00	9.72e+02
Combustion, Crumb in Fibre	5.87e+06	4.61e+05	4.79e+03	6.24e+04	1.01e+00	8.23e+02
Reverse Logistics	5.63e+06	4.46e+05	2.65e+03	2.02e+04	3.28e+00	1.01e+03
Processing, Moulded	3.41e+06	2.00e+05	2.36e+03	1.30e+04	7.78e+00	3.72e+03
Transport, Molded Product	1.75e+06	8.04e+04	9.97e+02	4.89e+03	1.31e+00	2.22e+02
Electricity Production CA-BC	1.34e+06	5.31e+04	2.92e+03	3.53e+03	1.38e+00	1.19e+02
Binders, Pour-in-Place	1.00e+06	7.19e+04	8.87e+02	4.66e+03	2.97e+00	1.44e+03
Transport, Mulch, tire-derived	7.44e+05	3.02e+04	3.72e+02	1.93e+03	5.48e-01	8.57e+01
Material Handling	6.67e+05	1.74e+05	3.61e+02	6.23e+03	2.55e-01	3.43e+02
Processing, Crumb	4.77e+05	1.22e+04	7.83e+01	6.79e+02	1.23e-01	3.16e+01
Asphalt Binder	4.67e+05	2.01e+05	1.29e+02	5.92e+03	1.21e-01	3.63e+02
Transport, steel scrap, tire-derived	4.46e+05	2.05e+04	2.54e+02	1.25e+03	3.35e-01	5.66e+01
Transport, Crumb rubber, tire-derived	2.55e+05	1.17e+04	1.45e+02	7.12e+02	1.91e-01	3.23e+01
Transport, Processing waste	2.28e+05	1.05e+04	1.30e+02	6.37e+02	1.71e-01	2.89e+01
Transport, Crumb rubber, in asphalt	2.28e+05	8.60e+03	1.06e+02	5.69e+02	1.67e-01	2.49e+01
Transport, Surface replacement, tire derived	7.71e+04	3.55e+03	4.39e+01	2.16e+02	5.79e-02	9.78e+00
Waste, Tire-derived, to Landfill	1.18e+04	1.62e+03	1.05e+01	6.99e+01	8.19e-03	3.50e+00
Iron ore, in cement kiln, displaced	-7.80e+04	-2.57e+04	-2.21e+02	-1.24e+03	-5.92e-02	-5.08e+01
Sand, displaced	-8.63e+04	-1.18e+04	-1.10e+02	-5.52e+02	-3.92e-02	-2.39e+01
Bitumen binder, displaced	-2.27e+05	-1.96e+04	-1.71e+02	-1.99e+03	-4.31e-01	-9.07e+01
Gravel, displaced	-4.88e+05	-6.41e+04	-5.14e+02	-3.27e+03	-2.42e-01	-1.37e+02
Concrete product, displaced	-5.10e+05	-2.94e+04	-1.97e+02	-1.40e+03	-8.25e-02	-6.37e+01
Wood chips, displaced	-5.70e+05	-9.71e+04	-5.01e+02	-3.57e+03	-3.17e-01	-1.97e+02
Mineral infill, displaced	-2.05e+06	-9.41e+04	-6.08e+02	-9.91e+03	-5.64e-03	-1.69e+02
Road construction, avoided	-3.26e+06	-4.93e+05	-3.55e+03	-2.24e+04	-2.22e+00	-1.08e+03
Transport, Displaced	-3.42e+06	-2.41e+05	-1.85e+03	-1.38e+04	-2.49e+00	-5.76e+02
Primary rubber, displaced	-9.05e+06	-6.28e+05	-9.99e+02	-2.67e+04	-7.92e-01	-1.39e+03
Steel, displaced	-9.28e+06	-2.05e+05	-1.42e+03	-1.40e+04	1.90e-01	-6.26e+02
Primary rubber, in molded product, displaced	-2.40e+07	-1.41e+06	-2.10e+04	-1.14e+05	-1.17e+01	-4.17e+03
Heat, coal, cement kiln, displaced	-2.46e+07	-1.56e+06	-1.40e+04	-1.82e+05	-3.89e+00	-2.92e+03

A.2 Unit Models - Impacts per Tonne of Tires managed

See Figure 9.

Table A-2: Net total results for unit processing routes, one tonne of tires.

	Global Warming kg CO2 eq	Smog Air kg O3 eq	Particulates PM2.5 eq	Acidification kg SO2 eq	Ozone Depletion kg CFC-11 eq	Eutrophication kg N eq
BC-tdf-ng	5.43e+02	1.28e+02	1.34e+00	1.79e+01	1.38e-04	2.09e-01
BC-poured	3.37e+02	2.32e+01	4.26e-01	1.90e+00	1.66e-03	7.81e-01
BC-sidewalls	1.88e+02	1.39e+01	9.11e-02	6.33e-01	1.33e-04	3.32e-02
BC-agg	1.14e+02	1.09e+01	5.79e-02	4.61e-01	6.55e-05	2.36e-02
BC-poured-sand	2.58e+01	2.88e+01	3.37e-01	1.60e+00	1.42e-03	7.79e-01
BC-rap-nm	-1.15e+01	6.12e+01	-9.08e-02	8.61e-01	-4.97e-05	8.39e-02
BC-molded-concrete	-5.97e+01	6.80e+00	1.62e-01	3.83e-01	4.58e-04	1.76e-01
BC-mulch	-1.00e+02	-2.90e+00	1.79e-02	-1.42e-01	4.84e-05	-8.29e-03
BC-mulch-sand	-2.16e+02	8.06e-01	-1.30e-02	-2.11e-01	-4.45e-05	-6.35e-03
BC-tdf	-2.18e+02	7.05e+00	2.26e-01	3.22e+00	8.00e-05	3.06e-03
BC-pyrol-oil	-2.23e+02	-1.24e+01	-2.05e-01	-1.80e+00	-3.40e-04	-8.58e-02
BC-pyrol	-3.09e+02	-8.33e+00	-1.53e-01	-1.06e+00	-3.21e-04	-7.77e-02
BC-blast-mats	-3.84e+02	-1.59e+01	-5.10e-01	-1.22e+00	-1.93e-05	-3.67e-02
BC-crumb-infill	-6.64e+02	-2.06e+01	-8.29e-02	-2.98e+00	1.60e-04	-3.28e-02
BC-culls	-7.25e+02	-5.50e+00	-3.86e-01	-9.97e-01	-2.08e-03	-7.34e-01
BC-molded	-1.09e+03	-5.69e+01	-8.82e-01	-5.23e+00	-7.60e-05	-2.17e-02
BC-rap	-1.35e+03	-1.40e+02	-1.54e+00	-8.28e+00	-9.57e-04	-3.57e-01
BC-devulc	-1.76e+03	-9.17e+01	-4.32e-01	-8.79e+00	1.55e-04	-1.52e-01
BC-crumb-with-tdf	-1.94e+03	-9.34e+01	-4.95e-01	-8.81e+00	1.19e-04	-1.71e-01
BC-retread	-1.98e+03	-1.22e+01	-5.25e-01	-2.12e+00	-6.11e-03	-2.23e+00
BC-crumb	-1.99e+03	-9.97e+01	-5.63e-01	-9.73e+00	7.25e-05	-1.79e-01

Appendix B Displacement Relationships

The quantity of each displaced product that is equivalent to a tonne of tires is determined on a basis of functional equivalency. The physical displacement value is multiplied by a market displacement rate to determine the estimated displacement of primary production. We perform sensitivity analysis on the displacement rate, by default considering 75% displacement, with 50% and 100% as outer bounds for most products (see the ISO report, Section 2.2.4).

Table B-1: Displacement relationships modeled in the report. The rates shown here are the product of an economic displacement factor and a technical displacement factor, and include three values used for sensitivity analysis. (Table 3.18 in the ISO report)

Tire-derived Product	units	Displaces	low | rate | hi	unit	distance
Culls to Reuse	kg	Tire purchase	0.8 | 1.33 | 1.75	USD*	
Retreaded tire	kg	Tire purchase	2.39 | 3.5 | 4.77	USD*	
Devulcanized Rubber	kg	Primary rubber	0.5 | 0.75 | 1	kg	
Molded	tonne	Rubber	0.5 | 0.75 | 1	tonne	1200 km / 500 km
Molded	tonne	Concrete	1.42 | 2.13 | 2.84	tonne	500 km
Sidewalls	tonne	Bag of Gravel	0.8 | 0.9 | 1	tonne	1000 km / 100 km
Blast Mat	m2	Steel blast mat	0.3 | 0.75 | 1.2	m2	500 km / none
Mulch	tonne	Wood Chips	1.2 | 1.8 | 2.4	tonne	500 km
Mulch	tonne	Sand	2.6 | 3.8 | 5.1	tonne	500 km
Crumb	tonne	Rubber	0.5 | 0.75 | 1	tonne	none / 3500 km**
Crumb	tonne	Plastic Infill	0.2 | 0.5 | 0.8	tonne	1200 km / none
Pour-in-Place	tonne	Wood Chips	2.13 | 3.2 | 4.26	tonne	500 km
Pour-in-Place	tonne	Sand	4.54 | 6.81 | 9.08	tonne	500 km
Crumb	tonne	in Roadway	55 | 82.5 | 110	m	650 km / none
TDA	tonne	Gravel	1.36 | 1.53 | 1.7	tonne	100 km
TDF	MJ	Coal / NG	0.8 | 0.9 | 1	MJ	
Steel in Kiln	tonne	Iron Ore	0.7 | 1.05 | 1.4	tonne	
TDF (Fiber)	MJ	Coal / NG	0.8 | 0.9 | 1	MJ	550 km / 200 km†
Pyrolysis fuel	kg	Fuel oil	0.5 | 0.75 | 1	kg	
Pyrolysis char	kg	Carbon black	0.25 | 0.38 | 0.5	kg	
Pyrolysis fuel	MJ	Fuel oil, combusted	0.8 | 0.9 | 1	MJ	
Steel	tonne	to Scrap	0.5 | 0.75 | 1	tonne	500 km / none

* USD/kg in 2013 producer prices
** 10 000 km transport by ocean freight displaced for 35% rest-of-world (non-US) market share
† 200 km displaced transport by train; applies only to coal production