

End-of-Life Tire Management LCA



A Comparative Analysis for Alberta Recycling Management Authority

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Executive Summary

Albertans discard over five million motor vehicle tires annually. These tires are all currently recycled for a number of different applications, including aggregate in engineered landfills and manufactured products. As a result of the range of existing and emerging tire waste management options, the Alberta Recycling Management Authority (Alberta Recycling) wants to better understand the full life cycle environmental impacts of the leading options available today. This information can be used in three important ways:

To identify all the key risks when choosing between recycling options.

To determine mitigation requirements upon having selected a given management option.

To support and inform policy decisions on waste management activities in Alberta.

The analysis in this report provides a life cycle inventory of a range of likely, currently available tire recycling options. Table ES-1 presents the options evaluated, along with the original product or material that would be displaced by each option. Many more applications for tire waste exist, and new recycled tire products frequently come to market. Rather than being exhaustive, the options assessed in this analysis are considered representative of the range of possible alternatives.

Table ES-1. Options evaluated and displaced baselines

Recycling/Re-use Option	Displaced Material or Process (Baseline)
Tire Derived Aggregate (TDA)	Gravel
Crumb	Synthetic rubber currently used for athletic fields
Manufactured Products: Wood	Wood rig mat
Manufactured Products: Cement	Concrete curb
Manufactured Products: Asphalt	Asphalt shingles
Tire Derived Fuel (TDF): Coal Plants	Coal-based electricity
Tire Derived Fuel (TDF): Cement Kilns	Coal
Tire Derived Fuel (TDF): Incineration	Electricity from the Alberta grid

This analysis follows the ISO 14044 life cycle assessment (LCA) principles and framework, although it has not been verified against the ISO LCA requirements and guidelines. A full life cycle assessment, which would include a comparison of results against local and regional contexts, was not performed because specific locations for new recycling operations have not been considered. The system activities included within the boundary were selected based on a qualitative assessment. Life cycle maps for each option were created to help ensure that all

activities and processes are captured and accounted for. As a first step, a qualitative scoping exercise was performed to identify key environmental issues and priority indicators to quantify. A range of air emissions are quantified, as well as total power (electricity) and fossil fuel (FF) input. While background is provided on some of the key issues, the results of this analysis focus on the quantitative comparison of key indicators for which data exists. This analysis has the following limitations:

- Data availability was limited for certain indicators.
- An uncertainty analysis is not included.
- The inclusion of a range of potential thermal conversion technologies should be considered when quality data is available and their potential is real.
- A complete impact assessment, whereby quantitative results are compared against local and regional context, has not been completed.
- Land and water parameters are not quantified due to lack of available data.

Table ES-2 provides the percent difference between each option and its associated baseline. These results help answer the question: “*What are the differences in environmental benefits for each of the options considered?*”

Table ES-2. Key indicator differences between options and their associated baselines

	Power Input (kWh / T tires recycled)	On-site FF Input Reqs (GJ / T tires recycled)	GHG (kg CO ₂ e / T tires recycled)	ADP (kg / T tires recycled)	PM (g / T tires recycled)	CO (g / T tires recycled)	VOC (g / T tires recycled)	Dioxins / Furans (ug / T tires recycled)	PAH (mg / T tires recycled)	Heavy Metals (mg / T tires recycled)
TDA vs Gravel Leachate	1916%	-68%	-36%	672%	1572%	307%	580%	41%	-91%	2%
Rubber vs Timber Rig Mats	23%	123%	-1%	-5%	6%	-52%	186%	147%	-35%	338%
Rubber vs Concrete Curbs	50%	110%	-67%	-44%	-69%	-29%	40%	-100%	-85%	21%
Rubber vs Asphalt Shingles	407%	6%	-67%	-84%	-66%	47%	-86%	-50%	540%	-84%
Tire vs PP Crumb	49%	-86%	-34%	45%	773%	-60%	-27%	-52%	-70%	78%
TDF vs Coal (Power Plant)	37%	-1%	-3%	44%	113%	92%	-5%	55%	-2%	1%
TDF vs Coal (Cement)	-2%	0%	-1%	41%	8%	12%	6%	55%	-15%	-12%
T2E vs AB Grid Power	-90%	-98%	-8%	-65%	-24%	159%	396%	356288%	-100%	78%

Abbreviations: FF = fossil fuel; GHG = greenhouse gases; ADP = acid deposition precursors; PM = particulate matter; CO = carbon monoxide; VOC = volatile organic chemicals; PAH = polycyclic aromatic hydrocarbons.

Figure ES-1 illustrates the net difference between an option and its baseline per environmental parameter. These results help answer the question: “*For a given parameter, which recycling option provides the greatest benefits?*” Figure ES-1 particularly helps identify those environmental parameters for which there is a significant difference in performance across all options.

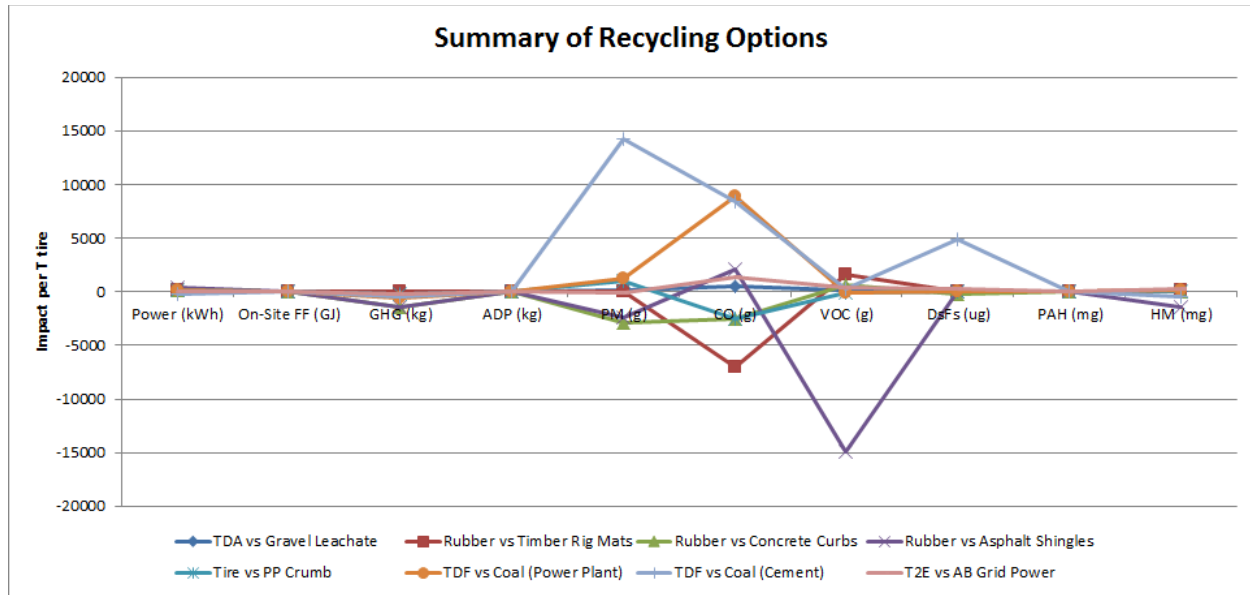


Figure ES-1. Impact of recycling options per environmental parameter

Based on the results of this life cycle inventory, the following conclusions can be made:

- » The benefits of remanufacturing tires into rubber products greatly depends on whether the displaced material is concrete, wood or an asphaltene product.

There is no single outright “winner” that outperforms its associated baseline across the board. For each option there are typically both net increases and decreases of varying environmental parameters.

Displacing concrete or asphalt shingles shows the most overall benefits of all the options.

- a. Displacing concrete and asphalt shingles delivers the highest greenhouse gas (GHG) net benefits.
- b. Rubber curbs over concrete also delivers significant reductions in particulate matter (PM) and carbon monoxide (CO) and marginal reductions in acid deposition precursors (ADP), but it results in a net increase of volatile organic compound (VOC) emissions.
- c. Displacing asphalt shingles also delivers relatively significant reductions across multiple indicators, particularly VOCs. Increases in CO emissions are associated with this option, but the increase is less than the coal displacement options (coal power or cement kiln).

Those options that could be considered to demonstrate little overall benefit, based on the air parameters assessed, are TDA to replace gravel for landfill leachate collection systems and tire manufactured products to replace wood ones.

The TDF options result in net benefits compared against their baselines on a number of different options, but each TDF option has several parameters that would increase as a result of its implementation.

Using the Results

While no “outright winners” emerged from this analysis, the results provide some extremely valuable information for any decision-making process around these options. The following examples show some ways these results can be used:

1. When considering a given tire management option for other than environmental reasons, these results provide insights into which environmental impacts should be of concern and potentially addressed.
2. When basing decisions around specific environmental objectives, these results will help inform the option that best meets these objectives. For example, using tires to replace concrete curbs helps advance Alberta’s existing GHG reduction policy objectives.
3. While using tires over gravel for engineered landfill purposes avoids the use of virgin materials and associated land impacts, selecting other tire recycling options would help avoid some of the net environmental impact increases that result from using tires for landfill leachate collection systems.
4. When considering waste-to-energy related policy decisions in the province of Alberta, these results can inform questions around specific air emission impacts.

Next Steps

While these results help answer some important questions, the following recommendations are provided for further consideration:

1. When considering a potential recycling facility in Alberta, research the local environmental context to determine whether certain environmental issues are of particular relevance to the recycling option in question.
2. Given that environmental impacts are ultimately dependent on the ability to incorporate pollution control systems across the life cycle, be sure to inquire about the extent to which controls have been used to minimize emissions or energy use when selecting a management option.
3. With the emergence of different waste-to-energy technologies, a detailed analysis of the environmental impacts when incorporating tires into the waste should be performed across a range of viable technology options when reliable data is available.

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1. Introduction

Few Albertans realize the sheer volume of tires discarded in the province annually. Albertans alone discard over five million tires per year, or 15 kilograms of tires per person - all of which are currently utilized by the province's tire recycling industry. Indeed, since 1992 Albertans have recycled over 59.4 million tires.

As of twenty years ago, Alberta primarily managed waste tires by combusting them in cement kilns. Since then, a variety of re-use and recycling options has been considered with many new approaches deployed. In particular, waste-to-energy recovery in the province has been gaining attention as potential solution for tire disposal.

As a result of the different existing and emerging tire waste management options, the Alberta Recycling Management Authority (Alberta Recycling) is interested in better understanding the full life cycle environmental impacts of the most likely options. This information can be used in three important ways:

- » To identify all the key risks when choosing between recycling options.
- » To determine mitigation requirements upon having selecting a given management option.
- » To support and inform policy decisions on waste management activities in Alberta.

This initiative follows an initial phase that investigated the GHG impacts associated with the post-use life cycle activities of 10 different management options. This first phase drew on the insights of an expert steering committee, of which Pembina was one participant. Alberta Recycling engaged Pembina as the lead consultant for this second more comprehensive phase, which draws on key learnings and select data from the original work. The same steering committee guided both the first and second phases.

The objectives of this analysis and report are three-fold:

- » To provide awareness of available leading tire waste management options, and their environmental benefits and risks from a life cycle perspective.

To provide useful information to Alberta Recycling to inform tire waste management decision making processes.

To provide useful information to community members, policy makers and interested stakeholders to inform their own understanding of tire waste management options, and to help identify and inform their questions.

1.1 Overview of Report Structure and LCA Approach

This analysis is consistent with ISO 14040:2006 Life Cycle Assessment (LCA) Principles and Framework. The first part of the report includes an overview of the objectives, audiences considered and the options assessed (1.0 Introduction). This is followed by an overview of the issues identified along with a description of the general life cycle activities considered (2.0 Scoping). The next major part of the report includes the presentations of the results (Sections 3.0

and 4.0), which focus on the quantitative differences in key environmental parameters across options. Section 3.0 helps inform the risks and benefits associated with the individual management options typically considered, whereas Section 4.0 helps understand the best possible option on a per parameter basis.

High level context for these issues is commented on where appropriate; however, this analysis did not include an impact assessment whereby the quantitative results were placed into specific regional or local context. As such, this analysis is more focused on developing a Life Cycle Inventory (or LCI) in order to discern quantitative differences between options as opposed to a more comprehensive LCA with environmental context.

1.1.1 Life Cycle Process

While this analysis follows ISO's LCA principles and framework, it has not been verified against this or ISO 14044:2006 LCA Requirements and Guidelines.¹ Each technology system assessed provides an equivalent suite of co-products, whether energy or material based.

It should be noted that the true environmental impact of any technology or process can only be determined when the total amount of environmental output is quantified over a given time period. This is referred to as the 'absolute' outputs. This report only considers output 'intensity,' or rather the amount of environmental output per unit of input (tonnes tires). This approach is used in this analysis for comparative purposes.

1.2 Audiences for this Report

Table 1 below summarizes the key audiences considered for this report.

Table 1. Audiences

Level of Priority	Audience
Primary audience	Alberta Recycling Management Authority
Secondary audiences	Government of Alberta, Alberta Environment General public

1.3 Options Assessed

Table 2 below provides a summary of the options assessed in this analysis and the rationale for their inclusion. These options were selected since they represent the range of options currently being used or considered in Alberta. The manufactured product options are selected based on the displaced proxy products and raw materials (i.e., wood, concrete and asphalt).

¹ ISO 14044 applies the term 'unit process' for the individual discrete activities within the life cycle, or system, of a given technology. Pembina refers to these specifically as 'activities' through this report, and not unit processes.

Table 2. Options Assessed

Recycling/Re-use Option	Description	Rationale
Tire Derived Aggregate (TDA)	Used as a layer in a landfill for the purposes of leachate management to facilitate hydraulic conductivity prior to collection of the leachate.	60% ² of tire waste is currently used for this application in Alberta representing 32,000 tonnes of TDA per year.
Crumb	Used as a rubber foundation for athletic fields.	This is currently the primary application of crumb.
Manufactured Products (Wood Displacement)	A rig mat, or large mat placed on the ground for ground protection and improved traction of drilling rigs, is used as a proxy.	Many wood products could potentially be replaced by tires. Rig mats typically made out of wood have increasingly been made out of recycled tires.
Manufactured Products (Concrete Displacement)	Vehicle curbs in parking lots used as a proxy.	There are several retailers of tire recycled curbs and the market for this is growing.
Manufactured Products (Asphalt Displacement)	Roof shingles.	This is an emerging market for waste tires, having being sold in North America since 1993. ³
Tire Derived Fuel (TDF) – Coal Plants	Processed and added to coal feedstock displacing up to an average of 10% on an energy basis.	Approximately 20% of TDF is used for coal plants in the U.S. Along with coal plants and cement kilns, TDF is also used in paper and pulp mills, and industrial boilers.
TDF – Cement Kilns	Whole tires processed and added to coal feedstock displacing up to an average of 10% on an energy basis. Steel in tires displaces a small portion of iron ore inputs.	TDF for cement kilns is primary market for used tires in the U.S., with 40% of all TDF being used in kilns. Along with coal plants and cement kilns, TDF is also used in paper and pulp mills, and industrial boilers.
TDF – Incineration	100% end-of-life tires incinerated for the purposes of energy recovery.	Several plants have existed in the U.S., with 7% of TDF used in dedicated facilities. While not necessarily being considered for Alberta, it is included as a representative waste-to-energy option. Also included because actual data exists. Further, other waste-to-energy technologies are still relatively immature.

² Alberta Recycling Management Authority, *Implications of Using Tire Derived Aggregate for Landfill Leachate Collection Systems – Literature Review* (2009), i.

³ <http://www.articlesnatch.com/Article/Why-Choose-Rubber-Roofing-Shingles/1150009>. Accessed May 18 2010.

1.3.1 Options Not Assessed

A plethora of products could be manufactured using recycled tires, such as mulch for playgrounds, a range of mats or molded products, automotive products and even animal bedding. All of these could not reasonably be modelled in this analysis and as such, proxy products have been used to represent the range of potential products.

At this point in time there are limited applications, and associated environmental performance data, of thermal conversion technologies that using waste tire as a fuel. As such, only incineration was modelled in this analysis. Waste-to-Energy (Thermal Conversion) includes information on the state of emerging thermal conversion technologies and their likely application in the waste tire market.

1.3.2 Displaced Processes

Each of these options is compared against a baseline, or what would have otherwise happened in the absence of the particular option occurring. Through this, we determine the net environmental benefit or impact. In this particular analysis, there are two sets of baselines:

- » what would have happened to the tires otherwise.

in the absence of the waste tire providing a particular service (e.g., crumb for landfill leachate management) what would otherwise be used to provide this value added service (e.g., gravel for landfill).

In Alberta, the existing tire management approach is generally 60% to leachate, 30% to crumb, and 10% to manufactured products.⁴ For each option assessed in this analysis, it is assumed that the default tire management approach in Alberta, or baseline, would be the same. Because it would be the same baseline regardless of the recycling option assessed, this analysis does not include subtracting the environmental impacts associated with the default option as this would actually have no bearing on the *net* quantitative results. Indeed, this approach makes for a more straightforward comparison given that the default approach in Alberta also includes some of the options being independently assessed in this analysis.

The following table includes the displaced processes or materials for the given option being considered.

Table 3. Displaced Materials or Processes

Recycling/Re-use Option	Displaced Material or Process
Tire Derived Aggregate (TDA)	Gravel
Crumb	Synthetic rubber currently used for athletic fields
Manufactured Products: Wood	Wood rig mat
Manufactured Products: Cement	Concrete curb

⁴ Verbal communication with Alberta Recycling, meeting January 29, 2010.

Manufactured Products: Asphalt	Asphalt shingles
Tire Derived Fuel (TDF) – Coal Plants	Coal-based electricity
TDF – Cement Kilns	Coal
TDF – Incineration	Electricity from the Alberta grid

1.4 Limitations of Analysis

While this initiative can be considered the most comprehensive life cycle analyses of tire waste management options in Canada, there are some limitations that should be recognized and potentially addressed in future iterations. These are listed here:

Data availability was limited for certain indicators.

An uncertainty analysis is not included.

The inclusion of a range of potential thermal conversion technologies should be considered when quality data is available and their potential is real.

A complete impact assessment whereby quantitative results are compared against local and regional context has not been completed.

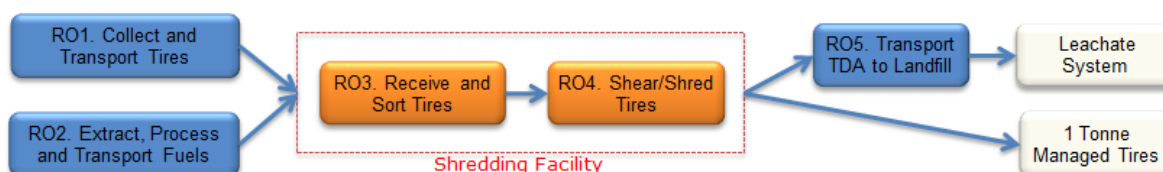
Land and water parameters are not quantified due to lack of available data; however, qualitative discussions are provided where appropriate.

The data sources used in this analysis have some limitations, highlighted throughout the report and further discussed in Data Limitations and Assumptions.

2. Issues Scoping

2.1 Life Cycle Activity Maps

Life cycle activity maps outlining the steps or key discrete activities for each option considered in the LCA were developed. These maps help ensure that all activities and processes are captured and accounted for.



Items contained within the red box happen on site at the recycling/manufacturing facility where red boxes indicate activities that *may* occur and orange boxes indicate activities that will occur. Blue boxes refer to upstream and downstream processes such as transportation and resource extraction. White boxes refer to functional units.

Complete activity maps for all activities are included in the appendix.

The results for each of the tire recycling options assessed are broken into categories of life cycle stages. These stages and what is included are described in Table 4 below.

Table 4. Life cycle Stages

Stage	Description
Fuel Production	Extraction and transportation of fuels for electricity production, space heating, operating equipment and transportation of goods.
Collection	Collection of tires and transportation to processing site.
Processing	On-site storage, shearing, shredding and crumbing of tires. Also includes combustion for TDF options.
Manufacturing	Production of final tire-derived product. Applies only to manufactured products options.
Transport End User	Transporting final product to user (i.e. TDA leachate to a landfill).
End Usage	End use of any by-products of the tire recycling stream (i.e. steel recycling)

Results for the displaced option, or baseline, are provided as a single number and not broken into upstream collection, transportation or manufacturing categories.

2.1.1 Boundary Selection

The system activities included within the boundary were selected based on Pembina's qualitative assessment as to the primary sources of environmental outputs. A quantitative boundary selection exercise involving the energy, mass or economic inputs to activities relative to the functional unit was outside the scope of this initiative. Based on Pembina's familiarity and experience with the life cycle of material and energy supply systems, all key activities are included for the purposes of technology comparison.

The core elements of any systems evaluated in this analysis are the specific recycling process and the associated processes that are displaced. However, upstream emissions (e.g., transportation, resource extraction, fuel combustion, electricity generation) and downstream emissions (transportation emissions) were also included for both the recycling processes and displaced processes to ensure a life cycle perspective was taken. Impacts generated during construction and decommissioning activities are not included. These emissions are typically quite small once amortized over the life of a project in order to be reported on an annual basis. Downstream impacts such as off-gassing and leaching of installed products are not included since these effects are dependent on a variety of conditions and are therefore highly variable making them difficult to effectively model. However, these impacts are discussed qualitatively in Section 2.2 below.

2.2 Issue Exploration and Identification

A qualitative assessment of the activities within each option was performed using Pembina's issues scoping templates. This includes first gaining an understanding of the "sub-activities" or the individual activities occurring within a given activity. For example, crumbing would involve such things as on-site transportation, electricity inputs, blade replacements over its lifespan, as well as lubricants and oils for ongoing maintenance. Understanding this helps to inform and ultimately identify material and energy inputs as well as environmental (and social or economic, if desired) outputs. From this, all potential environmental parameters can be determined and assessed against a given set of criteria in order to select those for modeling.

The following describes some of the key environmental issues identified at a high level for manufactured Tire-Derived Products and for Tire-Derived Fuel. As storage is a key feature in many of the systems, the risk and impacts of tire fires are also described qualitatively. Criteria for selecting the environmental parameters modelled are also provided, along with the parameters themselves and a description of these parameters. Completed Issues Scoping Template provides the completed issues scoping templates.

2.2.1 Tire-Derived Products

Studies have shown that tire crumb (and TDA) can release chemicals into the surrounding environment through the air, or be volatilized and leach into water.⁵ A range of toxic

⁵ Mattima, Mary Jane, Et Al. *Examination of Crumb Rubber Produced from Recycled Tires*. Department of Analytical Chemistry, The Connecticut Agricultural Experiment Station (Accessed May 17, 2010) http://www.ct.gov/caes/lib/caes/documents/publications/fact_sheets/examinationofcrumbrubberac005.pdf

hydrocarbons are noted and can potentially be volatilized, including chemicals such as benzothiazole, butylated hydroxyanisole, n-hexadecane and 4-(t-octyl) phenol. Leached chemicals are typically heavy metals including zinc, selenium lead and cadmium.

A European study found that the use of tire crumb for indoor fields is cause for potential health concerns. The study found that the use of rubber granules generated from synthetic rubbers (i.e. Ethylene-Propylene-Diene-Monomer or EPDM) can actually lead to lower levels of pollutants than TDA.⁶ Further, fields using tire crumb had volatile organic compound (VOC) levels up to three times higher than fields using synthetic rubbers. A variety of other studies examining the impacts of tires through both lab tests and field tests in indoor and outdoor environments show varying levels of VOCs and metals.⁷

More recently, a U.S. EPA department has suggested that they should undertake a full risk assessment of using tire crumb for playgrounds stating that there is insufficient data surrounding the health effects of using tire crumb.⁸

Additionally, the recycling of tires into new tire-derived products such as rubber mats includes the use of a binding agent or glue. Pembina was able to identify a polyurethane binding agent that is considered an allergen, which may cause respiratory failure in some cases.

2.2.1.1 Displaced TDA Products

Some manufactured products displaced by tire-derived products, such as concrete, wood or asphalt, can also release certain chemicals to the environment. Concrete products can off-gas formaldehydes and other chemicals depending on the additives used. Asphalt products can also off-gas a variety of chemicals. Meanwhile, wood products, depending on their treatment, can also off-gas a variety of chemicals or even potentially leach after a certain period of time.

2.2.2 Tire Derived Fuel

Public opposition to thermal conversion, or waste-to-energy, technologies has had a significant negative impact on the development of technology applications. Historically, incineration technologies were targeted, in part, due to a number of well-publicized uncontrolled fires in the past.⁹ Examples include the March 2002 tire fire in Roanoke County, Virginia, which engulfed 30 million tires,¹⁰ and the February 1990 tire fire in Hagersville, Ontario, which involved 14

⁶ Norweigan Pollution Control Authority/Norweigan Institute for Air Research (2006). *Measurement of Air Pollution in Indoor Artificial Turf Halls* (accessed May 17, 2010) http://www.parks.sfgov.org/wcm_recpark/SPTF/NIAP1105.pdf

⁷ California Integrated Waste Management Board (2007). *Evaluation of Health Effects of Recycled Waste Tires in Playground and Track Products* (accessed May 17, 2010) <http://www.calrecycle.ca.gov/publications/Tires/62206013.pdf>.

⁸ US EPA Region 8 (January 2008). *Potential Risks of Tire Crumb* (accessed March 17, 2010) http://www.peer.org/docs/epa/09_1_6_epa_tire_warnings.pdf.

⁹ Virginia Department of Environmental Quality, State Advisory Board (November 2007) *Use of Tire-Derived Fuel in Virginia* (accessed April 21, 2010) http://www.deq.state.va.us/export/sites/default/air/sab/Tire_Derived_Fuel.pdf.

¹⁰ Virginia Department of Environmental Quality, State Advisory Board (November 2007) *Use of Tire-Derived Fuel in Virginia* (accessed April 21, 2010) http://www.deq.state.va.us/export/sites/default/air/sab/Tire_Derived_Fuel.pdf.

million tires.¹¹ Despite differences between incineration and uncontrolled fires, the public opposition mounted against any combustion of TDF. The probability and associated impacts of tire fires is described in detail in the following section.

More recently, public concern about the environmental impacts of thermal conversion facilities in North America has shifted toward the potential release of multiple contaminants into the air via stack emissions and into water through ash leachate.¹² Typical environmental management issues associated with TDF, also commonly cited by concerned environmental groups, are listed here:^{13,14,15,16}

- Air pollution (particulates, NO_x, SO₂, CO, metals, acid gases and dioxins)
- GHG emissions and associated contribution to climate change
- Water pollution
- Inefficiency of energy conversion
- Solid waste products, including ash and other by-products
- Quantity of freshwater used for process cooling
- Health, safety and odour impacts

Other environmentally-related issues cited by opposition groups include the following:

- Creation of disincentives for waste reduction
- Diversion of waste from composting and recycling
- Diversion of funding from other waste management programs
- Operational issues experienced by pilot projects

Groups such as Greenpeace, Friends of the Earth and the Global Anti-Incineration Alliance have publicly opposed thermal conversion projects worldwide.¹⁷ These groups have promoted zero-waste initiatives in a number of municipalities in order to reduce waste generation and combat development of thermal conversion technologies.¹⁸ Public and organized opposition to thermal

¹¹ CBC Digital Archives (February 12, 1990) "The Hagersville Tire Fire" (accessed April 21, 2010) http://archives.cbc.ca/on_this_day/02/12/.

¹² United Nations Environment Programme (no date) Regional Overviews and Information Sources – North America, Topic d: Incineration (accessed April 21, 2010) http://www.unep.or.jp/ietc/ESTdir/Pub/MSW/RO/North_A/Topic_d.asp.

¹³ Energy Justice website: <http://www.energyjustice.net/tires/>.

¹⁴ The Blue Ridge Environmental Defense League (February 2009) *Waste Gasification: Impacts on the Environment and Public Health* (accessed April 21, 2010) <http://www.bredl.org/pdf/wastegasification.pdf>.

¹⁵ Greenaction for Health and Environmental Justice and Global Alliance for Incinerator Alternatives (June 2006) *Incinerators in Disguise: Case Studies of Gasification, Pyrolysis, and Plasma in Europe, Asia, and the United States*, P. 10 (accessed April 25, 2010) <http://www.durhamenvironmentwatch.org/Incinerator%20Files/incineratorsindisguisereportjune2006.pdf>.

¹⁶ Pat Marida, Sierra Club, Central Ohio Group (2004) "Expert Analyzes Proposed Tire Pyrolysis Plant" (COG Newsletter, January/February 2004) (accessed April 30, 2010) <http://ohio.sierraclub.org/central/ExpertTire.asp>.

¹⁷ Andrew Knox, University of Western Ontario (February 2005) *An Overview of Incineration and EFW Technology as Applied to the Management of Municipal Solid Waste (MSW)*, (prepared for ONEIA Energy Subcommittee), P. 24 (accessed April 27, 2010) <http://www.oneia.ca/files/EFW%20-%20Knox.pdf>

¹⁸ http://www.no-burn.org/downloads/North_America_2009_Review-1_1.pdf

conversion technologies have contributed to numerous approval disruptions for projects, with seven occurring in North America in 2009 alone.¹⁹

2.2.2.1 TDF – Cement Kilns

Cement kiln emissions control measures are typically lower than those at other facilities such as power plants, thus there is historically heightened concerns with associated air emissions.²⁰ Further, stack tests used to determine the change in emissions when using tires may not be representative of actual operating conditions. During such tests, operators may run with excess air to help ensure more complete combustion and control kiln conditions more precisely than normal. Kilns also have been known to have combustion upsets where smoke will be emitted. In such events toxic emissions will be more probable.²¹

2.2.2.2 TDF – Coal Electricity

Any issues identified with using tires at coal electricity generating stations were similar to TDF applications for cement plants.

2.2.2.3 TDF – Dedicated Tire-to-Energy Facility

There are very few dedicated tire-to-energy facilities globally, with four known listed below. One operating in Sterling, Connecticut, and run by Exeter energy has failed to meet environmental performance requirements on a number of occasions,²² however, its operating license was recently extended.²³ Other known dedicated tire-to-energy facilities include: Modesto, California. This plant was shut down due to an uncontrolled tire fire adjacent to the plant and subsequent safety concerns.²⁴

Ford Height, Illinois. This plant was bought by Geneva Energy in 2005. Since 2006, it has been issued four pollution violations. In addition, it has not been issued an operating permit from the Illinois EPA and there is no timeline for doing so. Recently, a motion to consider tires burned at this site as a renewable fuel failed to pass through senate.²⁵

A proposed facility in Minnesota was cancelled by the proponent (Heartland Energy & Recycling, LLC) after citizen environmental groups successfully lobbied for the proposed plant to be subject to a full environmental review and environmental impact statement.²⁶

¹⁹ Global Alliance for Incinerator Alternatives (2009) *Stop Incinerators – North America, 2009 in Review* (accessed April 30, 2010) http://www.no-burn.org/downloads/North_America_2009_Review-I_1.pdf.

²⁰ Carman, Neil (1997). *Comments to California Integrated Waste Management Board* (accessed May 18, 2010) <http://www.energyjustice.net/tires/files/carmandangers.html>.

²¹ Ibid.

²² Energy Justice. *Exeter Energy LLC Tire Incinerator in Sterling, CT: Incomplete Timeline of Operations/Violations* (access May 18, 2010) <http://www.energyjustice.net/tires/exeter.pdf>.

²³ Connecticut Department of Environmental Protection (April 2010). *Exeter Energy Operating Permit* (accessed May 18, 2010) http://www.ct.gov/dep/lib/dep/air/permits/titlev_permits/exeter.pdf.

²⁴ Energy Justice. *Tire Burning Facilities* (accessed May 18, 2010). <http://www.energyjustice.net/tires/burners.html>.

²⁵ Fitzpatrick, Lauren (May 5, 2010). "Burning tires almost green in Illinois." *Southtown Star* (access May 18, 2010) <http://www.southtownstar.com/news/2235194,050510tirebill.article>.

²⁶ South Eastern Minnesotans for Environmental Protection. *SEMEP History* (accessed May 18, 2010) <http://www.semep.org/Accomplishments.htm>.

A dedicated tire-to-energy facility was proposed for Erie, Pennsylvania by Erie Renewable Energy LLC. This plant was cancelled at the original location. A new site in Crawford County, following permitting construction could begin later this year.²⁷

2.2.3 Probability and Environmental Impact of Tire Fires

Tire fires have been virtually eliminated in recent years due to improved storage conditions. Scrap tires are difficult to ignite and are very difficult to extinguish once a fire starts. They do; however, remain a possibility if proper storage conditions are not enforced.

Tire fires will emit many chemical compounds hazardous to human health and the environment. These emissions include PAHs, dioxins/furans, PCBs, heavy metals, VOCs and carcinogens. Even relatively small tire fires can result in high levels of toxic air emissions higher than the emission sources from activities modeled in this life cycle analysis.

Tire fires represent an example of an event with a very low probability of occurring but with very high environmental impacts. Such events are difficult to incorporate into life cycle evaluations because they occur infrequently (if at all) and are not part of the average day-to-day activities. These events can theoretically be incorporated into the analysis by considering the probability of occurrence and the severity of impact; however, this study assumes that the risk of a tire fire is sufficiently low is therefore not quantified in the analysis.

A summary of research on tire fires can be found in Tire Fires.

2.3 Environmental Parameters Quantified

The issues scoping exercise helped to identify environmental impacts across all tire waste management options being considered. The following criteria were used to select parameters for quantification in this analysis:

- Data availability
- Frequency of occurrence
- Materiality
- Regional implications
- Data consistency (e.g., different studies had similar results)

Using the criteria above as a guide, and performing further associated research as required, the following parameters were selected for quantification in this analysis:

Greenhouse gas emissions

- Acid deposition
 - » Includes the emissions of acids and acid forming gasses (e.g., NO_x, SO_x, NH₃, HCL)

²⁷ Trading Markets. (April 7, 2010) "Erie Renewable Energy to move tires-to-energy plant to Crawford: Energy plant set for Crawford" (accessed May 18, 2010) http://www.tradingmarkets.com/news/stock-alert/ip_erie-renewable-energy-to-move-tires-to-energy-plant-to-crawford-energy-plant-set-for-crawford-895725.html

- » Measured in SO₂ equivalents, or SO₂e
- Total particulate matter
- Carbon monoxide emissions
- VOC emissions
- Dioxins and furans emissions
- Polycyclic aromatic hydrocarbons
- Heavy metal emissions

Given increased attention to low cost energy supply, as well as fossil fuel energy inputs being an indicator of environmental impact, the following two energy-related parameters were quantified:

- i. Electricity (power) input
- ii. On-site fossil fuel input (i.e. diesel, natural gas, coal, and other on-site fuels associated with heat and transportation, and in some instances chemical feedstocks. In the case of displaced coal at a coal power plant or cement kiln, the energy content of the displaced coal is included.)

Land use, solid waste and water use were also considered as impacts; however, upon further research it was determined that these would not be quantified as the impacts were either considered relatively insignificant or there was a lack of data.

2.3.1 Description of Environmental Issues

Table 5 below provides an overview of the indicators of environmental impacts considered for use in the LCA.

Table 5: Environmental indicators, impacts and associated technologies.

Environmental indicator	Measure	Relevance and importance of indicator
Power Input	kWh	In Alberta, electricity generation is primarily from coal and therefore has a relatively large environmental footprint. The power input of processes is therefore an important indicator of environmental stress.
On-site Fossil Fuel inputs	GJ	Processes that require more fossil fuels for processes such as transportation or heating are less environmentally friendly. Typically fuels used for these purposes include coal, natural gas, diesel and propane – all of which lead to greenhouse gas emissions and other environmental impacts. The energy content of the fuel consumed to generate the heat or power that the system provides are also included in this category when appropriate (i.e. for TDF options). The diesel required as a chemical feedstock for binding agent production is also included in this category, however synthetic rubber to make the tires is not consider a fossil fuel input for this analysis as it is a waste product.
Greenhouse	kg or t CO ₂ e	Emissions resulting from human activities are substantially increasing the atmospheric concentrations of several significant

Gases (GHGs)		greenhouse gases, especially carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O). These are increasing the greenhouse effect, resulting in an overall average warming of the earth's surface. Health Canada has identified eight significant health concerns associated with climate change including temperature-related morbidity and mortality, extreme weather events, and air pollution-related effects.²⁸ Current climate science calls for an aggregate reduction in industrialized countries' emissions to 25 to 40% below the 1990 level by 2020 and 85 to 90% below 1990 levels by 2050.²⁹ CO₂ emissions that originate from biogenic sources are not included in this analysis, as an equivalent amount of CO₂ will be re-sequestered in the growth of the plant material from which it came. Thus, only CO₂ emissions from fossil fuel sources are accounted for, including transportation fuels and the combustion of plastics.
Acid Deposition (ADP) - NO _x , SO _x , HCL, H ₂ SO ₄	g or kg SO ₂ e	Contributes to acid deposition leading to impacts on soils, lakes, forests, crops and buildings. When present with non-methane VOCs, acids are also a contributing factor to ground level ozone, which can cause adverse effects on humans, including lowered lung function and the development of chronic respiratory diseases. Ground-level ozone also has significant impact on reducing the productivity of agricultural crops and forests. NO_x has approximately 70% the acidifying potential of SO₂. See NMOCs below for more information on ground-level ozone. Equivalency factors are used to relate emissions of various acids and acid forming compounds.
Particulate Matter (PM)	kg PM	Particulate matter is comprised of tiny pieces of solid and liquid matter small enough to be suspended in the air. The finest of these particulates are primarily soot and exhaust combustion products that may irritate the respiratory tract and contribute to smog formation. Secondary sources of PM result from SO₂, NO_x and NMOC emissions that act as precursors to PM formation in the atmosphere. Of particular concern are PM 10 and PM 2.5 particulates – fine particulates smaller than 10 and 2.5 microns in size that can penetrate deep into the lungs. These particulates can have a serious effect on respiratory function and have been linked to causing cancer, especially those particulates from diesel exhaust which contain carcinogenic fuel combustion products.³⁰
Carbon Monoxide	g CO	Carbon monoxide is a toxic gas. At low levels it causes fatigue and can cause chest pain for people with heart disease. At higher concentrations it can cause impaired vision and coordination along with headaches, dizziness, confusion and nausea. At very high

²⁸ <http://www.hc-sc.gc.ca/ewh-semt/climat/impact/index-eng.php>.

²⁹ The Case for Deep Reductions: Canada's Role in Preventing Dangerous Climate Change, An investigation by the David Suzuki Foundation and the Pembina Institute, 2005.

³⁰ R.F. Webb Corporate Ltd., *The Environmental Effects of Transportation Fuels – Final Report*, Ottawa, ON: Natural Resources Canada, 1993.

		concentrations CO exposure is fatal. Acute effects include angina, impaired vision and reduced brain function. ³¹
Volatile Organic Compounds (NMOCs)	g NMVOC	When present with NO _x , non-methane VOCs are key precursors to the production of ground-level ozone. The relationship between ground-level ozone and the NO _x and NMVOC precursors involves a very complex non-linear photo-oxidation process, and therefore representing the quantities and concentration of these precursors provides only a rough proxy for the actual environmental impacts of ground-level ozone. The scale of environmental impacts is regional, which can cause adverse effects on humans, including lowered lung function and the development of chronic respiratory diseases. Ground-level ozone also has significant impact on reducing the productivity of agricultural crops and forests.
Dioxins and Furans	ug	Dioxins and furans are generated from a wide range of combustion sources. There are 210 different dioxins and furans, all of which have the same basic chemical structure with chlorine atoms as part of their make-up. Furans are similar, but have a different structure. These substances vary widely in toxicity. They work their way up the food chain by moving into and remaining stored in body fat. Health effects associated with human exposure to dioxins include skin disorders, such as chloracne, liver problems, impairment of the immune system, the endocrine system and reproductive functions, effects on the developing nervous system and other developmental events, and certain types of cancers. ³²
Polycyclic Aromatic Hydrocarbons (PAHs)	mg	Some PAHs have been identified as carcinogens, mutagens and teratogens. ³³
Air Emissions – Heavy Metals (Mercury, Lead, Cadmium)	g	The atmospheric levels of these heavy metals are typically low, however, they contribute to the deposition and build-up in soils. Such heavy metals are persistent in the environment as they do not biodegrade and are subject to bioaccumulation in food chains.

2.4 Quality of Data

2.4.1 Data Selection

Data from a number of sources was used for this LCA and are listed below.

- Actual operating data (i.e. electricity and heating use at recycling facilities).
- NRCAN and Environment Canada data.

³¹ EPA, *An Introduction to Indoor Air Quality: Carbon Monoxide* (accessed May 19, 2010) <http://www.epa.gov/iaq/co.html>.

³² Health Canada. http://www.hc-sc.gc.ca/iyh-vsv/enviro/dioxin_e.html#is. Accessed May 29th, 2008.

³³ Luch, A. (2005). *The Carcinogenic Effects of Polycyclic Aromatic Hydrocarbons*. London: Imperial College Press.

- Pembina's own LCI database drawing on a variety of sources.
- National Renewable Energy Laboratory (NREL) LCA database.
- Other sources such as emissions tests and facility operating licences.

Actual data representing operations occurring in Alberta and Canada were obtained to the extent possible. The NREL LCA database was the next key source of operating data. NREL is a branch of the US Department of Energy and has increasingly become a key source of LCA information in North America based on its comprehensiveness. Pembina is also confident in this database as it has cross referenced many of its factors and also been in discussions with its staff.

All data sources are fully referenced in Data Sources.

2.4.2 Uncertainty

While the data sources used in this analysis are considered as reliable as any leading LCA, some uncertainty will always exist for numerous reasons. For example, the data is only representative of a generic process, the data may not be current, or there is limited information provided about the dataset. Some of the uncertainty associated with the data used in this analysis stems from:

Multiple datasets are required as a single dataset does not always include all environmental parameters

Some datasets either make no reference to a parameter or assigns it a zero, in which case it is difficult to determine if that means there is no release of that parameter or if it was not measured. Note that in all cases where a pollutant was not reported, it is reported as DNR, or Did Not Report, in this analysis.

Emission factors for some processes are based on test burns done at a variety of facilities and therefore averaged.

3. Results: Comparison of Emissions by Recycling Option

This section summarizes the life cycle results for each recycling option compared against its baseline scenario. The results for each recycling option are summarized into a combination graph that contains both bar charts and line charts. Each recycling option graph displays three series of data:

- » The emissions from the tire recycling activities are categorized into life cycle stages and graphed as a bar chart with the bars presented above the horizontal x-axis.
- » The emissions from the baseline scenario, or displaced process, are graphed as a bar chart and presented as a negative number, or credit, as these impacts would now be avoided. The avoided impacts from the displaced options are presented below the horizontal x-axis.
- » The net difference between the recycling option and the baseline scenario is presented as a line chart. A value below the x-axis indicates a net benefit of that parameter where a value above indicates a net increase.

It is important to note that the units for each of the parameters on the graphs are different from one another in order to ensure all parameters can be displayed on the same graph. While this is useful to capture all information on a single figure, the relative importance of the results can be misleading at times. For example, there may be a large change in the relative amount of a given parameter between the two cases compared, but at times these large changes do not show on the graph. This is purely because of the scales used, as there are different units for the different parameters. While the figures below provide a good indication of differences per parameter, each parameter must be considered independently and not be compared against each other. Further, it is important to consider the magnitude of change for a given parameter (i.e., how many times larger or smaller is the recycling option vs. the baseline), particularly if it was a relatively large number to begin with (i.e. the baseline). See the results comments for a discussion of results, and Table 7 for data on net life cycle differences between options per parameter.

The description of net increases or decreases compared to the baseline in each of the sub sections below include highlights of those parameters that were considered to have the most significant changes relative to the other options, as provided in Section 4.

3.1 Tire Derived Aggregate

In this recycling option, tires are sheared and shredded and used in landfills as a leachate collection system. The use of TDA displaces gravel that is the traditional material used for landfill applications. Figure 1 below compares the environmental indicators between using TDA and gravel for landfill leachate collection systems.

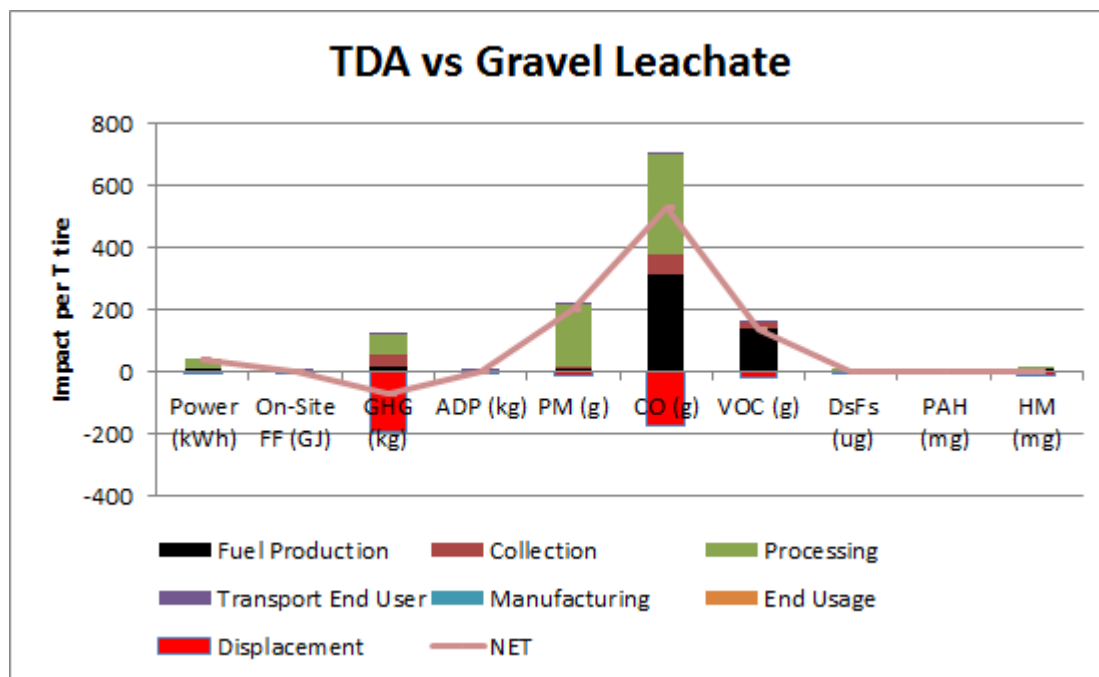


Figure 1: TDA vs Gravel for Leachate Collection System Results

Net Increases:

PM, CO and VOC emissions increase with this recycling option.

- » Net PM emissions increase with this recycling option due to the high diesel consumption used for inventory management at the shredding facility. Inventory management is performed using small mobile equipment.
- » Net CO and VOC emissions increase due to the increased off-site emissions of upstream fuel production in the recycling option over the baseline scenario (black bars for recycling option in Figure 1 above).

Net Decreases:

GHGs are the only real net benefits for going with the recycling TDA option. This is primarily due to the displacement of fossil fuels used to quarry and transport gravel. However, the net benefit is much less than with other options (see Section 4).

3.2 Manufactured Products: Rig Mats

In this recycling option, tires are sheared/shredded/crumbed, mixed with a binding agent and reformed into rubber rig mats. This comparison assumes that reformed rubber rig mats displace

timber rig mats made from traditional sawmill timber. The comparison of environmental indicators between rubber and timber rig mats is summarized in Figure 2 below.

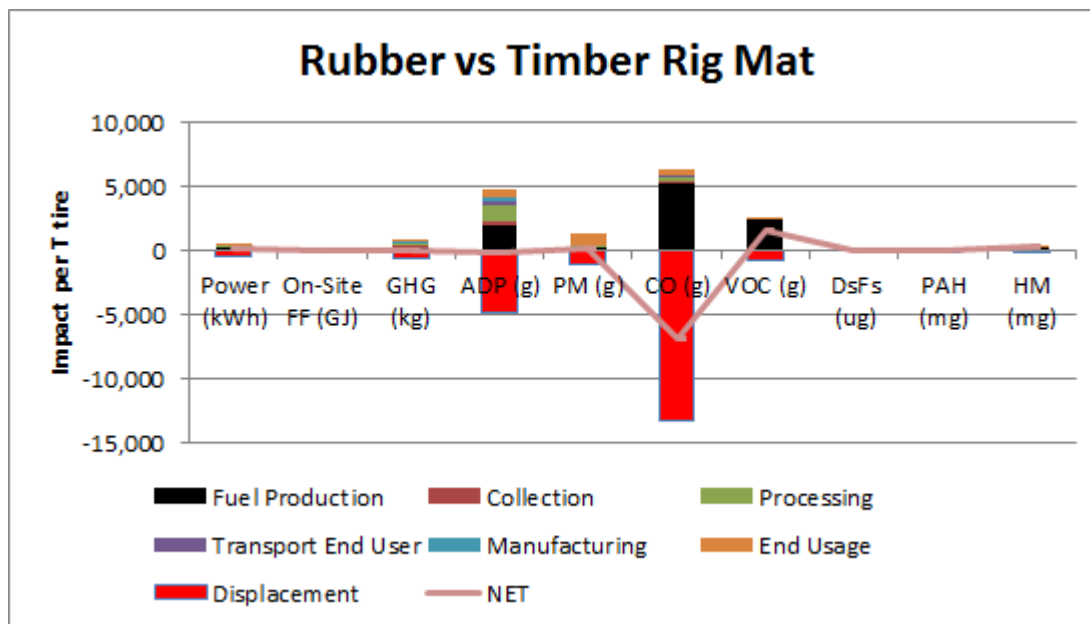


Figure 2: Rubber vs Timber Rig Mats Results

Net Increases:

On-site fossil fuel input, GHG, VOC, dioxins/furans and heavy metals show net increases in emissions.

- » Producing rubber rig mats increases fossil fuel inputs more than any other recycling option (see Section 4.2 On-site Fossil Fuel Inputs below). The increase is not seen in Figure 2 due to scaling of this data to GJ.
- » VOC and heavy metals both increase due to the increased use of Alberta grid power at the remanufacturing facility to shred, crumb and mold rubber products. Conversely, producing timber rig mats in the baseline scenario has significantly fewer emissions as there is much less electricity demand.
- » Net heavy metal emissions increase over the baseline scenario is mainly attributed to upstream fuel production (i.e. diesel, coal and natural gas) and steel recycling.

Net Decreases:

PM and CO emissions result in a net decrease, although PM only slightly.

- » CO emissions decrease due to the high CO emissions in the baseline scenario from sawmill and virgin steel activities. It is suspected that CO emissions at a steel plant result from incomplete combustion of coal and coke in the coke and steel making processes.
- » PM emissions decrease from the timber rig mat baseline scenario because there are high PM emissions from sawmill activities.

3.3 Manufactured Products: Concrete for Curbs

In this recycling option, tires are sheared/shredded/crumbed, mixed with a binding agent and reformed into rubber curbs. This comparison assumes that reformed rubber curbs displace pre-formed concrete curbs (or any other preformed concrete product). The comparison of environmental parameters between rubber and concrete curbs is summarized in Figure 3 below.

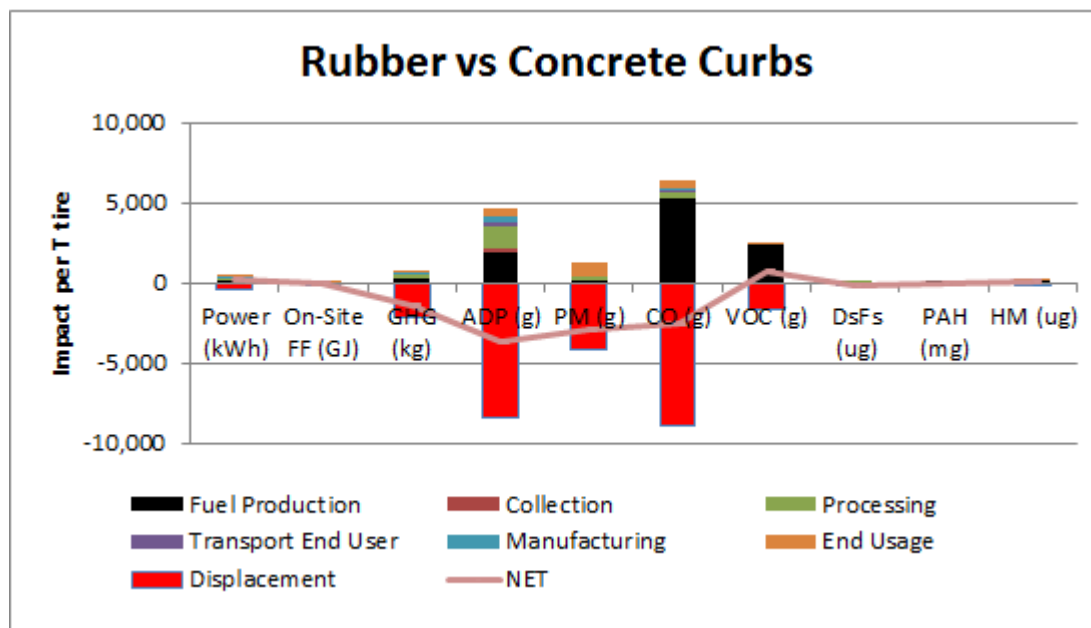


Figure 3: Rubber vs Concrete Curbs Results

Net Increases:

Power input, on-site fossil fuel input, VOC and heavy metals emissions show a net increase with the recycling option.

- » Power input requirements increase because steel is recycled in an electric arc furnace and manufacturing the rubber binding agent requires additional power input.
- » On-site fossil fuel inputs increase due to the high fossil fuel requirements to manufacture the binding agent. The overwhelming proportion of this energy is diesel fuel used as a feedstock for the binding agent.
- » VOC emissions increase due to the relatively low emissions from concrete production compared to those emitted in the recycling case. In the recycling case, the majority of the VOCs emitted are from off-site upstream diesel fuel production. Diesel fuel is used throughout the recycling option but the majority of the diesel (92%) is used to manufacture the binding agent.
- » Heavy metals emissions increase due to steel recycling and fuel production (Alberta electricity, diesel and natural gas) activities.

Net Decreases:

GHG, PM and CO emissions show a net reduction with the recycling option.

- » GHG emissions show a significant decrease due to the high energy requirement of the concrete plant in the baseline scenario.
- » PM emissions decrease due to the high on-site emissions at the cement plant.
- » CO emissions decrease as virgin steel production has high CO emissions as discussed in the rig mats section above.

3.4 Manufactured Products: Asphalt Shingles

In this recycling option, tires are sheared, shredded and crumbed, mixed with a binding agent and reformed into rubber roofing shingles. This comparison assumes that reformed rubber shingles will displace asphalt shingles. As a rubber roofing products is slightly more expensive it is possible it would displace other comparable higher premium products such as shakes or tiles rather than asphalt shingles. While this may be the case, the difference in environmental impacts from displacing shakes (wood) or concrete tiles could be considered similar to results from the timber mat or concrete curbs recycling options including in this report. The comparison of environmental parameters between rubber and asphalt shingles is summarized in Figure 4 below.

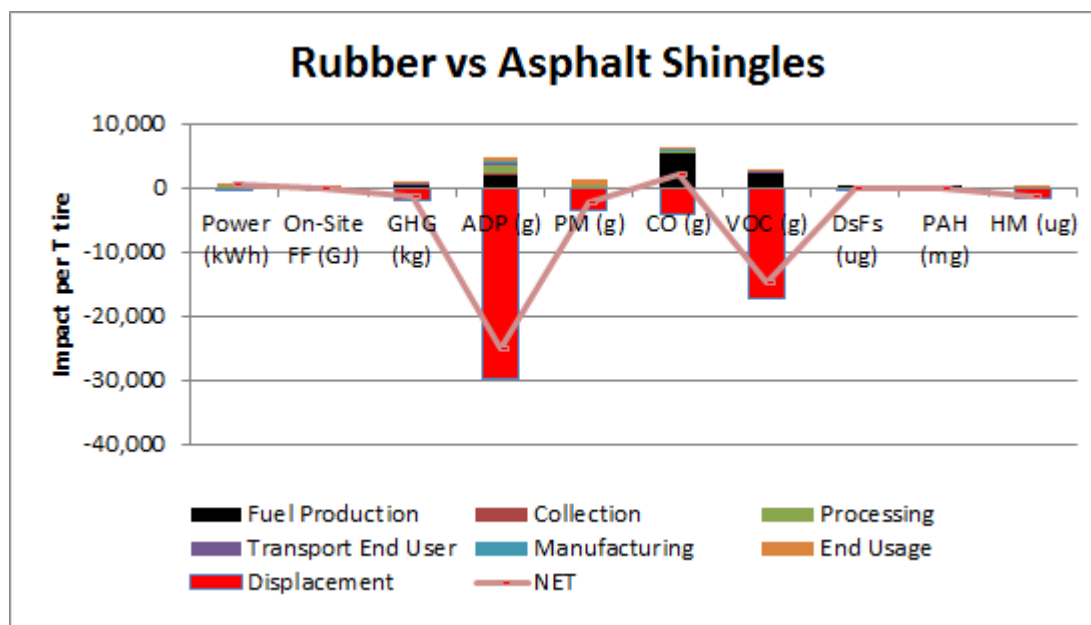


Figure 4: Rubber vs Asphalt Shingles Results

Net Increases:

Power input and CO emissions result in net increases for the recycling option.

- » Power input increases are largely due to the off-site upstream production of the fuels and the rubber binding agent. Large amounts of power are also required to recycle steel which is performed in an electric arc furnace.

Net Decreases:

GHG, ADP, PM, VOC and heavy metals emissions decreased for the recycling option. Each of these environmental emissions decrease because of the high emissions to produce asphalt shingles in the baseline case.

3.5 Crumb

In this recycling option, tires are sheared, shredded and crumbed. This comparison assumes that rubber tire crumb will displace polypropylene crumb as a rubber foundation for athletic fields. Polypropylene crumb is a synthetic rubber that is used for numerous applications whose physical properties are close to crumb. In practice tire-derived crumb is only used on athletic surfaces as an enhancement product and would not displace existing material. However, for the purposes of this analysis it is assumed that polypropylene crumb would have been used otherwise. The comparison of environmental parameters between rubber and polypropylene crumb is summarized in Figure 5 below.

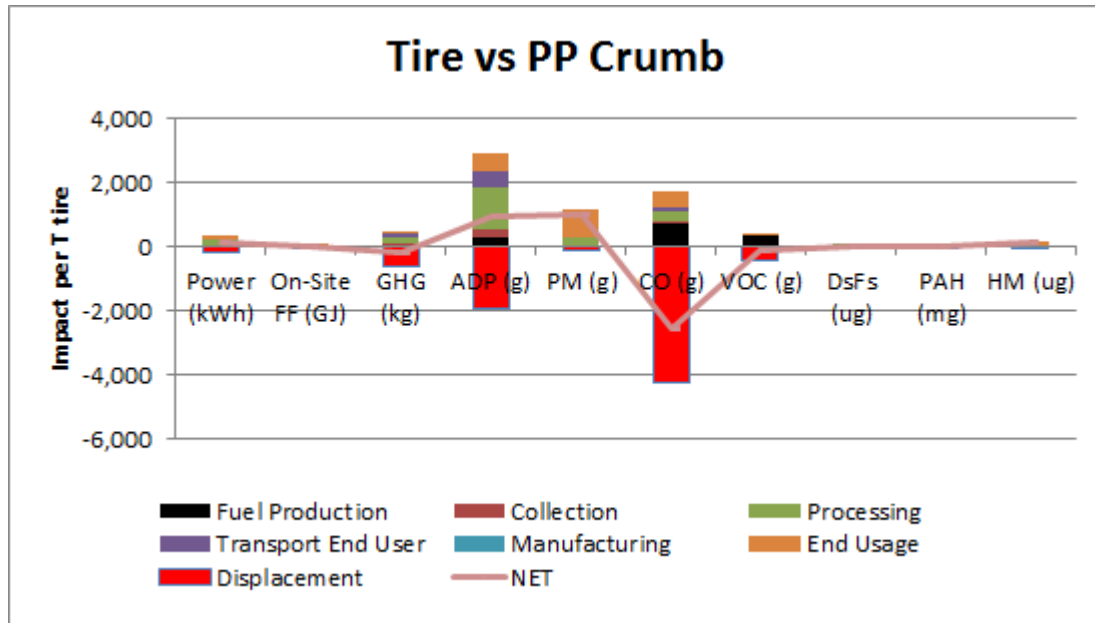


Figure 5: Tire vs PP Crumb Results

Net Increases:

Power input, ADP, PM and heavy metal emissions increase with the recycling option.

- » Power input requirements as well as ADP and PM emissions increase from recycling steel in an electric arc furnace.
- » Heavy metals emissions increase due to steel recycling activities.

Net Decreases:

On-site fossil fuel input, GHG, CO and VOC emissions decreased with the recycling option.

- » On-site fossil fuel input demand decreases due to the smaller amounts of energy required to shred and crumb tires compared with the baseline scenario where polypropylene crumb is manufactured using significant quantities of natural gas.
- » GHG emissions decrease as the recycling option only requires electricity and NG to crumb tires where the baseline scenario combusts more fossil fuels to produce polypropylene crumb.
- » CO shows a net benefit as the intensity from producing virgin steel is very high.

3.6 Tire Derived Fuel: Displace Coal at Power Plant

In this recycling option, tires are sheared, shredded and combusted at a coal power plant displacing traditional bituminous coal fuel. The comparison of environmental parameters between tire and coal combustion at the power plant is summarized in Figure 6 below.

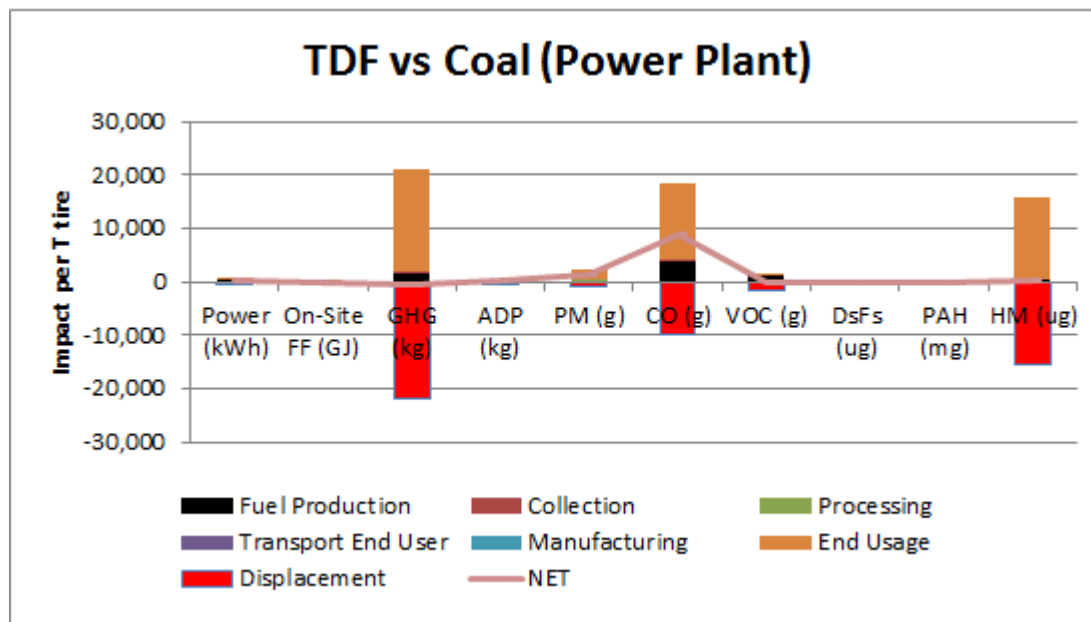


Figure 6: TDF vs Coal (at Power Plant) Results

Net Increases:

Power input, ADP, PM, CO, dioxins/furans and heavy metals emissions all increase with this recycling option.

- » Power input requirements increase due to the electricity demand to de-wire tires at the coal plant.
- » ADP emissions increase due to the fuel switch between coal and tires.
- » PM emissions increase due to the high emissions of recycling steel compared with virgin steel production and the fuel switch between coal and tire fuel.
- » CO emissions increase due to fuel switching from coal to tire fuel. Emissions are reported to be 539% higher with 10% tire fuel feedstock.
- » Dioxin/furan emissions increase due to the fuel switch from coal to tires. Fuel switching increases dioxin/furan emissions by 55%.
- » Heavy metals increase mainly due to tire combustion at the coal facility. The data set used³⁴ indicates that lead (Pb) emissions increase by 3% when combusting with a 10% TDF feed.

Net Decreases:

GHG and VOC emissions decrease with this recycling option.

³⁴ EPA, Office of Research and Development, *Air Emissions from Scrap Tire Combustion* (Washington, DC, 1997).

- » GHG are a benefit because virgin steel production has high GHG emissions compared with steel recycling. GHGs are also reduced from fuel switching between coal and tires.
- » VOC emissions decrease because virgin steel production has higher VOC emissions compared with steel recycling.

3.7 Tire Derived Fuel: Displace Coal at Cement Kilns

In this recycling option, tires are sheared and combusted at a cement facility displacing traditional bituminous coal fuel in the kilns. The comparison of environmental parameters between tire and coal combustion in the cement kilns is summarized in Figure 7 below.

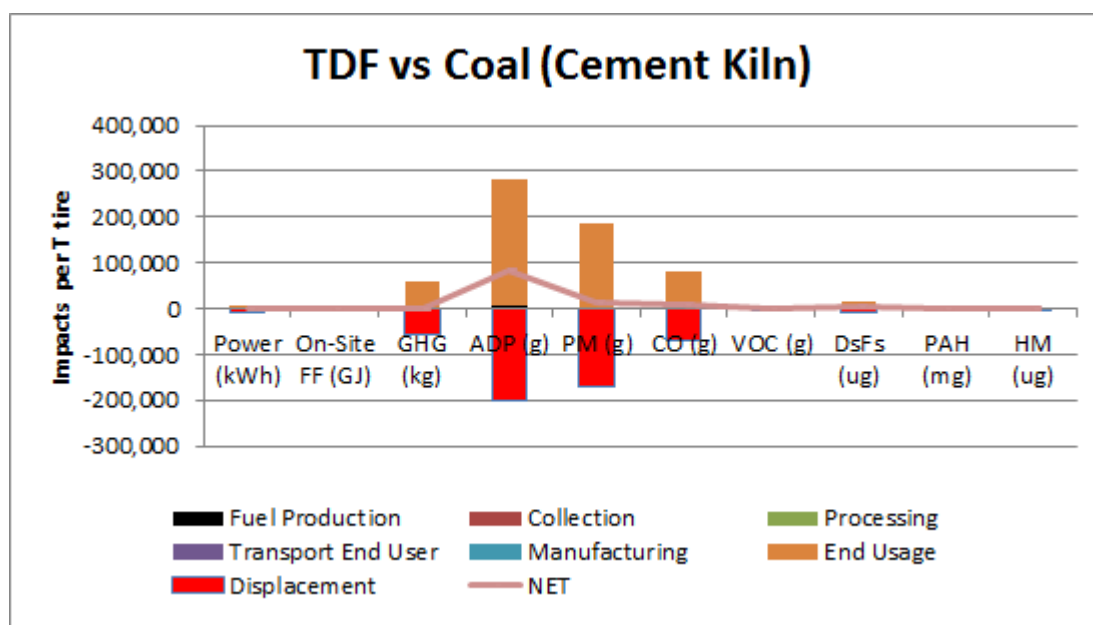


Figure 7: Cement Kiln Results

Net Increases:

PM, CO, VOC and dioxins/furans emissions increase with this recycling option.

- » The PM, CO, VOC and dioxins/furans increases at the cement plant are largely due to fuel switching from coal to tires.

Net Decreases:

Power input demand, GHGs and heavy metal emissions decrease with this recycling option.

- » Power input demand drops in for the recycling option because less electricity is used to shred tires when compared with the baseline scenario where electricity is required to extract and process coal.
- » GHGs emissions decrease on-site from fuel switching from coal to tires (1.4% decrease supplying 10% of kiln heat using tires).

- » Heavy metal emissions decrease from fuel switching from coal to tires (13% decrease using a 10% TDF feed). The dataset used³⁵ indicates a 35% reduction of chromium, 12% reduction of mercury, 4% reduction of manganese and a 14% reduction in nickel.

3.8 Tire Derived Fuel: Dedicated Tire to Energy (T2E) Plant

In this recycling option, tires are incinerated at a dedicated tire-to-energy (T2E) facility that takes a 100% tire feedstock and produces electricity displacing grid electrical power. This analysis assumes the grid is located in Alberta. The comparison of environmental parameters between the T2E facility and Alberta grid power is summarized in Figure 8 below. Note that emissions presented for the T2E facility are actually emission allowance limits and not operating data, as operating data was not available.

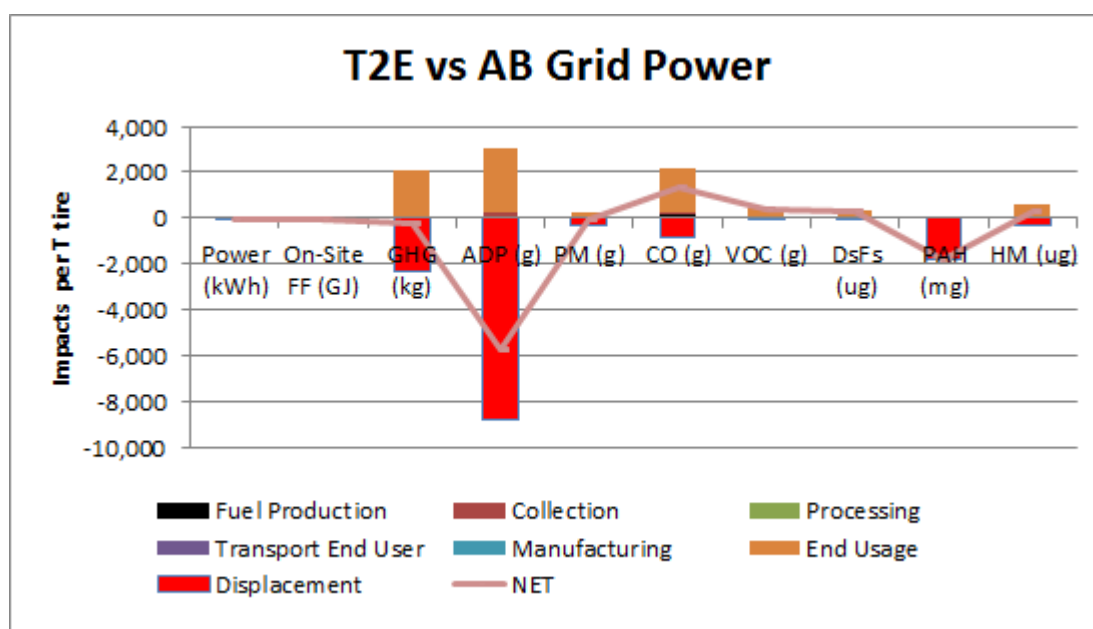


Figure 8: Dedicated Tire to Energy Facility vs Alberta Grid Power Results

Net Increases:

CO, VOC, dioxin/furans and heavy metal emissions increase for this recycling option. Each of these environmental indicators increases due to the T2E facility.

- » There is a dramatic increase in dioxins/furans emissions at the dedicated tire-to-energy facility compared with the baseline scenario of Alberta grid power.; This is because the data used to model the tire-to-energy facility represents the maximum allowable emission limits of the Exeter plant in Connecticut. This comparison illustrates a data limitation given maximum allowable emission limits are not actual. . While this data limitation is recognized, it was the only available data at the time of this analysis and can be considered to be an inherently conservative value.

³⁵ The Scrap Tire Management Council, *The Use of Scrap Tires in Rotary Cement Kilns* (Washington, DC).

Net Decreases:

On-site fossil fuel inputs, ADP, GHGs, PM and PAH emissions decrease for this recycling option.

- » Fossil fuel inputs decrease given the coal and natural gas-derived Alberta grid power is displaced. While future supply sources are uncertain, a supply-demand gap of 56,000 GWh projected out until 2028 currently exists.³⁶ Should lower-carbon sources be developed in closing this gap, there would be less of a decrease in fossil fuel inputs.
- » GHG and PM emissions decrease due to the lower on-site GHG emissions of combusting tires over combusting coal/natural gas. They are also lowered from off-site activities as collecting tires is less GHG intensive than extracting, processing and collecting coal/natural gas.
- » PAH emissions show an overall decrease; however, PAH emission data for the incineration of tires and for the baseline (AB grid power) was not available. Incinerating tires will likely have an effect on PAHs but it is uncertain whether this will be an increase or a decrease at this time. The decrease that is seen in these results is due to reduction in PAH emissions of off-site activities (extraction, processing and transportation of fuels). While not having PAH data for incineration is a clear limitation, given PAHs existed at other parts of the life cycle this was considered important to still include.

3.9 Results Summary

The results by environmental parameter are summarized in Table 6 and Table 7 below for net changes and by % over baseline scenario respectively.

Table 6: Summary of Net Emission Changes

	Power Input (kWh / T tires recycled)	On-site FF Input Reqs (GJ / T tires recycled)	GHG (kg CO ₂ e / T tires recycled)	ADP (kg / T tires recycled)	PM (g / T tires recycled)	CO (g / T tires recycled)	VOC (g / T tires recycled)	Dioxins / Furans (ug / T tires recycled)	PAH (mg / T tires recycled)	Heavy Metals (mg / T tires recycled)
TDA vs Gravel Leachate	39	-2	-69	1.1	201	529	132	0.0006	0	0.2
Rubber vs Timber Rig Mats	103	19	-11	0	74	-6,984	1,554	0.01	0	202
Rubber vs Concrete Curbs	185	18	-1,438	-4	-2,862	-2,533	682	-179.2001	-1	45
Rubber vs Asphalt Shingles	445	2	-1,408	-25	-2,418	2,037	-14,903	-0.02	0	-1,403
Tire vs PP Crumb	106	-22	-221	1	998	-2,580	-124	-0.01	0	71
TDF vs Coal (Power Plant)	144	-2	-606	82	1,188	8,890	-86	14	-2	137
TDF vs Coal (Cement)	-220	-1	-499	81	14,187	8,349	246	4,932	-3	-494
T2E vs AB Grid Power	-30	-26	-194	-6	-77	1,333	349	301	-2	250

Table 7: Summary of % Change in Emissions over Baseline Scenarios

³⁶ Tim Weis and Jeff Bell, *Greening the Grid – Powering Alberta’s Future with Renewable Energy*, (Drayton Valley AB: The Pembina Institute, 2009), 16.

	Power Input (kWh / T tires recycled)	On-site FF Input Reqs (GJ / T tires recycled)	GHG (kg CO ₂ e / T tires recycled)	ADP (kg / T tires recycled)	PM (g / T tires recycled)	CO (g / T tires recycled)	VOC (g / T tires recycled)	Dioxins / Furans (ug / T tires recycled)	PAH (mg / T tires recycled)	Heavy Metals (mg / T tires recycled)
TDA vs Gravel Leachate	1916%	-68%	-36%	672%	1572%	307%	580%	41%	-91%	2%
Rubber vs Timber Rig Mats	23%	123%	-1%	-5%	6%	-52%	186%	147%	-35%	338%
Rubber vs Concrete Curbs	50%	110%	-67%	-44%	-69%	-29%	40%	-100%	-85%	21%
Rubber vs Asphalt Shingles	407%	6%	-67%	-84%	-66%	47%	-86%	-50%	540%	-84%
Tire vs PP Crumb	49%	-86%	-34%	45%	773%	-60%	-27%	-52%	-70%	78%
TDF vs Coal (Power Plant)	37%	-1%	-3%	44%	113%	92%	-5%	55%	-2%	1%
TDF vs Coal (Cement)	-2%	0%	-1%	41%	8%	12%	6%	55%	-15%	-12%
T2E vs AB Grid Power	-90%	-98%	-8%	-65%	-24%	159%	396%	356288%	-100%	78%

The following are critical observations we can pull from the above results:

The benefits of remanufacturing tires into rubber products greatly depends on the displaced material, whether it be concrete, wood, or an asphaltene product.

There is no single outright “winner”. For each option there are typically both net increases and decreases of varying environmental parameters. Some options, however, have few net decreases in emissions and therefore raise the valid question of whether such management options are an appropriate approach. The answer, of course, will be dependent on the local context and whether one particular parameter may drive a decision more than another.

Those options that could be considered to demonstrate little overall benefit, based on the air parameters assessed, are TDA to replace gravel for landfill leachate collection systems and tire manufactured products to replace wood ones.

- » An important factor is the consideration of raw materials that might otherwise be in short supply. Thus, while replacing gravel or wood products may show questionable benefit from an air emission perspective, and possibly even water or land, extraction of the original resource itself (i.e. gravel or wood) would be avoided which may in and of itself have significant benefits depending on the situation.

Displacing concrete curbs and asphalt shingles reduces GHG emissions more than any other recycling option. Displacing concrete also delivers the benefits of reducing ADP, PM and CO where displacing asphalt shingles delivers benefits on ADP, PM and VOCs.

There are some decreases in airborne PAHs, with the most significant relative change being a 100% decrease in the T2E option. While recycling tires into roofing shingles to displace asphalt shingles shows in a large increase in PAH emissions; PAH emissions from the production of asphalt shingles was not available. Thus, the increase noted can be considered conservative.

The TDF application in coal plants result in an increase in HM emissions while application in cement kilns results in a decrease in HM emissions. The data used for these recycling options came from different sources and may contribute to the inconsistency. However, other reasons such as heavy metal concentration in tire rubber, whether data includes emissions from tires that are not de-wired, and varying types of rubber used in tires, could all contribute to apparent discrepancies.

No TDF option shows decreases across the board. Many of the emission increases however, such as ADP and CO, can be mitigated through environmental controls and as such may differ from plant to plant.

- » The tire-to-energy options show moderate GHG benefits (net basis), and all result in CO and dioxin/furan increases. While the absolute amounts of GHG reductions are certainly material relative to many of the other options, the percent change from the baseline is relatively minor.
- » The cement kiln option shows considerable PM and dioxin/furan increases.
- » Coal power plant shows an increase in ADP emissions, however this will largely be a factor of the on-site environmental controls.
- » Both the cement kiln and T2E facility show VOC increases.

When reflecting on the results, it is important to recall the key data limitations which are summarized here:

- » Limited data is available for dioxin/furans, but the data that exists indicates that there will be an increase for the TDF applications (coal, cement, tire incineration). Dioxin/furan emissions can be destroyed on-site by allowing for high combustion temperatures, adequate combustion times and turbulence to distribute heat.³⁷ Hence dioxin/furan emissions will vary drastically from site-to-site depending on how aggressively they are managed.

Dioxin/furans, PAH and heavy metals have incomplete data. While data exists for some activities, many activities do not have sufficient data and thus it is important to draw any major conclusions with caution.

³⁷ The Dow Chemical Company. *Dow Sustainability – How Dioxins and Furans are Formed*. Accessed online May 2010 at <http://www.dow.com/commitments/debates/dioxin/definitions/how.htm>

4. Results: Comparison of Options by Environmental Parameter

4.1 Power Input

Electricity input demand for each of the eight recycling options is compared in Figure 9 below. The vertical axis on this chart has been scaled to display the net values of each option but the full range of the values (i.e. max/min) for the TDF (cement kiln) data are actually not displayed in order to effectively present the other options.

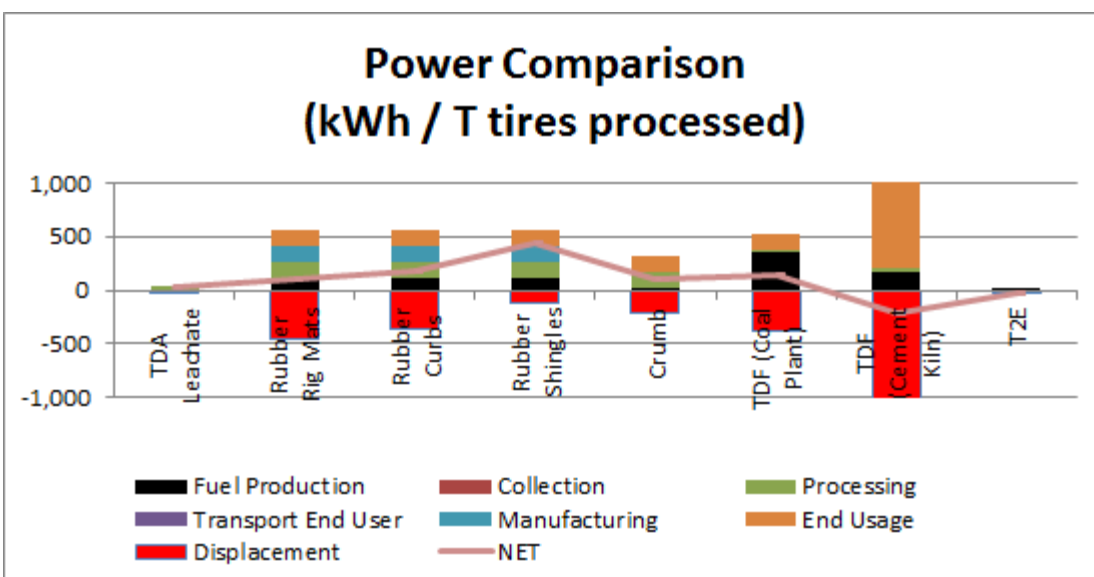


Figure 9: Electricity Input Results

Net Increases:

Seven of the eight tire recycling options required more input electricity than their displaced option. That is, more electricity was required to process the tires over that which would have been required for the corresponding baseline scenario. Producing rubber shingles when compared with producing asphalt shingles showed the greatest net increase in electrical input demand.

- » Some recycling options displace more power inputs over others noted under the displacement category (red bars) in Figure 9 above.
- » The tire re-manufacturing facility that produces TDA leachate, rig mats, curbs, shingles and crumb uses electricity on-site for shearing, shredding, crumbing and forming products. There is also off-site electricity demand to manufacture the binding agent used in new products as well as to recycle steel separated from the tires.
- » Manufacturing asphalt shingles required a relatively small amount of input electricity required and this combined with the high tire recycling electricity input requirements resulted in rubber roofing shingles having the highest net increase in electricity input.

Net Decreases:

Only TDF for cement production shows a net decrease.

- » The displacement of electricity required for off-site coal mining operations in the base case results in a net benefit for the TDF option.

4.2 On-site Fossil Fuel Inputs

On-site fossil fuel input demand for each of the eight recycling options is compared in Figure 10 below. The vertical axis on this chart has been scaled to display the net values of each option but the full range of the values (i.e. max/min) for the TDF (cement kiln) data are actually not displayed in order to effectively present the other options.

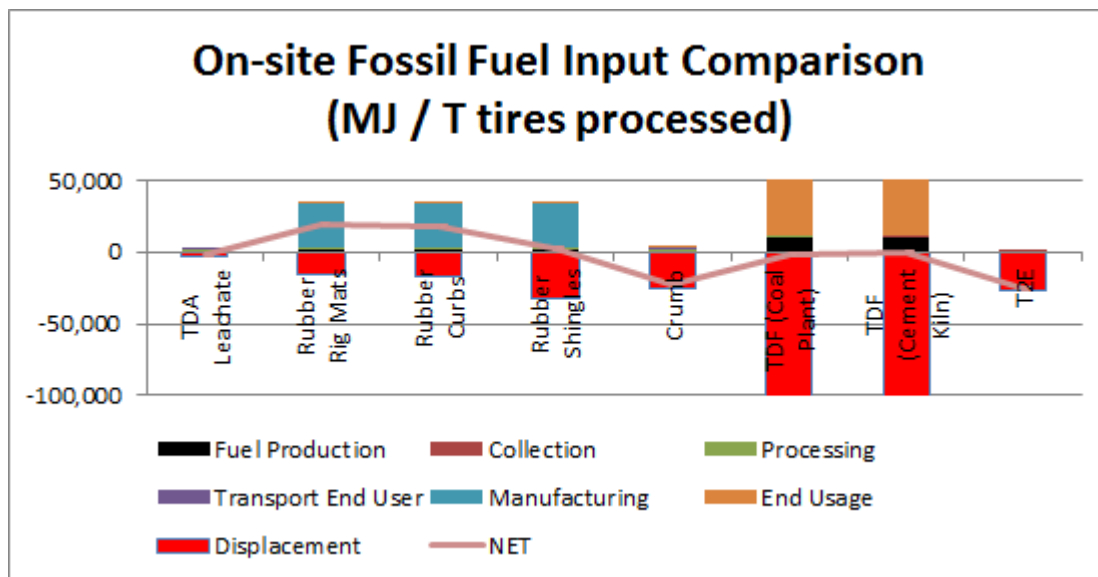


Figure 10: Energy Input Results

Net Increases:

Rubber rig mats, curbs and shingles show a net increase in fossil fuel consumption.

- » Producing rubber rig mats requires the most energy input requirements of all recycling options.

- » The increase in energy inputs for re-manufactured tire products is due to off-site fossil fuel production/transportation and large fossil fuel requirements to manufacture the binding agent. There is also a large natural gas requirement at the manufacturing facility to mold new products and heat buildings.

Net Decreases:

The crumb and T2E recycling options show the most significant net decrease in fossil fuel requirements.

- » T2E has the largest net decrease in fossil fuel inputs. There are minimal fossil fuel inputs in the incineration of tires compared with the AB grid displaced scenario where coal and natural gas are fossil fuel inputs to power generation.
- » Crumb shows a net decrease because of the high fossil fuel requirements to produce polypropylene and the high amount of energy used to make virgin steel in the baseline scenario (whereas it is an electric arc furnace in the recycling case).

4.3 GHGs

GHG emissions for each of the eight recycling options are compared in Figure 11 below. The vertical axis on this chart has been scaled to display the net values of each option but the full range of the values (i.e. max/min) for the TDF (coal plant) and TDF (cement kiln) data are actually not displayed in order to effectively present the other options.

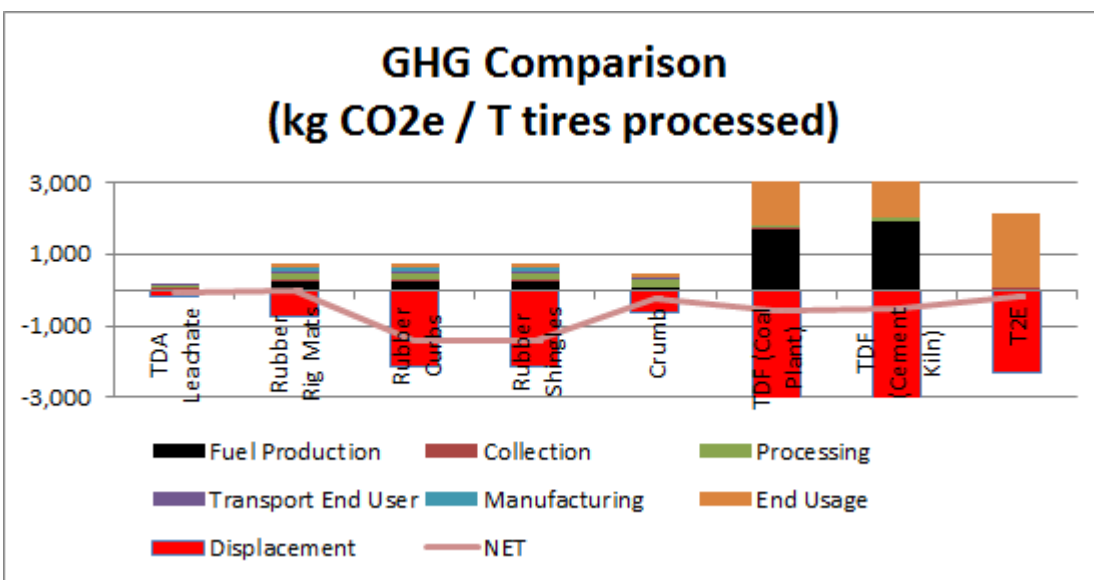


Figure 11: GHG Results

Net Increases:

Rubber rig mats are the only recycling option that produces slightly more GHG than its baseline scenario. The GHG emissions to produce rubber rig mats result from diesel fuel used for transportation and manufacturing binding agent. While rubber curbs and shingles also have high GHG emissions in the recycling case, they have much larger GHG emissions in their baseline scenarios.

Net Decreases:

Rubber curbs and rubber shingles show a significant net benefit on GHGs while TDF (coal plant) and TDF (cement kiln) show a more marginal decrease on GHGs.

- » Rubber curbs and shingles have the largest GHG benefit. This is mainly due to the large GHG emissions from manufacturing concrete and asphalt compared with a recycled product.
- » TDF (coal power) and TDF (cement kiln) also show net GHG benefits. GHG emissions are decreased on-site and off-site equally and contribute to the relatively larger net GHG benefit.

4.4 Acid Deposition Precursors

ADP emissions for each of the eight recycling options are compared in Figure 12 below. The vertical axis on this chart has been scaled to display the net values of each option but the full range of the values (i.e. max/min) for the TDF (cement kiln) data are actually not displayed in order to effectively present the other options.

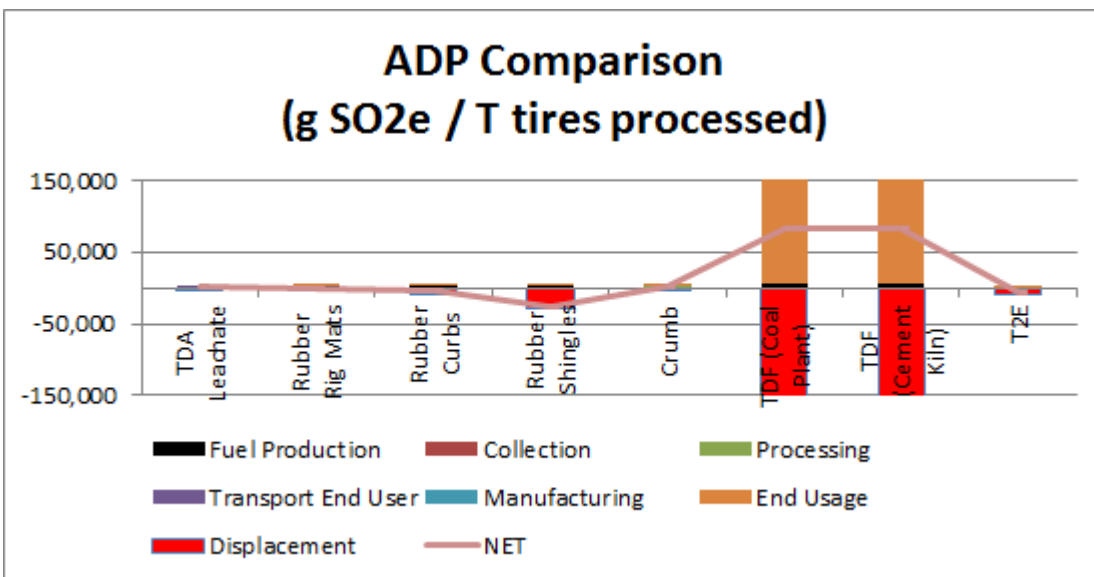


Figure 12: ADP Results

Net Increases:

TDF coal plant and TDF cement kiln recycling options result in the greatest net increase in ADP emissions due to the on-site fuel switching from coal to tires. EPA data for coal power plants³⁸ shows that NO_x and SO₂ emissions increase by 56% and 21%, respectively.

Net Decreases:

The rubber shingles option shows the largest decrease in ADP emissions. Tires recycled into rubber curbs and the T2E facility also show decreases to a lesser extent.

- » Rubber shingles produces a net decrease of ADP emissions due to the large ADP on-site emissions of producing asphalt shingles in the baseline scenario.

4.5 Particulate Matter

PM emissions for each of the eight recycling options are compared in Figure 13 below. The vertical axis on this chart has been scaled to display the net values of each option but the full range of the values (i.e. max/min) for the TDF (cement kiln) data are actually not displayed in order to effectively present the other options.

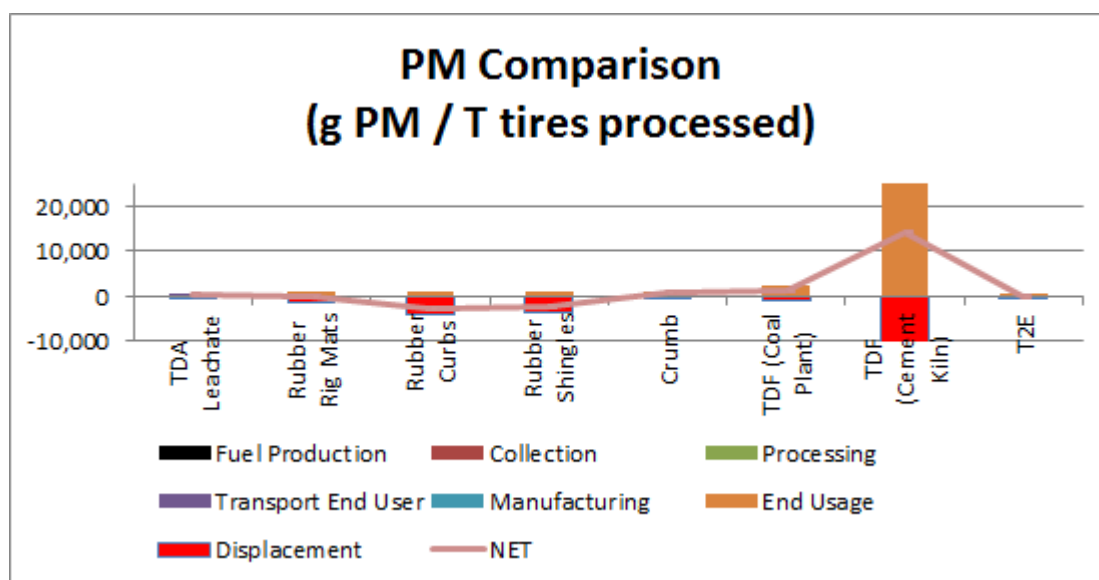


Figure 13: Particulate Matter Results

Net Increases:

TDF cement kiln shows a significant net increase in PM emissions.

- » The large increase in PM emissions for the cement kiln option are due to on-site emissions from switching a portion of the coal feedstock for tires. This would be dependent on the PM environmental control technologies incorporated on site.

Net Decreases:

Rubber curbs and rubber shingles showed the most significant net decrease in particulate matter.

³⁸ EPA - Air Emissions From Scrap Tire Combustion (Facility B)

- » The large net benefit on PMs for rubber curbs and rubber shingles is due to the large PM emissions in the baseline scenario to manufacture concrete curbs and asphalt shingles respectively.

4.6 CO

CO emissions for each of the eight recycling options are compared in Figure 14 below. The vertical axis on this chart has been scaled to display the net values of each option but the full range of the values (i.e. max/min) for the TDF (cement kiln) data are actually not displayed in order to effectively present the other options.

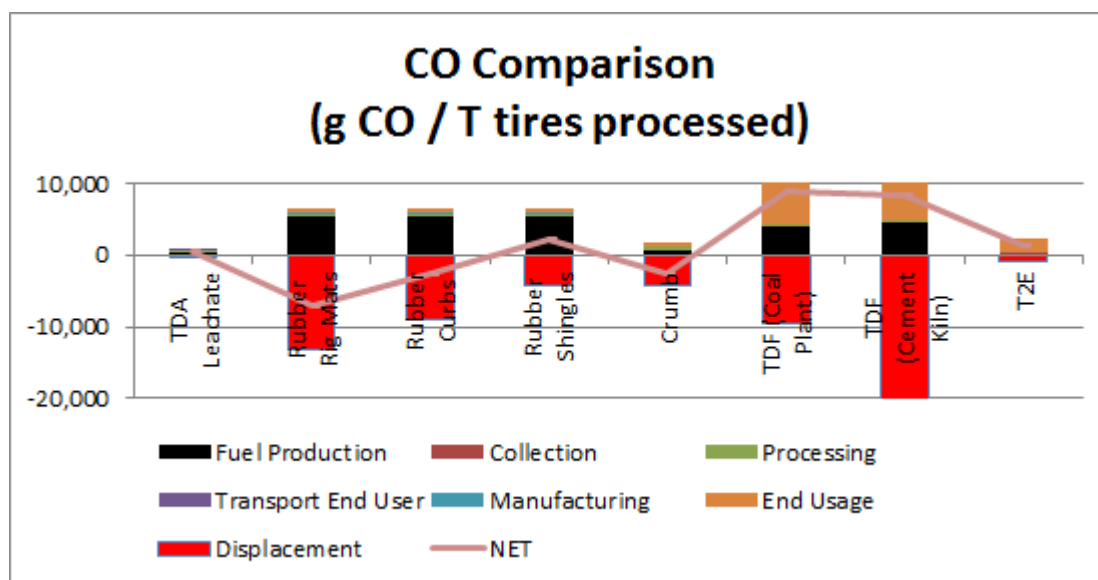


Figure 14: Carbon Monoxide Results

Net Increases:

TDF coal power and TDF cement kiln options showed the most significant net increases in CO emissions while the rubber shingles, TDA leachate and TDF T2E showed marginal increases in CO emissions.

- » The increase in CO emissions at the coal power plant and the cement kiln is due to the on-site fuel switching from coal to tires. This may be due to incomplete combustion of the rubber material.

Net Decreases:

Rubber rig mats, rubber curbs and tire crumb showed significant net decreases of CO emissions.

- » Decreases for these three recycling operations are mostly seen from the large CO emissions in the baseline scenarios to produce virgin steel. The rubber rig mat recycling option also showed an on-site decrease of CO from processing timber rig mats.

4.7 VOC

VOC emissions for each of the eight recycling options are compared in Figure 15 below.

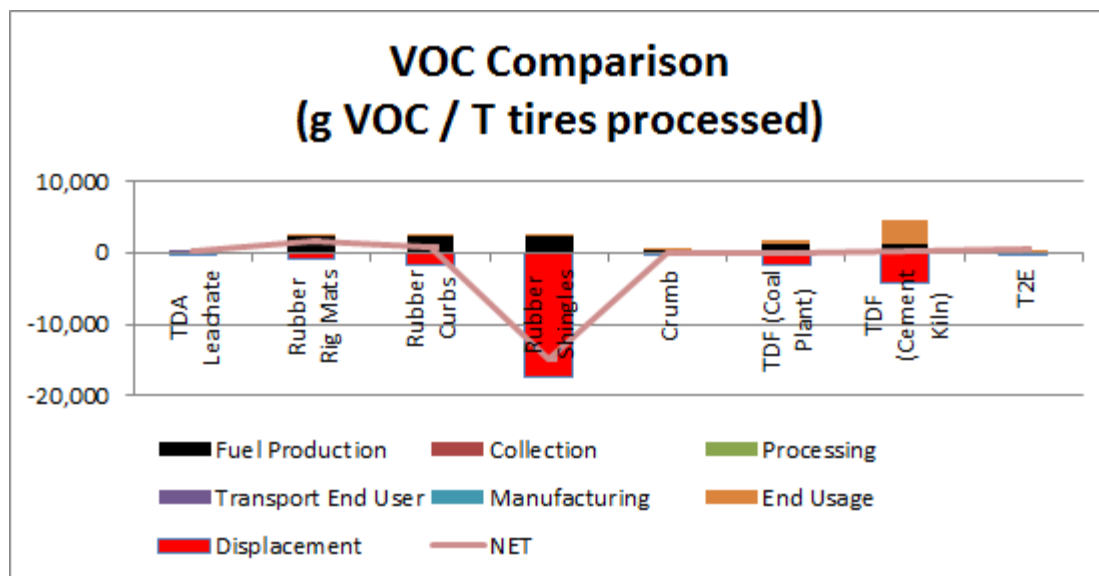


Figure 15: VOC Results

Net Increases:

Rubber rig mats showed the biggest increase in VOC emissions; however all those that did have increases (TDA, rubber rig mats, rubber curbs, cement kiln and T2E) showed relatively marginal increases when compared to the VOC emissions decrease from the rubber shingles recycling option.

- » The increase in VOC emissions to make rubber rig mats is due to the increased use of diesel in the recycling option over the baseline scenario combined with the high VOC emission intensity to produce diesel.

Net Decreases:

Not surprisingly rubber shingles showed a significant net decrease in VOC emissions while tire crumb and TDF coal power showed marginal net decreases.

- » The large VOC benefits are due to the high VOC emissions of asphalt shingle production in the baseline scenario.

4.8 Dioxins and Furans

Dioxin and furan emissions for each of the eight recycling options are compared in Figure 16 below.

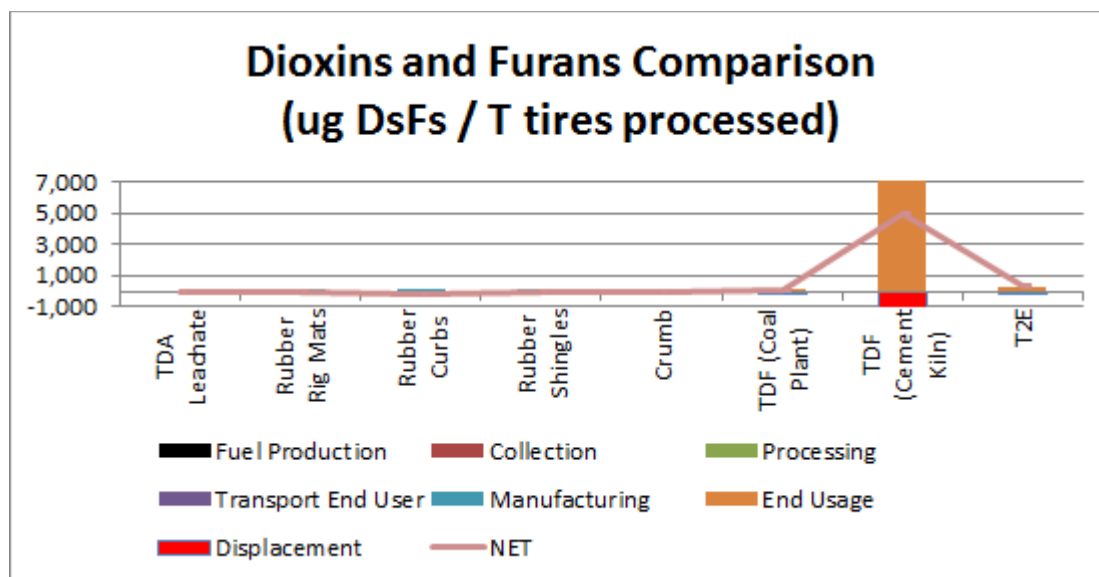


Figure 16: Dioxin and Furan Results

Net Increases:

Only cement kiln and TDF T2E recycling options reported any levels of dioxin/furan emissions. All other recycling options showed negligible results compared with cement kiln and TDF T2E options.

Dioxin and furan emissions are unwanted byproducts generated from industrial chemical and combustion processes.³⁹ Of the eight recycling options considered, TDF (coal plant), TDF (cement kiln) and T2E are of most concern since it is expected they will have the largest on-site emissions.

Data on dioxins and furans for each of the three TDF options come from multiple sources of data, with the cement kiln data originating from a single cement plant. Since dioxin and furan emissions can be somewhat managed by modifying the combustion process, each site will have different levels of emissions. As such, any conclusions must be drawn with caution as actual emissions of dioxins and furans will be site specific.

Net Decreases:

None.

4.9 PAH

PAH emissions for each of the eight recycling options are compared in Figure 17 below. The vertical axis on this chart has been scaled to display the net values of each option but the full range of the values (i.e. max/min) for the TDF (coal plant and cement kiln) data are actually not displayed in order to effectively present the other options.

³⁹ United Nations Environment Programme. 2000. *Dioxin and Furan Inventories. National and Regional Emissions of PCDD/PCDF*. Accessed online May 2010 at <http://www.bvsde.paho.org/bvsacd/cd27/dioxininventory.pdf>.

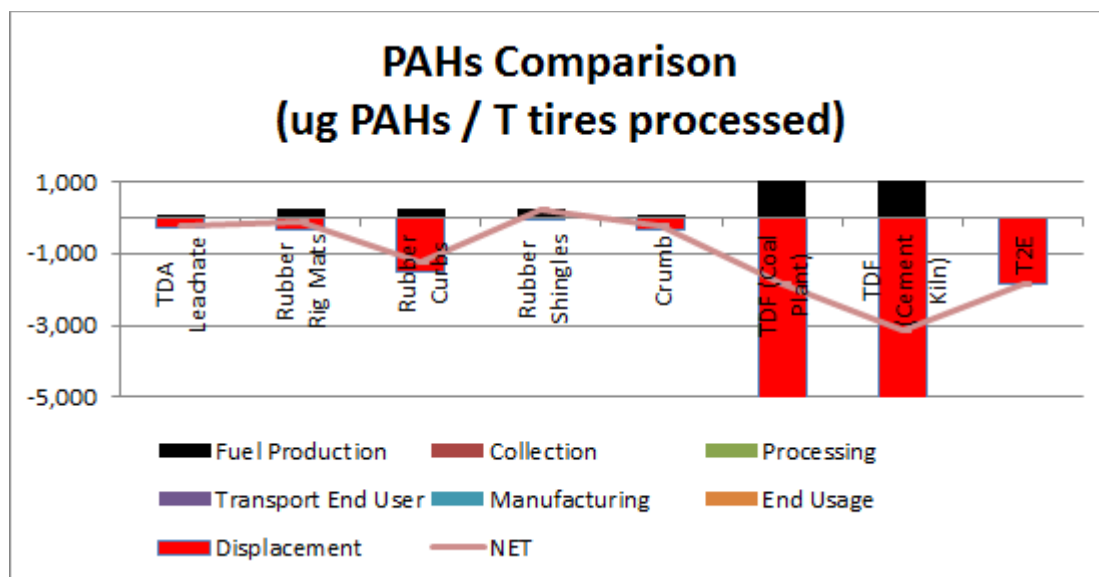


Figure 17: PAH Results

Net Increases:

The rubber shingle recycling option was the only option to show a net increase in PAH emissions. This increase is entirely from the PAH emitted to produce and transport coal and natural gas used to generate Alberta grid power. The other re-manufactured rubber products (TDA leachate, rubber rig mats, rubber curbs and tire crumb) do not show increases because they have higher PAH emissions in their baselines thereby resulting in net decrease.

Net Decreases:

The TDF options (cement kilns, coal power plant and T2E) showed the most significant decreases in PAH emissions. However, the following data limitations must be considered when using this data:

- » For the coal power plant and the cement kiln recycling options, data was not available on how PAH emissions change with fuel switching of coal to tires. The decreases seen are only from off-site upstream fuel production.
- » For the T2E recycling option, PAH emissions data was not available for the dedicated tire to energy facility. The decreases seen are also from off-site upstream fuel production and do not include any changes in PAHs that result from fuel switching from coal to tires.

4.10 Heavy Metals

Heavy metal emissions for each of the eight recycling options are compared in Figure 18 below. The vertical axis on this chart has been scaled to display the net values of each option but the full range of the values (i.e. max/min) for the TDF (coal power and cement kiln) data are actually not displayed in order to effectively present the other options.

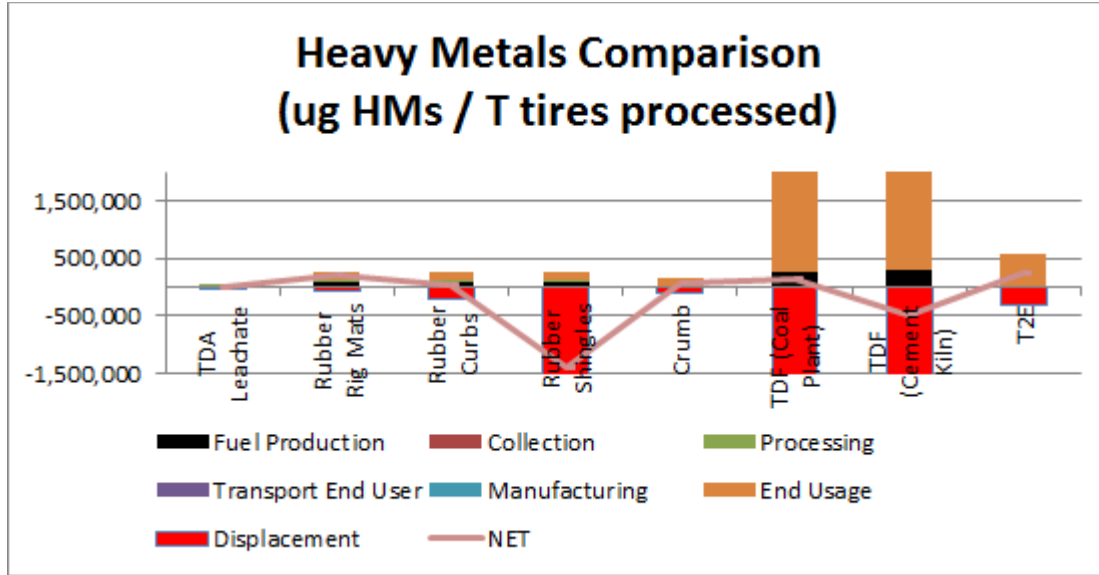


Figure 18: Heavy Metal Results

Net Increases:

Rubber rig mats, rubber curbs, tire crumb and TDF coal power showed net increases of heavy metal emissions.

- » These recycling options show a net increase due to steel recycling. While rubber shingles also have steel recycling as part of the system they show a net decrease in HM emissions as manufacturing asphalt shingles emits much higher levels of heavy metals.

Net Decreases:

TDF cement kiln and rubber shingles show a significant net decrease of heavy metal emissions.

- » TDF cement kiln shows a net decrease because heavy metal emissions decrease when fuel switching from coal to rubber. A decrease in heavy metal emissions in the coal power plant recycling option is not seen since steel is recycled producing enough heavy metal emissions to negate the decreases from fuel switching.
- » Rubber shingles show a net benefit because of the high heavy metal emission intensity from producing asphalt shingles.

It is important to note that while heavy metal emission factors were available for the recycling options, they were not available for some of the baseline activities such as production of construction timber and precast concrete as well as other off-site activities (truck transportation, combustion of gasoline, light fuel oil, LPG, produce construction timber, produce precast concrete). Should HM be associated with any of these baseline activities then there would be further net decreases or the net increases would not be to the same extent. Accordingly, results need to be assessed with caution given the data limitations.

4.11 Results Summary

The net results for each of the eight recycling options are presented in Figure 19 below. This chart combined with Table 6 and Table 7 from the previous chapter provide the complete picture of how each option performs across all the parameters quantified. On a per parameter basis, Figure 19 readily illustrates which options clearly underperform (points furthest from the x-axis) as well as which parameters show little difference between options.

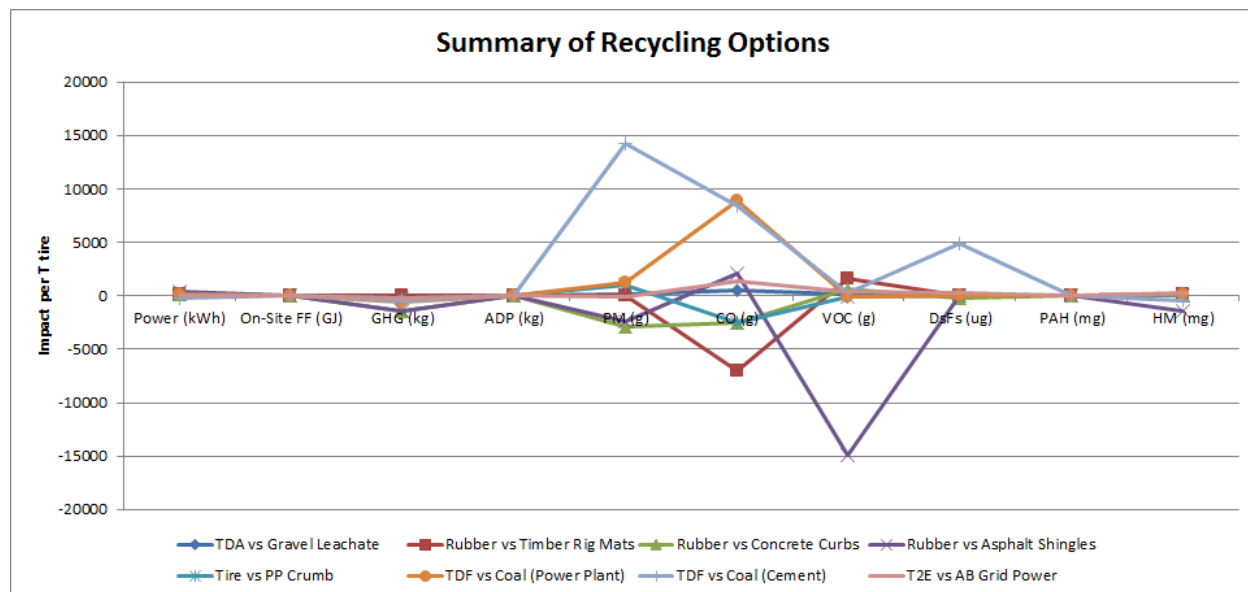


Figure 19: Recycling Option Results

The summary charts and data tables presented here are intended to provide a high level comparison across the eight recycling options to inform future decisions on tire waste management options in Alberta. They will help to inform the following questions:

1. What impacts should we be concerned about when selecting a given management/recycling option?
2. Which option(s) perform best for a given environmental indicator of interest?

And, more difficultly,

3. Which option(s) perform best when considering all indicators?

Conclusions are drawn in the following section based on this results summary.

5. Conclusions

While Albertans discard a significant amount of tires on an annual basis, fortunately there are different options for end-of-life applications of these tires. The environmental outputs of eight prominent options have been quantified on a life cycle basis in this analysis. Like many, if not most, LCAs there is no single option that demonstrates overwhelmingly benefits over others. Rather, this life cycle analysis has helped to:

- identify the key environmental issues of concern when selecting a particular management option.
- understand which options demonstrate the most benefits for a given environmental indicator.
- understand which option demonstrates the most overall environmental benefits.

Based on these questions and the associated qualitative and quantitative analysis, the following general conclusions can be drawn:

- » Of all the recycling options assessed, no single option showed a net benefit for all of the indicators quantified.
- » Air emissions are a critical environmental output from all of the different options considered. While terrestrial and water (quantity and quality) impacts certainly may exist, no options were seen as to have any unique or relatively significant impacts in these areas. This was determined through a qualitative assessment by Pembina and reinforced by our review of existing data.

Some specific conclusions on the relative performance of the options can be drawn as well.

- » Displacing concrete and asphalt shingles show the most overall benefits of all the options.
- » Displacing concrete and asphalt shingles delivers the highest GHG net benefits.
- » Rubber curbs over concrete also delivers significant reductions in PM, CO, and marginal reductions in ADP, but does result in a net increase of VOC emissions.
- » Displacing asphalt shingles also delivers relatively significant reductions across multiple indicators, particularly VOCs. While there are increases in CO emissions associated with this option, the increase is less than the coal displacement options (coal power or cement kiln).

Two options demonstrated fewer overall benefits than the others, based on both the number of parameters that decreased as a result of the recycling option and the magnitude of the decreases: TDA to replace gravel for landfill leachate collection systems and tire manufactured products to replace wood ones.

Note that the benefits of avoiding resource extraction, such as gravel or virgin steel, were not specifically quantified in this analysis. Thus, while some recycling options may show few overall benefits in air emissions the avoidance of raw natural materials should also be considered, particularly in the local context.

While this LCA uses the best available data, certain data limitations exist. Key data limitations are:

- » Certain data for dioxins/furans, PAHs and heavy metals were not readily available(see Table 8 to Table 10 in Section 7.
- » Air emission limits, not actual, were incorporated for the dedicated tire-to-energy facility in this analysis.
- » Many air emissions can be further reduced at a variety of activities through emission control measures. This could be through mitigation control technologies or through new, more energy efficient, technologies. Many times cost is the key barrier to further reducing environmental impacts.

Using the Results

While no “outright winners” emerged from this analysis, the results provide some extremely valuable information for any decision-making process around these options. The following examples show some ways these results can be used:

- » When considering a given tire management option for other than environmental reasons, these results provide insights into which environmental impacts should be of concern and potentially addressed.
- » When basing decisions around specific environmental objectives, these results will help inform the option that best meets these objectives. For example, using tires to replace concrete curbs helps advance Alberta’s existing GHG reduction policy objectives.
- » While using tires over gravel for engineered landfill purposes avoids the use of virgin materials and associated land impacts, selecting other tire recycling options would help avoid some of the net environmental impact increases that result from using tires for landfill leachate collection systems.
- » When considering waste-to-energy related policy decisions in the province of Alberta, these results can inform questions around specific air emission impacts.

Next Steps

While these results help answer some important questions, the following recommendations are provided for further consideration:

- » When considering a potential recycling facility in Alberta, perform research on the local environmental context to inform whether certain environmental issues are of particular relevance to the recycling option in question.
- » Given the environmental impacts are ultimately dependent on the ability to incorporate pollution controls systems across the life cycle, when selecting a management option ensure to inquire about the extent to which controls have been used to minimize emissions or energy use.
- » With the emergence of different waste-to-energy technologies, a detailed analysis of the environmental impacts when incorporating tires into the waste should be performed across a range of viable options when reliable data is available.

6. Life Cycle Activity Maps

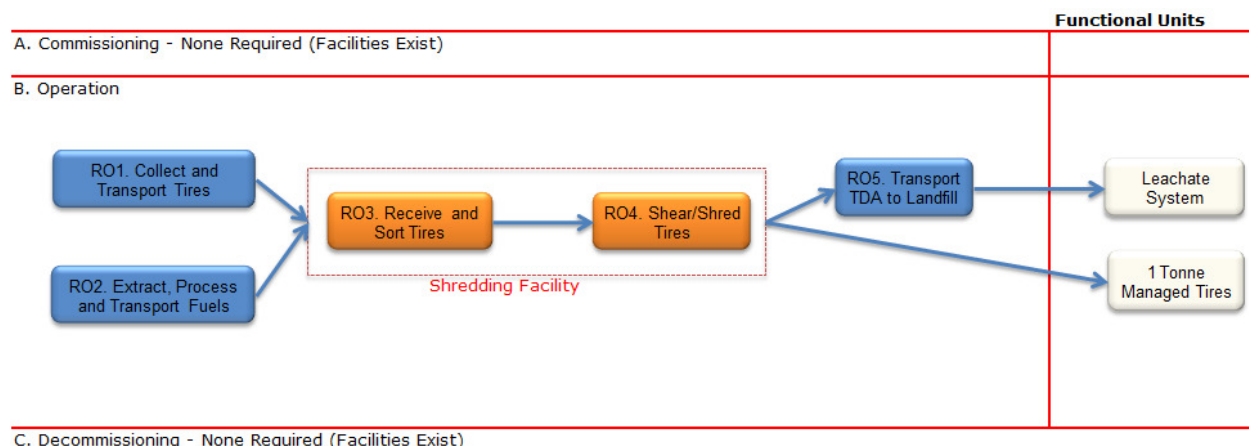


Figure 20: Activity Map – Recycle Tires into TDA Leachate Collection System

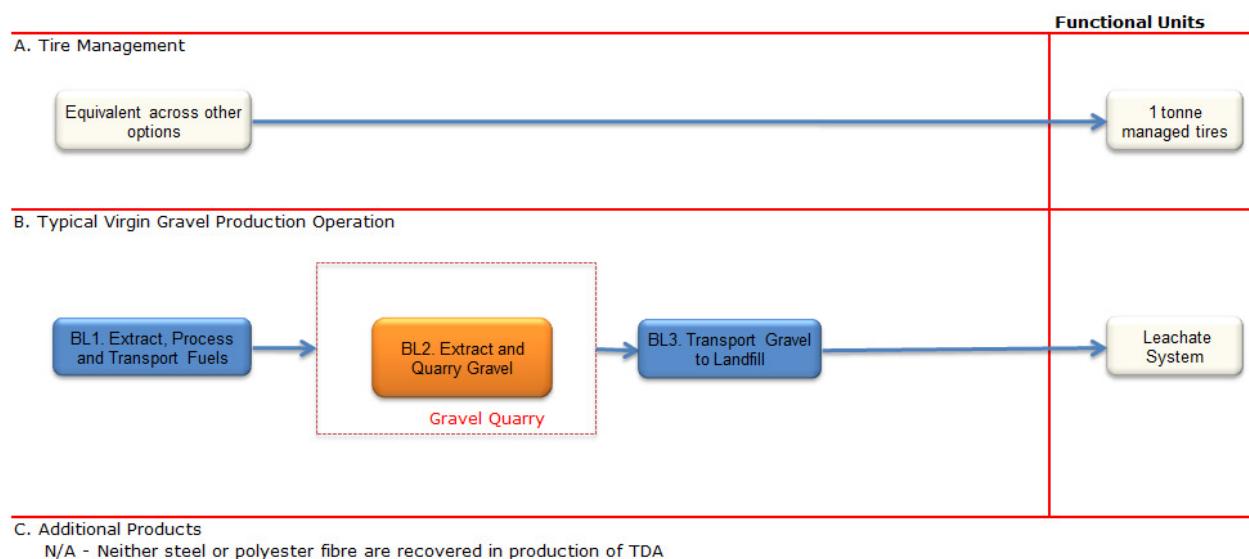


Figure 21: Activity Map – Produce Gravel Leachate Collection System

Life Cycle Activity Maps

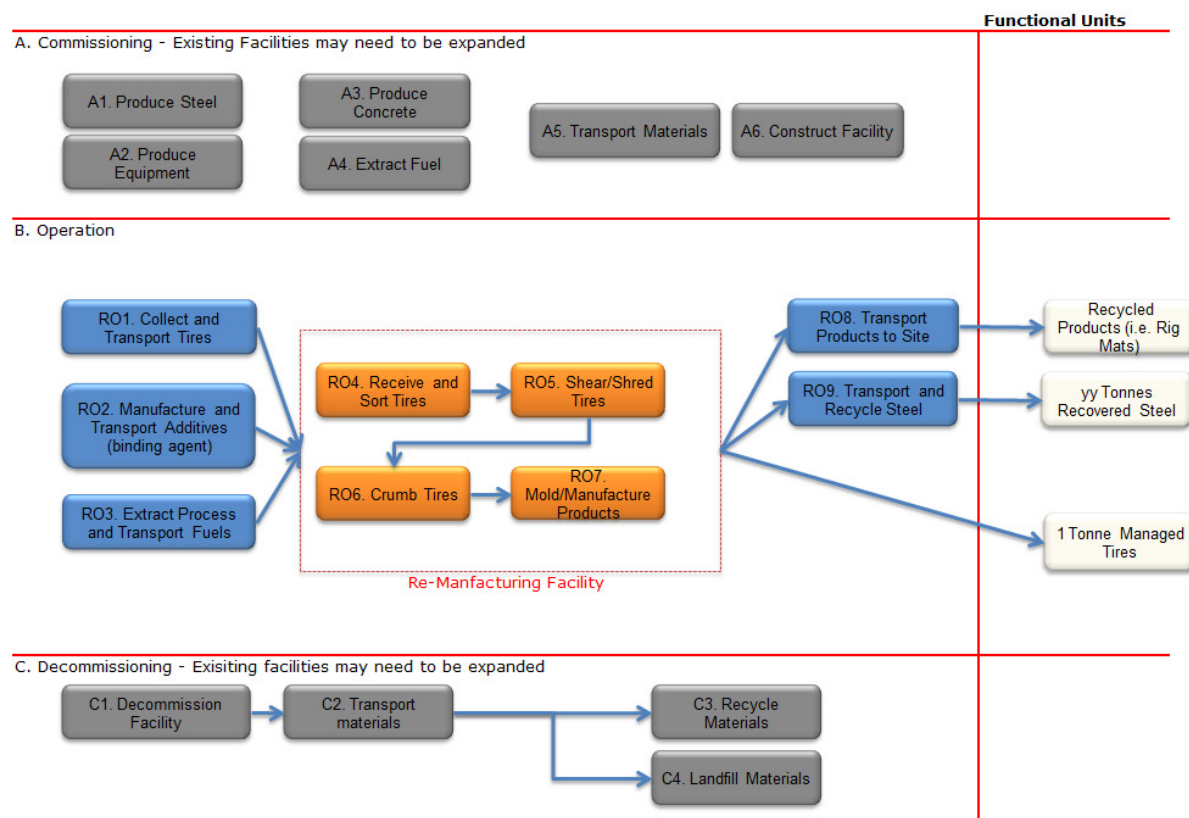


Figure 22: Activity Map – Recycle Tires into Rubber Rig Mats

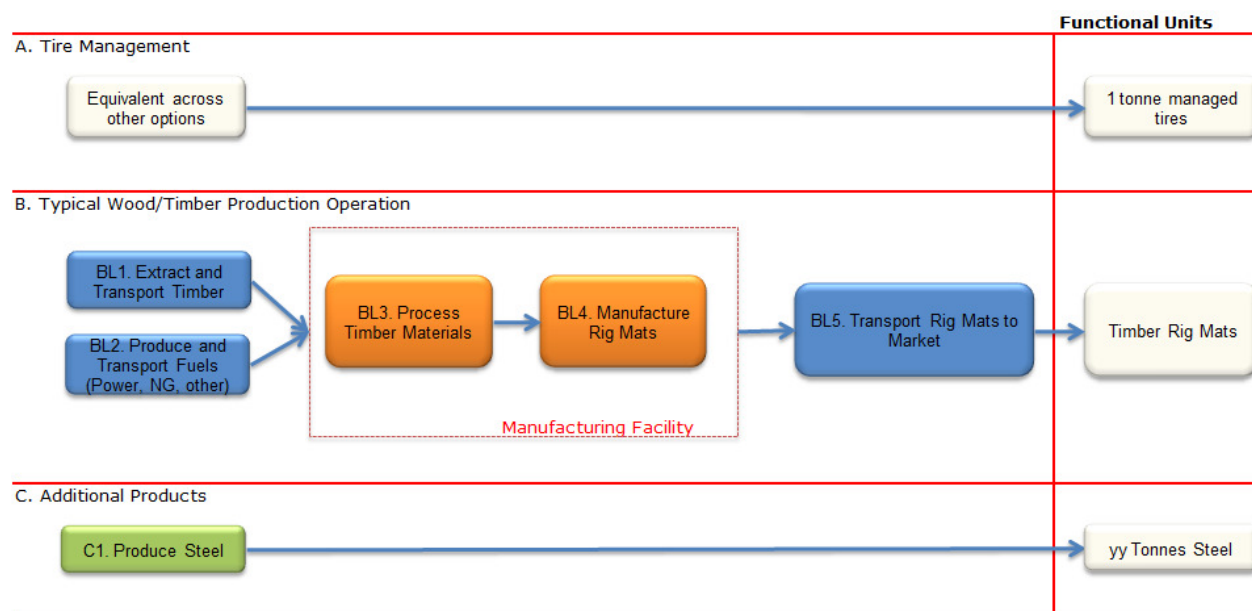


Figure 23: Activity Map – Produce Timber Rig Mats

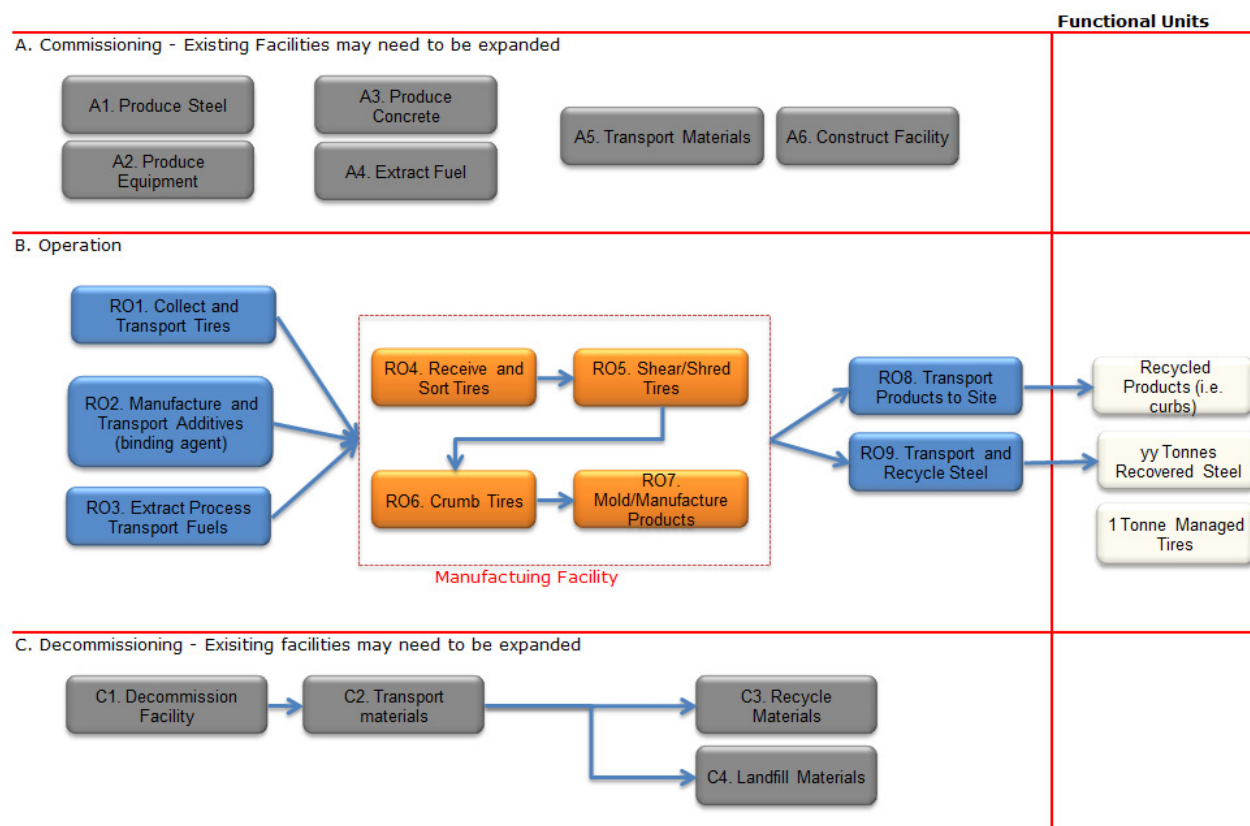


Figure 24: Activity Map – Recycle Tires into Rubber Curbs

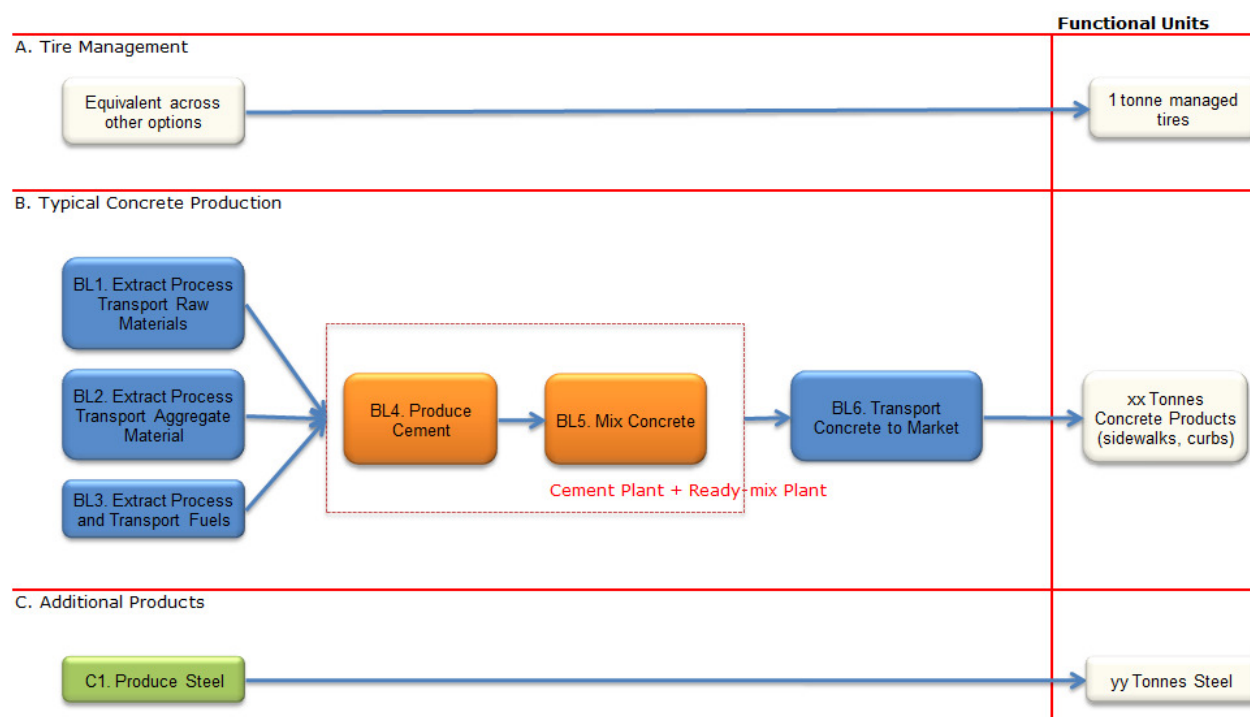


Figure 25: Activity Map – Produce Concrete Curbs

Life Cycle Activity Maps

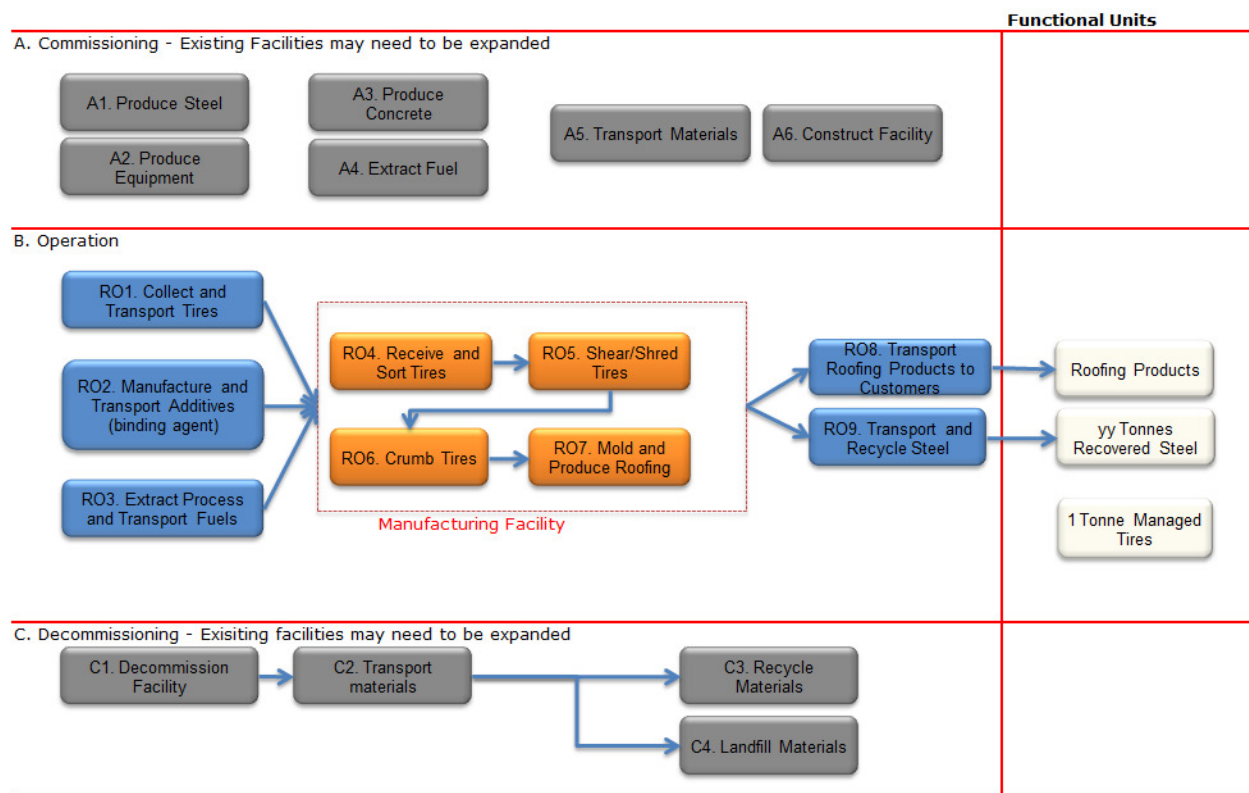


Figure 26: Activity Map – Recycle Tires into Rubber Shingles

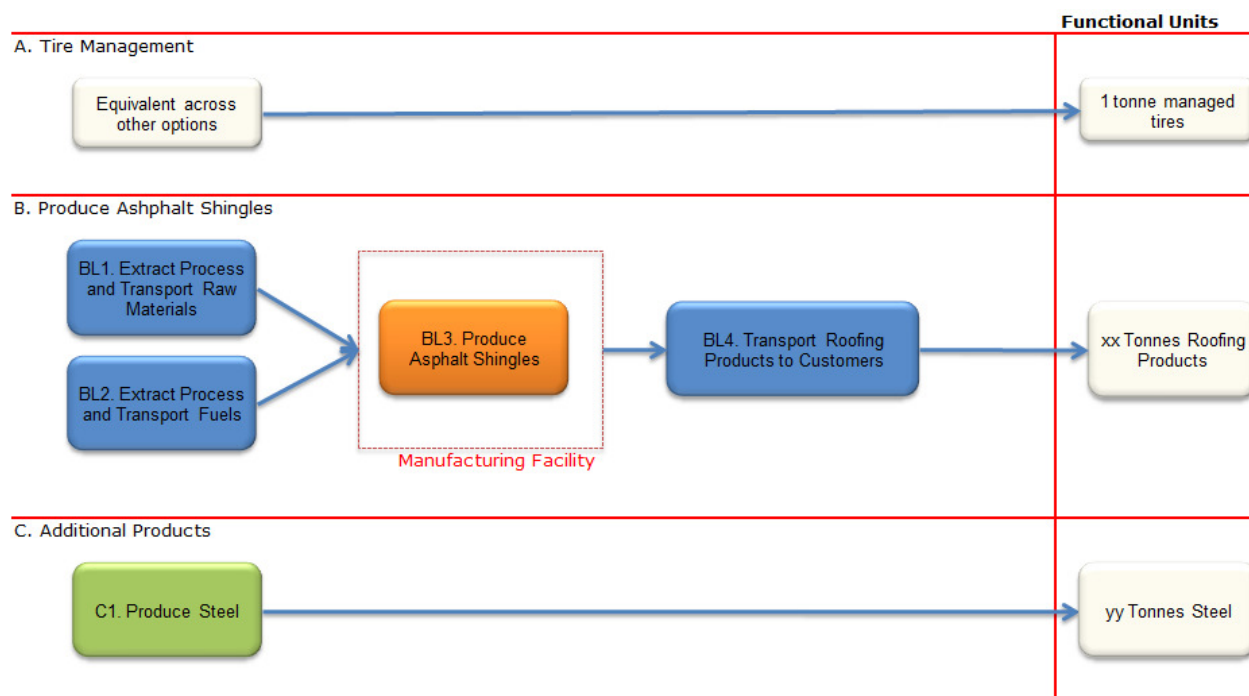


Figure 27: Activity Map – Produce Asphalt Shingles

Life Cycle Activity Maps

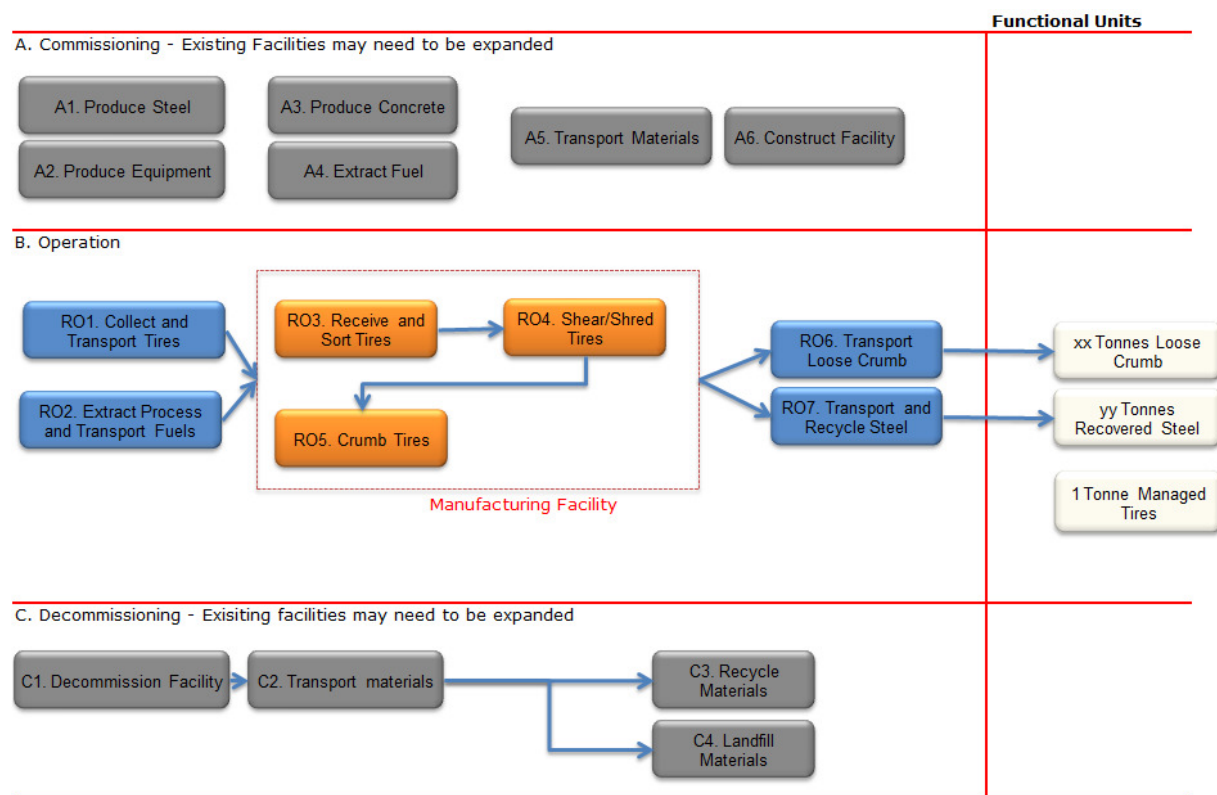


Figure 28: Activity Map – Recycle Tires into Crumb

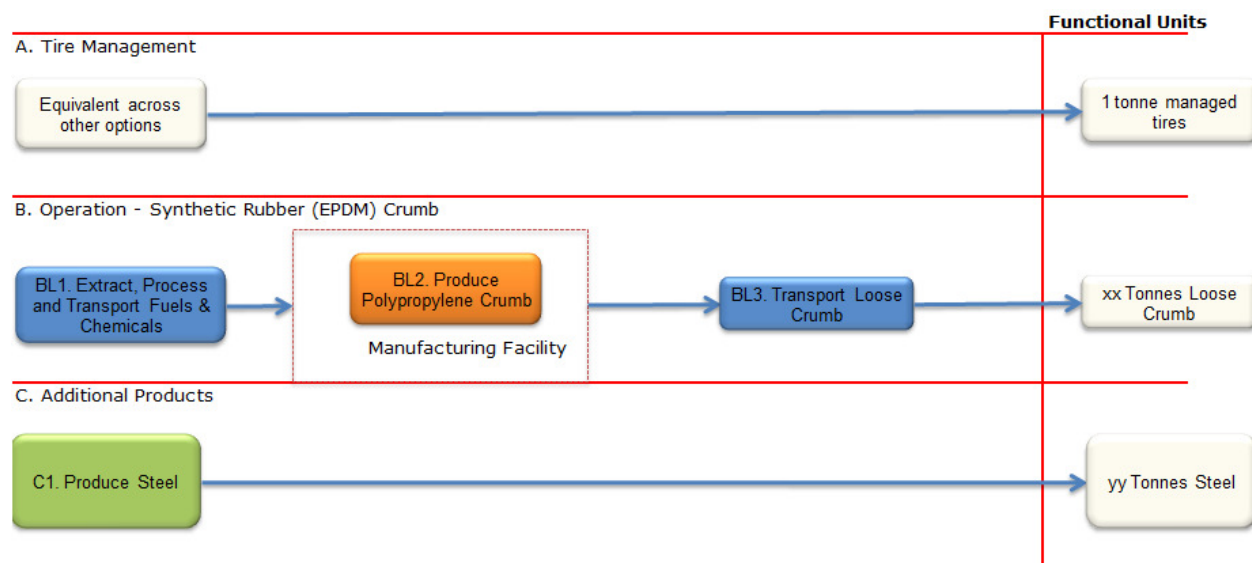


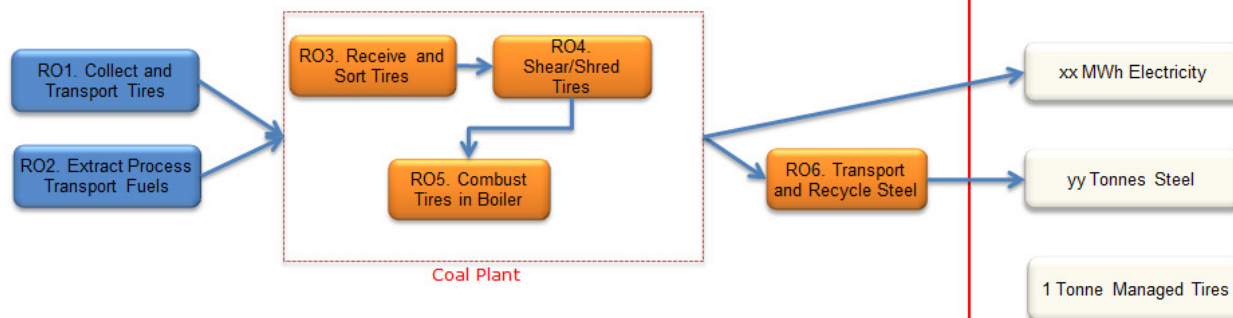
Figure 29: Activity Map – Produce EPDM Crumb

Life Cycle Activity Maps

A. Commissioning - Construction of shredding/crumbing facility



B. Operation



C. Decommissioning - Shredding/Crumbing Facility



Figure 30: Activity Map – Process Tires at Coal Power Plant

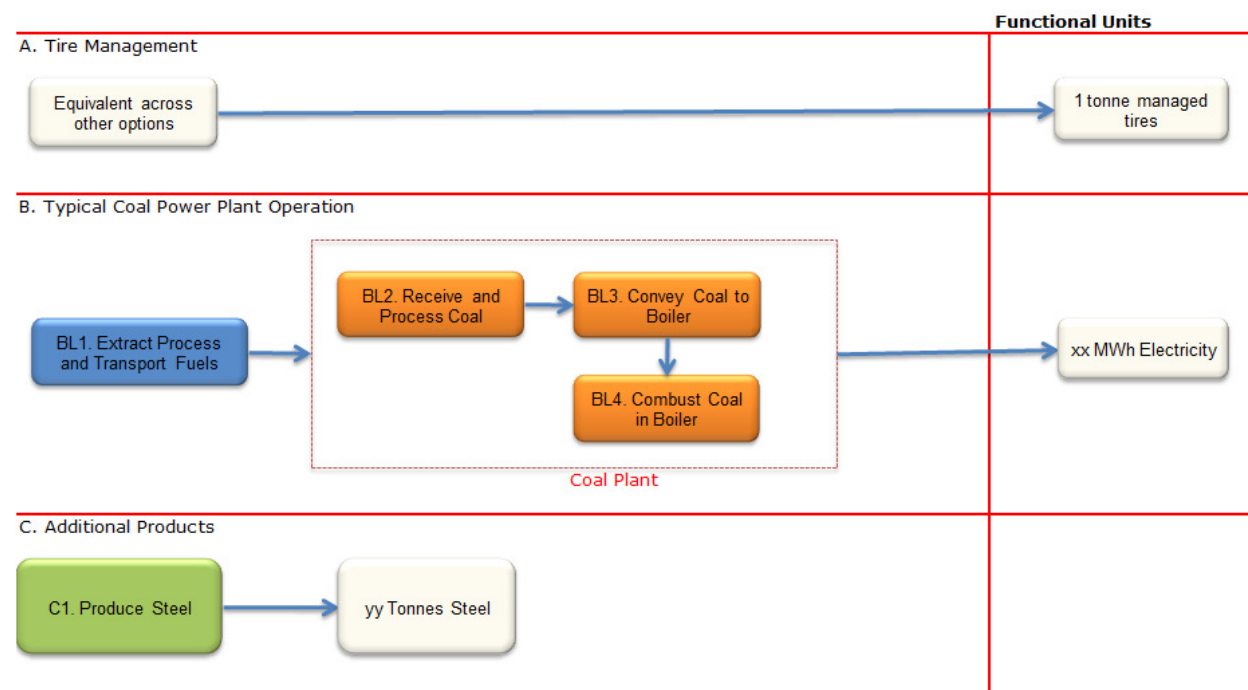


Figure 31: Activity Map – Produce Power from Bituminous Coal

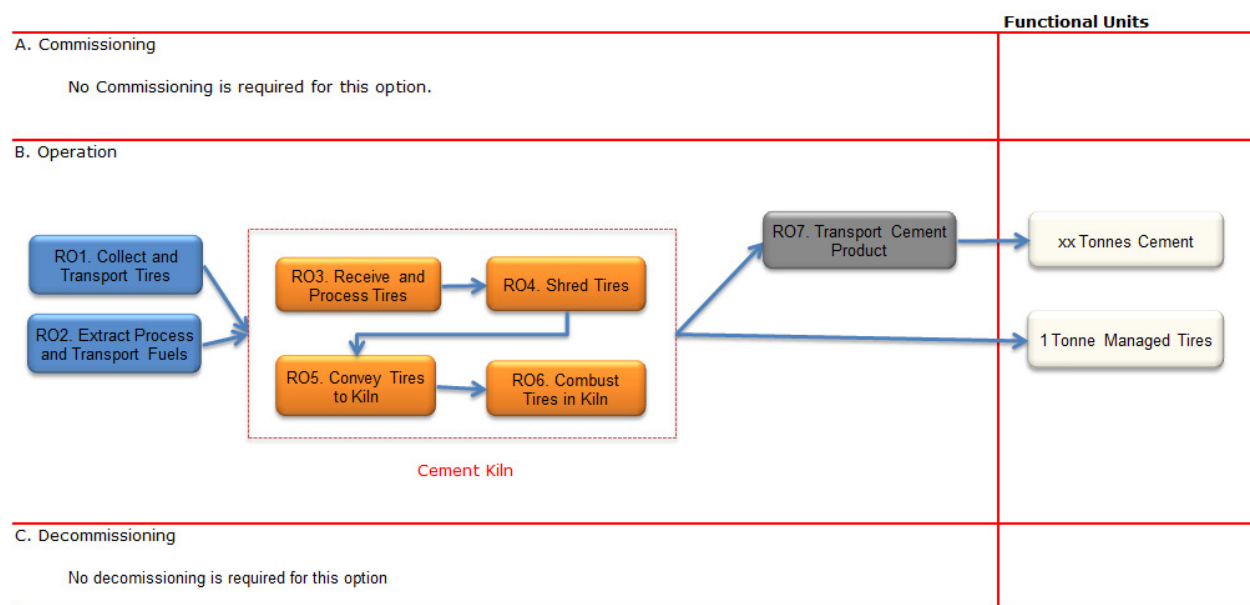


Figure 32: Activity Map - Process Tires in Cement Kiln

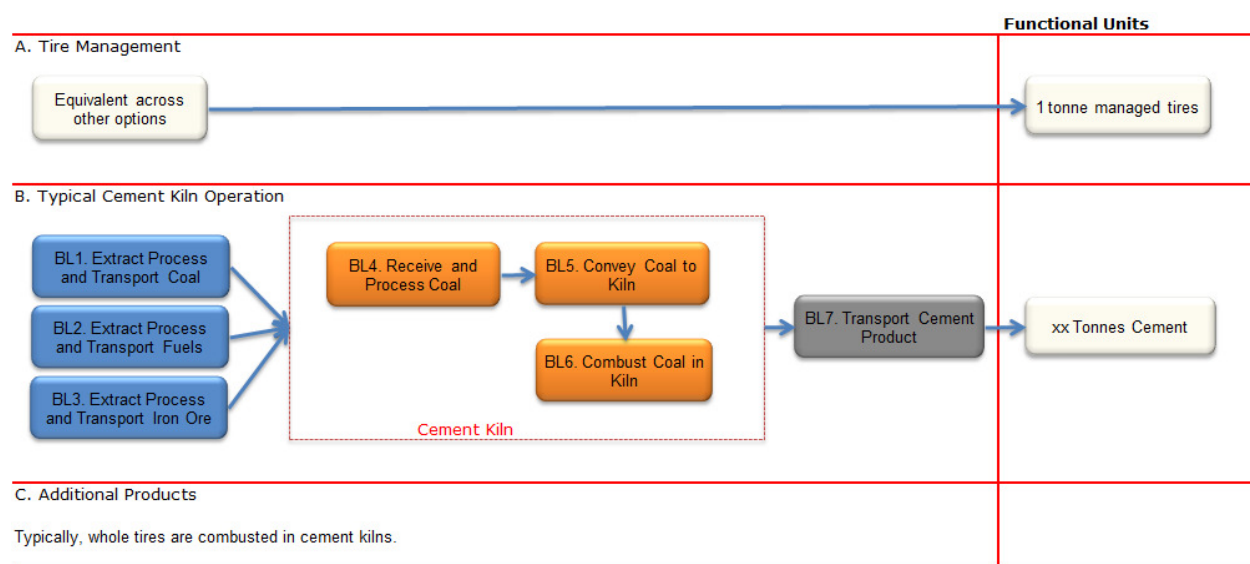


Figure 33: Activity Map - Produce Cement

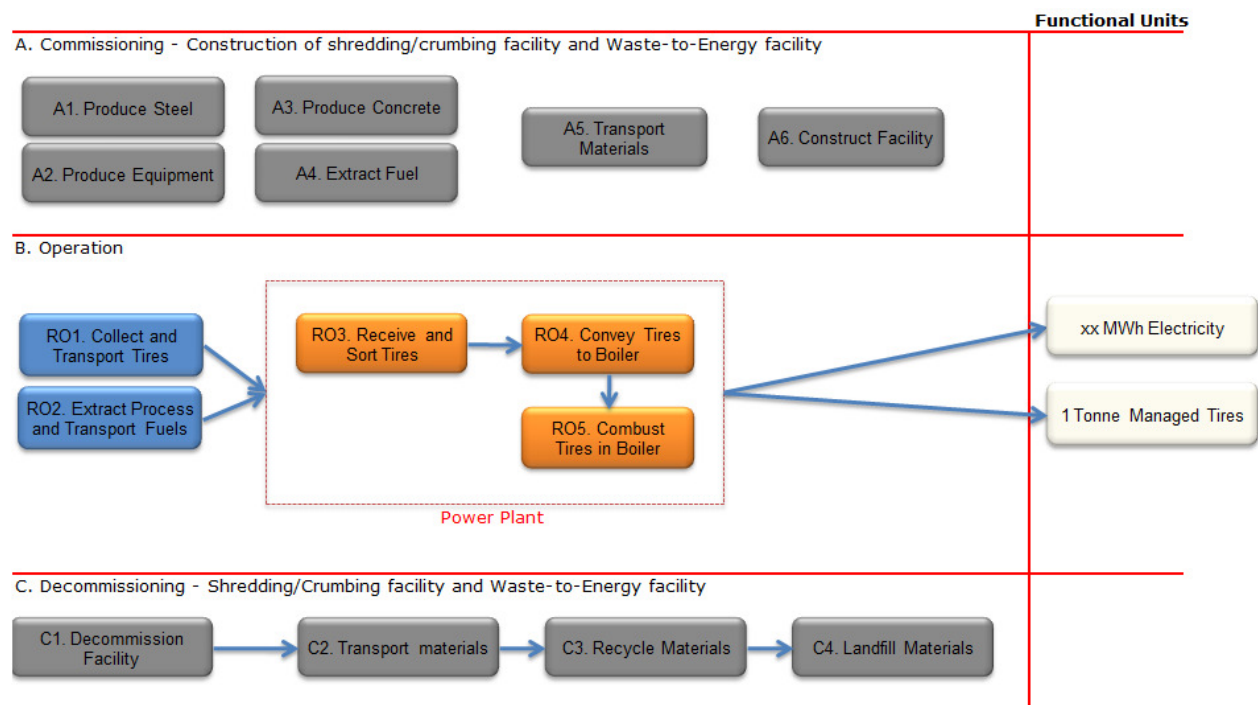


Figure 34: Activity Map - Process Tires in Dedicated Tire to Energy (T2E) Plant

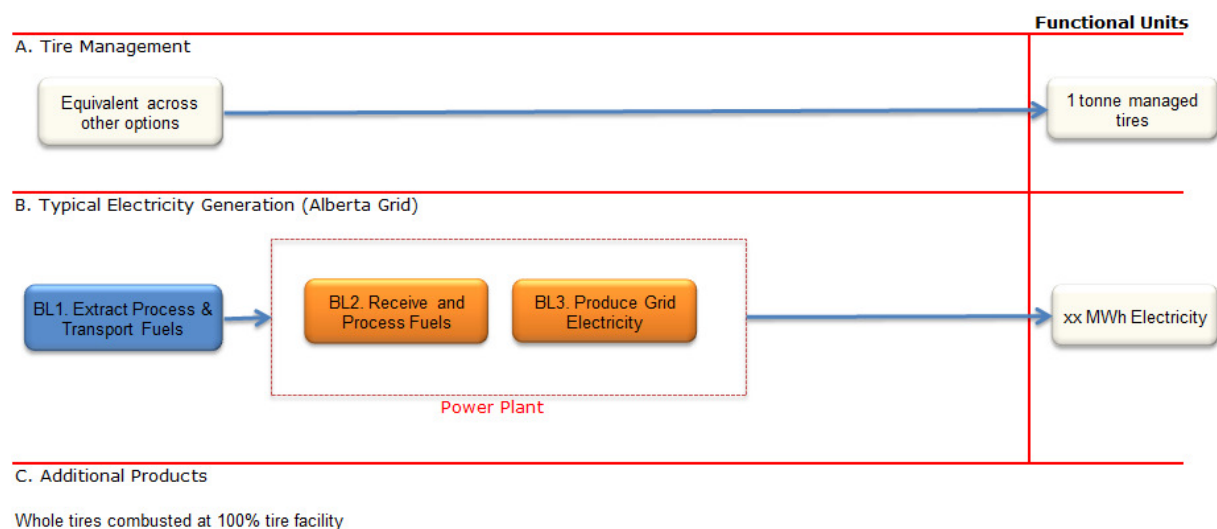


Figure 35: Activity Map - Produce Power Alberta Power Grid

7. Data Limitations and Assumptions

7.1 General Data Limitations

- » There is a large discrepancy between the heavy metal emissions for recycling steel (dataset from Europe) vs. manufacturing virgin steel (dataset from USA). Heavy metals will be emitted from process and electricity production activities. Recycling steel uses a substantial amount of electricity in an electric arc furnace and this will impact the steel recycling emission factors since emissions are dependent on the grid fuel mix. This study uses an RTI steel recycling dataset where lead (Pb) was the only heavy metal considered from 3 steel recycling operations (Canada, USA, Europe). To complete the dataset for the heavy metals category, additional heavy metals (mercury, cadmium, arsenic, chromium, cobalt and manganese) were added to the RTI dataset as these are emitted from the production of AB power grid. These additions assumed an electricity consumption of 3.66 GJ electricity per tonne of scrap steel processed.⁴⁰

Data was readily available for all environmental indicators except for dioxins/furans, PAHs and heavy metals. Activities where this data was not available are shown in the following tables. However, the absence of data does not necessarily reflect that these particular emissions are generated from these activities.

Table 8, Table 9 and Table 10 below describe where data was not reported for each activity of each recycling option for dioxins/furans, PAHs and heavy metals.

Table 8: Data Limitations for Dioxins/Furans

Recycling Option	Activity
All	All transportation activities (e.g. transportation of tires or final products).
Rubber rig mats, rubber curbs, rubber shingles	Produce manufacturing binding agent.
Rubber rig mats (baseline)	Produce construction timber.
Rubber curbs (baseline)	Produce precast concrete.
Rubber crumb (baseline)	Produce polypropylene and propylene.

⁴⁰ ICF, *Determination of the Impact of Waste Management Activities on GHG Emissions: 2005 Update* (2005), p128. Exhibit B-14 Energy Use for Recycled Production of Steel.

Rubber rig mats, rubber curbs, rubber shingles, tire crumb, TDF (Coal Power Plant)	Recycle steel. ⁴¹
Supporting activities	Combustion of natural gas, gasoline, diesel, light fuel oil, LPG and bituminous coal in equipment. Operation of inventory management equipment. Upstream production of natural gas. Extract crude oil. Transport crude oil (pipeline). Refine crude oil. Transport by train. Transport by barge.

Table 9: Data Limitations for PAHs

Recycling Option	Activity
All	All transportation activities (e.g. transportation of tires or final products).
Rubber shingles (baseline)	Produce asphalt shingles.
Rubber rig mats, rubber curbs, rubber shingles	Produce manufacturing binding agent.
Rubber rig mats (baseline)	Produce construction timber.
Rubber curbs (baseline)	Produce precast concrete.
Rubber crumb (baseline)	Produce polypropylene. Mine and crush limestone.
T2E	Process tires in T2E
Rubber rig mats, rubber curbs, rubber shingles, tire crumb, TDF (Coal Power Plant)	Recycle steel.
Supporting activities	Combustion of natural gas, diesel, heavy fuel oil, LPG and bituminous coal in equipment. Operation of inventory management equipment.

⁴¹ Steel recycling results in the formation of dioxins/furans. The Canadian Council of Ministers of the Environment notes that 7% of Canada's dioxins/furans annual emissions are from steel recycling. Accessed online May 2010 at http://www.ccme.ca/ourwork/air.html?category_id=95.

	Upstream production of natural gas. Extract crude oil. Transport crude oil (pipeline). Refine crude oil. Transport by train. Transport by barge.
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Table 10: Data Limitations for Heavy Metals

Recycling Option	Activity
All	All transportation activities (e.g. transportation of tires or final products).
Rubber rig mats, rubber curbs, rubber shingles	Produce manufacturing binding agent.
Rubber rig mats (baseline)	Produce construction timber.
Rubber curbs (baseline)	Produce precast concrete.
Rubber crumb (baseline)	Produce propylene. Mine and crush limestone.
Supporting activities	Combustion of gasoline, diesel, light fuel oil and LPG in equipment. Operation of inventory management equipment. Upstream production of natural gas. Extract crude oil. Transport crude oil (pipeline). Refine crude oil. Transport by train. Transport by barge.

Recycling Option 2 - 4 (Rubber Rig Mats, Rubber Curbs, Rubber Shingles)

Used the production of methylene diphenyl diisocyanate to estimate the impacts of the production of the binding agent for the rubber product.

Recycling Option 5 (Rubber Crumb)

Baseline for this option is EPDM crumb as per a Swedish LCA⁴² that examined end-of-life tires. EPDM crumb can be used on athletic fields in place of tire crumb.

- » As with the Swedish LCA there was no data available for the manufacturing of EPDM. Following a similar procedure we estimated the impacts based on a 50% mix of calcium carbonate and polypropylene. As a precursor to polypropylene the impacts of manufacturing propylene were included.
- » Assumed no additional energy was required for the crumbing of the EPDM due to a lack of information.

Recycling Option 6 (TDF Coal Power Plant)

Shredded tires with the steel removed are used in coal power plants. Using tire shred allows for a more controlled feed rate and more consistent combustion efficiency. The EPA notes that “the optimum size of the tire pieces is 1 inch x 1 inch and it must be de-wired”⁴³

The data used for displacing coal with tires was provided by the EPA for a 10% displacement. This displacement is assumed on an energy basis. The energy content of shredded tire with steel removed was set at 32,000MJ/tonne⁴⁴, while for coal it was set at 25,430MJ/tonne. As a result each tonne of tire shred replaces 1.26 tonnes of coal.

The impact on specific emissions are shown in Table 11 below.

- » The change in CO₂ emissions is based on data provided by CANMET which compares the emissions of tire shred with the steel removed to that of thermal coal.
- » For all other indicators, the change in emissions are based on test data from EPA (1997), Air Emissions from Scrap Tire Combustion:
 - Facility B (tested at 5% and 10% TDF)
 - Facility C (tested at 7% TDF)
 - Facility D (tested at 5%, 10%, 15% and 20% TDF)
- » If testing was done at a mix other than 10% it was assumed that the results could scale linearly (i.e. the emissions change at 5% would be half that at 10%).
- » The worst case scenario for each emissions type was taken to ensure a conservative forecast of the impacts of using TDF.
- » These changes in emissions are applied to the emissions of generating coal electricity using 100% coal based on data from NREL.

Table 11: Change in Emissions at Coal Plant

Measure	Change 0%-10% by energy	Observed Change	Source
PM	19%	29% at 15% TDF	EPA - Facility D
SO ₂	56%	28% at 5% TDF	EPA - Facility B

⁴² Hallberg, Lisa et al (2006). *Comparative Life Cycle Assessment of the Utilization of Used Tyres*.

⁴³ EPA, *Tire Derived Fuel* (accessed May 19, 2010) <http://www.epa.gov/waste/conserve/materials/tires/tdf.htm>

⁴⁴ Alexandra Pehlken and Elhachmi Essadiqi, *Scrap Tire Recycling in Canada, CANMET Material Technology Laboratory* (2005). Table 8-3.

NOx	21%	15% at 7%TDF	EPA - Facility C
HCl	-33%	-23% at 7% TDF	EPA - Facility C
HF	-40%	-28% at 7% TDF	EPA - Facility C
CO	539%	378% at 7% TDF	EPA - Facility C
CH4	141%	99% at 7% TDF	EPA - Facility C
Lb	3%	3% at 10% TDF	EPA - Facility C
Dioxins + Furans	55%*		Based on Cement Kiln Data
CO2	-17%	-17% at 100% tires	CANMET

Dioxin/furan data from coal to tire fuel switch was not available. It is assumed that emissions will increase similarly at the coal plant as at the cement kiln. Dioxin/furan emissions are estimated using the cement kiln data on a per tonne tire combusted basis.

Recycling Option 7 (TDF Cement Kiln)

Both whole tires and shred can be used at cement kilns. We have assumed the use of tire shred with steel intact.

An energy balance was performed to determine how much coal is displaced with tires. The energy content of tires was set at 27,000 MJ/tonne, while for coal it was set at 25,430MJ/tonne. As a result each tonne of tires replaces 1.06 tonnes of coal.

We have assumed a 10% TDF mix by energy. However our methodology would produce the same results if a different mix was selected.

Based on literature it was assumed that no additional ash is produced through the use of tires.⁴⁵

The impacts on specific emissions are shown in Table 12.

- » The change in CO2 emissions is based on data provided by CANMET which compares the emissions of whole tires to that of thermal coal.
- » For all other indicators, the change in emissions are best on test data reported for in three different reports:
 - EPA (1997), *Air Emissions from Scrap Tire Combustion*⁴⁶
 - Scrap Tire Management Council (2005), *The Use of Scrap Tires in Rotary Cement Kilns*
 - Delta Air Quality Services (1999), *AB2588 Emissions Testing at California Portland Cement Company's Colton Plant; Coal and Coal with Tires Firing*.
- » If testing was done at a mix other than 10% it was assumed that the results could scale linearly (i.e. the emissions change at 5% would be half that at 10%).
- » The worst case scenario for each emissions type was taken to ensure a conservative forecast of the impacts of using TDF.
- » These changes in emissions are applied to the emissions of a cement kiln using 100% coal based on data from NREL.

Table 12: Change in Emissions at Cement Kiln

⁴⁵ Alexandra Pehlken and Elhachmi Essadiqi, *Scrap Tire Recycling in Canada, CANMET Material Technology Laboratory* (2005).

⁴⁶ See data for Facility I

Measure	Change 0%-10% by energy	Observed Change	Source
CO2	-1.4%	-14% at 100% tires	CANMET ⁴⁷
PM	8.2%	8.01lbs/hr at 11% vs 7.35lbs/hr	Delta Air Quality Services ⁴⁸
SO2	2.5%	7% at 28% TDF	Scrap Tire Management Council ⁴⁹
CO	4.6%	36% at 28% TDF	Scrap Tire Management Council
NOx	-11.8%	-33% at 28% TDF	Scrap Tire Management Council
Metals	-12.5%	-35% at 28% TDF	Scrap Tire Management Council
VOCs	13.2%	37% at 28% TDF	Scrap Tire Management Council
HCL	2299%	0.43 at 11% vs 0.017	Delta Air Quality Services
Dioxins + Furans	54.5%	1.68 @11% vs 1.05	Delta Air Quality Services

Recycling Option 8 (TDF T2E)

Emissions for the dedicated tire-to-energy facility are based off of the emissions limits set for the Exeter facility located in Sterling, CT. The latest operating permit was issued in April, 2010. A summary of the key emission limits is presented below:

Table 13: Exeter Emission Limits

Factor	Value	Units
Ouputs - NOx	0.12	lb/MMBTU
Ouputs - Sox	0.109	lb/MMBTU
Ouputs - PM	0.02	lb/MMBTU
Ouputs - CO	0.167	lb/MMBTU
Outputs - VOC	0.03	lb/MMBTU
Outputs - H2SO4	0.028	lb/MMBTU
HCL	29	ppmv wet HCL @ 12% CO2
Dioxin & Furans	30	ng/dscm @ 12% CO2
Mercury	0.0038	mg @ 12% CO2
Cadmium	0.006	mg @ 12% CO2

Emissions limits expressed in lb/MMBTU were converted to g/GJ and then g/tonne of tire assuming 27GJ/tonne of tires.⁵⁰

CO2 emissions were assumed to be 2080kg/tonne of tires based on CANMET data.⁵¹

⁴⁷ Alexandra Pehlken and Elhachmi Essadiqi, *Scrap Tire Recycling in Canada*, CANMET Material Technology Laboratory (2005).

⁴⁸ Delta Air Quality Services (1999), *AB2588 Emissions Testing at California Portland Cement Company's Colton Plant; Coal and Coal with Tires Firing*.

⁴⁹ Michael Blumenthal, *The Use of Scrap Tires in Rotary Cement Kilns*, Scrap Tire Management Council, Washington D.C. (2005).

⁵⁰ Alexandra Pehlken and Elhachmi Essadiqi, *Scrap Tire Recycling in Canada*, CANMET Material Technology Laboratory (2005).

⁵¹ Alexandra Pehlken and Elhachmi Essadiqi, *Scrap Tire Recycling in Canada*, CANMET Material Technology Laboratory (2005).

Emissions of HCL, dioxins and furans, mercury, cadmium and lead expressed in lb/mmmbtu were estimated by creating a conversion factor for “mg/dscm” to “lb/mmmbtu” based on additional emission limit information for NO_x, SO_x, PM and CO.

Acidification Equivalency Coefficients

Acidification, or “ADP” in this analysis is calculated for each activity using the coefficients found in Table 14 below. Each species of acid emissions are taken in relation to sulfur dioxide. All acid emissions are summed in units of SO₂e or SO₂ equivalent.

Table 14: Acidification Coefficients⁵²

Substance	Chemical Formula	kg H+ moles-e / kg substance	Coefficients
Nitrogen Dioxide	NO ₂	40	0.79
Ammonia	NH ₃	95	1.88
Hydrochloric Acid	HCl	45	0.88
Hydrofluoric Acid	HF	81	1.60
Sulfur Dioxide	SO ₂	51	1.00
Nitric Oxide	HNO ₃	61	1.21
Nitrogen Oxides	NO _x	40	0.79
Sulfur Oxides	SO _x	51	1.00

Heavy Metals Considered

In the USA of the 189 elements and compounds that are defined as HAPs (hazardous air pollutants), “known or suspected of causing cancer or other serious health effects” 11 are metals: As, Be, Cd, Co, Cr, Hg, Mn, Ni, Pb, Sb, Se (CCT, 1997).

Some of these elements are in very small amounts necessary for humans (Cu, Se, Cr, Ni) whilst others are carcinogenic or toxic at small or very small amounts, affecting for example the central nervous system (Hg, Pb, Se, As), the kidneys or liver (Hg, Pb, Se, Cd, Cu) or the skin, bones or teeth (Ni, Sb, Cd, Se, Cu, Cr).

Based on this information, we have adopted the US EPA’s list of metals classified as hazardous air pollutants for the tire LCA study. This includes:

- Arsenic and its compounds (As)
- Beryllium and its compounds (Be)
- Cadmium and its compounds (Cd)
- Cobalt and its compounds (Co)
- Chromium and its compounds (Cr)
- Mercury and its compounds (Hg)

⁵² EPA (2002). *Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI)*. Obtained through personal communication with Jane Bare (email) April 2010.

Manganese and its compounds (Mn)

Nickel and its compounds (Ni)

Lead and its compounds (Pb)

Antimony and its compounds (Sb)

Selenium and its compounds (Se)

Displacement Ratios

Rubber products will displace their baseline counterparts based on volume to mass ratio and lifespan. These are shown as “Material Displacement” and “Lifespan Displacement” columns in Table 15 below. A “Total Displacement” column is calculated by multiplying the preceding two columns together. These displacement ratios are used to determine how much activity will be displaced in the baseline scenario when recycling 1 tonne of tires.

Table 15: Displacement Ratios

Material	Material Displacement	Lifespan Displacement	Total Displacement	Units
Gravel	1.7	unknown	1.7	T gravel / T tires
Timber	1	3	3	T timber / T tires
Concrete Curbs	1.4	4	5.6	T concrete / T tires
Asphalt Shingles	2	unknown	2	T asphalt shingles / T tires
EPDM Crumb	1.22	1	1.22	T EPDM crumb / T tire crumb
Coal (coal plant)	1.26	1	1.26	T coal saved / T tire shred
Coal (cement kilns)	1.06	1	1.06	T coal saved / T tires

The operating performance of rubber products over their baseline products was not analyzed. For example, the insulation effects of using rubber shingles over asphalt shingles were not considered.

8. Waste-to-Energy (Thermal Conversion)

This section examines waste-to-energy options that are currently available and could potentially be used to manage tire waste. These technologies were not included in the LCA due to a lack of technology maturity for application with tires as well as an associated lack of data. Incineration, gasification, pyrolysis and plasma technologies are discussed. For each we include:

- Description of technology status (mature, emerging)
- State of the technology
- Highlights of information, if any, and related TDF applications
- Best known information sources for the technology

8.1 Incineration

8.1.1 Description of Technology

During incineration, waste is combusted and heat from the combustion process is used to generate steam, which is then used for district heating, industrial processes or power generation.

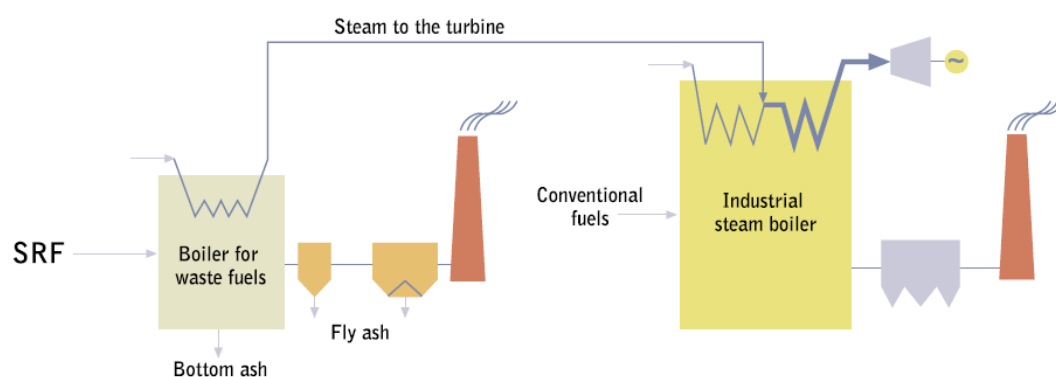


Figure 36. Incineration process diagram.⁵³

The incineration process also produces waste residue in the form of flue gases and ash. An air pollution control system (APC) cleans the flue gas using a variety of air pollution control units before the flue gas is released to the atmosphere. Bottom ash and other inorganic components in the waste, are either disposed of in landfills or when possible, used as aggregate for various

⁵³ IEA Bioenergy (2003) *Municipal Solid Waste and its Role in Sustainability: A Position Paper Prepared by IEA Bioenergy* (accessed April 20, 2010) http://www.ieabioenergy.com/media/40_IEAPositionPaperMSW.pdf.

processes such as cement and road construction. Fly ash is not useable and must be disposed of in a hazardous waste disposal site. Because bottom ash is often used as aggregate, on average, waste incineration reduces the mass of waste sent to landfill by 90%.⁵⁴

Tests of incinerator ash indicate that it is often not suitable as an aggregate material and can be a difficult material to dispose of. For example, one study noted that “the presence of large amounts of heavy metals (Zn, Pb, Cu, etc.) and also alkali chlorides and sulphates in the ash formed during the MSW incineration apart from their contribution in the ash-related problems also constitute a significant problem regarding the treatment and disposal of the generated ash material in an economical and environmentally friendly way.”⁵⁵ Bottom ash specifically “has proven to be a highly inhomogeneous and difficult to handle ash material.”⁵⁶ However, a portion of the ash produced at incinerators in Sweden is used as road construction material.⁵⁷

8.1.2 State of the technology for use with MSW or MSW and tires

Low tipping fees at regional landfills in North America provide relatively inexpensive disposal of MSW.⁵⁸ This has reduced the competitiveness of capital-intensive MSW-to-energy, however, the amount of solid waste processed in WTE facilities varies significantly by region.⁵⁹

Sweden operates a fleet of 29 incinerators that collectively processed 4,099,800 tonnes of municipal and industrial waste in 2006.⁶⁰ Eighteen of these 29 plants produce electricity. One new incineration facility and two new boilers were installed in Sweden in 2008.⁶¹

In 2005, there were 98 WTE facilities operating with the use of MSW in the United States,⁶² and an additional twelve MSW incineration facilities in England and Wales.⁶³

Lurgi Lentjes AG operates a fluidized bed combustion plant in Frankfurt Nordweststadt, Germany.⁶⁴ The plant accepts 20 tonnes per hour of MSW and generates electricity using a steam

⁵⁴ *Avfall Sverige: Swedish Waste Management*, "Swedish Waste Management," (Avfall Sverige, 2007).

⁵⁵ F.J. Frandsen S. Arvelakis, "Study on Analysis and Characterization Methods for Ash Material from Incineration Plants," (Technical University of Denmark, 2005).

⁵⁶ *Ibid.*

⁵⁷ *Avfall Sverige: Swedish Waste Management* (2009) "Swedish Waste Management." (accessed April 20, 2010) <http://www.avfallsverige.se/m4n?oid=english>.

⁵⁸ *United Nations Environment Programme* (no date) *Regional Overviews and Information Sources – North America*, Topic d: Incineration (accessed April 21, 2010) http://www.unep.or.jp/ietc/ESTdir/Pub/MSW/RO/North_A/Topic_d.asp.

⁵⁹ *United Nations Environment Programme* (no date) *Regional Overviews and Information Sources – North America*, Topic d: Incineration (accessed April 21, 2010) http://www.unep.or.jp/ietc/ESTdir/Pub/MSW/RO/North_A/Topic_d.asp.

⁶⁰ *Avfall Sverige: Swedish Waste Management* (2009) "Swedish Waste Management." (accessed April 20, 2010) <http://www.avfallsverige.se/m4n?oid=english>.

⁶¹ *Avfall Sverige: Swedish Waste Management* (2009) "Swedish Waste Management." (accessed April 20, 2010) <http://www.avfallsverige.se/m4n?oid=english>.

⁶² Andrew Knox, University of Western Ontario (February 2005) *An Overview of Incineration and EFW Technology as Applied to the Management of Municipal Solid Waste (MSW)*, (prepared for ONEIA Energy Subcommittee), P. 33 (accessed April 27, 2010) <http://www.oneia.ca/files/EFW%20-%20Knox.pdf>.

⁶³ Andrew Knox, University of Western Ontario (February 2005) *An Overview of Incineration and EFW Technology as Applied to the Management of Municipal Solid Waste (MSW)*, (prepared for ONEIA Energy Subcommittee), P. 35 (accessed April 27, 2010) <http://www.oneia.ca/files/EFW%20-%20Knox.pdf>.

cycle turbine.⁶⁵ The plant was originally constructed in 1964 and revamped in 1983, and has recently received a number of emissions control upgrades including flue gas cleaning units and replacement of the original incineration lines.⁶⁶

Algonquin Power Energy From Waste Inc. has been operating an MSW WTE facility since 1992 in Brampton, Ontario that uses an incinerator coupled with a steam turbine to generate electricity.⁶⁷ The facility consumes 500 tonnes of MSW per day and generates an output of 15 MWe.⁶⁸ The company has stated that air emissions of greatest concern for facility operators are particulate matter, nitrogen oxides and sulfur dioxide.⁶⁹

Montenay Inc. also operates a WTE incineration facility in South Burnaby, British Columbia that converts 830 tonnes of waste to steam and electricity each day.⁷⁰ The facility has been operating since 1988, but has received a number of upgrades to its emissions control technologies over the years.⁷¹ Among its emissions control equipment are a carbon injection system to reduce mercury emissions and an ammonia injection system to manage nitrogen oxide emissions.⁷²

Incineration technologies have received criticism in the past for their environmental performance, particularly with respect to air emissions including dioxins, furans and mercury.⁷³ However, developments in emissions control technologies have improved the environmental performance of these systems.⁷⁴ Reductions in mercury emissions from incinerators is due in part to air emission criteria and guidelines, but is also due to reduced amounts of mercury in commercial products.⁷⁵

⁶⁴ Lurgi Lentjes AG (no date) Plant Profile: Nordweststadt, Germany (accessed April 27, 2010) <http://www.thermalnet.co.uk/docs/33b%20Greil%20NordweststadtLille.pdf>.

⁶⁵ Lurgi Lentjes AG (no date) Plant Profile: Nordweststadt, Germany (accessed April 27, 2010) <http://www.thermalnet.co.uk/docs/33b%20Greil%20NordweststadtLille.pdf>.

⁶⁶ Lurgi Lentjes AG (no date) Plant Profile: Nordweststadt, Germany (accessed April 27, 2010) <http://www.thermalnet.co.uk/docs/33b%20Greil%20NordweststadtLille.pdf>.

⁶⁷ Algonquin Power website: http://www.algonquinpower.com/business/facility/alternative_peel.asp.

⁶⁸ Algonquin Power website: http://www.algonquinpower.com/business/facility/alternative_peel.asp.

⁶⁹ Andrew Knox, University of Western Ontario (February 2005) *An Overview of Incineration and EFW Technology as Applied to the Management of Municipal Solid Waste (MSW)*, (prepared for ONEIA Energy Subcommittee), P. 33 (accessed April 27, 2010) <http://www.oneia.ca/files/EFW%20-%20Knox.pdf>.

⁷⁰ Greater Vancouver Regional District (June 2007) *Waste-to-Energy Facility* (accessed April 27, 2010) http://www.city.burnaby.bc.ca/_shared/assets/Sanitation_-_Burnaby_Waste_Energy_Facility_Fact_Sheet4383.pdf.

⁷¹ Greater Vancouver Regional District (June 2007) *Waste-to-Energy Facility* (accessed April 27, 2010) http://www.city.burnaby.bc.ca/_shared/assets/Sanitation_-_Burnaby_Waste_Energy_Facility_Fact_Sheet4383.pdf.

⁷² Greater Vancouver Regional District (June 2007) *Waste-to-Energy Facility* (accessed April 27, 2010) http://www.city.burnaby.bc.ca/_shared/assets/Sanitation_-_Burnaby_Waste_Energy_Facility_Fact_Sheet4383.pdf.

⁷³ Andrew Knox, University of Western Ontario (February 2005) *An Overview of Incineration and EFW Technology as Applied to the Management of Municipal Solid Waste (MSW)*, (prepared for ONEIA Energy Subcommittee), P. 9 (accessed April 27, 2010) <http://www.oneia.ca/files/EFW%20-%20Knox.pdf>.

⁷⁴ Andrew Knox, University of Western Ontario (February 2005) *An Overview of Incineration and EFW Technology as Applied to the Management of Municipal Solid Waste (MSW)*, (prepared for ONEIA Energy Subcommittee), P. 8 (accessed April 27, 2010) <http://www.oneia.ca/files/EFW%20-%20Knox.pdf>.

⁷⁵ Andrew Knox, University of Western Ontario (February 2005) *An Overview of Incineration and EFW Technology as Applied to the Management of Municipal Solid Waste (MSW)*, (prepared for ONEIA Energy Subcommittee), P. 10 (accessed April 27, 2010) <http://www.oneia.ca/files/EFW%20-%20Knox.pdf>.

Toxic compounds, dioxins and furans are concentrated in fly and bottom ash,⁷⁶ which must be managed as hazardous waste. Dioxins and furans are not only released from incinerated materials, but new dioxins and furans are also formed through the incineration process itself.⁷⁷ Landfilling is one management option, however, ash may also be incorporated into concrete for use in roads and pathways.⁷⁸

8.1.3 Potential for use of tires as a feedstock

TDF incineration facilities have been economically problematic in the State of Virginia. The Tire Energy Corporation, at that time the only user of waste tires for fuel in Virginia, closed its Martinsville facility in July 2007 because there were not enough clients to purchase steam and costs were too high.⁷⁹ The Cogentrix facility in Chesterfield County had intended to resume its use of TDF in August 2007, following a hiatus during which it retrofitted boilers and feed systems.⁸⁰ However, sale of the facility was predicted to delay the use of tire-derived fuel until 2008 or later.

In the U.S., Exeter Energy Ltd. in Sterling, Connecticut operates a dedicated tire-to-energy facility that burns mainly whole tires.⁸¹ However, records show that the environmental performance of the facility has been fraught with challenges – the facility has been served with complaints and notices of violation.⁸²

In terms of efficiency, increasing rubber and plastic materials content in incinerator feedstock would improve the return on energy inputs.⁸³ However, the energy gained from incineration of rubber is less than the energy that would be gained from recycling rubber materials, thus creating a net energy loss in the bigger picture.⁸⁴

⁷⁶ Andrew Knox, University of Western Ontario (February 2005) *An Overview of Incineration and EFW Technology as Applied to the Management of Municipal Solid Waste (MSW)*, (prepared for ONEIA Energy Subcommittee), P. 62 (accessed April 27, 2010) <http://www.oneia.ca/files/EFW%20-%20Knox.pdf>.

⁷⁷ Andrew Knox, University of Western Ontario (February 2005) *An Overview of Incineration and EFW Technology as Applied to the Management of Municipal Solid Waste (MSW)*, (prepared for ONEIA Energy Subcommittee), P. 62 (accessed April 27, 2010) <http://www.oneia.ca/files/EFW%20-%20Knox.pdf>.

⁷⁸ Andrew Knox, University of Western Ontario (February 2005) *An Overview of Incineration and EFW Technology as Applied to the Management of Municipal Solid Waste (MSW)*, (prepared for ONEIA Energy Subcommittee), P. 62 (accessed April 27, 2010) <http://www.oneia.ca/files/EFW%20-%20Knox.pdf>.

⁷⁹ Virginia Department of Environmental Quality, State Advisory Board (November 2007) *Use of Tire-Derived Fuel in Virginia* (accessed April 21, 2010) http://www.deq.state.va.us/export/sites/default/air/sab/Tire_Derived_Fuel.pdf.

⁸⁰ Virginia Department of Environmental Quality, State Advisory Board (November 2007) *Use of Tire-Derived Fuel in Virginia* (accessed April 21, 2010) http://www.deq.state.va.us/export/sites/default/air/sab/Tire_Derived_Fuel.pdf.

⁸¹ Connecticut Department of Environmental Protection (2003) *Recycling and Disposal of Scrap Tires* (accessed April 20, 2010) <http://www.ct.gov/dep/cwp/view.asp?A=2714&Q=324902>.

⁸² Energy Justice Network (no date) *Exeter Energy Inc. Tire Incinerator in Sterling, CT – Incomplete Timeline of Operations/Violations* (accessed April 27, 2010) <http://www.energyjustice.net/tires/exeter.pdf>.

⁸³ Andrew Knox, University of Western Ontario (February 2005) *An Overview of Incineration and EFW Technology as Applied to the Management of Municipal Solid Waste (MSW)*, (prepared for ONEIA Energy Subcommittee), P. 29 (accessed April 27, 2010) <http://www.oneia.ca/files/EFW%20-%20Knox.pdf>.

⁸⁴ Andrew Knox, University of Western Ontario (February 2005) *An Overview of Incineration and EFW Technology as Applied to the Management of Municipal Solid Waste (MSW)*, (prepared for ONEIA Energy Subcommittee), P. 29 (accessed April 27, 2010) <http://www.oneia.ca/files/EFW%20-%20Knox.pdf>.

Tire incineration has been more popular in Japan. Table 16 (below) highlights four TDF incineration facilities that were operating in Japan in 2007.

Table 16. TDF incineration facilities operating in Japan in 2007⁸⁵

Company	Factory	Incinerator type	Purpose
Bridgestone Corp.	Tochigi plant Amagi plant	Fluidized-bed incinerator Grate incinerator	Power generation Heat source for boiler
Yokohama Rubber Co., Ltd.	Mie plant	Grate incinerator	Heat source for boiler
Sumitomo Rubber Industries, Ltd.	Nagoya plant Shirakawa plant Miyazaki plant	Grate incinerator Pyrolysis incinerator Grate incinerator	Cogeneration Heat source for boiler Heat source for boiler
Toyo Tire & Rubber Co., Ltd.	Sendai plant Kuwana plant	Grate incinerator Grate incinerator	Cogeneration Heat source for boiler

Proposals for tire WFE incineration facilities in Minnesota and Ontario have been rejected by governments within recent years.⁸⁶ Much of the public opposition to tire incineration facilities appears to be focused on real and received human and environmental health risks posed by air emissions.

Yet, the World Council on Sustainable Development claims that emissions from TDF incineration under controlled conditions are no greater than those from other fuels.⁸⁷ The Council sites lower carbon emissions than coal or petroleum coke, and reductions in nitrogen oxide, sulfur dioxide and carbon dioxide emissions as compared to combustion of virgin fossil fuels.⁸⁸ Ash is stated to contain fewer heavy metals than ash from coal combustion.⁸⁹

8.1.4 Best known data sources for technology applications for MSW or MSW and tire feedstock

Andrew Knox, University of Western Ontario (February 2005) An Overview of Incineration and EFW Technology as Applied to the Management of Municipal Solid Waste (MSW), (prepared for ONEIA Energy Subcommittee), <http://www.oneia.ca/files/EFW%20-%20Knox.pdf>.

⁸⁵ World Business Council for Sustainable Development (2007) *Managing End-of-Life Tires – Full Report* (accessed April 27, 2010) http://www.wbcsd.org/DocRoot/IBTHZFGcpBK5OxTDXlpS/EndOfLifeTires_171208.pdf.

⁸⁶ Don Hopey (August 10, 2008) “Tire-to-energy plant is a hot issue in Erie” (Pittsburgh Post-Gazette) (accessed April 27, 2010) <http://www.post-gazette.com/pg/08223/903223-454.stm>.

⁸⁷ World Business Council for Sustainable Development (2007) *Managing End-of-Life Tires – Full Report* (accessed April 27, 2010) http://www.wbcsd.org/DocRoot/IBTHZFGcpBK5OxTDXlpS/EndOfLifeTires_171208.pdf.

⁸⁸ World Business Council for Sustainable Development (2007) *Managing End-of-Life Tires – Full Report* (accessed April 27, 2010) http://www.wbcsd.org/DocRoot/IBTHZFGcpBK5OxTDXlpS/EndOfLifeTires_171208.pdf.

⁸⁹ World Business Council for Sustainable Development (2007) *Managing End-of-Life Tires – Full Report* (accessed April 27, 2010) http://www.wbcsd.org/DocRoot/IBTHZFGcpBK5OxTDXlpS/EndOfLifeTires_171208.pdf.

World Business Council for Sustainable Development (2007) Managing End-of-Life Tires – Full Report,
http://www.wbcsd.org/DocRoot/IBTHZFGcpBK5OxTDXlpS/EndOfLifeTires_171208.pdf.

8.2 Gasification

8.2.1 Description

Gasification

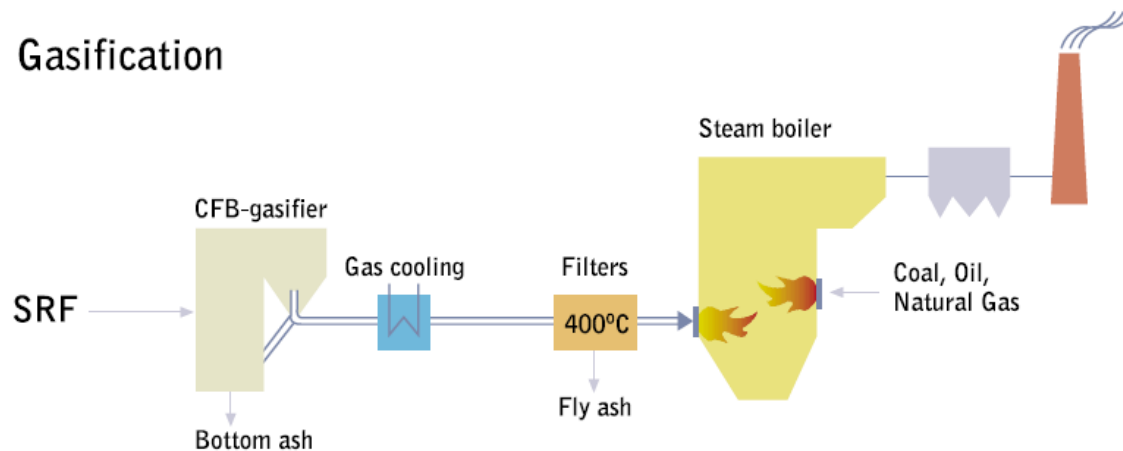


Figure 37. Gasification process diagram.⁹⁰

Gasification involves transforming feedstock into a highly combustible gas.⁹¹ This is typically accomplished by heating and oxidizing biomass fuel in an oxygen-deprived environment, which prevents complete combustion of the fuel and releases syngas.⁹²

“Syngas,” or synthesis gas, is a man-made gas consisting of hydrogen and carbon monoxide.⁹³

Where there is a market for syngas, gasification systems will only be used to produce a syngas that can be sold to a consumer, however, syngas can also be combusted to generate electricity.

There are two main types of gasification systems used to produce heat, power or CHP. Closed-coupled biomass gasification systems produce a syngas that is directly burned to produce heat.⁹⁴

⁹⁰ IEA Bioenergy (2003) *Municipal Solid Waste and its Role in Sustainability: A Position Paper Prepared by IEA Bioenergy* (accessed April 20, 2010) http://www.ieabioenergy.com/media/40_IEAPositionPaperMSW.pdf.

⁹¹ Yan Jinyue, Per Alvfors, Lars Eidensten, and Gunnar Svedberg, “A future for biomass” (The American Society of Mechanical Engineers, 1997).

<http://www.memagazine.org/backissues/membersonly/october97/features/biomass/biomass.html> (accessed September 24, 2009).

⁹² Carolyn Roos, “Clean Heat and Power Using Biomass Gasification for Industrial and Agricultural Projects,” (Northwest CHP Application Centre. 2008).

⁹³ Shell Chemicals, *Glossary & Trademarks* (no date)

http://www.shell.com/home/content/chemicals/footer/tools/glossery_trademarks.html (accessed November 23, 2009).

⁹⁴ David Peterson and Scott Haase, National Renewable Energy Laboratory (NREL) (2009) Market Assessment of Biomass Gasification and Combustion Technology for Small- and Medium-Scale Applications.

Two-stage gasification systems produce a syngas that is conditioned so that the gas is cleaner and can be burned in other applications, such as gas turbines and engines.⁹⁵

8.2.2 State of the technology

Gasification of MSW, or MSW and tires is currently at the pilot scale in Canada.⁹⁶

Energos currently operates six MSW grate gasification plants in Germany and Norway.⁹⁷

Enerkem and the University of Sherbrooke constructed a pilot-scale MSW gasification plant based on the Biosyn process coupled to steam cycle and gas engine in 2002.⁹⁸ The plant remains operational, and produces syngas, methanol and second-generation ethanol.⁹⁹ Enerkem is now working with the City of Edmonton to construct a fluidized bed MSW gasification facility to produce methanol and ethanol.¹⁰⁰ The syngas produced will be used to generate electricity.¹⁰¹ The modular configuration of Enerkem's systems enables facilities to be scaled to desired feedstock input and energy production.¹⁰² The system can be configured to utilize between 500 kg per hour and 15 tonnes per hour.¹⁰³

Entech has installed small-scale grate gasification systems for MSW-biomass coupled to steam cycle turbines at a resort complex and a university.¹⁰⁴ These systems convert 30 t/day and 50t/day, respectively, of MSW-biomass into energy.

Interstate Waste Technologies developed their ThermoSelect technology as a pilot-scale facility in Karlsruhe, Germany and Chiba, Japan.¹⁰⁵ The Thermoselect process uses gasification of MSW

⁹⁵ David Peterson and Scott Haase, National Renewable Energy Laboratory (NREL) (2009) Market Assessment of Biomass Gasification and Combustion Technology for Small- and Medium-Scale Applications.

⁹⁶ Jeff Takeyasu, Trimark Engineering (2007) *Southern Alberta Energy Partnership – Waste to Energy Treatment Alternatives Study*, P. 7.

⁹⁷ Energos website: http://www.energ.co.uk/gasification_technology.

⁹⁸ Foth & Van Dyke and Associates, Inc. (September 2004) *Updated Study of Alternative Waste Processing Technology – Ramsey/Washington County Resource Recovery Project*, P. 67 (accessed April 25, 2010) http://www.co.ramsey.mn.us/NR/rdonlyres/C9000BB9-1C1A-43F5-8E1D-80A0A7E6AF35/5665/PC_Research_Study_on_Alternate_Waste_Processing.pdf.

⁹⁹ Enerkem website: <http://www.enerkem.com/index.php?module=CMS&id=10&newlang=eng>.

¹⁰⁰ Enerkem website: <http://www.enerkem.com/index.php?module=CMS&id=22&newlang=eng>.

¹⁰¹ Jeff Takeyasu, Trimark Engineering (2007) *Southern Alberta Energy Partnership – Waste to Energy Treatment Alternatives Study*, P. 52.

¹⁰² Jeff Takeyasu, Trimark Engineering (2007) *Southern Alberta Energy Partnership – Waste to Energy Treatment Alternatives Study*, P. 51.

¹⁰³ Jeff Takeyasu, Trimark Engineering (2007) *Southern Alberta Energy Partnership – Waste to Energy Treatment Alternatives Study*, P. 51.

¹⁰⁴ Entech website: <http://www.entech.net.au/ws2/>.

¹⁰⁵ Foth & Van Dyke and Associates, Inc. (September 2004) *Updated Study of Alternative Waste Processing Technology – Ramsey/Washington County Resource Recovery Project*, P. 59-61 (accessed April 25, 2010) http://www.co.ramsey.mn.us/NR/rdonlyres/C9000BB9-1C1A-43F5-8E1D-80A0A7E6AF35/5665/PC_Research_Study_on_Alternate_Waste_Processing.pdf.

coupled to a gas engine. The Karlsruhe facility was closed in 2004 following a number of environmental violations and technical problems.¹⁰⁶

Environmental advantages of fluidized bed gasification systems include fewer emissions of trace organics, due to mechanical turbulence and high residence times, as well as more complete combustion and higher ash quality when feedstocks are processed to small particle size.¹⁰⁷

Relatively simple design, long service life and low capital cost and maintenance costs make these systems economically attractive.¹⁰⁸ Fluidized bed systems are also capable of accommodating a wide range of feedstock types and rates of feedstock input.¹⁰⁹ However, these systems require skilled operators and are sensitive to variations in particle size.¹¹⁰

8.2.3 Potential for use of tires as a feedstock

No pilot or commercial gasification projects using tires as a feedstock were discovered.

8.2.4 Best known data sources for technology applications for MSW or MSW and tire feedstock

University of California Riverside (March 2006) *Technology Evaluation and Economic Analysis of Waste Tire Pyrolysis, Gasification, and Liquefaction* (prepared for the State of California, Integrated Waste Management Board),
<http://www.calrecycle.ca.gov/publications/Tires/62006004.doc>.

Jeff Takeyasu, Trimark Engineering (2007) Southern Alberta Energy Partnership – Waste to Energy Treatment Alternatives Study.

Foth & Van Dyke and Associates, Inc. (September 2004) Updated Study of Alternative Waste Processing Technology – Ramsey/Washington County Resource Recovery Project,
[http://www.co.ramsey.mn.us/NR/rdonlyres/C9000BB9-1C1A-43F5-8E1D-80A0A7E6AF35/5665/PC Research Study on Alternate Waste Processing.pdf](http://www.co.ramsey.mn.us/NR/rdonlyres/C9000BB9-1C1A-43F5-8E1D-80A0A7E6AF35/5665/PC%20Research%20Study%20on%20Alternate%20Waste%20Processing.pdf).

¹⁰⁶ Greenaction for Health and Environmental Justice and Global Alliance for Incinerator Alternatives (June 2006) *Incinerators in Disguise: Case Studies of Gasification, Pyrolysis, and Plasma in Europe, Asia, and the United States*, P. 10 (accessed April 25, 2010)

<http://www.durhamenvironmentwatch.org/Incinerator%20Files/incineratorsindisguisereportjune2006.pdf>.

¹⁰⁷ Jeff Takeyasu, Trimark Engineering (2007) Southern Alberta Energy Partnership – Waste to Energy Treatment Alternatives Study, P. 51.

¹⁰⁸ Jeff Takeyasu, Trimark Engineering (2007) Southern Alberta Energy Partnership – Waste to Energy Treatment Alternatives Study, P. 51.

¹⁰⁹ Jeff Takeyasu, Trimark Engineering (2007) Southern Alberta Energy Partnership – Waste to Energy Treatment Alternatives Study, P. 51.

¹¹⁰ Jeff Takeyasu, Trimark Engineering (2007) Southern Alberta Energy Partnership – Waste to Energy Treatment Alternatives Study, P. 51.

8.3 Pyrolysis

8.3.1 Description

Pyrolysis involves thermal decomposition of feedstock (e.g. MSW) into oils, gases, and char under oxygen-free conditions.^{111,112} All products of pyrolysis may be used as combustible fuels.¹¹³ Relative proportions of the resulting products created depend on heat, pressure and duration of treatment.¹¹⁴ Pyrolysis has also been proposed as a method to break down tires into marketable products such as steel, oil and carbon black.¹¹⁵

8.3.2 State of the technology

At present, pyrolysis is most commonly used to produce coke from coal. Pyrolysis feedstocks now include MSW, agricultural wastes and wastewater treatment sludge, however, application of pyrolysis technologies to solid waste streams does not have a long history.¹¹⁶ There are currently few providers of this type of technology.¹¹⁷ Pyrolysis of MSW or MSW and tires is currently at the pilot scale in Canada.¹¹⁸ In fact, the only commercial-scale MSW pyrolysis facility ever constructed in the U.S. was developed in California and shut down after two years of operation due to failure to produce a marketable oil product.¹¹⁹

Compact Power utilizes tube pyrolysis and gasification of MSW coupled to a steam cycle turbine to generate electricity.¹²⁰ Its first commercial plant was developed in Bristol, UK and included two pyrolysis tubes, which were used to process 8,000 tonnes of waste each year.¹²¹

Organic Energy has developed three small to mid-sized facilities; one in Norway and two in Korea. Seven additional plants are being developed.¹²² Their modular technology systems are capable of consuming between 3,500 and 7,500 tonnes of MSW each year.¹²³

¹¹¹ U.S. EPA (2010) *Scrap Tires - Science/Technology webpage* (accessed April 20, 2010)
<http://www.epa.gov/epawaste/conservation/materials/tires/science.htm>.

¹¹² Splainex Ecosystems Ltd. (2008) *Pyrolysis as Recovering Value from Waste* (accessed April 20, 2010)
http://www.splainex.com/waste_recycling.htm.

¹¹³ Splainex Ecosystems Ltd. (2008) *Pyrolysis as Recovering Value from Waste* (accessed April 20, 2010)
http://www.splainex.com/waste_recycling.htm.

¹¹⁴ Splainex Ecosystems Ltd. (2008) *Pyrolysis as Recovering Value from Waste* (accessed April 20, 2010)
http://www.splainex.com/waste_recycling.htm.

¹¹⁵ U.S. EPA (2010) *Scrap Tires - Science/Technology webpage* (accessed April 20, 2010)
<http://www.epa.gov/epawaste/conservation/materials/tires/science.htm>.

¹¹⁶ Jeff Takeyasu, Trimark Engineering (2007) *Southern Alberta Energy Partnership – Waste to Energy Treatment Alternatives Study*, P. 52.

¹¹⁷ Jeff Takeyasu, Trimark Engineering (2007) *Southern Alberta Energy Partnership – Waste to Energy Treatment Alternatives Study*, P. 52.

¹¹⁸ Jeff Takeyasu, Trimark Engineering (2007) *Southern Alberta Energy Partnership – Waste to Energy Treatment Alternatives Study*, P. 7.

¹¹⁹ Jeff Takeyasu, Trimark Engineering (2007) *Southern Alberta Energy Partnership – Waste to Energy Treatment Alternatives Study*, P. 56.

¹²⁰ Friends of the Earth (2002) *Briefing: Pyrolysis and gasification*, P. 4.

¹²¹ Friends of the Earth (2002) *Briefing: Pyrolysis and gasification*, P. 4.

Brightstar Environmental has patented its Solid Waste Recycling and Energy Recovery, or SWERF®, process that uses tube pyrolysis coupled to a gas engine to generate energy.^{124,125} The firm's pilot plant in Wollongong, Australia was closed in 2002 due to financial issues.¹²⁶ Additional plants had been proposed, but were never developed.

In March 2010, S4 Energy Solutions LLC announced plans to develop a plasma gasification facility at Waste Management's Columbia Ridge Landfill in Arlington, Oregon.¹²⁷ The company is a joint venture by Waste Management, Inc. and InEnTec LLC. The facility is expected to come online within the year.¹²⁸

Environmental benefits of pyrolysis systems include the ability to create few air emissions with the use of lower-cost pollution control equipment.¹²⁹ High process temperatures trap pollutants such as heavy metals and sulfur in bottom ash therefore, emissions are typically lower than those of incinerators.¹³⁰ Emissions control equipment may only be required on turbines or boilers.¹³¹

Small, localized units, such as those developed by Organic Energy, allow waste to be processed near the source and reduce capital and transportation costs,¹³² however, these units are often more costly relative to large-scale facilities.¹³³ Typical design specifications are for plants utilizing MSW in the range of 25,000 to 40,000 tonnes per year, and feedstock must be shredded prior to use.¹³⁴

¹²² Jeff Takeyasu, Trimark Engineering (2007) *Southern Alberta Energy Partnership – Waste to Energy Treatment Alternatives Study*, P. 55.

¹²³ Jeff Takeyasu, Trimark Engineering (2007) *Southern Alberta Energy Partnership – Waste to Energy Treatment Alternatives Study*, P. 55.

¹²⁴ Fichtner Consulting Engineers Ltd. (March 2004) *The Viability of Advanced Thermal Treatment of MSW in the UK*, P. 58 (accessed April 25, 2010) <http://www.esauk.org/publications/reports/thermal%20treatment%20report.pdf>.

¹²⁵ Energy Developments Ltd. (2002) *Annual Report of 2002* (accessed April 23, 2010) http://www.energydevelopments.com.au/_dbase_upl/EDL_AnnualReport2002.pdf.

¹²⁶ Friends of the Earth (2002) *Briefing: Pyrolysis and gasification*, P. 5.

¹²⁷ No author (March 11, 2010) "Waste Management To Deploy First Plasma Gasification System" (Sustainable Business; reprinted by the Matter Network) (accessed April 26, 2010) <http://www.matternetwork.com/2010/3/waste-management-deploy-first-plasma.cfm>.

¹²⁸ No author (March 11, 2010) "Waste Management To Deploy First Plasma Gasification System" (Sustainable Business; reprinted by the Matter Network) (accessed April 26, 2010) <http://www.matternetwork.com/2010/3/waste-management-deploy-first-plasma.cfm>.

¹²⁹ Jeff Takeyasu, Trimark Engineering (2007) *Southern Alberta Energy Partnership – Waste to Energy Treatment Alternatives Study*, P. 55.

¹³⁰ Jeff Takeyasu, Trimark Engineering (2007) *Southern Alberta Energy Partnership – Waste to Energy Treatment Alternatives Study*, P. 56.

¹³¹ Jeff Takeyasu, Trimark Engineering (2007) *Southern Alberta Energy Partnership – Waste to Energy Treatment Alternatives Study*, P. 56.

¹³² Jeff Takeyasu, Trimark Engineering (2007) *Southern Alberta Energy Partnership – Waste to Energy Treatment Alternatives Study*, P. 55.

¹³³ Jeff Takeyasu, Trimark Engineering (2007) *Southern Alberta Energy Partnership – Waste to Energy Treatment Alternatives Study*, P. 56.

¹³⁴ Jeff Takeyasu, Trimark Engineering (2007) *Southern Alberta Energy Partnership – Waste to Energy Treatment Alternatives Study*, P. 56.

Start up periods also tend to be shorter for pyrolysis facilities than for incineration facilities. Pyrolysis facilities can also operate below full capacity.¹³⁵

The failure of commercial-scale MSW pyrolysis to date has been attributed to high costs, system complexity and inability to accommodate feedstock inconsistencies.¹³⁶

8.3.3 Potential for use of tires as a feedstock

Beven Recycling partnered with the UK Atomic Energy Authority in 2002 to operate a tire pyrolysis facility for four to five years in Witney, UK.¹³⁷ Environmental Waste International also operated a four-year tire pyrolysis pilot plant for four years, between 1994 and 1998.¹³⁹

Table 17(below) outlines 2006 data about tire pyrolysis, gasification and liquefaction plants across the world.

Table 17. Tire pyrolysis, gasification and liquefaction plants in 2006¹⁴⁰

¹³⁵ Jeff Takeyasu, Trimark Engineering (2007) *Southern Alberta Energy Partnership – Waste to Energy Treatment Alternatives Study*, P. 56.

¹³⁶ Jeff Takeyasu, Trimark Engineering (2007) *Southern Alberta Energy Partnership – Waste to Energy Treatment Alternatives Study*, P. 56.

¹³⁷ University of California Riverside (March 2006) *Technology Evaluation and Economic Analysis of Waste Tire Pyrolysis, Gasification, and Liquefaction* (prepared for the State of California, Integrated Waste Management Board) (accessed April 21, 2010) <http://www.calrecycle.ca.gov/publications/Tires/62006004.doc>.

¹³⁸ Recycling Research Institute (2002) “UK Joint Venture uses Pyrolysis Process” (Scrap Tire News) (accessed April 21, 2010) <http://www.scraptirenews.com/99dec3.html>.

¹³⁹ University of California Riverside (March 2006) *Technology Evaluation and Economic Analysis of Waste Tire Pyrolysis, Gasification, and Liquefaction* (prepared for the State of California, Integrated Waste Management Board) (accessed April 21, 2010) <http://www.calrecycle.ca.gov/publications/Tires/62006004.doc>.

¹⁴⁰ University of California Riverside (March 2006) *Technology Evaluation and Economic Analysis of Waste Tire Pyrolysis, Gasification, and Liquefaction* (prepared for the State of California, Integrated Waste Management Board) (accessed April 21, 2010) <http://www.calrecycle.ca.gov/publications/Tires/62006004.doc>.

Company	Technology	Status of Technology	State/Region	Country
ACM Polyflow	Pyrolysis	Pilot plant	Ohio	USA
Alycon Engineering S.A.	Pyrolysis	Reference plant operating		Switzerland
Ande Scientific	Pyrolysis – bench scale	Not actively promoted	West Midlands	UK
Beven Recycling	Pyrolysis	Demonstration plant – no longer used	Whitney	UK
BPI	Pyrolysis – demo	Not active		UK
Conrad Industries Inc.	Pyrolysis	Pilot plant	Washington	U.S.
Environmental Waste International	Microwave Pyrolysis	Pre-commercial	Ontario	Canada
Hebco International	Pyrolysis	Design - Not actively promoted	Quebec	Canada
Theroux Environmental Consulting Services	Plasma arc gasification	Pre-commercial	California	U.S.
Traidec	Pyrolysis	Pilot scale—status unknown		France
Weidleplan (LIG)	Pyrolysis	Status unknown		Germany

A 2008 investigation into the use of tires for pyrolysis by Nova Scotia Environment expressed hesitation about the use of tire pyrolysis technologies based on a “high rate of business failure.”¹⁴¹ There are currently no commercial-scale tire pyrolysis facilities operating in North America, Japan or Europe.¹⁴² However, Nova Scotia Environment conceded that it would evaluate a pyrolysis facility if a technology provider was able to present a sound technical and financial feasibility review.¹⁴³

The only two commercial-scale tire pyrolysis facilities in the world are located in Kaohsiung, Taiwan, and Shanghai, China.^{144,145} The Shanghai facility is operated by Kimkey (Shanghai)

¹⁴¹ Nova Scotia Environment (September 2008) *Interdepartmental committee on used-tire management in Nova Scotia, Report to the Minister of Environment* (accessed April 26, 2010) <http://www.gov.ns.ca/nse/waste/docs/TireStrategy.pdf>.

¹⁴² Nova Scotia Environment (September 2008) *Interdepartmental committee on used-tire management in Nova Scotia, Report to the Minister of Environment* (accessed April 26, 2010) <http://www.gov.ns.ca/nse/waste/docs/TireStrategy.pdf>.

¹⁴³ Nova Scotia Environment (September 2008) *Interdepartmental committee on used-tire management in Nova Scotia, Report to the Minister of Environment* (accessed April 26, 2010) <http://www.gov.ns.ca/nse/waste/docs/TireStrategy.pdf>.

¹⁴⁴ University of California Riverside (March 2006) *Technology Evaluation and Economic Analysis of Waste Tire Pyrolysis, Gasification, and Liquefaction* (prepared for the State of California, Integrated Waste Management Board) (accessed April 21, 2010) <http://www.calrecycle.ca.gov/publications/Tires/62006004.doc>.

¹⁴⁵ Nova Scotia Environment (September 2008) *Interdepartmental committee on used-tire management in Nova Scotia, Report to the Minister of Environment* (accessed April 26, 2010) <http://www.gov.ns.ca/nse/waste/docs/TireStrategy.pdf>.

Environmental S&T Co. Ltd. and produces heating oil (35%-45%), carbon black (35%-40%), steel wire (15%-30%) and gas (5%-12%).¹⁴⁶

Delta Energy, based in North Dakota, claims to have developed a commercially-ready tire pyrolysis application. The technology conducts pyrolysis at a temperature of 800 F, and produces butane-propane, oil and solid carbon.¹⁴⁷ The company established a successful pilot-scale facility in 2002 that produced one gallon of butane-propane, 1.4 gallons of oil and 8 pounds of carbon per 20 pounds of shredded tires.¹⁴⁸ The waste stream was approximately 2 to 3% of the original input, by weight.¹⁴⁹

Due to the size of the pilot facility, the butane-propane was flared; at the commercial scale, this fuel would be used for heating and for generating electricity onsite.¹⁵⁰ The carbon product consisted of 80% carbon and 20% additives, and was sold to manufacturers of mining belts and tires.¹⁵¹

Delta Energy representatives state that the pilot facility met all applicable U.S. EPA air quality requirements.¹⁵² They are now seeking to develop four to five new commercial plants in Canada and the U.S.

Carbon Green Inc. recently completed construction of their 800,000 tire-per-year commercial-scale pyrolysis facility in Cyprus.¹⁵³ This facility is currently the largest pyrolysis plant in the world.¹⁵⁴ The Carbon Green process converts used tires into high-grade steel, a #2 diesel equivalent oil, a clean-burning gas¹⁵⁵ and a unique product called Carbon Green™ - a carbon black substitute accredited and accepted by the European Union.^{156,157} The diesel oil can be used to generate electricity offsite, and the gas can be used either on or offsite to generate electricity for the plant or sold for carbon credits.¹⁵⁸ Facility design is based on a two-year pilot project

¹⁴⁶ Kimkey (Shanghai) Environmental S&T Co., Ltd. website: <http://www.kimkeyoo.com/pyrolysisssystem.asp>.

¹⁴⁷ Duane Erickson, Manager, Delta Energy, personal communication, April 22, 2010.

¹⁴⁸ Duane Erickson, Manager, Delta Energy, personal communication, April 22, 2010.

¹⁴⁹ Duane Erickson, Manager, Delta Energy, personal communication, April 22, 2010.

¹⁵⁰ Duane Erickson, Manager, Delta Energy, personal communication, April 22, 2010.

¹⁵¹ Duane Erickson, Manager, Delta Energy, personal communication, April 22, 2010.

¹⁵² Duane Erickson, Manager, Delta Energy, personal communication, April 22, 2010.

¹⁵³ Carbon Green Inc. (no date) Factsheet: Recycling Today's Waste for Tomorrow's Energy (accessed May 11, 2010) http://www.carbongreeninc.com/docs/FactSheet_nd.pdf.

¹⁵⁴ Carbon Green Inc. (no date) Factsheet: Recycling Today's Waste for Tomorrow's Energy (accessed May 11, 2010) http://www.carbongreeninc.com/docs/FactSheet_nd.pdf.

¹⁵⁵ Marketwire (April 13, 2010) "Carbon Green Inc. Files 8K/A-1 and Provides Update on Operations" (accessed May 11, 2010) <http://www.marketwire.com/press-release/Carbon-Green-Inc-Files-8K-A-1-and-Provides-Update-on-Operations-OTC-Bulletin-Board-CGNI-1146774.htm>.

¹⁵⁶ Carbon Green Inc. (no date) Factsheet: Recycling Today's Waste for Tomorrow's Energy (accessed May 11, 2010) http://www.carbongreeninc.com/docs/FactSheet_nd.pdf.

¹⁵⁷ Marketwire (April 13, 2010) "Carbon Green Inc. Files 8K/A-1 and Provides Update on Operations" (accessed May 11, 2010) <http://www.marketwire.com/press-release/Carbon-Green-Inc-Files-8K-A-1-and-Provides-Update-on-Operations-OTC-Bulletin-Board-CGNI-1146774.htm>.

¹⁵⁸ Marketwire (April 13, 2010) "Carbon Green Inc. Files 8K/A-1 and Provides Update on Operations" (accessed May 11, 2010) <http://www.marketwire.com/press-release/Carbon-Green-Inc-Files-8K-A-1-and-Provides-Update-on-Operations-OTC-Bulletin-Board-CGNI-1146774.htm>.

operated in Europe.¹⁵⁹ The company claims that the technology is profitable without the support of government subsidies¹⁶⁰ and that the facility will be cash-flow positive by May 2010.¹⁶¹ Full production is also anticipated to be reached by May 2010.

8.3.4 Best known data sources for technology applications for MSW or MSW and tire feedstock

Duane Erickson, Manager, Delta Energy.

University of California Riverside (March 2006) *Technology Evaluation and Economic Analysis of Waste Tire Pyrolysis, Gasification, and Liquefaction* (prepared for the State of California, Integrated Waste Management Board),

<http://www.calrecycle.ca.gov/publications/Tires/62006004.doc>.

Jeff Takeyasu, Trimark Engineering (2007) *Southern Alberta Energy Partnership – Waste to Energy Treatment Alternatives Study*.

Friends of the Earth (2002) *Briefing: Pyrolysis and gasification*.

¹⁵⁹ Carbon Green Inc. (no date) *Factsheet: Recycling Today's Waste for Tomorrow's Energy* (accessed May 11, 2010) http://www.carbongreeninc.com/docs/FactSheet_nd.pdf.

¹⁶⁰ Carbon Green Inc. (no date) *Factsheet: Recycling Today's Waste for Tomorrow's Energy* (accessed May 11, 2010) http://www.carbongreeninc.com/docs/FactSheet_nd.pdf.

¹⁶¹ Marketwire (April 13, 2010) "Carbon Green Inc. Files 8K/A-1 and Provides Update on Operations" (accessed May 11, 2010) <http://www.marketwire.com/press-release/Carbon-Green-Inc-Files-8K-A-1-and-Provides-Update-on-Operations-OTC-Bulletin-Board-CGNI-1146774.htm>.

8.4 Plasma

8.4.1 Description

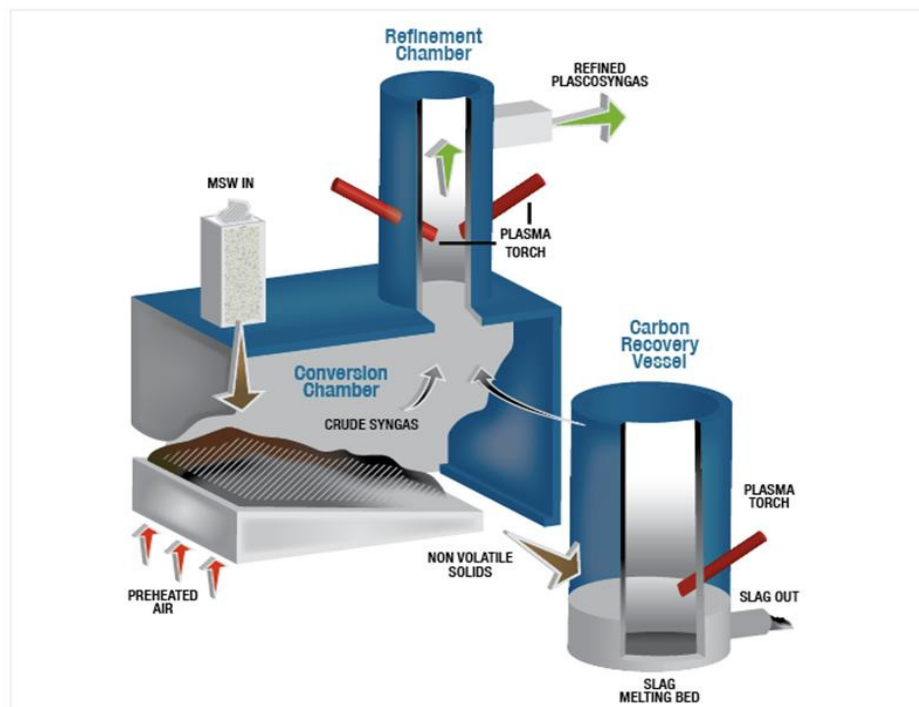


Figure 38. Plasma conversion process diagram.

The plasma conversion uses electrically generated plasma torches to convert feedstock into gas and a slag byproduct¹⁶² in an oxygen-deprived environment under controlled temperatures. The resulting synthetic fuel gas, or “syngas,” is cleaned and then used to operate internal combustion engines to generate electricity. The remaining inert materials contained in the waste, such as metal, dirt and glass components, which cannot be converted into fuel-gas, are treated by a third plasma torch to form an glass-like slag product. Once processed in this way, the slag is completely inert and stable and can be sold as aggregate for roads or construction materials.

The MSW stream enters the primary chamber of the converter where the material is gasified by heat recovered from the gases exiting the refining chamber. Within the refining chamber, there are two plasma torches. The gasified product from the primary chamber contains carbon monoxide, hydrogen and tars together with unreacted carbon. This gas is refined into a cleaner, lighter syngas in the secondary chamber. Process air and plasma heat are combined with the syngas and the plasma heat is adjusted to maintain the desired process chamber conditions. All long chain hydrocarbons are destroyed in the process.

Resulting syngas is sent to a recuperator to heat process air and then cooled prior to undergoing gas cleaning.

¹⁶² The Blue Ridge Environmental Defense League (February 2009) *Waste Gasification: Impacts on the Environment and Public Health* (accessed April 21, 2010) <http://www.bredl.org/pdf/wastegasification.pdf>.

8.4.2 State of the technology

Plasma arc gasification of MSW or MSW and tires is currently at the developmental stage in Canada,¹⁶³ however, plasma arc technology has been well established in the steel and construction industries.¹⁶⁴

A pilot-scale plasma arc facility for MSW was constructed in Yoshii, Japan in 1999.¹⁶⁵ The project led to development of a full-scale commercial facility in Utashinai City, Japan that became operational in 2003.

PEAT International also constructed a plasma arc facility capable of utilizing a variety of wastes at the National Cheng Kung University in Tainan City, Taiwan.¹⁶⁶ The facility has been operating at a demonstration scale since 2005 and consumes three to five tonnes of waste per day.¹⁶⁷

Two Canadian companies, Plasco Energy Group and Pyrogenesis Canada Inc., market plasma arc systems for MSW. While Pyrogenesis Canada Inc. has only demonstrated their technology for MSW at the pilot scale,¹⁶⁸ Plasco Energy Group currently operates two MSW plasma arc gasification facilities; one in Ottawa, Ontario and the other in Castellgali, Spain.¹⁶⁹ The Ottawa facility is the only plasma arc facility operating in North America¹⁷⁰ and was developed as a commercial-scale demonstration project through a partnership with the City of Ottawa. The plant has been consuming 85 tonnes per day of MSW and delivering power to the grid since 2007.^{171,172} The Castellgali facility utilizes five tonnes of waste per day and operates as a demonstration centre.¹⁷³ Plasco has been commissioned to develop two additional facilities: a 400-tonne per day community facility in Ottawa and a 200-tonne per day facility in Red Deer,

¹⁶³ Jeff Takeyasu, Trimark Engineering (2007) *Southern Alberta Energy Partnership – Waste to Energy Treatment Alternatives Study*, P. 58.

¹⁶⁴ Jeff Takeyasu, Trimark Engineering (2007) *Southern Alberta Energy Partnership – Waste to Energy Treatment Alternatives Study*, P. 57.

¹⁶⁵ Foth & Van Dyke and Associates, Inc. (September 2004) *Updated Study of Alternative Waste Processing Technology – Ramsey/Washington County Resource Recovery Project*, P. 59-61 (accessed April 25, 2010) http://www.co.ramsey.mn.us/NR/rdonlyres/C9000BB9-1C1A-43F5-8E1D-80A0A7E6AF35/5665/PC_Research_Study_on_Alternate_Waste_Processing.pdf.

¹⁶⁶ Nevadans Against Garbage (December 2009) *What about plasma arc waste disposal* (accessed April 26, 2010) <http://nolandfill.files.wordpress.com/2009/12/plasmaarc.pdf>.

¹⁶⁷ Nevadans Against Garbage (December 2009) *What about plasma arc waste disposal* (accessed April 26, 2010) <http://nolandfill.files.wordpress.com/2009/12/plasmaarc.pdf>.

¹⁶⁸ Pyrogenesis Canada Inc. website: http://www.pyrogenesis.com/pdfs/pyro_prrs.pdf.

¹⁶⁹ Plasco Energy Group website: <http://www.plascoenergygroup.com/?Projects>.

¹⁷⁰ Marc J. Rogoff and Bruce J. Clark, SCS Engineers (May 2009) *Letter to Joseph E. Buck, Public Works Director, City and Borough of Juneau, Alaska re: Feasibility Study for Plasma Arc Gasification and Waste to Energy Options for the Management of Juneau's Waste – Opinion Letter* (accessed April 27, 2010).

¹⁷¹ Plasco Energy Group, ZeroWasteOttawa website: <http://www.zerowasteottawa.com/en/About-Project/>.

¹⁷² Nevadans Against Garbage (December 2009) *What about plasma arc waste disposal* (accessed April 26, 2010) <http://nolandfill.files.wordpress.com/2009/12/plasmaarc.pdf>.

¹⁷³ Plasco Energy Group website: <http://www.plascoenergygroup.com/?Projects>.

Alberta.¹⁷⁴ The Red Deer facility is expected to come online in late 2010.¹⁷⁵ These additional projects will be financed, built and operated by Plasco, reducing the burden of financial risk to the host municipalities.

Sunbay Energy Corp. has been commissioned to develop an MSW and TDF plasma arc gasification facility in Port Hope, Ontario that will consume 360 tonnes of feedstock per day.¹⁷⁶ However, Sunbay has undergone recent restructuring and development of the facility has been delayed.¹⁷⁷

Advanced Plasma Power constructed a test facility in Farington, Oxfordshire that produces hydrogen, syngas, energy and vitrified gravel from refuse-derived feedstock.¹⁷⁸ A commercial test facility has been developed in Swindon, Wiltshire and a commercial facility that is expected to use 100,000 tonnes-per-day is being planned for a third location in the UK.¹⁷⁹

Table 18 (below) provides a list of proposed plasma arc gasification projects in North America.

Table 18. Proposed plasma gasification projects in North America¹⁸⁰

¹⁷⁴ Nevadans Against Garbage (December 2009) What about plasma arc waste disposal (accessed April 26, 2010) <http://nolandfill.files.wordpress.com/2009/12/plasmaarc.pdf>.

¹⁷⁵ Nevadans Against Garbage (December 2009) What about plasma arc waste disposal (accessed April 26, 2010) <http://nolandfill.files.wordpress.com/2009/12/plasmaarc.pdf>.

¹⁷⁶ Sunbay Energy Corp. website: <http://www.sunbayenergy.com/>.

¹⁷⁷ Kris McDavid (March 25, 2010) "Sunbay Energy optimistic about Miramichi plant" (Times & Transcript) (accessed April 26, 2010) <http://timetranscript.canadaeast.com/search/article/996045>.

¹⁷⁸ Nevadans Against Garbage (December 2009) What about plasma arc waste disposal (accessed April 26, 2010) <http://nolandfill.files.wordpress.com/2009/12/plasmaarc.pdf>.

¹⁷⁹ Nevadans Against Garbage (December 2009) What about plasma arc waste disposal (accessed April 26, 2010) <http://nolandfill.files.wordpress.com/2009/12/plasmaarc.pdf>.

¹⁸⁰ Marc J. Rogoff and Bruce J. Clark, SCS Engineers (May 2009) Letter to Joseph E. Buck, Public Works Director, City and Borough of Juneau, Alaska re: Feasibility Study for Plasma Arc Gasification and Waste to Energy Options for the Management of Juneau's Waste – Opinion Letter (accessed April 27, 2010). http://www.juneau.lib.ak.us/clerk/ASC/COTW/2009/documents/2009-05-06_SCS_Engineers_Opinion_Letter_to_Joe_Buck_re_Plasma-Arc_Gasification_and_Waste-to-.pdf.

Location	Technology / Material	Status
Plasco Energy Group / Ottawa, Canada	Plasma Arc / MSW	Operational / 85 TPD 400 TPD Expansion Planned
City of Tallahassee, FL	Plasma Arc / MSW	Negotiation w/vendor
Logite International, Bingham County, ID	Gasification / MSW	Groundbreaking / 100 TPD – estimated 2010 completion
Gainesville Regional Utility, FL	Incineration of Biomass, MSW, wood wastes, tires	Planning & Construction – estimated 2013 completion
St. Lucie County, FL	Plasma Arc / MSW	Financing / Delayed ?
Los Angeles County, CA	Anaerobic digestion, Gasification / MSW	RFP for Pilot Plant “competition”
BRI Energy, Fayetteville, AR	Gasification / MSW	Operational (?) / 1.3 TPD
IES, Romoland, CA	Pyrolysis / MSW	Operational (?) / 50 TPD
Koochiching Economic Development Authority, MN	Plasma Arc / MSW	Planning Grant/ Feasibility Study
Sun Energy Group, LLC New Orleans	Plasma Arc / MSW	Planning
Aitkin County, MN	Plasma Arc / MSW	Planning Grant/Feasibility Study
Pyrogenesis, Eglin Air Force Base, Okaloosa County, FL	Plasma Arc/MSW	Permitting
StarTech, Puerto Rico	Plasma Arc/MSW	Planning
Plasco Energy, Red Deer, Canada	Plasma Arc/MSW	Planning – 300 TPD
Sunbay Energy, Ontario, Canada	Gasification/ MSW & Tires	400TPD – Broke ground 2008
City of Marion, IA	Plasma Arc/ MSW	Economic Analysis
Linn County, IA	Plasma Arc / Flood Debris	Temp. Demonstration 2 TPD
Santa Cruz County, CA	Plasma Arc / MSW	Voted down
City of Sacramento, CA	Plasma Arc / MSW	Vote Delayed

There are currently six key technical challenges to energy generation from MSW using plasma technology: heat transfer, scale and modularity, heterogeneity, relatively low calorific value, relatively high moisture content (30 to 60% by weight), and high ash content.¹⁸¹

The plasma arc is a relatively localized heat source; therefore, scaling up the technology for commercial application poses technical challenges.¹⁸² Use of multiple plasma arcs has been recommended as a possible solution.¹⁸³ However, use of multiple torches and multiple refractory lined reactors increases capital cost significantly.

The heterogenous nature of MSW and variability of input particle size also produces technical challenges.¹⁸⁴ Waste composition, heat transfer rates and residence times must be adjusted accordingly.

The majority of plasma facilities that use MSW feedstock are plasma gasification facilities, as opposed to plasma pyrolysis.¹⁸⁵ Plasma gasification of MSW can generate significant amounts of tar and particulate matter, which increases facility costs, particularly when the process aims to

¹⁸¹ Juniper Consultancy Services Ltd. (2009) *Plasma Technologies: A Decision-Maker's Guide*, P. 17.

¹⁸² Juniper Consultancy Services Ltd. (2009) *Plasma Technologies: A Decision-Maker's Guide*, P. 18.

¹⁸³ Juniper Consultancy Services Ltd. (2009) *Plasma Technologies: A Decision-Maker's Guide*, P. 18.

¹⁸⁴ Juniper Consultancy Services Ltd. (2009) *Plasma Technologies: A Decision-Maker's Guide*, P. 18.

¹⁸⁵ Juniper Consultancy Services Ltd. (2009) *Plasma Technologies: A Decision-Maker's Guide*, P. 18.

recover syngas.¹⁸⁶ Consequently, treating large volumes of MSW using plasma technology presently carries significant technical risk.¹⁸⁷

While the relatively low calorific value of MSW does not pose a technical challenge for plasma gasification, it may cause facilities to be uneconomical.¹⁸⁸ And while plasma technologies can accommodate a range of moisture contents, the upper limit for feedstock moisture has been postulated to be around 75%.¹⁸⁹ Higher moisture feedstocks also require additional energy input for plasma gasification.

Inorganic ash is required to maintain stable and adequate slag formation during plasma gasification.¹⁹⁰ If ash content of MSW is insufficient, slag-forming additives may be required, resulting in additional cost.¹⁹¹

An additional technical issue, that appears to have been addressed during construction of Plasco's Ottawa facility, is the durability of liners in the equipment.¹⁹² High temperatures and chlorine compounds released from feedstock have led to rapid liner breakdown in other facilities.¹⁹³ Plasco appears to have overcome this issue with the use of lower operating temperatures and a brick liner.¹⁹⁴

Systems are available in the range of five to 200 tonnes per day, but capital and operating costs of plasma arc technology are typically high.¹⁹⁵ Some suppliers of plasma arc technology claim that the process is emissions-free,¹⁹⁶ but these claims have yet to be solidly substantiated.

8.4.3 Potential for use of tires as a feedstock

There are presently few proposals for dedicated tire plasma arc technologies and applications. W2 Energy Inc. of Toronto announced in March 2009 that the company would be developing three separate four-tonne per day tire plasma arc facilities in each of three separate countries.¹⁹⁷ The tires will be converted into syngas, which will be used to produce diesel and electricity,

¹⁸⁶ Juniper Consultancy Services Ltd. (2009) *Plasma Technologies: A Decision-Maker's Guide*, P. 18.

¹⁸⁷ Juniper Consultancy Services Ltd. (2009) *Plasma Technologies: A Decision-Maker's Guide*, P. 18.

¹⁸⁸ Juniper Consultancy Services Ltd. (2009) *Plasma Technologies: A Decision-Maker's Guide*, P. 18.

¹⁸⁹ Juniper Consultancy Services Ltd. (2009) *Plasma Technologies: A Decision-Maker's Guide*, P. 18.

¹⁹⁰ Juniper Consultancy Services Ltd. (2009) *Plasma Technologies: A Decision-Maker's Guide*, P. 18.

¹⁹¹ Juniper Consultancy Services Ltd. (2009) *Plasma Technologies: A Decision-Maker's Guide*, P. 18.

¹⁹² Nevadans Against Garbage (December 2009) *What about plasma arc waste disposal* (accessed April 26, 2010) <http://nolandfill.files.wordpress.com/2009/12/plasmaarc.pdf>.

¹⁹³ Nevadans Against Garbage (December 2009) *What about plasma arc waste disposal* (accessed April 26, 2010) <http://nolandfill.files.wordpress.com/2009/12/plasmaarc.pdf>.

¹⁹⁴ Nevadans Against Garbage (December 2009) *What about plasma arc waste disposal* (accessed April 26, 2010) <http://nolandfill.files.wordpress.com/2009/12/plasmaarc.pdf>.

¹⁹⁵ Jeff Takeyasu, Trimark Engineering (2007) *Southern Alberta Energy Partnership – Waste to Energy Treatment Alternatives Study*, P. 59.

¹⁹⁶ Jeff Takeyasu, Trimark Engineering (2007) *Southern Alberta Energy Partnership – Waste to Energy Treatment Alternatives Study*, P. 59.

¹⁹⁷ W2 Energy website: <http://w2energy.com/main/pages/posts/w2-energys-4-ton-per-day-plant-eliminates-tires-and-creates-energy15.php>.

using a steam turbine.¹⁹⁸ Plasco's pending plasma MSW plant approvals in both Ottawa and Red Deer could presumably entertain the application of tires as part of their feedstock.

8.4.4 Best known data sources for technology applications for MSW or MSW and tire feedstock

Juniper Consultancy Services Ltd. (2009) *Plasma Technologies: A Decision-Maker's Guide*.

Jeff Takeyasu, Trimark Engineering (2007) *Southern Alberta Energy Partnership – Waste to Energy Treatment Alternatives Study*.

¹⁹⁸ W2 Energy website: <http://w2energy.com/main/pages/posts/w2-energys-4-ton-per-day-plant-eliminates-tires-and-creates-energy15.php>.

9. Completed Issues Scoping Template Example

Scoping templates were completed for each of the eight recycling options at the beginning of the project to identify potential environmental issues. Table 19 below is an example of a scoping template for the TDF (Cement Kiln) recycling option.

Table 19. Example Scoping Template

PEMBINA INSTITUTE LCVA UNIT PROCESS SCOPING WORKSHEET									
Upstream Process(es) Primary: Tire collection and delivery to site. Secondary Services, Operations, Materials: Shredding and/or crumbing. Production of additives (Zn Oxide)			UNIT PROCESS # Name: Tire Derived Fuels (TDF) Cement Kilns Primary Output Unit: Heat GJ		Downstream Process(es) or Product(s) Primary: Offset Coal combustion Co-Products:				
INPUTS					OUTPUTS				
<i>Permits</i>	<i>L/M/H</i>	<i>Notes/Questions</i>	Activities/Sub-Processes: Pre-processing (shredding) Production and transportation of Additives (Zinc Oxide) System Assumptions: Design Considerations: Procurement Considerations: Catastrophic Failure Considerations: Potential Data Sources: Dalhousie University ICF Report Sonneviera UK Environment Agency Continental Assessment		<i>Operational Risks</i>	<i>L/M/H</i>	<i>Notes/Questions</i>		
Zoning	L				Catastrophic Failure				
Environmental Approval	M				Technology Dependability				
Materials Handling	M				Extreme Weather Events				
Waste Disposal	M				Operability				
Construction Approval					Fires or Explosions				
					Logistical Inefficiencies				
<i>Economic Resources</i>	<i>L/M/H</i>	<i>Notes/Questions</i>			<i>Air Quality Impacts</i>	<i>L/M/H</i>	<i>Notes/Questions</i>		
Capital Expenditures	L				Greenhouse Gas emissions	L	Reduced		
Operating Costs	L				Acid Rain Precursor emissions	L	Nox, SO2 reduced		
Finance Implications	L		Smog and particulates	L	NM/VOCs reduced				
Taxation Implications	M		Ozone Depletion		Unclear				
			Toxic air emissions (HAPs)		Unclear				
			Odour		Unclear				
<i>Energy Resources</i>	<i>L/M/H</i>	<i>Notes/Questions</i>	<i>Water Quality Impacts</i>	<i>L/M/H</i>	<i>Notes/Questions</i>				
Electricity	M	Not sure how this will be impacted by tires.	Toxic Effluent	M	Unclear				
Nat. Gas			Biological Oxygen Demand						
Diesel	M	Not sure how this will be impacted by tires.	Heat						
Gasoline									
Propane			<i>Land Use Impacts</i>	<i>L/M/H</i>	<i>Notes/Questions</i>				
			Landfill Waste Disposal	M	Unclear how different from coal waste.				
<i>Water Resources</i>	<i>L/M/H</i>	<i>Notes/Questions</i>	Wildlife Wilderness/Habitat						
Cooling		Not sure how this will be impacted by tires.	Cultural Property						
Process			Recreational / Agricultural						
Steam			Rezoning						
			<i>Workplace Community Impacts</i>	<i>L/M/H</i>	<i>Notes/Questions</i>				
<i>Land Resources</i>	<i>L/M/H</i>	<i>Notes/Questions</i>	Employee Wellness						
Footprint - Permanent	L		Health & Safety						
Footprint - Temporary	L		Career Progression						
			Employment Equity						
<i>Human Resources</i>	<i>L/M/H</i>	<i>Notes/Questions</i>	<i>Local Community Impacts</i>	<i>L/M/H</i>	<i>Notes/Questions</i>				
Workload			Health, Safety & Security						
Transfers			Long Term Stability						
New Hires			Community Investment						
Contracts			Social Equity / Cultural						
			Noise / Aesthetics						
<i>Community Contribution</i>	<i>L/M/H</i>	<i>Notes/Questions</i>	Education / Capacity Building						
Consultation/Engagement			<i>Economic Impacts</i>	<i>L/M/H</i>	<i>Notes/Questions</i>				
Involvement			Corporate Reputation						
Infrastructure			Revenue Generation						
Political Support	M	Unclear at this time.							
Goods and Services									
<i>Economic</i>	<i>L/M/H</i>	<i>Notes/Questions</i>							
Capital Expenditures	L								
Operating Costs	L								
Finance Implications									
Taxation Implications									

10. Tire Fires

10.1.1 Probability and Environmental Impact of Tire Fires

While tire fires occur relatively infrequently, they are serious situations often requiring community evacuation, sustained firefighting efforts and expensive cleanups. Tire fires result in considerable environmental impact and safety concerns. These are summarized below, along with some discussion on the frequency of tire fires, examples of notable tire fires, and tire storage management advice to reduce tire ignition risk and mitigate tire fire severity.

10.1.1.1 Cause and Common Ignition Sources

Any mass storage of recycled tires carries an inherent fire risk. Arson is the leading cause of tire fires. Other igniters have been grass and forest fires, lightning strikes and accidental starts, such as from cigarettes, welding or fire on adjacent properties.¹⁹⁹

Improper tire storage is a key contributing cause of tire fires, with such factors as increasing pile size, code violations, numerous changes in ownership and high personnel turnover leading to increased fire risk.²⁰⁰

Scrap tires are difficult to ignite; however, once a tire fire starts it is very difficult to control and extinguish. Tires burn well because of their high flame temperature and their hollow doughnut shape, which traps oxygen, making it very challenging to eliminate air supply. Tire fires can burn for months or, in some cases, even years.²⁰¹

10.1.1.2 Key Environmental and Safety Issues

Tire fires can have serious environmental and safety impacts and consequences, described in more detail below.

Environmental

Fire causes tires to break down into hazardous compounds including gases, oil and heavy metals. Tire fires are characterized by incomplete combustion, producing thick clouds of toxic black smoke and a highly flammable oily residue.²⁰² The average passenger car tire is estimated to produce about eight litres of oily residue when burned.²⁰³ For every million tires consumed by fire, about 208,000 litres of runoff oil containing dangerous chemicals is produced, which can leach into soil, ground and surface water unless effectively contained.²⁰⁴

¹⁹⁹ Slaughter, Rodney. "Rings of Fire: Tire Fire Prevention and Suppression" California State Fire Marshal, June 2004.

²⁰⁰ Slaughter, Rodney. "Rings of Fire: Tire Fire Prevention and Suppression" California State Fire Marshal, June 2004.

²⁰¹ Slaughter, Rodney. "Rings of Fire: Tire Fire Prevention and Suppression" California State Fire Marshal, June 2004.

²⁰² Murray, W., Government of Canada, Science and Technology Division, 1996, Accessed at <http://dsp-psd.pwgsc.gc.ca/Collection-R/LoPBdP/BP/bp431-e.htm>.

²⁰³ Rubber Manufacturers Association, April 2003

²⁰⁴ United States Environmental Protection Agency. Accessed at www.epa.gov/osw/conserve/materials/tires/fires.htm

In addition to run off oil, tire fires produce at least 32 toxic gases.²⁰⁵ Hazardous air pollutants released by tire fires include polycyclic aromatic hydrocarbons (PAHs), dioxins, furans, hydrogen chloride, benzene, styrene, butadiene and polychlorinated biphenyls (PCBs); and metals such as arsenic, cadmium, nickel, zinc, mercury, chromium, and vanadium.^{206,207} Tire fires are also sources of air contaminants including particulates, sulfur oxides (SO_x), nitrogen oxides (NO_x), carbon monoxide (CO) and volatile organic compounds (VOCs).²⁰⁸

Health Hazards

The criteria and hazardous air pollutants from tire fires can represent significant short- and long-term health hazards to firefighters and nearby residents. Depending on the length and degree of exposure, health effects can include irritation of the skin, eyes and mucous membranes, respiratory effects, central nervous system depression and cancer. Ash from tire fires contains heavy metals, which settles on surrounding lands and can be hazardous to responders and residents.²⁰⁹ Firefighters and others working near a large tire fire should be equipped with respirators and skin protection.²¹⁰

10.1.1.3 Example Tire Fires

Between 1996 and 1998 alone, 59 tire fires were reported across the United States involving approximately 20 million tires stored outdoors.²¹¹ Select examples of major North American tire fires are provided below.

1983 - Rhinehart, Virginia: Seven million tires burned at a tire storage facility producing a plume of smoke 3,000 feet high and nearly 50 miles long, and deposited air pollution emissions in three states. The fire burned for nine months, polluting nearby water sources with lead and arsenic. The site where the fire occurred was cleaned up as a Superfund project between 1983 and 2002.²¹²



1990 - Hagersville, Ontario: Fourteen million tires were set on fire at the Tyre King Recycling facility as a result of teen vandalism. At the time, this was the largest tire fire ever. It burned for 17 days and drove 4,000 people from their homes.²¹³ This incident caused many Canadian

²⁰⁵ U.S Fire administration Technical Report Series, "Special Report: Scrap and Shredded Tire Fires", December 1998

²⁰⁶ United States Environmental Protection Agency, "Air Emissions from Scrap Tire Combustion", October 1997

²⁰⁷ United States Environmental Protection Agency. Accessed at www.epa.gov/osw/conservation/materials/tires/fires.htm

²⁰⁸ United States Environmental Protection Agency, "Air Emissions from Scrap Tire Combustion", October 1997

²⁰⁹ Integrated Waste Management Board, California, "Tire Pile Fires: Prevention, Response, Remediation", September 2002

²¹⁰ United States Environmental Protection Agency, "Air Emissions from Scrap Tire Combustion", October 1997

²¹¹ Slaughter, Rodney. "Rings of Fire: Tire Fire Prevention and Suppression" California State Fire Marshal, June 2004

²¹² United States Environmental Protection Agency. Accessed at <http://www.epa.gov/reg3hwmd/npl/VAD980831796.htm>

, February 1990,

²¹³ WasteWatch, 2003 and Canadian Chemical News, "Analytical che

provinces to investigate their scrap tire management, resulting in initiation of programs to promote tire recycling and market development for recycled tire products.²¹⁴ Ten of the hundreds of firefighters who were at the Hagersville tire fire have been diagnosed with rare and aggressive forms of cancer, with suspected links to exposure at the fire.²¹⁵

1998 – Tracy, California: A grass fire ignited seven million tires at an unlicensed facility. Following an initial response, federal, state and local agencies determined the best course of action was to let the fire “burn itself out” due to the site’s geography and concern that putting water on the fire might generate excessive amounts of hazardous wastewater that in turn would contaminate groundwater. The fire burned for 28 months until it was small enough to be extinguished with foam and water.²¹⁶

1999 - Westley, California: A stockpile of millions of scrap tires at a waste-to-energy facility operated by Modesto Energy Limited Partnership was ignited by a lightning strike. The fire’s large smoke plume impacted nearby farming communities and caused widespread concern of potential health effects from exposure to the smoke emissions. The tire fire also produced large volumes of pyrolytic oil that ignited and flowed into the drainage of an intermittent stream. An effective response to the oil and tire fires was beyond the capabilities of local and state agencies. It took 30 days to extinguish the fire. Total EPA response costs were \$3.5 million.²¹⁷

Risk Mitigation

Extinguishing tire fires is technically challenging, requiring special skills, training, equipment and procedures. Appropriate response plans and fire pre-planning are essential, in conjunction with local and regional fire departments.

Appropriate tire storage management practices can reduce fire risk,²¹⁸ these include:

Site scrap tire facilities an appropriate distance from other facilities and potential fire hazards



Select a relatively level site to reduce oil runoff in the event of a fire, and/or include oil runoff containment in site development

Tire Recyclers,
2005. Image credit:

²¹⁴ Murray, W., Government of Canada, Science and Technology Division, 1996, Accessed at <http://dsp-psd.pwgsc.gc.ca/Collection-R/LoPBdP/BP/bp431-e.htm>.

²¹⁵ <http://www.simcoereformer.ca/ArticleDisplay.aspx?e=2206720>.

²¹⁶ California Department of Toxic Substance Control, Fact Sheet, “Public Comment Period Begins For The Tracy Tire Fire Site Draft.

Remedial Action Plan”, July 2003.

²¹⁷ United States Environmental Protection Agency. Accessed at www.epa.gov/osw/conservation/materials/tires/fires.htm.

²¹⁸ U.S Fire administration Technical Report Series, “Special Report: Scrap and Shredded Tire Fires”, December 1998.

Maintain fire breaks and fire lanes for access

Minimize potential ignition sources – install lightning rods and security for arson prevention

Prohibit heating devices and ignition sources such as welding or open flame near tires

Eliminate brush, grass and other combustibles within the storage area and for an appropriate distance around the perimeter

Comply with recommended tire pile height and total area restrictions

Design an effective automatic sprinkler system for indoor tire shredding or crumbing equipment

The severity of tire fire incidents can be reduced by:

Storing tires away from people and communities

Having an effective fire evacuation plan for the surrounding community

Working with the fire department to develop an emergency response plan and a fire crew response plan that addresses the unique challenges of tire fires

11. Data Sources

The major datasets used in this analysis are summarized in Table 20 below. Wherever possible, Alberta specific data was used to model the Alberta context as closely as possible. Datasets where Alberta specific data was not possible are indicated in the last column in the table.

Table 20: Datasets Used in Analysis

Dataset	Data Source	Specific to AB
Produce Asphalt Shingles	Athena Sustainable Materials Institute, <i>A Life Cycle Inventory of Selected Commercial Building Products</i> (April 2001). Chapter 2.	N
Produce Portland Cement	Portland Cement Association, <i>Life Cycle Inventory of Portland Cement Concrete</i> (2007).	N
Produce Timber	Chalmers University of Technology, <i>LCA of Building Frame Structures, Environmental Impact over the Life Cycle of Wooden and Concrete Frames</i> (1997).	N
Produce Concrete	Portland Cement Association, <i>Life Cycle Inventory of Portland Cement Concrete</i> (2007).	N
Produce Virgin Steel	NREL, <i>Life Cycle Inventory Database</i> . http://www.nrel.gov/lci/ (accessed Jan to Sept 2010).	N
Shear and Shred Tires	Navigant Consulting, LCA Tire Recycling_v19CS.xlsx. Phase 1 of life cycle inventory summarizing GHG emissions for recycling options.	Y
Crumb Tires	Navigant Consulting, LCA Tire Recycling_v19CS.xlsx.	Y
Manufacture Tire Products	Navigant Consulting, LCA Tire Recycling_v19CS.xlsx.	Y
Process Tires in Cement Kiln	(1) Scrap Tire Management Council, <i>The Use of Scrap Tires in Rotary Cement Kilns</i> (2005). (2) Delta Air Quality Services, <i>AB2588 Emissions Testing at California Portland Cement Company's Colton Plant; Coal and Coal with Tires Firing</i> (1999). (3) CANMET, <i>Scrap Tire Recycling in Canada</i> (2005)	N
Process Tires in T2E	Connecticut Department Environmental Protection, <i>Operating Permit for Exeter Energy. Permit to operate from April 2010 to April 2015</i> (2010).	N

Refine Crude Oil	NREL, <i>Life Cycle Inventory Database</i> .	Y
Transport Crude Oil	(1) U.S. Dept of Energy AP42. (2) M. Deluchi, <i>Emission of Greenhouse Gases from the use of Transportation Fuels and Electricity, Volume 2</i> (1991)., Appendix A.	N
Extract Crude Oil	CAPP, <i>A National Inventory of Greenhouse Gas (GHG), Criteria Air Contaminant (CAC) and Hydrogen Sulphide (H₂S) Emissions by the Upstream Oil and Gas Industry</i> (2004).	Y
Extract Bituminous Coal	NREL, <i>Life Cycle Inventory Database</i> .	N
Process Tires in Coal Plant	(1) EPA, <i>Air Emissions from Scrap Tire Combustion</i> 1997). (2) NREL, <i>Life Cycle Inventory Database</i> .	N
Produce Polypropylene Crumb	NREL, <i>Life Cycle Inventory Database</i> .	N
Mine and Crush Limestone	NREL, <i>Life Cycle Inventory Database</i> .	Y
Produce Polypropylene	NREL, <i>Life Cycle Inventory Database</i> .	Y
Produce Propylene	NREL, <i>Life Cycle Inventory Database</i> .	Y
Recycle Steel	(1) RTI International, <i>Life Cycle Inventory Data Sets for Material Production of Aluminum, Glass, Paper, Plastic, and Steel in North America</i> (2003). (2) ICF Consulting, <i>Determination of the Impact of Waste Management Activities on GHG Emissions: 2005 Update Final Report</i> (2005).	Y
Extract Iron Ore	Statistics Canada, <i>Metal Ore Mining. NAICS 2122</i> (2006), http://www.statcan.gc.ca/pub/26-223-x/26-223-x2006000-eng.pdf .	Y
Extract Aggregate	Statistics Canada, <i>Non-metallic Mineral Mining and Quarrying NAICS 2123</i> (2005), http://www.statcan.gc.ca/pub/26-226-x/26-226-x2006000-eng.pdf .	Y
Produce Binding Agent	NREL, <i>Life Cycle Inventory Database</i> .	Y