State of Oregon Department of Environmental Quality

Impact modeling for the Waste Impact Calculator

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Introduction and companion documents

The Waste Impact Calculator (WIC) is a simplified tool for quantifying the life cycle environmental benefits of waste materials, and projecting the life cycle impact consequences of various materials management practices.

WIC was designed for the state of Oregon and specifically references material categories tracked in that state. However, users in other locales may find it useful nonetheless. For many waste materials, the majority of life cycle impacts are associated with the production stage of the life cycle, which given the nature of inter-state and international trade, will vary little from place to place.

The general goals and conventions of WIC are spelled out in a companion document, *Technical Overview of the Waste Impact Calculator*. A few expressions of WIC are spelled out in another document, *Example Applications of the Waste Impact Calculator*.

This document, *Impact Modeling for the Waste Impact Calculator*, elucidates in detail the definitions of WIC's material names and the modeling assumptions used to define impacts for each material and process. Even more detail on specific data sources used in impact modeling can be found in a companion spreadsheet, *Appendix-A-WasteImpactCalculatorMasterDataList.xlsx*.

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Acronyms and Abbreviations

ADP	Abiotic Depletion Potential
AP	Acidification Potential
AWARE	Available Water Remaining Methodology
DEQ	Oregon Department of Environmental Quality
ELCD	European Life Cycle Database
EoL	End of life
EP	Eutrophication Potential
GHG	Greenhouse Gas
GTP	Global Temperature Potential
GWP	Global Warming Potential
ILCD	International reference Life Cycle Data system
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
NMVOC	Non-methane Volatile Organic Compound
NOx	Nitrogen Oxides
ODP	Ozone Depletion Potential
PED	Primary Energy Demand
POCP	Photochemical Ozone Creation Potential
SFP	Smog Formation Potential
SOx	Sulfur Oxides
TRACI	Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts
VOC	Volatile Organic Compound

Scope of Waste Impact Calculator

The following sections describe the general scope of the project and connects it back to the above goals. This includes, the identification of the specific material categories and dispositions to be assessed, the declared unit, data quality and representativeness, the system boundary, allocation procedures, and cut-off criteria of the study.

Product Systems

The product systems, henceforth referred to as material categories, studied are different combinations of material production and their respective end of life dispositions. The table below enumerates a full list of material categories included in the waste impact calculator. The syntax is as follows – material category name (life cycle stage), so for example "Aluminum (production)" represents the estimated cradle-to-gate emissions for the production of aluminum or "Wood (incinerationER)" represents the estimated gate-to-grave emissions for the incineration of wood with energy recovery.

Table 1 – List of Material Categories and Dispositions Studied

Material Category	Dispositions
Aluminum (production)	Aluminum (incinerationNoER) Aluminum (landfilling) Aluminum (recyclingGeneric)
Accepted Other Steel (production)	Accepted Other Steel (incinerationNoER) Accepted Other Steel (landfilling) Accepted Other Steel (recyclingGeneric)
AsepticContainers (production)	AsepticContainers (incinerationER) AsepticContainers (landfilling) AsepticContainers (recyclingGeneric)
AsphaltRoofing (production)	AsphaltRoofing (incinerationER) AsphaltRoofing (incinerationNoER) AsphaltRoofing (landfilling) AsphaltRoofing (recyclingGeneric)
Cardboard (production)	Cardboard (incinerationER) Cardboard (incinerationNoER) Cardboard (landfilling) Cardboard (recyclingGeneric)
Carpeting (production)	Carpeting (incinerationER) Carpeting (incinerationNoER) Carpeting (landfilling) Carpeting (recyclingGeneric)
Electronics (production)	Electronics (landfilling) Electronics (recyclingGeneric)
EPS (production)	EPS (incinerationER) EPS (landfilling) EPS (recyclingGeneric)
FoodWaste (production)	FoodWaste (incinerationER) FoodWaste (incinerationNoER) FoodWaste (landfilling) FoodWaste (recyclingGeneric)

	FoodWaste (anaerobicDigestion) FoodWaste (composting)
FreezerBoxes (production)	FreezerBoxes (incinerationER) FreezerBoxes (landfilling) FreezerBoxes (recyclingGeneric)
GableTopCartons (production)	GableTopCartons (incinerationER) GableTopCartons (landfilling) GableTopCartons (recyclingGeneric)
Glass (production)	Glass (incinerationNoER) Glass (landfilling) Glass (recyclingToContainer) Glass (recyclingToFiberglass) Glass (recyclingToAggregate) Glass (recyclingPozzolan) Glass (reuse)
GypsumWallboard (production)	GypsumWallboard (incinerationNoER) GypsumWallboard (landfilling) GypsumWallboard (recyclingGeneric)
HDPE (production)	HDPE (incinerationER) HDPE (landfilling) HDPE (recyclingGeneric)
LDPE (production)	LDPE (incinerationER) LDPE (landfilling) LDPE (recyclingGeneric)
Newsprint (production)	Newsprint (incinerationER) Newsprint (landfilling) Newsprint (recyclingGeneric)
Nonrecyclables (production)	Nonrecyclables (incinerationER) Nonrecyclables (incinerationNoER) Nonrecyclables (landfilling)
Paperboard (production)	Paperboard (incinerationER) Paperboard (landfilling) Paperboard (recyclingGeneric)
PaperFiber (production)	PaperFiber (incinerationER) PaperFiber (incinerationNoER) PaperFiber (landfilling) PaperFiber (recyclingGeneric)
PET (production)	PET (incinerationER) PET (landfilling) PET (recyclingGeneric)
PlasticFilm (production)	PlasticFilm (incinerationER) PlasticFilm (incinerationNoER) PlasticFilm (landfilling) PlasticFilm (recyclingGeneric)
PlasticOther (production)	PlasticOther (incinerationER) PlasticOther (incinerationNoER) PlasticOther (landfilling) PlasticOther (recyclingGeneric)
PP (production)	PP (incinerationER) PP (landfilling) PP (recyclingGeneric)
PrintingWritingPaper (production)	PrintingWritingPaper (incinerationER) PrintingWritingPaper (landfilling) PrintingWritingPaper (recyclingGeneric)
PS (production)	PS (incinerationER)

	PS (landfilling) PS (recyclingGeneric)
RigidPlastic (production)	RigidPlastic (incinerationER) RigidPlastic (incinerationNoER) RigidPlastic (landfilling) RigidPlastic (recyclingGeneric)
ScrapMetal (production)	ScrapMetal (incinerationNoER) ScrapMetal (landfilling) ScrapMetal (recyclingGeneric)
Textiles (production)	Textiles (incinerationER) Textiles (incinerationNoER) Textiles (landfilling) Textiles (recyclingGeneric)
TinnedCan (production)	TinnedCan (incinerationNoER) TinnedCan (landfilling) TinnedCan (recyclingGeneric)
Wood (production)	Wood (landfilling) Wood (incinerationER) Wood (composting) Wood (reuseGeneric)
YardDebris (production)	YardDebris (anaerobicDigestion) YardDebris (composting) YardDebris (incinerationER) YardDebris (incinerationNoER) YardDebris (landfilling)

Declared Unit and Reference Flows

Since the function of the system(s) under consideration is not specified, the waste impact calculates impacts based on a declared unit of 1 Short Ton for each material and disposition. As such, the declared unit ignores the key function and ancillary attributes (durability, quality, quantity) of the materials assessed.

System Boundary

The system boundary for the waste impact calculator is “cradle to gate” plus “end of life.” Figure 1 shows the system boundary for all material and disposition combinations in the waste impact calculator.

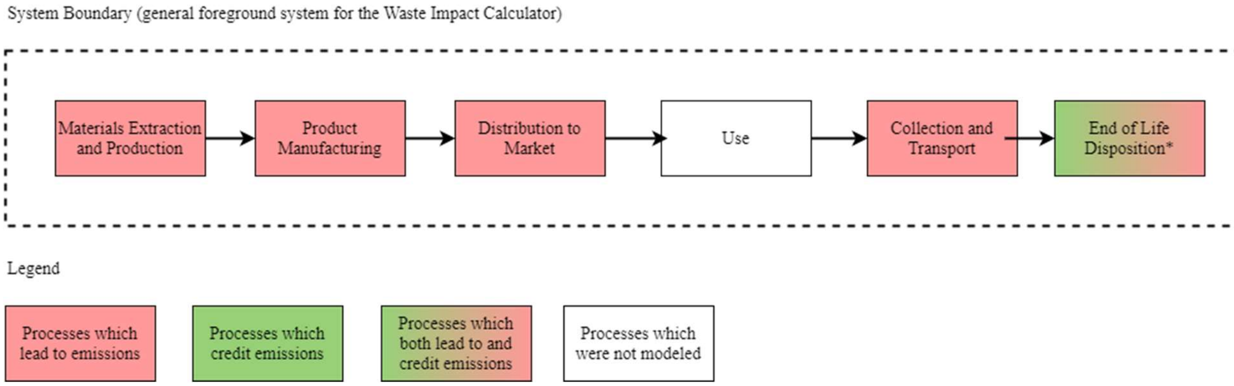

Figure 1 – General System Boundary for Waste Impact Calculator
*end of life disposition can include various different treatments such as landfilling, incineration, aerobic composting, anaerobic digestion, or recycling

Table 2 - System Boundary

Included	Excluded
✓ Raw material extraction, processing, and production ✓ Finished product manufacturing ✓ Transportation and fuel usage to distribute finished products ✓ Local route transport and distribution for materials at end of life	× Use related activities or emissions (e.g., electricity consumption, preparation and cooking food, refrigeration) × Maintenance × Installation × Packaging of product × Transportation for process materials × Capital equipment × Personnel transportation × Construction and maintenance of capital equipment (with exceptions) × Human labor and employee commuting

Time Period

The material and disposition categories are based on data from Oregon's Material Recovery Survey from 2018[1] and Waste Composition Study from 2016/2017[2]. To the extent possible, background data drawn from GaBi come from the year 2019, however some data within the GaBi database that originated from other sources that may be older. Data from the Ecoinvent database tends might be older, from the years 2007-2011.

Technology Representativeness

[1] https://www.oregon.gov/deq/recycling/Pages/Survey.aspx
[2] https://www.oregon.gov/deq/mm/Pages/Waste-Composition-Study.aspx

This study is intended to represent various material production and disposition options for key material categories, so the foreground system covers technology related to extraction, production, and transportation, as well as disposition (landfilling or composting) of various materials in Oregon. The background system includes electricity, thermal energy, energy carriers (e.g., fuels), and other materials (packaging, ancillaries).

The material categories are representations of typical material compositions and manufacturing processes for things found in Oregon's waste stream. To represent technology as accurately as possible the following priority was used for data selection:

1. US industry-average inventories similar materials and technology, aggregated from primary data of multiple manufacturers.
2. Defining a product "recipe" and relevant manufacturing data obtained from LCA databases (GaBi or Ecoinvent) and/or from literature.
3. Aggregated life cycle inventories (from GaBi or Ecoinvent) that approximate the material composition and manufacturing for a given material category.

Geographical Scope

The study is intended to represent global material production and disposition or recovery within the state of Oregon. Where US specific data were not available, global average, European, or in some instances data from other regions were used as proxies.

Allocation

No allocation was necessary (if there was co- or by-product) for the foreground systems of the model. Allocation of background data (energy and materials) are defined by the source database (GaBi or Ecoinvent), in which case the specific allocation for materials and energy carriers purport to follow the rules of ISO 14044 section 4.3.4.3.

End-of-life allocation generally follows the requirements of ISO 14044, section 4.3.4.3.

Energy recovery: In cases where materials are sent to waste incineration, they are linked to an inventory that accounts for waste composition and heating value as well as for regional efficiencies and heat-to-power output ratios. Credits are assigned for power outputs using the appropriate regional grid mix for Oregon (NWPP) and US average thermal energy/steam from natural profiles.
Landfilling: In cases where materials are sent to landfills, they are linked to an inventory that accounts for waste composition, regional leakage rates (due to technology and climate zone), landfill gas capture and utilization.
Composting: In cases where materials are sent to compost, they are linked to an inventory that accounts for waste composition, composting methodology and crediting (via substitution) for avoided emissions.
Substitution Credits: A credit is granted to the system for the outputs of end of life treatments (i.e. recycling). This credits is are defined, specifically, in each of the material category sections below.

Cut-off Criteria

No cut-off criteria are defined for this study, as the model predominantly relies on All available energy and material flow data have been included in the model.

LCIA Methodology and Impact Categories

DEQ has selected the impact assessment categories and other metrics shown in Table 3 and Table 4. Most of the impact assessment categories are based on the TRACI 2.1 impact assessment methodology as its characterization factors are representative of the U.S. However the waste impact calculator also reports characterization factors from other methods, such as the AWARE or the IPCC directly.

Table 3 - Description of Impact Categories Included (adapted from Quartz descriptions)

Impact Category	Description	Unit	Reference
Global Warming Potential (GWP100 and GWP20, with and without biogenic carbon)	Greenhouse gas emissions, such as carbon dioxide, methane, and nitrous oxides. These emissions increase the absorption of radiation emitted by the earth, accelerating the natural greenhouse effect. As a result of a warming planet, adverse impacts on ecosystem and human health are expected.	kg CO_2 equivalent	(Bare, 2011) (IPCC, 2013)
Eutrophication Potential (EP)	Measures releases of macronutrients, like nitrogen and phosphorus. Nutrient enrichment may cause an undesirable shift in species composition and elevated biomass production in both aquatic and terrestrial ecosystems. In aquatic ecosystems, increased biomass production may lead to depressed oxygen levels, because of the additional consumption of oxygen in biomass decomposition.	kg N equivalent	(Bare, 2011)
Acidification Potential (AP)	Emissions that cause acidifying effects to the environment. The acidification potential is a measure of a molecule's capacity to increase the hydrogen ion (H^+) concentration in the presence of water. Potential effects include fish mortality, forest decay and the deterioration of building materials.	kg SO_2 equivalent	(Bare, 2011)
Smog Formation Potential (SFP)	Emissions of precursors that contribute to ground level smog formation (mainly ozone O_3), produced by the reaction of VOC and carbon monoxide in the presence of nitrogen oxides under the influence of UV light. Ground level ozone may be injurious to human health and ecosystems and may also damage crops.	kg O_3 equivalent	(Bare, 2011)
Ozone Depletion Potential (ODP)	Air emissions that contribute to the depletion of the stratospheric ozone layer. The ozone layer is a protective barrier that shields the earth from ultraviolet radiation. If depleted, more of this radiation is able to reach the earth's surface with detrimental effects on all living things.	kg CFC-11 equivalent	(Bare, 2011)
Human Health Particulate Matter (PM2.5)	Particulate matter released into the air, these are an indicator of air quality and have implications to the health of humans and other species.	kg PM2.5 equivalent	(Bare, 2011)
Toxicity (Human and Eco)	Toxic emissions that are directly harmful to the health of humans and other species.	CTUe (cases/kg_emitted)	(Rosenbaum, et al., 2008)

Impact Category	Description	Unit	Reference
		CTUh (Potentially Affected Fraction of speices.m3.day/kg emitted)	

Table 4 - Description of Environmental Indicators

Indicator	Description	Unit	Reference
Primary Energy Demand (PED)	Total amount of primary energy extracted from the earth. PED is expressed in energy demand from non-renewable resources (e.g., petroleum, natural gas, etc.) and energy demand from renewable resources (e.g., hydropower, wind energy, solar, etc.). Efficiencies in energy conversion (e.g., power, heat, steam, etc.) are taken into account.	MJ (lower heating value)	(Guinée, et al., 2002)
Blue Water Consumption	The net intake and release of fresh water across the life of the product system. Blue water refers to surface and ground water only (excluding rainwater, green water). Water consumption is typically defined as "water removed from, but not returned to the same drainage basin. Water consumption can be because of evaporation, transpiration, product integration or release into a different drainage basin or the sea. Evaporation from reservoirs is considered water consumption." This is not an indicator of environmental impact without the addition of information about regional water availability.	kg of water	(thinkstep, 2016)
Water Scarcity	An indicator of water use relative the available water remaining (AWARE) per area, within a given watershed.	m3-world eq.	(Boulay, 2016 (under revision))

It is critical to note that the impact categories represent potentials—they are approximations of environmental impacts that could occur if emissions would follow a specific impact pathway and meet certain conditions in the receiving environment. Additionally, the inventory only captures that fraction of the total environmental burden that corresponds to the declared unit (i.e., the relative approach of LCA). Results are therefore relative expressions only and do not predict actual impacts. Nor do they measure the exceedance of thresholds, safety margins, hazards, or risks.

DEQ has chosen not to include any weighting or grouping scheme, as this would implicitly require a value-based judgement and is not scientifically based (ISO, 2006). Further, since the study is comparing the environmental impacts of different material categories, without considering their function, each impact is reported separately and thus it is not possible to compare different impact categories to each other. Nor is it possible to derive comparative assertions between material categories.

Interpretation

The primary analysis quantifying the environmental impacts of each material and disposition combination be interpreted on an impact-by-impact basis. These results will be calculated for each individual material and disposition combination. Final results are provided in the waste impact calculator tool.

The results are interpreted in terms of the contribution of each life cycle stage, either “cradle to gate” or “end of life.”

Data Quality

The data used to create the inventory model was selected to be as complete, consistent and representative as possible in order to fulfill the goal and scope of the study.

- Primary data is considered to be of the highest precision, followed by calculated and estimated data.
- Completeness is judged based on the completeness of the inputs and outputs per unit process and the completeness of the unit processes themselves.
- Consistency refers to modeling choices and data sources. The goal is to ensure that differences in results occur due to actual differences between product systems, and not due to inconsistencies in modeling choices, data sources, emission factors, or other.
- Representativeness expresses the degree to which the data matches the geographical, temporal, and technological requirements defined in the study’s goal and scope.

An evaluation of the data quality with regard to these requirements is provided in Section 6 of this report.

Assumptions and Limitations

Key assumptions employed in the underlying LCA model are enumerated below:

- The model assumed
-

Limitations

- Lack of primary data
- Function of materials and products is excluded
- Use phase is excluded, so absolute impacts of the full life cycle are not reported

Software and Database

The LCA model and associated Life Cycle Inventory (LCI) were developed using the GaBi ts Software system. GaBi is developed and maintained by thinkstep AG. The GaBi (Service Pack 40, Content Version 2020.1) and Ecoinvent (v3.5) databases were used for life cycle inventory data of raw materials and processes.

Critical Review

A third-party review is required to make any comparative assertions and to ensure consistency between the study and International Standards. The waste impact calculator model and this documentation have undergone internal quality assurance and an external review by a third-party. See the documentation folder of the “wic-base” repository, in particular https://github.com/OR-Dept-Environmental-Quality/wic-base/tree/main/documentation/independent-technical-review, for details from the external review. That said, because the waste impact calculator does not include a functional unit, comparative assertions should not be derived from the potential environmental impacts that the tool calculates.

General Model Parameters

This section describes general modeling parameters that apply to all material categories.

Transportation

Transport (Production to market)

For each material category, transportation from the "gate" of the production facility to the "market" is modeled. The impacts of this transportation are reported separately from the "cradle to gate" impact of the material category itself. Distances and mode are based on data taken from a 2004 memo from ICF to EPA that included for material commodities. The transportation distances and modes are based on data from the Bureau of Transportation Statistics Commodity Flow Survey (BTS, 2013).

Transport (Use to end of life)

At the end of the useful life of a material, the model includes transportation to collect and convey the material to end of life disposition. The impacts of this transportation are reported separately from the "end of life" impact of the material category itself. This leg of transportation is important for the calculation of alternative recovery rates, as it allows any improvements (e.g. more efficient trucks) to be modeled distinctly.

Distance/mode to landfill – the transportation here includes regional route pickup-up (e.g. curbside) and conveyance to a transfer station, ultimately including transport from the transfer station to landfill. Current assumptions are drawn from US EPA's WARM documentation and discussions with DEQ's lead material recovery and disposal data scientist. Specific mode and distance are provided below:

- Residential route pickup (20 miles in class 6 truck). The distance and truck type is based on the ICF memo to EPA on WARM transport. The distance to transfer station is assumed to be included in the residential route pickup.
- Distance to Landfill (162.2 miles in class 8a Truck). This distance is an estimate and reflects the distance from Bend to Portland Metro (a value from DEQ believes to be an overestimate) based on the geography and distribution of people in Oregon. The truck type is based on the ICF memo to EPA on WARM transport.

Distance/mode to recycling – the transportation here includes curbside pickup to MRF to final recycler.

- Residential route pickup (20 miles in class 6 truck). The distance and truck type is based on the ICF memo to EPA on WARM transport. The distance to transfer station or material recovery facility is assumed to be included in the residential route pickup.
- Distance to final recycling treatment is based on the same distances/modes as the upstream transport in production (based on ICF memo and BTS statistics), assuming that these materials must travel the inverse of distribution. This assumption is made due to the fact that the actual supply chain and fate of materials recovered in Oregon is not known for each material category beyond the states borders. In some select instances where recycling takes place within the state of Oregon or where the end of life recycling treatment was a hypothetical future treatment, other transportation distances were assumed.

Distance/mode to compost - the transportation here includes curbside pickup to MRF to final recycler.

- Residential route pickup (20 miles in class 6 truck). The distance and truck type is based on the ICF memo to EPA on WARM transport. The distance to transfer station or material recovery facility is assumed to be included in the residential route pickup.
- Distance to compost facility (162.2 miles in class 8a Truck). This distance is an estimate and reflects the distance from Bend to Portland Metro (a value from DEQ believes to be an overestimate) based on the geography and distribution of people in Oregon. The truck type is based on the ICF memo to EPA on WARM transport.

Distance/mode to Anaerobic Digestion - the transportation here includes curbside pickup to MRF (or similar transfer station) to digester.

- Residential route pickup (20 miles in class 6 truck). The distance and truck type is based on the ICF memo to EPA on WARM transport. The distance to transfer station or material recovery facility is assumed to be included in the residential route pickup.
- Distance to anaerobic digestion facility (162.2 miles in class 8a Truck). This distance is an estimate and reflects the distance from Bend to Portland Metro (a value from DEQ believes to be an overestimate) based on the geography and distribution of people in Oregon. The truck type is based on the ICF memo to EPA on WARM transport.

Distance/mode to Incinerator - the transportation here includes curbside pickup to MRF (or similar transfer station) to Incinerator.

- Residential route pickup (20 miles in class 6 truck). The distance and truck type is based on the ICF memo to EPA on WARM transport. The distance to transfer station or material recovery facility is assumed to be included in the residential route pickup.
- Distance to Incineration facility (162.2 miles in class 8a Truck). This distance is an estimate and reflects the distance from Bend to Portland Metro (a value from DEQ believes to be an overestimate) based on the geography and distribution of people in Oregon. The truck type is based on the ICF memo to EPA on WARM transport.

Distance/mode for Reuse – in a one instance (glass bottle reuse) an end of life scenario for reuse has been modeled. The transportation associated with reuse, is assumed to just include locale route pickup, as this scenario is specific to glass bottle reuse, conducted by the Oregon Beverage Recycling Coalition, in the Portland Metro area.

- Residential route pickup (20 miles in class 6 truck). The distance and truck type is based on the ICF memo to EPA on WARM transport. The distance to transfer station or material recovery facility is assumed to be included in the residential route pickup.

Biogenic Carbon

The handling of biogenic carbon innate in wood products (lumber and paper) is accounted for in the waste impact calculator. Biogenic carbon is also relevant to any other organic materials which perform photosynthesis, such as crops related to food production, however unlike wood, the fluxes of biogenic carbon in food production are on short-term time scales (e.g. annual) and so are typically not relevant to an assessment of carbon on 100 or 20 year time scales. That said, fluxes of biogenic carbon are included (when the appropriate impact category is selected) across the life cycle stages modeled for both wood and food (or any other organic materials). Uptake and emissions are included in the "cradle to gate" production stage and similarly storage and emissions are reflected at the "end of life" treatments for relevant material categories. The fluxes of carbon during upstream production and end of life disposition are based on the secondary datasets used to model these materials.

However, through researching the source data used to model wood products DEQ has opted to include two different methods for augmenting the fluxes of biogenic carbon that occur during production. The justification for the inclusion of these two correction factors is that the existing datasets make the assumption that the source forests for wood products are "sustainably managed." Meaning that the GHG accounting assumes carbon neutrality of the forest, but this fails to acknowledge the reality of the sequestration service provided by forests. Data from the Oregon Department of Forestry's recent "Oregon Forest Ecosystem Carbon Inventory: 2001-2016[3]" shows that not all forest types in Oregon meet the neutrality assumption, namely 66% of wood harvests in Oregon originate from forests which have demonstrated net losses (approx. 8.5% per year) across the study period. This is shown in the figure below. Overall, forests in Oregon demonstrate net sequestrations, but this is a function of national forests and other federal/state forest land sequestering carbon.

[3] https://www.oregon.gov/odf/ForestBenefits/Documents/Forest%20Carbon%20Study/OR-Forest-Ecosystem-Carbon-2001-2016-Report-FINAL.pdf

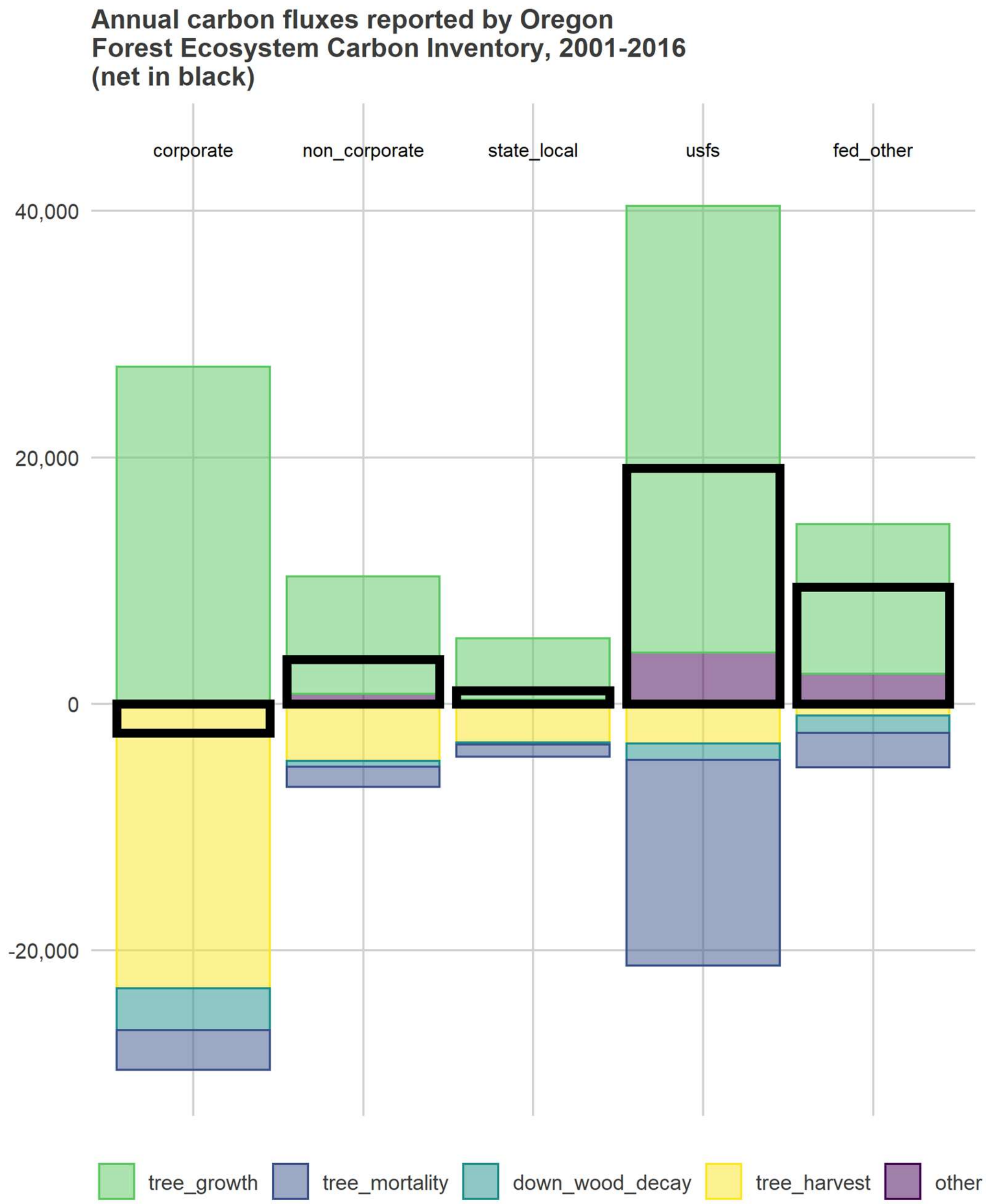

Figure 2 - annual carbon fluxes reported by Oregon Forest Ecosystem Carbon Inventory (in thousand metric tons of CO2e)

It is important to clarify some vocabulary and expectations, specifically surrounding the concept of "storing" carbon. The way this word has been used implies that somehow forest products actively sequester carbon. That is deceptive.

Let us be clear:

- **Only growing forests actually sequester carbon.**
- Carbon is **removed** from the forest when trees are harvested and made into products.

- Some of that carbon may be **maintained** in the product for greater or lesser amounts of time
- Given the inefficiency of the process of converting forest to product (e.g. the production and decay of slash) it is impossible that the carbon maintained in any product will be greater than the amount removed from the forest.

Though there are various methods for calculating the greenhouse gas emissions associated with forest products, there is little disagreement that some "technospheric" impacts should be included, for example – fossil (e.g. non-biogenic) fuel used in harvesting and processing, transportation, etc.

The disagreement falls in two areas:

- How to, or whether to, account for emissions of biogenic carbon in processing (e.g. burning hog fuel); and
- How to account for the effect of forestry on the landscape – because certainly forestry (e.g. thinning, harvesting) does affect the rate at which the landscape sequesters carbon.

Often there has been an assumption that biogenic carbon can be ignored, because (it is assumed) the carbon cycle balances out.

These assumptions are, quite simply, wrong – and wrong in a way that has infected even the concept of sustainable forestry.

- **Fact: the global carbon cycle is not steady state.** In the absence of humans, it has shown long term fluctuations. And for the past 100 years, humans (who are clearly biological) have increased atmospheric carbon dioxide radically.[4]
- **The distinction between anthropogenic and biogenic carbon fluxes is therefore artificial.** They clearly affect one another (see above). That implies that biogenic carbon should always be counted.
- **Most importantly for the waste impact calculator, forests are not steady state in terms of carbon.** Growing forests are *not* carbon-neutral, they sequester carbon in an impressive way, as recent inventories in the West have shown.[5] This sequestration has ecological value (for example in Oregon forest sequestration amounts to about half of our sector-based emissions), and the loss of that value needs to be recognized.
- **Accordingly, the frequent premise that forest products represent no biogenic emissions if they come from carbon neutral forests is wrong.** Forest products represent a *loss* of

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[4] NOAA, "Climate Change: Atmospheric Carbon Dioxide," accessed April 1, 2020, https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide.

[5] Glenn A Christensen et al., "AB 1504 California Forest Ecosystem and Harvested Wood Product Carbon Inventory: 2006 – 2015," n.d., http://bofdata.fire.ca.gov/board_business/binder_materials/2017/dec17/full/full_14.1_ab_1504_california_forest_ecosystem_and_harvested_wood_product_carbon_inventory_2006_-2015.pdf; Christensen et al., "Oregon Forest Ecosystem Carbon Inventory: 2001-2016."

sequestration that would have happened in forest, had the forest been unharvested.[6] The EPA's concept of "forest carbon storage" reflects this idea.

- In short, the standard applied to forestry and forest products should not be carbon neutrality, but the **potential sequestration available from an unharvested forest**.

As such, the waste impact calculator's GHG accounting approach, for material categories that include biogenic carbon, uses the concept of active sequestration as the standard to which forests are held. When the production, use, and/or end-of-life treatment of forest products reduces active sequestration in forests, products should be charged with an appropriate set of GHG emissions.

The two methods, referred to as "Slash" and "EPA FCS," for deriving biogenic carbon correction factors are calculated as described below.

<u>Slash</u>

The slash factor charges for the forestry residue (slash) associated with wood harvest and production, when the residue left in the field decays or burns. This method is highly defensible, as it is undeniable that the production of forest products creates slash which leads to emissions, and furthermore this slash can clearly be quantified[7], yet appears to be omitted for the underlying wood life cycle inventories used. It should be noted, however, the slash factor likely underestimates the true GHG impact of harvest, because it only quantifies the slash left on the ground during harvest, and does not represent anything about the capability of the forest landscape to sequester carbon – which at least in the short term (i.e. 10-20 years) is likely to be reduced by harvest.

- Slash factor = (sequestered carbon per unit of product/0.7) – sequestered carbon per unit of product
- Augmented Slash production factor = old production factor + slash factor
- Augmented Slash recycling factor = old recycling factor + slash factor

The numerator of 0.7 in the first formula scales the carbon in the product up to the total amount of biomass found in the tree before harvest, relative to the carbon in the finished product. Meaning that all the residues (limbs, bark, or tree tops) associated with harvest are now accounted for in the total carbon per unit of product. This factor was derived from a compendium of various sources that measured amounts of logging slash, see memo in Appendix B.

<u>WARM's forest carbon storage factor</u>

WARM's source reduction impacts are the negative of production impacts. To implement WARM's carbon storage factor for source reduction in WIC, the model adds the negative of WARM's forest carbon storage source reduction factor to any other production-related impacts for relevant material categories.

- Augmented EPA FCS production factor = old production factor + -WARM net forest carbon storage for source reduction

[6] There are theoretical exceptions to this that some people might use to throw this point in doubt. In theory, very old forests are not sequestering much carbon – they have too much decay going on. However, this is basically just theoretical old growth stuff, which is a tiny part of the landscape and nonexistent on private timberland.

[7] See memo, "The quantity of logging slash in various sources: a compendium (updated 4/2/2020)"

Currently WARM's net forest carbon storage factors for source reduction range from -1.84 MTCO2E/short ton of product (for lumber) to -6.96 (for office paper). Flipping the signs, from 1.84 to 6.96 MTCO2E/short ton of product would be added to the waste impact calculator's production impacts.

Recycling is a little more complicated and comes into play for paper products. Recycling leads to reduced harvest and increased forest carbon storage, according to WARM, but not as much as source reduction. For example, office paper has a source reduction forest carbon storage value of -6.96 MTCO2E/short ton of product, and a recycling forest carbon storage value of -3.06.

Following the office paper example, I believe that 6.96 MTCO2E/short ton of product should be added as a charge to the production of office paper. But when recycling of office paper occurs, a credit of 3.06 MTCO2E may be applied to each ton of recycled product. More formally:

- Augmented EPA FCS recycling factor = old recycling factor + WARM forest net forest carbon storage for recycling (note this time there has been no sign flip).

Material Categories

This section provides general descriptions of the material categories modeled, by life cycle stage. For specific details on the background life cycle inventories used in each material category and disposition see Appendix A.

Accepted Other Steel

Accepted Other Steel (production)

This material category represents steel of vary types and alloys, that do not fall under the other specific categories where ferrous metals tracked (e.g. tinned cans or scrap metal) in DEQ's material recovery survey. Because of this generic nature, the model has been developed as an equally weighted average of four common form factors for steel products – cold rolled sheet, hot rolled sheet, plate, and rebar. The data are drawn from global averages developed by Worldsteel.

Accepted Other Steel (incinerationNoER)

Since the incineration of ferrous metals is not possible to generate electricity, this process is modeled just based on the incineration of an aggregation of inert ferrous materials (e.g. steel). This results in emissions and credits, due to the assumption that certain metals, ferrous and non-ferrous, can be recovered after incineration and recycled.

Accepted Other Steel (landfilling)

This model represents deposition of the specified waste material type, in this case mixed ferrous metals, to an average U.S. MSW landfill. The dataset represents the inputs and outputs of the landfill as a function of the composition of the material placed in it.

Accepted Other Steel (recyclingGeneric)

The recycling credits of steel are based on Worldsteel data. The "value of scrap" is calculated on the basis of the steel product cradle-to-gate LCIs.

Aluminum

Aluminum (Production)

Aluminum is used if varying ways. Aluminum cans are the primary form of aluminum represented by this material category, though other aluminum form factors (window frames, extrusions, or cast parts) do show-up in the waste stream in Oregon.

To best capture the production impacts the mix of all final products demanded in Oregon should be used. However, this information is not readily available for Oregon, so the US average market mix of primary and secondary content was used model the production of aluminum. Data was taken from the Aluminum Association (AA, 2013). This approach reasonably represents the mix, and thus the impact, of aluminum demanded and used in Oregon.

To model the production of aluminum a mix of the three most common production routes are used based on annual production volumes taken from the Aluminum Association datasets. The source of annual production volumes breaks down into rolled vs. extruded products only, for the rolled portion of production the model splits the total equally among cold and hot rolled aluminum.

1. 36.8% cold rolling (annual production volume - 3,415,608 MT - All Flat-Rolled Products, excl. foils)
2. 36.8% hot rolling (annual production volume - included in above number for cold rolling)
3. 26.4% extrusion (annual production volume - 1,224,720 MT)

The production of aluminum is based on data from the Aluminum Association for North American (NA) production, which itself represents the global supply chain for aluminum produced in North America (e.g. bauxite from Brazil, Guinea, Jamaica, and other regions). While the model assumes NA production, some fraction of material production occurs outside of this region and would result in different background systems (e.g. bauxite sources, energy grids, waste handling, etc.). The amount of production that happens outside of NA was not readily available and so aluminum demanded in Oregon is based on NA boundary conditions.

Aluminum (incinerationNoER)

Since the incineration of aluminum it is not possible to generate electricity, this process is modeled just based on the incineration of an aggregation of inert materials (e.g. glass or metals). This results in emissions and credits, due to the assumption that certain metals ferrous and non-ferrous can be recovered after incineration and recycled.

Aluminum (landfilling)

The modeling of landfilling is based on an average US landfill and representative composition, in this case for inert materials.

Aluminum (recyclingGeneric)

The recycling disposition includes the processing of collected aluminum materials and a material credit for the substitution of "aluminum can sheet", meaning that the recycling impacts account for secondary production of ingot + can sheet rolling. No decrease in quality due to recycling is calculated. It is assumed that 1 unit recycled offsets 1 unit of primary material.

Currently the model assumes a high quality of scrap (e.g. low copper/other content) and employs a value-corrected substitution approach. It takes the market value of recyclable scrap relative to primary material to determine the product-specific degree of quality loss and the appropriate End-of-Life credit. The credit is based on the substitution of Aluminum production, described above.

Aseptic Containers

AsepticContainers (production)

Aseptic containers are a type of packaging that is sterilized and filled under sterile conditions, in order to ensure shelf stability/safety of the product it contains. The model for this material category is based on material composition data obtained from a 2016 study entitled "Comparative LCA of beverage cartons with and without bio-based polymers[8]," specifically for TetraPak's Brik Aseptic container. The composition is summarized in the table below.

Table 5 - Aseptic Material Composition

Component	Mass (g/package)
Sleeve	
Paperboard	21.6
Aluminum Foil	1.4
Lamination (LDPE)	5.2
Opening	
Lid (HDPE)	1.4
Neck (LDPE)	1.6
Total	**31.2**

As with all material categories in the waste impact calculator, details on the underlying life cycle inventory data used to represent aseptic containers can be found in Appendix A.

AsepticContainers (incinerationER)

Because aseptic containers represent a mixture of inert and energetic materials, the incineration model handles each of these constituent materials separately, based on the proportions defined in the above production model. The incineration of the energetic materials (paper, HDPE, and LDPE) is modeled using secondary data for the incineration of each specific material in a waste incineration plant, in this case based on the incineration models PaperFiber (incinerationER), HDPE (incinerationER), and LDPE (incinerationER). Whereas the incineration of the inert materials (aluminum foil) is modeled using secondary data for the incineration of inert waste in a waste incineration plant, consistent with the Aluminum (incinerationNoER) model. In practice, single streams of material are not incinerated, instead a blend of municipal solid waste, including various materials are incinerated. The dataset attributes the

[8] https://assets.tetrapak.com/static/documents/sustainability/lca-tba-tb-biobased.pdf

emissions and credits (thermal and electrical energy) of incineration to the specific material in question, in this case plastics generically and inert materials.

AsepticContainers (landfilling)

Using the same proportions of materials described in the production section above, the landfilling of aseptic containers is based on an average US landfill and representative composition, in this case for plastics generically and inert materials.

AsepticContainers (recyclingGeneric)

The recycling of aseptic containers assumes that they are taken to a paper mill, where only the paper fiber is recycled and the remainder is landfilled. Using the proportion of constituents defined above in the production model the aluminum, HDPE, and LDPE are separated from the paper and sent to landfill. The modeling of the landfilling of these materials are based on the Aluminum (landfilling), HDPE (landfilling), and LDPE (landfilling), respectively. The paper recycling is based on the PaperFiber (recycling) model described in more detail below. It includes the burdens of processing the collected paper from aseptic and credits for the substitution of paper fiber production based on the PaperFiber (production) model.

Asphalt Roofing

AsphaltRoofing (production)

Asphalt roofing is defined in the material recovery survey as used roofing – post-consumer only, not industrial. Asphalt roofing is a combination of asphalt materials adhered to backing materials (in this case fiberglass). The background data used to model the asphalt roofing comes from a multi-producer industry average developed by ARMA, the Asphalt Roofing Manufacturer's Association. The average density of asphalt roofing in the model is 4.8 kg/m2.

AsphaltRoofing (incinerationER)

Because asphalt roofing is a mixture of inert and energetic materials, the incineration model assumes an equal split of these materials in an incinerator. The incineration of the energetic materials (bitumen, filler, and matrix) is modeled using secondary data for the incineration of plastic in a waste incineration plant. Whereas the incineration of the inert materials (fiberglass backing) is modeled using secondary data for the incineration of inert waste in a waste incineration plant. In practice, single streams of material are not incinerated, instead a blend of municipal solid waste, including various materials are incinerated. The dataset attributes the emissions and credits (thermal and electrical energy) of incineration to the specific material in question, in this case plastics generically and inert materials.

AsphaltRoofing (incinerationNoER)

The incineration of this blended category of plastics and inerts is modeled using the same secondary data as described above. However, the dataset attributes only the emissions associated with incineration and excludes any credits (thermal and electrical energy).

AsphaltRoofing (landfilling)
Using the same proportion of materials (50% plastics and 50% glass fiber backing/mineral fillers), the landfilling of asphalt roofing materials is based on an average US landfill and representative composition, in this case for plastics generically and inert materials.

AsphaltRoofing (recyclingGeneric)
The recycling of asphalt roofing is modeling using proxy data for the recycling process, as no background data or primary data were available to reflect the recycling process. Following the same equal split of plastics and inert materials, the recycling disposition includes the processing of collected asphalt roofing materials and a material credit for the substitution of bitumen and gravel. No decrease in quality due to recycling is calculated. However, loses in quantity are included for the plastics share of the roofing material, as part of the recycling process. It is assumed that 1 unit recycled offsets 0.858 units of primary material.

Cardboard

Cardboard (production)
The cardboard category is defined as Kraft linerboard and container-board cartons of corrugated paper (waxed or unwaxed) and Kraft paper bags. Excludes converting plant waste paper (i.e. DLK clippings and local grocery bag waste). To represent this material in the waste impact calculator background data from the American Forest & Paper Association study on the industry average corrugated product was used. This data reflects the industry average amount of post-consumer recycled paper fiber inputs of 0.464 units for every 1 unit of finished cardboard. Similarly, 1.17 units of woodchips are consumed for every unit of finished cardboard produced.

This model also includes the biogenic carbon correction factor sets described in detail above, in the eponymously named biogenic carbon section. In short, these factors augment the flows of biogenic carbon that are associated with harvest from the forest.

Cardboard (incinerationER)
The incineration of cardboard is modeled using secondary data for the incineration of paper waste in a waste incineration plant. In practice, single streams of material are not incinerated, instead a blend of municipal solid waste, including various materials are incinerated. The dataset attributes the emissions and credits (thermal and electrical energy) of incineration to the specific material in question, in this case paper waste generically.

Cardboard (incinerationNoER)
The incineration of cardboard in this category is modeled using the same secondary data as described above. However, the dataset attributes only the emissions associated with incineration and excludes any credits (thermal and electrical energy).

Cardboard (landfilling)
The modeling of landfilling is based on an average US landfill and representative composition, in this case for paper materials placed in a landfill.

There are credits in the model for the substitution of electricity from the grid and thermal energy production from natural gas, as a result of the material-specific landfill gas generation and capture rates. The credits are for 0.22 MJ of electricity and 0.10 MJ of thermal energy per kg of paper waste.

Cardboard (recyclingGeneric)

Carpeting

Carpeting (production)

Carpeting can be manufactured out of multiple disparate synthetic (polyamide, polyethylene terephthalate) or natural materials (wool, sisal, jute). So characterizing the mix of carpet materials in this category is difficult. The waste impact calculator currently represents carpet production by using multiple background datasets based on differing fiber materials, including backing and different fiber counts/pile weights.

Using secondary data from a study[9] conducted by GUT (the Association of Environmentally Friendly Carpets) of vary luxury classes (e.g. fiber counts/pile weights and backing), the waste impact calculator estimates the cradle to gate impacts of carpet production. The fibers included are:

- Polyamide 6.6 (textile backing)
- Polyamide 6.6 (bitumen backing)
- Polyamide 6 (textile backing)
- Polyamide 6 (bitumen backing)
- Polypropylene (textile backing)

The luxury classes selected for the middle value (LC3) of the European Luxury Classes (from EN1307:2014). A carpet is given a Luxury Use Class from a LC1 to LC5, LC1 being the lowest class and LC5 being the highest.

Additionally the model includes data for polyethylene terephthalate fiber production, but does not backing production, due to lack of primary or secondary data for backing production.

Table 6 - Share of Carpet Fiber Type in Waste Impact Calculator

Main Carpet Fibers	Share by Fiber (where data is available)
Nylon	0.52
Polyester	0.19
Polypropylene	0.29

[9] https://www.eebguide.eu/eebblog/wp-content/uploads/2012/07/Product-Case-Study_Simplified-LCA.pdf

Finally, the ratio of the different fibers in the overall carpeting production mix is shown in the table above. It is based on data from 2014-2019 UK report[10] on carpet market size by raw material type, excluding the "other" category. This works out to the proportions shown in the table below.

Carpeting (incinerationER)

The incineration of carpeting is modeled using secondary data for the incineration of plastic waste in a waste incineration plant. In practice, single streams of material are not incinerated, instead a blend of municipal solid waste, including various materials are incinerated. The dataset attributes the emissions and credits (thermal and electrical energy) of incineration to the specific material in question, in this case plastics generically specifically. This is model currently does not account for the fractional share of the carpeting material that is backing, which may have a higher (bitumen) or lower (textile) net calorific value than the carpet fiber itself. The decision to use a generic plastic model instead approximates these differences.

Carpeting (incinerationNoER)

The incineration of carpeting in this category is modeled using the same secondary data as described above. However, the dataset attributes only the emissions associated with incineration and excludes any credits (thermal and electrical energy).

Carpeting (landfilling)

Similar to incineration, landfilling of individual carpeting fibers is not done in practice. Generally carpets are found mixed into standard municipal solid waste streams. The modeling of landfilling is based on an average US landfill and representative composition, in this case for plastics generically.

Carpeting (recyclingGeneric)

The recycling disposition includes the processing of collected carpeting materials and a material credit for the substitution of each fiber material, meaning that the recycling impacts account for secondary production of new granulate, but not new carpeting. No decrease in quality due to recycling is calculated. However, loses in quantity are included as part of the recycling process. It is assumed that 1 unit recycled offsets 0.858 units of primary material.

The model assumes that the backing material is removed prior to the recycling process and landfilled. So the model credits only the substitution of the fiber materials themselves. 78% of the mass is assumed to be backing and the remainder (22%) fiber material. The ratio of inert backing materials to carpet fiber was derived as an average of the reported materials from three EPDs for carpeting from Interface.

Electronics

Electronics (production)

Electronics are complex assemblies of multiple materials (plastics, glass, steel, aluminum, and various rare earth metals). Thus creating a genericized life cycle inventory to represent this broad array of

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[10] https://www.grandviewresearch.com/industry-analysis/europe-carpet-market-analysis

materials, form factors, and functions requires some oversimplification. 2015 data from a report[11] entitled "Development of a Sustainable Materials Management Modeling Framework" was used to devise a mix of different electronic products that make up this material category. Not all of the electronics flows tracked in this report are included in the mix below, due to omissions for which no existing life cycle inventory data was available.

The mix of electronics defined in the waste impact calculator is as follows:

Electronic Product	Share
LCD TV	0.34
LCD Monitor	0.01
Printer	0.36
Laptop	0.12
Desktop	0.17

Secondary data from the Ecoinvent database were used to represent these electronic products.

Electronics (landfilling)

The landfilling of electronic waste was modeled using the material composition of the weighted (based on 2018 Oregon eCycles data) average mix of electronic product outflows from US households (based on data from the report[12] mentioned above, specifically Table C-3 of that report. The resultant product is shown in the table below.

Table 7 - Material Composition of Electronic Outflow from Oregon households

	Ferrous Metal (steel)	Aluminum	Copper	Other Metals	Plastic	PCB	Flat panel display module (CCFL)	Flat panel display module (LED)	CRT Glass	CRT Lead	Battery	Other
Blu-Ray	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
DVD	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
VCR	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
MP3	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Digital Camcorder	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Digital Camera	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gaming Console	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
LED TV	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
LCD TV	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Plasma TV	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
CRT TV	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
LED Monitor	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

[11] Babbit et al. (2017) - https://www.rit.edu/gis/ssil/docs/Final%20Report%20SMM%20Phase%201%202017.pdf
[12] https://www.rit.edu/gis/ssil/docs/CTA-SSIL%20Final%20Report%20SMM%20Phase%202%202018.pdf

	Ferrous Metal (steel)	Aluminum	Copper	Other Metals	Plastic	PCB	Flat panel display module (CCFL)	Flat panel display module (LED)	CRT Glass	CRT Lead	Battery	Other
LCD Monitor	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
CRT Monitor	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Printer	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Laptop	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Desktop	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
E-reader	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tablet	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Smart Phone	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Basic Phone	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

This table forms the basis from the handling of electronic materials in landfill modeled using an average U.S. MSW landfill, customized for each of the specific materials in question.

There are credits in the model for the substitution of electricity from the grid and thermal energy production from natural gas, as a result of the material-specific landfill gas generation and capture rates.

Electronics (recyclingGeneric)

The same material composition data described above in the Electronics (landfilling) model form the basis for deriving material credits through electronics recycling. The recycling disposition includes the processing of plastic materials, steel, printed circuit boards, batteries, and LCDs recovered from electronics, but excludes the processing of some of the other materials (Lead and Copper) recovered from electronics, due to lack of data on recycling processes for these materials. A material credit for the substitution of each of the recovered materials is included in the model, meaning that the recycling impacts account for secondary production of new materials used in electronics, but not the electronics themselves. No decrease in quality due to recycling is calculated. However, material-specific loses in quantity are included as part of the recycling processes.

Some of the materials in electronics are not recyclable, these materials end up being landfilled. And so the categories “other metals” and “other materials” shown in the table above, are represented by an average U.S. MSW landfill, customized for each of the specific materials in question. There are credits in the model for the substitution of electricity from the grid and thermal energy production from natural gas, as a result of the material-specific landfill gas generation and capture rates.

Expanded Polystyrene

EPS (production)

Expanded Polystyrene is used for packaging materials and food serviceware. This model represents EPS in packaging applications and so includes formulation of the polymer into packaging via a foaming process. The foam is produced from a normal plastic which is turned into a porous material by expanding it with a blowing agent such as pentane or butane. The density of the EPS varies based on the ratio of polymer to blowing agent in the final product, here EPS is assumed to have a density of 20 kg / m3

EPS (incinerationER)

The incineration of EPS is modeled using secondary data for the incineration of polystyrene in a waste incineration plant. In practice, single streams of material are not incinerated, instead a blend of municipal solid waste, including various materials are incinerated. The dataset attributes the emissions and credits (thermal and electrical energy) of incineration to the specific material in question, in this case EPS specifically. This is the same model as is used for non-expanded polystyrene, described below.

EPS (landfilling)

Similar to incineration, landfilling of individual polymer streams is not done in practice. Generally plastics are found mixed into standard municipal solid waste streams. The modeling of landfilling is based on an average US landfill and representative composition, in this case for plastics generically. This is the same model as is used for non-expanded polystyrene, described below.

EPS (recyclingGeneric)

The recycling disposition includes the processing of collected PS materials and a material credit for the substitution of PS granulate, meaning that the recycling impacts account for secondary production of new granulate, but not new PS packaging. No decrease in quality due to recycling is calculated. However, loses in quantity are included as part of the recycling process. It is assumed that 1 unit recycled offsets 0.858 units of primary material.

No densification is currently included in the model. Which is a common practice for the recycling, typically chemical, of EPS. Since

Food

FoodWaste (production)

The food material category uses the US EPA's WARM v14 model[13] as the basis for defining the mix of different foods. The WARM model is ultimately based on the USDA's Loss-Adjusted Food Availability per capita dataset. The model uses weighted averages from Exhibit 1-7 in the WARM background document for organics, as shown below:

- Beef (9.3%)
- Poultry (11.0%)
- Grains (13.1%)
- Fruits and Vegetables (49.1%)
- Dairy Products (17.7%)

Beef – Based on data for cattle production from Ecoinvent.

13 https://www.epa.gov/sites/production/files/2016-03/documents/warm_v14_organic_materials.pdf

Poultry – This subcategory is modeled just using a life cycle inventory for chicken from the Ecoinvent database.

Grains – This subcategory is a mix of wheat, corn, and rice, it is modeled using data from the Ecoinvent database.

Fruits and Vegetables – This subcategory of food is a weighted average of potatoes, tomatoes, citrus, melons, apples, and bananas. A report[14] on the weighted import percentages for bananas by country of origin, was used to derive these inputs. The model uses data from the Ecoinvent database to represent each individual fruit or vegetable.

Dairy Products - According to WARM the "EPA used a regional average of milk production from five regions to model "generic milk" as a stand-in for specialty products such as chocolate milk and buttermilk." For the waste impact calculator has selected buttermilk (since LCI data is available) to represent the "generic milk" category. To model the impacts of various liquid milk products, the waste impact calculator uses LCI data for skim milk and cream and defined ratios of each to arrive the specific fat content.

- 1% - 98% skim and 2% heavy whipping cream
- 2% - 97% one percent and 3% heavy whipping cream
- Whole - 89% skim and 11% heavy whipping cream

To model mozzarella and cheddar cheese the waste impact calculator uses the same LCI based on cheese production. Ice cream is modeled based on the average ingredient mix and median value, taken from the University of Guelph's food science book[15].

Upstream transportation for food is embedded in the production model. This deviates from the other material production categories and reflects that varied supply chains of different foods. For example, the upstream transportation associated with banana production (one part of the overall model) is different in terms of distance and mode than wheat production (another part of the overall model).

No additional spoilage or losses are included in this material category, but this represents a limitation, as there is likely to be a fractional amount of food that perishes during distribution.

FoodWaste (incinerationER)

The incineration of food is modeled using secondary data used for biodegradable waste in a waste incineration plant. The datasets attribute the emissions and credits (thermal and electrical energy) of incineration to the specific material in question, in this case yard debris.

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[14] https://edis.ifas.ufl.edu/fe901

[15] https://www.uoguelph.ca/foodscience/book-page/ice-cream-mix-ingredients)

FoodWaste (incinerationNoER)

The incineration of food waste in this category is modeled using the same secondary data as described above. However, the dataset attributes only the emissions associated with incineration and excludes any credits (thermal and electrical energy).

FoodWaste (landfilling)

Food waste landfilling is modeled using secondary data on biodegradable waste, to an average U.S. MSW landfill. The dataset represents the inputs and outputs of the landfill as a function of the composition of the material placed in it.

There are credits in the model for the substitution of electricity from the grid and thermal energy production from natural gas, as a result of the material-specific landfill gas generation and capture rates.

FoodWaste (anaerobicDigestion)

The anaerobic digestion of food waste is modeled using secondary (background) data from Ecoinvent and is based on the operation of an anaerobic digester for biowaste. Credits are calculated based on the nutrient supply, in terms of N-P-K, from biowaste (derived from compost), as a proxy, since nutrient supply for digester sludge was not available. Anaerobic digestion also leads to the generation of methane and so a proportionate credit is granted for the substitution of the US average natural gas mix.

Additionally, a credit (input), based on a study[16] commissioned by Oregon DEQ and carried out by Jeff Morris of Sound Resources is included for soil carbon storage due to application of the digestate. The credit is defined as -0.08 kg CO2 / kg of waste (e.g. biowaste).

FoodWaste (composting)

Composting of food waste is modeled using secondary (background) data from GaBi and is based on an open windrow composting process. This composting process was found to be the most common technology for composting of organic materials here in Oregon, based on a survey of composters in Oregon. Credits are calculated based on the nutrient supply, in terms of N-P-K, from biowaste.

Additionally, a soil carbon storage credit (input), based on a study[17] commissioned by Oregon DEQ and carried out by Jeff Morris of Sound Resources is included for soil carbon storage due to application of the compost. The credit is defined as -0.12 kg CO2 / kg of waste (e.g. biowaste).

Freezer Boxes

FreezerBoxes (production)

Freezer boxes, as their name implies, are a coated paper container used for packaging frozen foods. The model for this material category is based on material composition data obtained from a 2016 study entitled "Comparative LCA of beverage cartons with and without bio-based polymers[18]," specifically for

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16 Food Waste Study - http://www.oregon.gov/deq/FilterDocs/FoodWasteStudyReport.pdf

17 Food Waste Study - http://www.oregon.gov/deq/FilterDocs/FoodWasteStudyReport.pdf

18 https://assets.tetrapak.com/static/documents/sustainability/lca-tba-tb-biobased.pdf

TetraPak's Brik container. The composition for freezer boxes is modified from this data by excluding the HDPE (closure) and aluminum foil. The composition is summarized in the table below.

Table 8 – Freezer Box Material Composition

Component	Mass (g/package)
Sleeve	
Paperboard	21.6
Aluminum Foil	0
Lamination (LDPE)	5.2
Opening	
Lid (HDPE)	0
Neck (LDPE)	1.6
Total	**28.4**

As with all material categories in the waste impact calculator, details on the underlying life cycle inventory data used to represent gable top cartons can be found in Appendix A.

FreezerBoxes (incinerationER)

Unlike aseptic containers, but like gable top cartons, freezer boxes contains materials which all have embodied energy, so the incineration model handles each of these constituent materials, based on the proportions defined in the above production model. The incineration of the energetic materials (paper and LDPE) is modeled using secondary data for the incineration of each specific material in a waste incineration plant, in this case based on the incineration models PaperFiber (incinerationER) and LDPE (incinerationER). In practice, single streams of material are not incinerated, instead a blend of municipal solid waste, including various materials are incinerated. The dataset attributes the emissions and credits (thermal and electrical energy) of incineration to the specific material in question, in this case plastics generically.

FreezerBoxes (landfilling)

Using the same proportions of materials described in the production section above, the landfilling of freezer boxes is based on an average US landfill and representative composition, in this case for plastics generically and paper materials. The modeling of the landfilling for freezer boxes is based on the LDPE (landfilling) and PaperFiber (landfilling) models, respectively.

FreezerBoxes (recyclingGeneric)

The recycling of freezer boxes assumes that they are taken to a paper mill, where only the paper fiber is recycled and the remainder is landfilled. Using the proportion of constituents defined above in the production model the LDPE is separated from the paper and sent to landfill. The modeling of the landfilling of this material is based on the LDPE (landfilling) model. The paper recycling is based on the PaperFiber (recycling) model described in more detail below. It includes the burdens of processing the collected paper from freezer boxes and credits for the substitution of paper fiber production based on the PaperFiber (production) model.

Gable Top Carton

GableTopCartons (production)

Gable top cartons are a type of packaging that is used for liquid containment, often for beverages such as diary, juices, water, or coffee. The model for this material category is based on material composition data obtained from a 2016 study entitled "Comparative LCA of beverage cartons with and without bio-based polymers[19]," specifically for TetraPak's Brik container. The composition is summarized in the table below.

Table 9 – Gable Top Carton Material Composition

Component	Mass (g/package)
Sleeve	
Paperboard	23.1
Aluminum Foil	0
Lamination (LDPE)	5.2
Opening	
Lid (HDPE)	1.4
Neck (LDPE)	1.3
Total	**31**

As with all material categories in the waste impact calculator, details on the underlying life cycle inventory data used to represent gable top cartons can be found in Appendix A.

GableTopCartons (incinerationER)

Unlike aseptic containers, gable top cartons contains materials which all have embodied energy, so the incineration model handles each of these constituent materials, based on the proportions defined in the above production model. The incineration of the energetic materials (paper, HDPE, and LDPE) is modeled using secondary data for the incineration of each specific material in a waste incineration plant, in this case based on the incineration models PaperFiber (incinerationER), HDPE (incinerationER), and LDPE (incinerationER). In practice, single streams of material are not incinerated, instead a blend of municipal solid waste, including various materials are incinerated. The dataset attributes the emissions and credits (thermal and electrical energy) of incineration to the specific material in question, in this case plastics generically.

GableTopCartons (landfilling)

Using the same proportions of materials described in the production section above, the landfilling of gable top cartons is based on an average US landfill and representative composition, in this case for plastics generically and paper materials. The modeling of the landfilling of these materials are based on the HDPE (landfilling), LDPE (landfilling) and PaperFiber (landfilling) models, respectively.

[19] https://assets.tetrapak.com/static/documents/sustainability/lca-tba-tb-biobased.pdf

GableTopCartons (recyclingGeneric)

The recycling of gable top cartons assumes that they are taken to a paper mill, where only the paper fiber is recycled and the remainder is landfilled. Using the proportion of constituents defined above in the production model the HDPE and LDPE are separated from the paper and sent to landfill. The modeling of the landfilling of these materials are based on the HDPE (landfilling) and LDPE (landfilling) models, respectively. The paper recycling is based on the PaperFiber (recycling) model described in more detail below. It includes the burdens of processing the collected paper from gable top cartons and credits for the substitution of paper fiber production based on the PaperFiber (production) model.

Glass

Glass (production)

Glass bottles and jars used to package food, beer, liquor, wine, juice, soft drinks, medicine, toiletries, and chemicals. Includes bottles that are returned by consumers to be washed and refilled. Excludes special formula glass, such as Pyrex glass.

The waste impact calculator models a market average mix of primary/secondary glass production would most accurately to reflect the materials in Oregon. The mix is based on composition data taken from the "Glass Guide[20]" on different glass types and market mix.

Glass (incinerationNoER)

Since the incineration of glass is not possible to generate electricity, this process is modeled just based on the incineration of an aggregation of inert materials (e.g. glass or metals). This results in emissions and credits, due to the assumption that certain metals ferrous and non-ferrous can be recovered after incineration and recycled.

Glass (landfilling)

The modeling of landfilling is based on an average US landfill and representative composition, in this case for inert materials.

Glass (recyclingToContainer)

To model the recycling process itself WIC uses an existing Ecoinvent dataset with modifications, as the process only seemed to account for sorting. It's not clear that crushing the glass is embedded in the process and the documentation does not specify.

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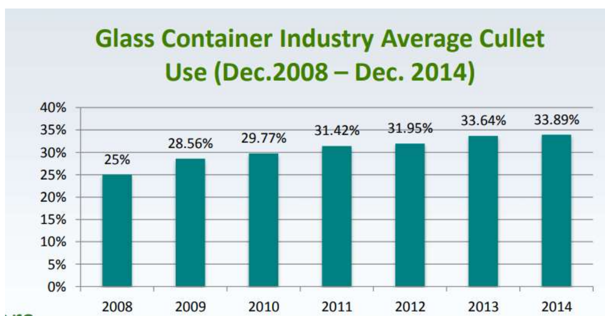
[20] https://www.energystar.gov/sites/default/files/buildings/tools/Glass-Guide.pdf

Credits for recycling of glass are modeled for the substitution of batch materials. Under this approach no decrease in quality due to recycling is calculated. It is assumed that 1 kg of cullet recycled offsets 1.2 kgs of primary material based on a GaBi dataset for EoL recycling of glass. The credits are granted on the basis of the raw materials for primary container glass production (quartz sand, limestone flour, alumina, and soda) shown in the table below, taken from table 3 below in the report entitled *Energy Efficiency Improvement and Cost Saving Opportunities for the Glass Industry*[21].

Table 3. Approximate composition of different glass types

Oxide	Container Glass	Float glass	Fiberglass (E-Glass)	Laboratory Ware
SiO_2 [w%]	73	72	54	80
B_2O_3 [w%]			10	10
Al_2O_3 [w%]	1.5	0.3	14	3
CaO [w%]	10	9	17.5	1
MgO [w%]	0.1	4	4.5	1
Na_2O [w%]	14	14		5
K_2O [w%]	0.6			

However, because the modeling approach is to apply credits based on the substitution of production of batch materials of the market mix, which itself already contains cullet, the amount of batch materials credited is corrected by the average recycled glass content of the market mix (here for container glass). This is based on the latest available statistic from the GPI on cullet use in container glass production of 33.89% in 2014.



Source - http://gpi.org/sites/default/files/GPI%20-%20Glass%20International%20Feb%202016.pdf

Glass (recyclingToFiberglass)

This recycling credit is essentially the same as the "recyclingToContainer" scenario, which is closed-loop container-to-container recycling. It would be possible to provide credits for avoiding batch materials used for primary fiberglass, which are a slightly different combination of materials (e.g. includes boric acid). However, giving credits for avoided boric acid use while assuming production impacts only for container glass (itself containing no boric acid), did not really make sense.

Credits for recycling of glass are modeled for the substitution of batch materials. Under this approach no decrease in quality due to recycling is calculated. It is assumed that 1 kg of cullet recycled offsets 1.2 kgs of primary material based on a GaBi dataset for EoL recycling of glass.

[21] https://www.energystar.gov/sites/default/files/buildings/tools/Glass-Guide.pdf

However, because our modeling approach is to apply credits based on the avoided burden of production of the "market mix", which itself already contains cullet, the amount of batch materials credited is corrected by the average recycled glass content of the market mix (here for fiberglass). This is based on statistics from NAIMA[22], shown in the screenshot below, on recycled content in fiberglass production (40-60%), the model uses the median value of 50%.

Comparing Environmental Benefits of Insulation Types

	FiberGlass	Mineral Wool	Spray Foam	Cellulose
Recycled Content	Typically contains 40-60% recycled content, depending on manufacturer and specific facility.	Products vary by makeup. Rock wool insulation contains 10-15% recycled blast furnace slag. Slag wool insulation contains 70-75% recycled blast furnace slag.	As a chemical product, it typically contains very little recycled content.	Generally has significant recycled content of 80% or more.

Glass (recyclingToAggregate)

To model the recycling process itself WIC uses an existing Ecoinvent dataset with modifications. Unlike the two previous recycling scenarios, here the credits are based on substitution of glass cullet for construction aggregate materials (typically limestone gravel).

Glass (recyclingPozzolan)

To model the recycling process itself WIC uses an existing Ecoinvent dataset with modifications. Additionally a process of grinding the glass cullet into a powder is included. In this scenario the credits are based on substitution of ground glass cullet for Portland cement.

Glass (reuse)

In this end of life scenario, glass bottles are collected for reuse. They undergo a washing and sterilization process, which was derived from primary data obtained from Fort George Brewery, as a proxy for bottle washing. Added electricity consumption (a value not provided by FGB) to dataset using data from a bottle washing manufacturer's technical specifications[23].

Inputs	Quantity (per kg of glass)	Unit
Glass bottle	1	kg
Hot water	0.608571	kg
Steam for detergent heating/keg steaming	0.050714	kg
CO_2	0.020286	kg
Sterile/compressed air	0.055786	Nm3
Acid concentrate 50%	1.622857	g
Electricity	0.001853	kWh

22 https://insulationinstitute.org/im-a-building-or-facility-professional/residential/environmental-considerations/
23 http://www.laxmipharmamachines.net/bottle-washing-machine.html

Outputs	Quantity (per kg of glass)	Unit
Wastewater	0.659286	kg
CO2	0.020286	kg
Glass bottle	1	kg

A credit for glass bottle reuse is modeled as the substitution of the glass production model.

Gypsum Wallboard

GypsumWallboard (production)

Drywall/gypsum waste is typically from construction and demolition materials, according to DEQ's material recovery survey. Here in the waste impact calculator an average gypsum board life cycle inventory aggregated by Eurogypsum. The data assumes an average density for gypsum wallboard of 10 kg/m2. This density is used to convert mass inputs to the waste impact calculator appropriately, so that the life cycle inventory can scale.

GypsumWallboard (incinerationNoER)

The incineration of gypsum is not possible to generate electricity, this process is modeled just based on the incineration of an aggregation of inert materials (e.g. glass or metals). This results in emissions and credits, due to the assumption that certain metals ferrous and non-ferrous can be recovered after incineration and recycled. While gypsum often contains a paper layer, it is assumed to be a fractional share of the total mass of the material entering the incinerator and so is ignored.

GypsumWallboard (landfilling)

The modeling of landfilling is based on an average US landfill and representative composition, in this case for inert materials.

GypsumWallboard (recyclingGeneric)

The data used to represent the recycling of gypsum wallboard at the end of life is based on data from Eurogypsum. In incorporates all the steps to process the collected gypsum and recycle it including the energy consumption (electricity and diesel) of crushing, mechanical separation of paper from the gypsum core of plasterboard and fine grinding of gypsum. A material credit for the substitution of gypsum wallboard production is calculated, meaning that the recycling impacts account for secondary production of new gypsum plaster and finished wallboard.   It is assumed that 1 unit recycled offsets 0.92 units of primary material.

High Density Polyethylene

HDPE (production)

This material category is specific, in that it represents production of polymer specific materials. High Density Polyethylene can be used for packaging containers, but also for other applications (e.g.

electronics or automotive). This model represents HDPE in packaging applications and so includes formulation of the polymer into packaging via injection molding.

HDPE (incinerationER)

The incineration of HDPE is modeled using secondary data for the incineration of polyethylene in a waste incineration plant. In practice, single streams of material are not incinerated, instead a blend of municipal solid waste, including various materials are incinerated. The dataset attributes the emissions and credits (thermal and electrical energy) of incineration to the specific material in question, in this case plastics generically.

HDPE (landfilling)

Similar to incineration, landfilling of individual polymer streams is not done in practice. Generally plastics are found mixed into standard municipal solid waste streams. The modeling of landfilling is based on an average US landfill and representative composition, in this case for plastics generically.

HDPE (recyclingGeneric)

The recycling disposition includes the processing of collected HDPE materials and a material credit for the substitution of HDPE granulate, meaning that the recycling impacts account for secondary production of new granulate, but not new HDPE packaging. No decrease in quality due to recycling is calculated. However, loses in quantity are included as part of the recycling process. It is assumed that 1 unit recycled offsets 0.858 units of primary material.

Low Density Polyethylene

LDPE (production)

This material category is specific, in that it represents production of polymer specific materials. Low Density Polyethylene can be used for packaging containers, bags, and films, but also for other applications (e.g. coatings). This model represents LDPE in packaging applications and so includes formulation of the polymer into packaging via an extrusion process.

LDPE (incinerationER)

The incineration of HDPE is modeled using secondary data for the incineration of polyethylene in a waste incineration plant. In practice, single streams of material are not incinerated, instead a blend of municipal solid waste, including various materials are incinerated. The dataset attributes the emissions and credits (thermal and electrical energy) of incineration to the specific material in question, in this case plastics generically.

LDPE (landfilling)

Similar to incineration, landfilling of individual polymer streams is not done in practice. Generally plastics are found mixed into standard municipal solid waste streams. The modeling of landfilling is based on an average US landfill and representative composition, in this case for plastics generically.

LDPE (recyclingGeneric)

The recycling disposition includes the processing of collected LDPE materials and a material credit for the substitution of LDPE granulate, meaning that the recycling impacts account for secondary production of new granulate, but not new LDPE packaging. No decrease in quality due to recycling is calculated. However, loses in quantity are included as part of the recycling process. It is assumed that 1 unit recycled offsets 0.858 units of primary material.

Newsprint

Newsprint (production)

DEQ's material recovery survey defines newsprint as printed ground-wood newsprint (minimally bleached fiber), newspaper inserts referred to as #1 news, and magazines. May include magazine type catalogs. Do not include waste from paper or cardboard mills or large commercial printing operations. These materials are industrial waste not post-consumer recyclables.

The modeling of newsprint in the waste impact calculator is based on secondary data from the Ecoinvent database, for the production of newsprint from virgin sources.

Newsprint (incinerationER)

The incineration of newsprint is modeled using secondary data for the incineration of paper waste in a waste incineration plant. In practice, single streams of material are not incinerated, instead a blend of municipal solid waste, including various materials are incinerated. The dataset attributes the emissions and credits (thermal and electrical energy) of incineration to the specific material in question, in this case paper waste generically. The credits are for 2.35 MJ of electricity and 0.619 MJ of thermal energy per kg of paper waste.

This is the same data and model used for the PaperFiber (incinerationER) disposition. It is applied through the material categories related to paper products.

Newsprint (landfilling)

The modeling of landfilling is based on an average US landfill and representative composition, in this case for paper materials placed in a landfill.

There are credits in the model for the substitution of electricity from the grid and thermal energy production from natural gas, as a result of the material-specific landfill gas generation and capture rates. The credits are for 0.22 MJ of electricity and 0.10 MJ of thermal energy per kg of paper waste.

This is the same data and model as used for the PaperFiber (landfilling) disposition. It is applied throughout the material categories related to paper products.

Newsprint (recyclingGeneric)

Much like the structure of all the other recycling models in the waste impact calculator, newsprint is handled in the same way. The emissions associated with the recycling process are accounted for, as is a credit for the substitution of paper fiber production. In this case, the recycling process is modeled using proxy data for paper production from 100% recycled content. The substitution credit is based on the PaperFiber (production) model described below.

No decrease in quality due to recycling is calculated. And, due to the aggregated nature of the recycling data used, no losses in quantity are included as part of the recycling process. This means that the recycling model results in a generous calculation of the substitution credit.

This model is identical to that of the PaperFiber (recyclingGeneric) model described below.

Nonrecyclables

Nonrecyclables (production)

Because of the ambiguous nature of this category, which is not defined in DEQ's materials recovery survey or waste composition study, this material category is calculated as the straight average of all other production categories in the waste impact calculator.

Nonrecyclables (incinerationER)

The incineration of nonrecycables is represented by secondary data for the incineration of municipal solid waste. The dataset includes both the emissions and credits (thermal and electrical energy) associated with an average mixture of materials in a waste incineration plant.

Nonrecyclables (incinerationNoER)

This model uses the same data as described above. However, the dataset attributes only the emissions associated with incineration and excludes any credits (thermal and electrical energy).

Nonrecyclables (landfilling)

The landfilling of nonrecyclables is modeled using secondary data for average municipal solid waste based on an average US landfill and representative composition.

Paperboard

Paperboard (production)

Paperboard is a common term used to describe paper that is typically of a thicker stock, however the term is somewhat ambiguous. Paperboard, because of this increased thickness, tends to have properties that allow it to be used in different applications, such as folded for boxes or cartons.

To represent this material in the waste impact calculator background data from the American Forest & Paper Association study on the industry average paperboard product was used. This data reflects the industry average amount of post-consumer recycled paper fiber inputs of 0.418 units for every 1 unit of finished paperboard. Similarly, 1.05 units of woodchips are consumed for every unit of finished cardboard produced.

This model also includes the biogenic carbon correction factor sets described in detail above, in the eponymously named biogenic carbon section. In short, these factors augment the flows of biogenic carbon that are associated with harvest from the forest.

Paperboard (incinerationER)

The incineration of newsprint is modeled using secondary data for the incineration of paper waste in a waste incineration plant. In practice, single streams of material are not incinerated, instead a blend of municipal solid waste, including various materials are incinerated. The dataset attributes the emissions and credits (thermal and electrical energy) of incineration to the specific material in question, in this case paper waste generically. The credits are for 2.35 MJ of electricity and 0.619 MJ of thermal energy per kg of paper waste.

This is the same data and model used for the PaperFiber (incinerationER) disposition. It is applied through the material categories related to paper products.

Paperboard (landfilling)

The modeling of landfilling is based on an average US landfill and representative composition, in this case for paper materials placed in a landfill.

There are credits in the model for the substitution of electricity from the grid and thermal energy production from natural gas, as a result of the material-specific landfill gas generation and capture rates. The credits are for 0.22 MJ of electricity and 0.10 MJ of thermal energy per kg of paper waste.

This is the same data and model as used for the PaperFiber (landfilling) disposition. It is applied throughout the material categories related to paper products.

Paperboard (recyclingGeneric)

Much like the structure of all the other recycling models in the waste impact calculator, paper board is handled in the same way. The emissions associated with the recycling process are accounted for, as is a credit for the substitution of paper fiber production. In this case, the recycling process is modeled using proxy data for paper production from 100% recycled content. The substitution credit is based on the PaperFiber (production) model described below.

No decrease in quality due to recycling is calculated. And, due to the aggregated nature of the recycling data used, no losses in quantity are included as part of the recycling process. This means that the recycling model results in a generous calculation of the substitution credit.

This model is identical to that of the PaperFiber (recyclingGeneric) model described below.

Paper Fiber

PaperFiber (production)

The paper fiber model in the waste impact calculator is an amalgamation of multiple background datasets for different paper fibers and types, all from the Ecoinvent database. It includes, an equally weighted proportions of each paper type. The types of paper included in this generic model are:

- Newsprint
- Tissue
- Melamine impregnated paper

- Lightweight coated paper
- Super calendared paper
- Mixed printing and writing paper

This model also includes the biogenic carbon correction factor sets described in detail above, in the eponymously named biogenic carbon section. In short, these factors augment the flows of biogenic carbon that are associated with harvest from the forest.

PaperFiber (incinerationER)

The incineration of newsprint is modeled using secondary data for the incineration of paper waste in a waste incineration plant. In practice, single streams of material are not incinerated, instead a blend of municipal solid waste, including various materials are incinerated. The dataset attributes the emissions and credits (thermal and electrical energy) of incineration to the specific material in question, in this case paper waste generically. The credits are for 2.35 MJ of electricity and 0.619 MJ of thermal energy per kg of paper waste.

This model is the framework for other paper-related incineration with energy recovery material categories in the waste impact calculator, it is applied throughout the tool.

PaperFiber (incinerationNoER)

The incineration of this blended category of plastics is modeled using the same secondary data as described above. However, the dataset attributes only the emissions associated with incineration and excludes any credits (thermal and electrical energy).

PaperFiber (landfilling)

The modeling of landfilling is based on an average US landfill and representative composition, in this case for paper materials placed in a landfill.

There are credits in the model for the substitution of electricity from the grid and thermal energy production from natural gas, as a result of the material-specific landfill gas generation and capture rates. The credits are for 0.22 MJ of electricity and 0.10 MJ of thermal energy per kg of paper waste.

This model is the framework for other paper-related landfilling material categories in the waste impact calculator, it is applied throughout the tool.

PaperFiber (recyclingGeneric)

Much like the structure of all the other recycling models in the waste impact calculator, paper is handled in the same way. The emissions associated with the recycling process are accounted for, as is a credit for the substitution of paper fiber production. In this case, the recycling process is modeled using proxy data for paper production from 100% recycled content. The substitution credit is based on the PaperFiber (production) model described above.

No decrease in quality due to recycling is calculated. And, due to the aggregated nature of the recycling data used, no losses in quantity are included as part of the recycling process. This means that the recycling model results in a generous calculation of the substitution credit.

Polyethylene Terephthalate

PET (production)

Polyethylene Terephthalate is a common polymer for packaging materials, predominantly for applications in beverage containers, but also can be for other applications (e.g. coatings, textiles, apparel, and other). This material category is specific, in that it represents production of polymer specific materials. This model represents PET in packaging applications and so includes formulation of the polymer into packaging via an injection molding process.

PET (incinerationER)

The incineration of PET is modeled using secondary data for the incineration of polyethylene terephthalate in a waste incineration plant. In practice, single streams of material are not incinerated, instead a blend of municipal solid waste, including various materials are incinerated. The dataset attributes the emissions and credits (thermal and electrical energy) of incineration to the specific material in question, in this case PET.

PET (landfilling)

Similar to incineration, landfilling of individual polymer streams is not done in practice. Generally plastics are found mixed into standard municipal solid waste streams. The modeling of landfilling is based on an average US landfill and representative composition, in this case for plastics generically.

PET (recyclingGeneric)

The recycling disposition includes the processing of collected PET materials and a material credit for the substitution of bottle grade PET granulate, meaning that the recycling impacts account for secondary production of new granulate, but not new PET packaging. No decrease in quality due to recycling is calculated. However, loses in quantity are included as part of the recycling process. It is assumed that 1 unit recycled offsets 0.858 units of primary material.

Plastic Film

PlasticFilm (production)

Oregon's material recovery survey deems plastic film to be plastic bags, sheeting, and shrink wrap. The most common material used to produce plastic film is Low Density Polyethylene. This model represents LDPE in film-based applications and so includes formulation of the polymer into packaging via an extrusion process.

PlasticFilm (incinerationER)

The incineration of LDPE is modeled using secondary data for the incineration of generic plastic waste in a waste incineration plant. In practice, single streams of material are not incinerated, instead a blend of municipal solid waste, including various materials are incinerated. The dataset attributes the emissions and credits (thermal and electrical energy) of incineration to the specific material in question, in this case plastic waste generically.

PlasticFilm (incinerationNoER)

The incineration of this blended category of plastics is modeled using the same secondary data as described above. However, the dataset attributes only the emissions associated with incineration and excludes any credits (thermal and electrical energy).

PlasticFilm (landfilling)

Similar to incineration, landfilling of individual polymer streams is not done in practice. Generally plastics are found mixed into standard municipal solid waste streams. The modeling of landfilling is based on an average US landfill and representative composition, in this case for plastics generically.

PlasticFilm (recyclingGeneric)

The recycling disposition includes the processing of collected LDPE film materials and a material credit for the substitution of LDPE granulate, meaning that the recycling impacts account for secondary production of new granulate, but not new LDPE flim packaging. No decrease in quality due to recycling is calculated. However, loses in quantity are included as part of the recycling process. It is assumed that 1 unit recycled offsets 0.858 units of primary material.

Plastic Other

PlasticOther (production)

This category is a catch-all from Oregon DEQ's material recovery survey defined as plastic products and plastic totes and pallets, excluding polyurethane foam (CP). Because of the ambiguous nature of this material category, it is represented in the waste impact calculator using the same data as the Rigid Plastics category.

As described below, the waste impact calculator models rigid plastic as a blend of three of the most common polymers for plastic packaging containers – high density polyethylene, polypropylene, and polyethylene terephthalate. The proportion of each polymer in the rigid plastics category is split evenly, for lack of primary data, as follows:

- HDPE 33% - based on "HDPE (production)" model described above
- PP 33% - based on "PP (production)" model described above
- PET 34% - based on "PET (production)" model described above

PlasticOther (incinerationER)

The incineration of this blended category of plastics is modeled using secondary data for the incineration of mixed plastics in a waste incineration plant. The dataset attributes the emissions and credits (thermal and electrical energy) of incineration to the specific material in question, in this case plastics generically.

PlasticOther (incinerationNoER)

The incineration of this blended category of plastics is modeled using the same secondary data as described above. However, the dataset attributes only the emissions associated with incineration and excludes any credits (thermal and electrical energy).

PlasticOther (landfilling)

Similar to incineration, landfilling of individual polymer streams is not done in practice. Generally plastics are found mixed into standard municipal solid waste streams. The modeling of landfilling is based on an average US landfill and representative composition, in this case for plastics generically.

PlasticOther (recyclingGeneric)

The recycling disposition includes the processing of collected mixed plastic materials and a material credit for the substitution of the "RigidPlastic (production)" model described below, meaning that the recycling impacts account for secondary production of new granulate and packaging. No decrease in quality due to recycling is calculated. However, loses in quantity are included as part of the recycling process. It is assumed that 1 unit recycled offsets 0.858 units of primary material.

Polypropylene

PP (production)

Polypropylene is a common polymer for packaging materials, but also can be for other applications (e.g. coatings, textiles, apparel, electronics, and automotive). This material category is specific, in that it represents production of polymer specific materials. This model represents PP in packaging applications and so includes formulation of the polymer into packaging via an injection molding process.

PP (incinerationER)

The incineration of PP is modeled using secondary data for the incineration of polypropylene in a waste incineration plant. In practice, single streams of material are not incinerated, instead a blend of municipal solid waste, including various materials are incinerated. The dataset attributes the emissions and credits (thermal and electrical energy) of incineration to the specific material in question, in this case PP specifically.

PP (landfilling)

Similar to incineration, landfilling of individual polymer streams is not done in practice. Generally plastics are found mixed into standard municipal solid waste streams. The modeling of landfilling is based on an average US landfill and representative composition, in this case for plastics generically.

PP (recyclingGeneric)

The recycling disposition includes the processing of collected PP materials and a material credit for the substitution of PP granulate, meaning that the recycling impacts account for secondary production of new granulate, but not new PP packaging. No decrease in quality due to recycling is calculated. However, loses in quantity are included as part of the recycling process. It is assumed that 1 unit recycled offsets 0.858 units of primary material.

Printing and Writing Paper

PrintingWritingPaper (production)

The printing and writing paper model of the waste impact calculator is an mixture of multiple background datasets for different paper fibers and types, all from the Ecoinvent database. It includes, an equally weighted proportions of each paper type. The types of paper included in this generic model are:

- Coated Wood Free (e.g. bleached)
- Uncoated Wood Free (e.g. bleached)

This model also includes the biogenic carbon correction factor sets described in detail above, in the eponymously named biogenic carbon section. In short, these factors augment the flows of biogenic carbon that are associated with harvest from the forest.

PrintingWritingPaper (incinerationER)

The incineration of newsprint is modeled using secondary data for the incineration of paper waste in a waste incineration plant. In practice, single streams of material are not incinerated, instead a blend of municipal solid waste, including various materials are incinerated. The dataset attributes the emissions and credits (thermal and electrical energy) of incineration to the specific material in question, in this case paper waste generically. The credits are for 2.35 MJ of electricity and 0.619 MJ of thermal energy per kg of paper waste.

This is the same data and model used for the PaperFiber (incinerationER) disposition. It is applied through the material categories related to paper products.

PrintingWritingPaper (landfilling)

The modeling of landfilling is based on an average US landfill and representative composition, in this case for paper materials placed in a landfill.

There are credits in the model for the substitution of electricity from the grid and thermal energy production from natural gas, as a result of the material-specific landfill gas generation and capture rates. The credits are for 0.22 MJ of electricity and 0.10 MJ of thermal energy per kg of paper waste.

This is the same data and model as used for the PaperFiber (landfilling) disposition. It is applied throughout the material categories related to paper products.

PrintingWritingPaper (recyclingGeneric)

Much like the structure of all the other recycling models in the waste impact calculator, printing and writing paper is handled in the same way. The emissions associated with the recycling process are accounted for, as is a credit for the substitution of paper fiber production. In this case, the recycling process is modeled using proxy data for paper production from 100% recycled content. The substitution credit is based on the PaperFiber (production) model described below.

No decrease in quality due to recycling is calculated. And, due to the aggregated nature of the recycling data used, no losses in quantity are included as part of the recycling process. This means that the recycling model results in a generous calculation of the substitution credit.

This model is identical to that of the PaperFiber (recyclingGeneric) model described below.

Polystyrene

PS (production)

Polystyrene is used for packaging materials and food serviceware, but also can be for other applications. It can be treated with various production processes, but is commonly injection molded, vacuum formed, or extruded. This model represents PS in packaging applications and so includes formulation of the polymer into packaging via an injection molding process. It is also distinct from expanded polystyrene, also known as “Styrafoam,” which is perhaps the most well know use of polystyrene.

PS (incinerationER)

The incineration of PS is modeled using secondary data for the incineration of polystyrene in a waste incineration plant. In practice, single streams of material are not incinerated, instead a blend of municipal solid waste, including various materials are incinerated. The dataset attributes the emissions and credits (thermal and electrical energy) of incineration to the specific material in question, in this case PS specifically.

PS (landfilling)

Similar to incineration, landfilling of individual polymer streams is not done in practice. Generally plastics are found mixed into standard municipal solid waste streams. The modeling of landfilling is based on an average US landfill and representative composition, in this case for plastics generically.

PS (recyclingGeneric)

The recycling disposition includes the processing of collected PS materials and a material credit for the substitution of PS granulate, meaning that the recycling impacts account for secondary production of new granulate, but not new PS packaging. No decrease in quality due to recycling is calculated. However, loses in quantity are included as part of the recycling process. It is assumed that 1 unit recycled offsets 0.858 units of primary material.

Rigid Plastic

RigidPlastic (production)

DEQ’s material recovery survey defines this category as any container made predominantly of plastic resin that is capable of maintaining its shape while holding a minimum of eight ounces and a maximum of five gallons. Excludes film plastic (PF) and plastic products such as toys (PO).

The waste impact calculator models rigid plastic as a blend of three of the most common polymers for plastic packaging containers – high density polyethylene, polypropylene, and polyethylene terephthalate. The proportion of each polymer in the rigid plastics category is split evenly, for lack of primary data, as follows:

- HDPE 33% - based on “HDPE (production)” model described above
- PP 33% - based on “PP (production)” model described above

- PET 34% - based on "PET (production)" model described above

RigidPlastic (incinerationER)

The incineration of this blended category of plastics is modeled using secondary data for the incineration of mixed plastics in a waste incineration plant. The dataset attributes the emissions and credits (thermal and electrical energy) of incineration to the specific material in question, in this case plastics generically.

RigidPlastic (incinerationNoER)

The incineration of this blended category of plastics is modeled using the same secondary data as described above. However, the dataset attributes only the emissions associated with incineration and excludes any credits (thermal and electrical energy).

RigidPlastic (landfilling)

Similar to incineration, landfilling of individual polymer streams is not done in practice. Generally plastics are found mixed into standard municipal solid waste streams. The modeling of landfilling is based on an average US landfill and representative composition, in this case for plastics generically.

RigidPlastic (recyclingGeneric)

The recycling disposition includes the processing of collected mixed plastic materials and a material credit for the substitution of the "RigidPlastic (production)" model described above, meaning that the recycling impacts account for secondary production of new granulate and packaging. No decrease in quality due to recycling is calculated. However, loses in quantity are included as part of the recycling process. It is assumed that 1 unit recycled offsets 0.858 units of primary material.

Scrap Metal

ScrapMetal (production)

DEQ's material recovery survey defines this category as appliances (e.g., discarded stoves, washers, dryers, refrigerators, and other large household appliances or "white goods") and all other non-industrial scrap metal. As such, scrap metal can represent a mix of various types, predominantly steel, but also including aluminum, copper, and other trace amounts of different metals. DEQ's waste composition study was used to estimate the mix as:

- Steel 72% - based on "AcceptedOtherSteel" model
- Aluminum 14% - based on "Aluminum" model
- Copper 14% - based on global average copper data from GaBi

ScrapMetal (incinerationNoER)

Since the incineration of scrap metal is not possible to generate electricity, this process is modeled just based on the incineration of an aggregation of inert ferrous materials (e.g. steel). This results in emissions and credits, due to the assumption that certain metals ferrous and non-ferrous can be recovered after incineration and recycled.

ScrapMetal (landfilling)

This model represents deposition of the specified waste material type, in this case mixed ferrous metals, to an average U.S. MSW landfill. The dataset represents the inputs and outputs of the landfill as a function of the composition of the material placed in it.

ScrapMetal (recyclingGeneric)

The recycling credits of steel are based on Worldsteel data. The "value of scrap" is calculated on the basis of the steel product cradle-to-gate LCIs.

Textiles

Textiles (production)

Textiles are derived from many different materials, both synthetic and natural (e.g. plant or animal). As such this material category represents an amalgam of different fibers. DEQ's material recovery survey defines this category as used clothing and other cloth goods that are recycled for use as rags, wiping cloths, etc. and the category does not include clothing collected for resale in thrift stores or other reuse.

Data from the Textile Exchanges' 2019 Preferred Fiber & Materials Market Report[24] provides details on the total fiber production share in 2018. The majority of textile fiber production (~80%), for which life cycle inventory data were available, where for Polyester, Cotton, and Polyamide (nylon). The table below illustrates the basis for the adjusted proportions of these fibers, that factor into the average emissions of textile production in the waste impact calculator.

Table 10 - Textile Fiber Production Share in 2018

Fiber	Share (%)	Quantity	Unit	Adjusted Share (%)
Polyester	51.5	55.105	mmt	64%
Cotton	24.4	26.108	mmt	30%
Nylon	5	5.35	mmt	6%
TOTAL		107	mmt	

Textiles (incinerationER)

The incineration of textiles is modeled in the waste impact calculator using secondary data for textile waste treated in a waste incineration plant. The dataset attributes the emissions and credits (thermal and electrical energy) of incineration to the specific material in question, in this case textiles. The net calorific heat value of the waste is 21 MJ/kg based on an average for textile waste.

Textiles (incinerationNoER)

The incineration of textiles is modeled using the same secondary data as described above. However, the dataset attributes only the emissions associated with incineration and excludes any credits (thermal and electrical energy).

[24] https://textileexchange.org/wp-content/uploads/2019/11/Textile-Exchange_Preferred-Fiber-Material-Market-Report_2019.pdf

Textiles (landfilling)

Here textile waste is modeled using an average U.S. MSW landfill, customized for the specific material in question. The dataset represents the inputs and outputs of the landfill as a function of the composition of the material placed in it.

There are credits in the model for the substitution of electricity from the grid and thermal energy production from natural gas, as a result of the material-specific landfill gas generation and capture rates.

Textiles (recyclingGeneric)

The recycling disposition includes the processing of collected mixed synthetic textile materials (Polyamide and Polyester), but currently lacks data for processing of cotton due to lack of data. Additionally, the model includes a material credit for the substitution of the material production for PET fibers, Nylon fibers, and cotton fibers meaning that the recycling impacts account for secondary production of new fibers, but not new textiles. No decrease in quality due to recycling is calculated. However, loses in quantity are included as part of the recycling process. For the synthetic fibers, it is assumed that 1 unit recycled offsets 0.858 units of primary material.

Tinned Can

TinnedCan (production)

This material category, according to DEQ's material recovery survey, represents steel food and beverage cans, including uncoated cans and cans with tin and other coatings. It is modeled in the waste impact calculator using global average aggregate data on tinned can production from Worldsteel.

TinnedCan (incinerationNoER)

Since the incineration of tinned cans is not possible to generate electricity, this process is modeled just based on the incineration of an aggregation of inert ferrous materials (e.g. steel). This results in emissions and credits, due to the assumption that certain metals ferrous and non-ferrous can be recovered after incineration and recycled.

TinnedCan (landfilling)

This model represents deposition of the specified waste material type, in this case mixed ferrous metals, to an average U.S. MSW landfill. The dataset represents the inputs and outputs of the landfill as a function of the composition of the material placed in it.

TinnedCan (recyclingGeneric)

The recycling credits of steel are based on Worldsteel data. The "value of scrap" is calculated on the basis of the steel product cradle-to-gate LCIs.

Wood

Wood (production)

Wood is used in varying ways. It can be burned as fuel, converted into pulp for paper production, or milled into solid wood products. This category of the waste impact calculator represents that final use, in dimensional lumber and engineered woods products. Of course there is a great degree of variability in the types of wood building products and so this model approximates that variability by blending different background life cycle inventories. To approximate wood, an equally weighted mix of the following wood products is used:

- Softwood Lumber
- Hardwood Lumber (based on White Oak)
- Plywood
- Other Engineered Wood (Particle Board, Glulam, OSB, Laminated Vaneer Lumber, and MDF)

All the background data for wood products comes from the Consortium for Research on Renewable Industrial Materials (CORRIM) life cycle inventories[25], except for data for hardwood lumber, which comes from the American Hardwood Export Council (AHEC) life cycle inventories. The datasets used represent typical/average boundary conditions for these various wood products.

The biogenic carbon associated with forestry and end of life disposition is included, along with correction factors, described in detail in the Biogenic Carbon section above. This material category is one, along with the paper categories, where the results including biogenic carbon and the correction factors should be considered along with results excluding biogenic carbon. The assumption of biogenic carbon neutrality for long-lived wood products oversimplifies changes that occur in the forest (landscape level) and at end of life (depending on disposition).

Wood (composting)

Composting of wood is modeled using secondary (background) data from GaBi and is based on an open windrow composting process. This composting process was found to be the most common technology for composting of organic materials here in Oregon, based on a survey of composters in Oregon. Credits are calculated based on the nutrient supply, in terms of N-P-K, from biowaste.

Additionally, a soil carbon storage credit (input), based on a study[26] commissioned by Oregon DEQ and carried out by Jeff Morris of Sound Resources is included for soil carbon storage due to application of the compost. The credit is defined as -0.12 kg CO_2 / kg of waste (e.g. biowaste).

Wood (incinerationER)

The incineration of wood is modeled in the waste impact calculator based on an assumed composition of 50 percent treated and 50 percent untreated wood material. The secondary data used for incineration are based on two inventories, one for untreated wood and a second for OSB particle board (as a proxy for all engineered/treated wood) in a waste incineration plant. The datasets attribute the emissions and credits (thermal and electrical energy) of incineration to the specific material in question, in this case wood waste.

Wood (landfilling)

As described above in the incineration section, the landfilling process splits the wood waste into two equal streams. This model represents deposition of the specified waste material type, in this case 50

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25 https://corrim.org/latest-reports/
26 Food Waste Study - http://www.oregon.gov/deq/FilterDocs/FoodWasteStudyReport.pdf

percent untreated wood and 50 percent treated wood, to an average U.S. MSW landfill. The dataset represents the inputs and outputs of the landfill as a function of the composition of the material placed in it.

There are credits in the model for the substitution of electricity from the grid and thermal energy production from natural gas, as a result of the material-specific landfill gas generation and capture rates

Wood (reuse)

Wood reuse is an emerging practice whereby dimensional lumber is recovered from an existing structure and then de-nailed, sorted, and resold for direct reuse in construction. The City of Portland, Oregon has adopted rules that require deconstruction of certain homes (based on their age)[27] and other jurisdictions in Oregon have followed suit with similar rules. To model wood reuse for the waste impact calculator the following steps are included: deconstruction practices at the site (mostly manual), sorting (manual), disposal of deconstructed by unusable lumber, transport of workers to the site, transport of recovered lumber to retail, and substitution of primary production of lumber from forests.

In 2019, DEQ studied deconstruction practices and collected data from real deconstruction projects in the City of Portland.[28] The following assumptions are included in this reuse model are based on the findings of that research:

- Deconstruction practices are mostly manual, using hand tools. So no electricity or fuel use associated with power tools are included in the model. One popular electric tool – de-nailing guns were excluded from the analysis.
- Transport to the work site is included and based on Table 8 divided by total pounds of wood salvaged per average home in Figure 5 in the aforementioned DEQ report on deconstruction (see footnote below). This results in 250 miles by passenger car for each short ton of wood recovered.
- Yield losses are estimated at 15% (e.g. for every 1 ton of wood in a home, 0.85 tons are suitable for reuse).
- The transport modes/distances for material recovery per unit of wood are based on the "deconstruction of recoverable wood" data in Table 7 and normalized per unit of wood (mass) recovered from Figure 5 in the aforementioned DEQ report on deconstruction (see footnote below). This results in 114 miles via class 8b truck.
- Disposition of wood that is recovered by not suitable for reuse are based on the “recoverable wood” data of Table 4 in the aforementioned DEQ report on deconstruction (see footnote below).
- Biogenic carbon fluxes follow the same assumptions and calculations described in the section of this reported on Biogenic Carbon.

Wood is that recovered and suitable for reuse is substituted for primary wood production, following the embodied burdens approach. A credit is given based on the wood_production_production model, described above, with one modification (a correction factor) to the wood_production_production model. This correction factor reflects the reality of what happens when lumber is reused. Not only is there a

[27] City of Portland – Deconstruction Rules - https://www.portland.gov/bps/decon/deconstruction-requirements
[28] Oregon DEQ – Deconstruction vs. Demolition - https://www.oregon.gov/deq/FilterDocs/DeconstructionReport.pdf

substitution of primary wood production (e.g. all fossil carbon emissions), but additionally since the forest is left intact (e.g. not harvested) then the biogenic carbon sequestration still occurs (even though no wood products are harvested from the forest). Mathematically, when subtracting an inventory for wood production, a negative input (e.g. a burden) of carbon dioxide occurs. To correct for this mathematical phenomenon a correction factor of -2.77kg of biogenic CO2/kg is used. It represents the amount of CO2 sequestered per kg of wood produced.

Yard Debris

YardDebris (production)

Yard debris includes pruning, bulky woody yard waste, leaves, grass clippings, and Christmas trees, as defined by DEQ's materials recovery survey. This type of organic waste emanates from residential sources. Unlike the other materials in the waste impact calculator, yard debris does not follow an industrial production process. The upstream "production" impacts of yard debris, therefore, are estimates based on the typical lawn and garden care activities such as energy use (e.g. mowing), water use, fertilizer demand, and pesticide application. Water use is further differentiated based on the amount that evaporates (estimated at 3%) and the amount that is applied but returns to groundwater.[29] The inventory below is based on three data sources[30] [31] [32]and estimates the inputs and outputs of lawn and garden care resulting in the "production" of yard debris.

Table 11 - Estimated Inputs and Outputs of Lawn and Garden Care

Inputs		Quantities	Amount	Units
	Fertilizer	Mass	36287762	kg
	mowing, by motor mower	Area	1.62E+11	sqm
	Pesticide	Mass	40823732	kg
	Water	Mass	1.1E+13	kg
Outputs				
		Quantities	Amount	Units
	Lawn and Garden	Mass	1.28E+11	kg
	Yard Debris	Mass	3.19E+10	kg

The fertilizer composition is based on a (10-5-5) N-P-K mix and the pesticide input is generic.

YardDebris (anaerobicDigestion)

The anaerobic digestion of yard debris is modeled using secondary (background) data from Ecoinvent and is based on the operation of an anaerobic digester for biowaste. Credits are calculated based on the nutrient supply, in terms of N-P-K, from biowaste (derived from compost), as a proxy, since nutrient

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[29] Evaporation of water from sprinkers - https://edis.ifas.ufl.edu/pdffiles/AE/AE04800.pdf
[30] Pesticide composition - https://www.epa.gov/sites/production/files/2017-01/documents/pesticides-industry-sales-usage-2016_0.pdf
[31] Fertilizer, Pesticide, and Fuel use - https://www.deep-roots-project.org/pesticides-toxic-fertilizers
32 Water Use - https://pubs.usgs.gov/circ/1441/circ1441.pdf

supply for digester sludge was not available. Anaerobic digestion also leads to the generation of methane and so a proportionate credit is granted for the substitution of the US average natural gas mix.

Additionally, a credit (input), based on a study[33] commissioned by Oregon DEQ and carried out by Jeff Morris of Sound Resources is included for soil carbon storage due to application of the digestate. The credit is defined as -0.08 kg CO2 / kg of waste (e.g. biowaste).

YardDebris (composting)

Composting of yard debris is modeled using secondary (background) data from GaBi and is based on an open windrow composting process. This composting process was found to be the most common technology for composting of organic materials here in Oregon, based on a survey of composters in Oregon. Credits are calculated based on the nutrient supply, in terms of N-P-K, from biowaste.

Additionally, a soil carbon storage credit (input), based on a study[34] commissioned by Oregon DEQ and carried out by Jeff Morris of Sound Resources is included for soil carbon storage due to application of the compost. The credit is defined as -0.12 kg CO2 / kg of waste (e.g. biowaste).

YardDebris (incinerationER)

The incineration of yard debris is modeled in the waste impact calculator based on an assumed composition of 50 percent woody material and 50 percent non-woody organic material (e.g. grass clippings, leaves, or stalks). The exact composition of yard debris is variable across regions and residential properties. The secondary data used for incineration are based on two inventories, one for wood and a second for biodegradable waste in a waste incineration plant. The datasets attribute the emissions and credits (thermal and electrical energy) of incineration to the specific material in question, in this case yard debris.

YardDebris (incinerationNoER)

The incineration of yard debris is modeled using the same secondary data as described above. However, the dataset attributes only the emissions associated with incineration and excludes any credits (thermal and electrical energy).

YardDebris (landfilling)

Following the same ratio for the composition of yard debris, as described above in the incineration section, the landfilling process splits the yard debris into two equal streams. This model represents deposition of the specified waste material type, in this case 50 percent untreated wood and 50 percent biodegradable waste, to an average U.S. MSW landfill. The dataset represents the inputs and outputs of the landfill as a function of the composition of the material placed in it.

There are credits in the model for the substitution of electricity from the grid and thermal energy production from natural gas, as a result of the material-specific landfill gas generation and capture rates.

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33 Food Waste Study - http://www.oregon.gov/deq/FilterDocs/FoodWasteStudyReport.pdf

34 Food Waste Study - http://www.oregon.gov/deq/FilterDocs/FoodWasteStudyReport.pdf

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http://www.gpi.org/recycling/glass-recycling-facts (has claim about co2 savings of glass recycling, 1 ton CO2e / 6 tons of glass recycled)

http://www.gpi.org/sites/default/files/N-American_Glass_Container_LCA.pdf

https://www.energystar.gov/sites/default/files/buildings/tools/Glass-Guide.pdf

a. Jeff Morris Study – best resource http://www.oregon.gov/deq/FilterDocs/FoodWasteStudyReport.pdf
b. WARM – Composting documentation (v13 - superseded) https://www3.epa.gov/warm/pdfs/Composting.pdf
c. WARM – organics documentation (v14) https://www.epa.gov/sites/production/files/2016-03/documents/warm_v14_organic_materials.pdf

ii. Some sources for benefits of compost application
   1. http://www.epa.nsw.gov.au/resources/waste/110171-compost-climate-change.pdf
   2. https://link.springer.com/article/10.1007%2Fs10021-013-9660-5

Glossary

Avoided burden approach

A method of recycling allocation, also referred to as system expansion, 0/100, or End-of-life recycling, whereby a share of the burden of primary material production is allocated to the subsequent life cycle based on the quantity of recovered secondary material. The result is an environmental credit at end of life.

Allocation

"Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems" (ISO 14040:2006, section 3.17).

Background (secondary) data

Data taken from generic or average life cycle inventories for the energy and materials. Can be upstream or downstream in the life cycle. The opposite of primary data.

Background system

"Those processes, where due to the averaging effect across the suppliers, a homogenous market with average (or equivalent, generic data) can be assumed to appropriately represent the respective process … and/or those processes that are operated as part of the system but that are not under direct control or decisive influence of the producer of the good…." (JRC 2010, pp. 97-98) As a general rule, secondary data are appropriate for the background system, particularly where primary data are difficult to collect.

Closed-loop and open-loop allocation of recycled material

"An open-loop allocation procedure applies to open-loop product systems where the material is recycled into other product systems and the material undergoes a change to its inherent properties."

"A closed-loop allocation procedure applies to closed-loop product systems. It also applies to open-loop product systems where no changes occur in the inherent properties of the recycled material. In such cases, the need for allocation is avoided since the use of secondary material displaces the use of virgin (primary) materials." (ISO 14044:2006, section 4.3.4.3.3).

Co-products

"Any of two or more products coming from the same unit process or product system." (ISO 14040:2006, section 3.10).

Cradle-to-gate

System boundary delineation from raw material extraction through to the so-called "gate" of the manufacturing facility, including upstream energy and material production, all associated transport, and on-site manufacturing.

Cradle-to-grave

System boundary delineation covering the entire product life cycle, from raw material extraction to end of life. This generally includes everything in the cradle-to-gate system boundaries plus the installation, use, and EoL disposition (e.g., landfill, recycling, composting, or incineration) stages of the product or system.

Cradle-to-cradle

A system boundary delineation that is the same as cradle-to-grave, but implies a specific fate (reuse or recycling) at end of life.

Cut-off approach

A method of recycling allocation in which the burden of the primary production is attributed to the first life cycle and the burden associated with secondary material recovery and refining is attributed to the subsequent life cycle.

Declared Unit

The quantity of a product used as the base unit for an environmental impact assessment. It is commonly used in lieu of a functional unit when the function of the of the system cannot be defined due to the exclusion of the use stage of the life cycle.

Foreground system

"Those processes of the system that are specific to it … and/or directly affected by decisions analyzed in the study." (JRC 2010, p. 97) This typically includes first-tier suppliers, the manufacturer itself and any downstream life cycle stages where the manufacturer can exert significant influence. As a general rule, specific (primary) data should be used for the foreground system.

Functional unit

"Quantified performance of a product system for use as a reference unit" (ISO 14040:2006, section 3.20).

GaBi

Life cycle assessment software and databases developed and distributed by Sphera, Inc.

Gate-to-grave

System boundary delineation covering one or more processes through to end of life. While the initial gate can vary, this generally includes everything after the cradle-to-gate boundary such as use, maintenance, and EoL disposition (e.g., landfill, recycling, composting, or incineration) stages of the product or system.

Human health endpoint

Disease symptom or related marker of a health impact on a human or other being, e.g., cancer or reproductive toxicity.

Impact assessment category

A “class representing environmental issues of concern to which life cycle inventory analysis results may be assigned.” (ISO 14040:2006, section 3.39).

Life cycle

A holistic view of a product or system as “consecutive and interlinked stages … from raw material acquisition or generation from natural resources to final disposal” (ISO 14040:2006, section 3.1).

Life Cycle Assessment (LCA)

“Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle” (ISO 14040:2006, section 3.2).

Life Cycle Inventory (LCI)

“Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle” (ISO 14040:2006, section 3.3).

Life Cycle Impact Assessment (LCIA)

“Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product” (ISO 14040:2006, section 3.4).

Life cycle interpretation

“Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations” (ISO 14040:2006, section 3.5).

Primary data

Data collected directly from a manufacturer, producer, vendor, or process operators often through process flow diagrams, financial or emissions reporting data, equipment specifications, or bills of material.

Appendix A: Life cycle inventories and other data sources

See companion spreadsheet, *Appendix-A-WasteImpactCalculatorMasterDataList.xlsx*.

Appendix B: References related to logging slash

The quantity of logging slash in various sources: a compendium (updated 4/2/2020)

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Source	***Estimate***	***Notes***
Table 40 of big Forest Service report, *Forest Resources of the United States*[35]	20% of harvested volume is left as "logging residue" in the field, for the united states: 3.7/18.2 thousand cubic feet=20%. Also 20% for Pacific Northwest.	Does not include stumps or limbs (i.e. the slash counted here is mostly tops and small trees that were innocent bystanders). If you add an extra correction for stumps and limbs (see below) it comes out to about 24%.
McKeever and Falk[36]	Roughly 30% of harvested volume is residue left in the field, because to the traditional measurement of residue (say 25%) you should add 14-24% *of that* to account for stumps and limbs	Agrees well with my back-of-the-envelope Oregon calculation (below).
Wilderness Society report[37]	40% of harvested volume is residue in the field. Range of 22-59%.	Draws on McKeever and Falk (see above)
Sierra Club glossy report	Based on Wilderness Society Report	
Nurmi and Raisanen[38]	39-69% of harvested wood is not useful as logs	Scandanavian study.. Species are different than in PNW
Hudiberg et al.[39]	"up to 40% of harvested wood does not become a product"	This includes some stuff combusted later which would be in our "technospheric" impacts.
Informal calculation for commercial private lands based on Oregon Forest	Residue could be 13%, but that does not include material in slash piles. Harvest of 22.9MMTCO2E, dead	Commercial private lands in the inventory have lost a relatively large amount of carbon in the dead woody

[35] Sonja N Oswalt et al., "Forest Resources of the United States, 2017," General Technical Report (US Department of Agriculture, Forest Service, 2019), https://www.fs.fed.us/research/publications/gtr/gtr_wo97.pdf.
[36] David B. McKeever and Robert H. Falk, "Woody Residues and Solid Waste Wood Available for Recovery in the United States, 2002," *European COST E31 Conference : Management of Recovered Wood Recycling Bioenergy and Other Options : Proceedings, 22-24 April 2004, Thessaloniki. Thessaloniki : University Studio Press, 2004: Pages 307-316.*, 2004, https://www.fs.usda.gov/treesearch/pubs/7113.
[37] Ann Ingerson, "Wood Products and Carbon Storage: Can Increased Production Help Solve the Climate Crisis?" (The Wilderness Society, 2009), https://www.sierraforestlegacy.org/Resources/Conservation/FireForestEcology/ThreatsForestHealth/Climate/CI-Ingerson-TWS2009.pdf.
[38] Tommi Räisänen and Juha Nurmi, "Impacts of Changing the Minimum Diameter of Roundwood on the Accumulation of Logging Residue in First Thinnings of Scots Pine and Norway Spruce," *Biomass and Bioenergy* 35, no. 7 (July 2011): 2674–82, https://doi.org/10.1016/j.biombioe.2011.03.002.
[39] Tara W. Hudiburg et al., "Meeting GHG Reduction Targets Requires Accounting for All Forest Sector Emissions," *Environmental Research Letters* 14, no. 9 (August 2019): 095005, https://doi.org/10.1088/1748-9326/ab28bb.

Source	***Estimate***	***Notes***
Ecosystem carbon inventory[40]	wood loss 3.4 in same time period. 3.4/(22.9+3.4)=13%.	debris pool. However, the inventory's methods don't include counting slash piles, so this is a low number. According to Yost (personal communication) the Oregon inventory basically includes slash in the harvest number.
Back-of-the-envelope calculation based on the Oregon Forest Ecosystem Carbon Inventory[41] and the slideshow "Oregon Forest Ecosystem Carbon Report"[42]	31% over the whole state of Oregon. Gross growth of 90 MMTCO2E per year. 35 of that is lost to harvest. Meanwhile, about 6.5 metric tons carbon, or 6.5*44/12=24MMTCO2E show up in products. 35-24=11. 11/35 is 31%.	It's remarkable how well this completely empirical estimate based on diverse sources aligns with the other figures. However note that not all of the wood products Oregonians use come from Oregon wood.

40 Glenn A Christensen et al., "Oregon Forest Ecosystem Carbon Inventory: 2001-2016," n.d., 347.
41 Ibid.
42 US Forest Service Inventory and Analysis, "Oregon Forest Ecosystem Carbon Report [on Carbon Stored in Timber Products]," https://www.oregon.gov/odf/ForestBenefits/Documents/Forest%20Carbon%20Study/BOF-20190907-Carbon-Report.pdf.