SimaPro 7

Database Manual

The Franklin US LCI 98 library

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1 Franklin US LCI Database

1.1 Introduction

This chapter summarizes the Franklin US LCI Database and can also be found in the SimaPro system descriptions in the Franklin library. It consists of life cycle inventory (LCI) data based upon experience of companies operating in the USA, statistical and literature sources.
Apart from a general description, the following system descriptions are included:

Commodity Fuel and Electricity Systems

Primary Fuel Production and Combustion (utility boilers, industrial boilers, mobile sources) of

- Coal
- Natural gas
- Petroleum Fuels
- Nuclear Fuel
- Liquefied Petroleum Gases
- Wood Wastes

Energy for Transportation
Energy Sources for Electricity Generation (composite kilowatt-hour)

Materials

Steel

- Basic oxygen furnace - sheet products (cans)
- Electric arc furnace (uses scrap steel)- sheet product
- Grey cast iron - automobile parts

Aluminum products - sheet products (beverage cans)
Plastics

- LDPE - (low density polyethylene) - film (trash bags, food packaging)
- HDPE (high density polyethylene)- milk bottles
- LLDPE - (linear low density polyethylene) - food wrap
- PP (polypropylene) – container closures
- PET (thermoplastic polyethylene terephthalate) - beverage or liquid food bottles
- GPPS (general purpose polystyrene) - clear drink cups
- EPS (expanded polystyrene) - foam packaging
- HIPS (high impact polystyrene) -drink cups
- PVC (polyvinyl chloride) - fluid containers

SBR rubber - rubber crumb
Natural rubber - rubber crumb
Paper and paperboard

- newsprint - as formulated in the USA
- bleached kraft products - bleached paperboard products
- tissue - paper towels
- unbleached kraft products – paper or paperboard products
- semichemical paperboard - corrugating medium
- corrugated boxes - shipping containers
- recycled paperboard - combination boxboard

Glass containers - beverage bottles

1.2 System descriptions

1.1.1 General System description

Description:

Each inventory table contains LCI information about the total life cycle system leading to the manufacture and use of a product.

- amounts of raw materials required to produce an output unit of the material, such as 1,000 lb of product, or 1,000 gal of fuel
- process energy required for the total system, listed by fuel and electricity quantities
- total system transportation between process steps and delivery of product to consumers, by mode of transportation, tonne-km and quantities of fuel for each mode
- process atmospheric emissions (discharges to the environment after controls)
- process waterborne emissions (discharges to the environment after controls)
- process solid waste (including pollution control and combustion wastes, in lb and ft^3)
- post consumer disposal of waste (in lb and ft^3)

The data are based upon a variety of sources. The primary data are from companies and other private or confidential sources, with public data used for commodity materials that frequently are not purchased from a specific source. In order to preserve confidentiality of our database, only total system values are reported. Individual unit processes are not included. The data are based upon experience primarily in the USA (except where noted), and use USA electricity grids, pollution controls and solid waste practices. Both virgin and recycling systems are specified for each material, or recycling is included in the systems at the average levels experienced in the USA.

1. Subsystems

Each product is the result of an extensive set of unit processes. The unit processes required for each product are listed. For most systems, no data for the use phase is included.

2. Cut-off Rules

It is the intent that all processes include a total "cradle-to-grave" scope, starting with the extraction of materials from the earth, and ending with the return of these materials to the earth as solid, liquid or gaseous wastes. In the case of fuels, it is necessary to also expend fuels to extract and refine those fuels. These are called pre-combustion requirements. The first level of pre-combustion fuels is included in fuel and energy values. Materials that comprise less than 1% of product weight are excluded. Capital equipment, including buildings and roads are not included. Personnel impacts such as drinking water and personal hygiene are not included. Heating and cooling of mining and manufacturing facilities are excluded. Carbon dioxide emissions are reported in two categories: fossil and non-fossil. The non-fossil portion results from use of biogenic or renewable fuels, such as wood. These emissions are generally considered to be part of a natural cycle, and are not considered here to contribute to global warming from anthropogenic sources. No emissions (except those arising from collection and transportation of waste) have been assigned to waste disposal by landfilling or by incineration. The reason is that the data relating emissions to a specific product are uncertain by as much as hundreds of percent, so that the data quality was considered unacceptable. The same is true of hazardous wastes. They generally occur at very low levels, and existing data do not allow a reasonable allocation to a specific product with acceptable accuracy. No data are included on water consumption that depletes the natural resource. The reason once again is a matter of data quality. Water consumption data generally do not specify the source of the water, so that once-through cooling water returned to its source is not distinguished from withdrawals from

drinking water resources and subsequent discharge to air or non-drinking water bodies. Thus, the natural resource disruption cannot be determined.

3. Allocation Rules

If a process produces multiple products, some method must be used to allocate the inputs and outputs to the various products. Where possible, specific unit processes have been identified for the product of interest. Where this cannot be done, allocation is on a mass basis.

4. Energy Model

For each process, energy required is listed by fuel. Purchased electricity generated outside plant boundaries is listed in terms of kilowatt-hours, which must then be converted to the fuels needed to generate that electricity. To do this, a composite kilowatt-hour was calculated from the fuel mix used in USA utilities. This is a conversion algorithm (listed as a process) that transforms kilowatt-hours into the source fuels used to generate and deliver electricity. To avoid double counting, electricity that is self-generated is included in process data only in terms of the fuel used and is not listed separately as electricity. Fossil fuels, which are used as a material resource, are listed in terms of the energy value removed from the natural resource. For example, natural gas used as a feedstock for petrochemical operations which eventually becomes a plastic resin is reported in terms of the megajoules of natural gas withdrawn from the fossil resource. Although wood is a conditionally renewable energy, its use in industrial processes is included in the total energy. Energy is reported in nine categories.

- total energy
- energy of material resource (by type of energy resource)
- coal
- natural gas
- petroleum
- hydropower
- nuclear
- wood
- other renewable

5. Transportation Model

The transportation model uses USA statistical data combined with the fuels modules. Average fuel consumption is used to calculate ton-mile factors for different modes of transportation. In some cases, trucks and rail cars are not loaded to weight capacity with lightweight products, such as plastic foam products. In that case, the ton-mile factors do not accurately represent the transportation fuel use because more trips would be needed to transport the same weight of products. In those cases, a correction factor is applied. For example, if a truck becomes fully loaded by volume with 40,000 lb when the average load is 80,000 lb, the ton-mile factors would need to be approximately doubled. Three modes of transportation are available.

- truck
- rail
- barges and ocean freighters

6. Waste Model

Solid waste data are collected in two broad categories: industrial wastes and post-consumer wastes. Industrial waste is generated by mining and manufacturing activities. These include processing losses, discards, and solids and sludge from pollution controls. These are frequently inorganic, and are disposed of most often in industrial landfills. Post-consumer wastes are product and packaging discards that go to

municipal waste management facilities. Agricultural wastes or other biogenic wastes that are left in fields to decompose are considered to be part of natural cycles that do not disrupt the environment and are not reported as wastes. Mining overburden and other inorganic mining wastes that are discarded in mining excavations at or near the production site are not reported as wastes.

Solid wastes are reported both in mass and volume units. Mass is the common unit in which waste data is reported, but landfills are filled with volume, not mass. These are alternative units and should not be combined. The volume units are considered to be more relevant, but less accurate. Volume factors are based upon measurements of waste as found in landfills.

For some materials, separate virgin and recycling systems are included. For other materials, recovery and recycling is included in the product systems at the average level currently being experienced. No emissions (except those arising from fuel use in collection and transportation of waste) have been assigned to waste disposal by landfilling or by incineration. The reason is that the data relating emissions to a specific product are uncertain by as much as hundreds of percent, so that the data quality was considered unacceptable. The same is true of hazardous wastes. They generally occur at very low levels, and existing data do not allow a reasonable allocation to a specific product with acceptable accuracy.

Recovery of post-consumer wastes for recycling can be either closed loop or open loop. In closed loop recycling, materials are recycled back into the same product. An example is glass bottles being recycled back into glass bottles. In a 100% closed loop system, no post-consumer solid wastes occur. In an open loop system, post-consumer materials are recovered for use in a different product. An example is plastic bottles recovered and used as a raw material for a textile product, which is discarded to waste after use. In this case, the plastic is used for two products and then becomes post-consumer solid waste. In the systems for open loop recycling, the post-consumer solid waste is considered to be a joint result for the two products. Thus, 1,000 lb of plastic is used in 2,000 lb of product, generating eventually a total of 1,000 lb of post-consumer waste, or 500 lb of waste for 1,000 lb of each product. However, the systems for open loop recycling show only 390 lb of post-consumer solid waste for 1,000 lb of product, because 22% of the 500 lb (110 lb) is incinerated.

The open loop recycling model is used for all plastics systems where both a virgin and recycled model are presented. To calculate any level of recycling for a product, these two models will need to be combined. For example, the average recovery for recycling high-density polyethylene (HDPE) is 10%. This can be modelled for 1,000 lb of blow moulded bottles by using 900 lb of the virgin model and 100 lb of the 100% recycled model. All thermoplastic recycling models share common recovery and mechanical processing data. No de-polymerisation or other complex processing is included.

7. Other Information

The key data included in this database were obtained from multiple private sources. The typical process is the submission of a detailed questionnaire to process facility engineering staff requesting LCI data. There is generally a period during which there are discussions between the analysts and plant engineers as the complex data is obtained and evaluated. Subsequently, the data are evaluated and peer reviewed for consistency and reasonableness. All of this typically proceeds under an umbrella of confidentiality. To protect the confidentiality, it is only possible to release the data when aggregated with other data. Therefore, process systems where this type of data is included cannot be specifically referenced. This is the case for all of the product systems included here, except for the commodity fuels and electricity model that was constructed from public data sources.

8. LCI Data Tables

LCI data tables are included for each system description. The tables show the amounts of fuel combusted and electricity in common units, such as kW-hr, gallons, etc., as well as process emissions. The database combines this information with the commodities fuel and electricity model to create tables with total energy requirements (in million Btu) and total emissions (including both process emissions and fuel related emissions).

1.1.2 Commodity Fuels And Electricity

Description:

This system description includes twenty-two tables listing the basic factors needed to transform LCI raw data on fuels, electricity and transportation into reports of energy consumption and emissions. The data are drawn from a variety of 57 public and private USA statistical sources, reports and telephone conversations with experts. The following tables of energy and emissions are included.

- combustion of coal in utility boilers
- combustion of coal in industrial boilers
- combustion of residual fuel oil in utility boilers
- combustion of residual fuel oil in industrial boilers
- combustion of distillate fuel oil in utility boilers
- combustion of distillate fuel oil in industrial boilers
- combustion of natural gas in utility boilers
- combustion of natural gas in industrial boilers
- combustion of fuel grade uranium
- combustion of natural gas in industrial equipment
- combustion of diesel fuel in industrial equipment
- combustion of gasoline in industrial equipment
- combustion of liquefied petroleum gas in industrial boilers
- combustion of wood in industrial boilers
- tractor-trailer gasoline powered trucks
- tractor-trailer diesel powered trucks
- single unit gasoline powered trucks
- single unit diesel powered trucks
- diesel powered locomotives
- barges
- ocean freighters
- generation and delivery of one composite kilowatt-hour of electricity

1. Subsystems

The system reports primary data on fuels and electricity that are used to construct fuel, electricity and transportation subsystems for use in LCI calculations requiring those subsystems. The data are USA averages.

2. Cut-off rules

The tables include energy removed from natural resources and the resulting emissions to the environment, including not only the fuel combustion itself, but also the precombustion fuels and energy needed to extract, process and transport the fuel or electricity to market. Successive iterations are performed to calculate the precombustion energy and emissions for the precombustion energy use, until successive

iterations result in negligible change (0.01%) in the result. The tables report fuel resource requirements and emissions from stationary and mobile internal and external combustion power sources, as well as from electricity generation.

3. Waste Model

The solid wastes listed in this model are primarily from waste treatment sludges from coal and uranium mining and processing operations, as well as from fuel combustion residues (ashes, etc.) and combustion pollution control devices (solids and sludges). These wastes are customarily landfilled at sites close to where they are produced, and often on the same private property where generated.

4. Other Information

For all other fields, the general descriptions apply.
The 57 sources of information used for this system are found in the source list.

1.1.3 Steel (Basic Oxygen Furnace)

Description:

This model describes the system for producing tin-coated steel strip products, such as food and beverage cans. The process is a typical virgin steel system, using a basic oxygen furnace (BOF), although recycled steel scrap comprises about 30% of the raw materials for the furnace. The largest sources of scrap steel are automotive bodies, construction wastes and appliances. Steel cans are actively recovered, achieving a 58% rate for food cans, and 64% for beverage cans. Overall, 38% of steel discarded to municipal waste is recovered and recycled. Internal industrial recycling is included in the process inventory table.

1. Subsystems

In addition to the fuels and electricity subsystems, the following subsystems are included in the data reported in the table.

- Coal mining
- Iron ore mining
- Limestone mining
- Oxygen manufacture
- Metallurgical coke manufacture
- Iron ore pellet production
- Iron ore sinter production
- Lime manufacture
- External scrap recovery and processing
- Blast furnace (pig iron production)
- Basic oxygen furnace
- Tin coated steel strip production
- Product manufacture
- Product disposal

2. Other Information

The data sources are a mix of actual plant data that has undergone peer review, supplemented by public and private statistical sources where necessary or appropriate. Because of the confidential nature of portions of the data, specific sources and references are not given.

For all other fields, the general descriptions apply. References are found in the source list.

1.1.4 Steel (Electric Arc Furnace)

Description:

Electric arc furnaces consume primarily scrap steel and manufacture a wide variety of special and commodity steel products. The product chosen for this model is cold-rolled steel sheet. The raw materials charged to the furnace are scrap steel, with small amounts of limestone and lime added. The scrap steel is from post-consumer sources.

1. Subsystems

In addition to the fuels and electricity subsystems, the following subsystems are included in the data reported in the table.

- Limestone mining
- Oxygen manufacture
- Lime manufacture
- External scrap recovery and processing
- Electric arc furnace
- Cold-rolled steel sheet manufacture
- Product disposal

2. Other Information

For all other fields, the general descriptions apply. References are found in the source list.

1.1.5 Grey Cast Iron Products

Description:

Foundries produce castings that are ready to use with a minimum of processing. These are formed by pouring molten iron into moulds, which are made by forming and shaping sand. Cast iron is classified as grey, ductile or malleable. About 80% of cast iron is grey iron. The grey cast iron industry is an important consumer of post-consumer iron and steel scrap in the USA. Industrial and post-consumer steel and iron scrap is mixed with pig iron and melted in a cupola furnace, although electric arc, induction or reverberatory furnaces are sometimes used. Foundries are often small operations although some very large foundries exist.

1. Subsystems

In addition to the fuels and electricity subsystems, the following subsystems are included in the data reported in the table.

- Coal mining
- Iron ore mining
- Oxygen production
- Coke production
- Sand mining
- Iron ore pellet production
- Sinter production
- Pig iron production
- External scrap recovery and processing

- Limestone mining
- Cast iron production
- Cast iron product disposal

2. Other Information

For all other fields, the general descriptions apply. References are found in the source list.

1.1.6 Aluminum Sheet Products

Description:

Two systems are provided. One is a 100% virgin system, and the other is a 100% recycled system. The models describe the manufacture, use and disposal of an aluminum sheet product, such as a can. For can bodies, the average recovery rate for aluminum cans being recycled back into cans is 63%, leaving a 37% virgin aluminum requirement. For aluminum can lids, the recycled content is 12%. A model for an "average" product can be constructed by mixing the two systems provided in a linear fashion. In the virgin system, nearly 100% of the aluminum is mined as bauxite ore in countries outside the USA. The bauxite is either imported or first converted to alumina near the mines. About 45% of the aluminum used in products manufactured in the USA is produced using imported alumina. The smelting of the alumina to produce aluminum metal is assumed to take place within the USA and Canada.

1. Subsystems

In addition to the fuels and electricity subsystems, the following subsystems are included in the data reported in the table.

- Limestone mining
- Lime manufacture
- Bauxite mining
- Alumina production
- Salt mining
- Sodium hydroxide manufacture
- Crude oil production
- Petroleum coke production
- Coal mining
- Metallurgical coke production
- Aluminum smelting
- Ingot casting
- Product manufacture
- Post-consumer aluminum product recovery
- Recovered product preparation and melting
- Aluminum product disposal

2. Energy Model

Aluminum systems have two anomalies that require adjustments in the standard energy models. Because bauxite is entirely imported and close to one-half of the alumina is imported, energy grids existing in the countries of origin were used. The two leading countries are Australia and Jamaica, accounting for over 60% of the imported bauxite. Other countries include Guinea, Brazil, Suriname and Guyana. Australia, Jamaica and Suriname account for most of the imported alumina. Also, within the USA and Canada, the production of alumina and primary aluminum is concentrated in regions where low cost electricity is

available. Regional power grids were used for North American production. The alumina production is concentrated in Texas and the southeastern region. Primary aluminum smelters draw purchased electricity primarily from the northwest and east central regions of the USA, and the Northeastern-Quebec region of Canada. Self-generated electricity is included in the fuels and power source data in the process table.

3. Waste Model

A unique problem with aluminum is the very large amount of solid waste generated during the production of alumina. It is called "red mud." It is a sludge that will not dewater easily, and is disposed of in large monofills. As shown in the tables, about 800 lb of red mud is created for each 1,000 lb of alumina produced.

4. Other Information

For all other fields, the general descriptions apply. References are found in the source list.

1.1.7 Low Density Polyethylene Products

Description:

Over two-thirds of the USA plastics packaging and disposable market is polyethylene products, and about one-fourth of that market is low density polyethylene (LDPE). It is used almost exclusively for packaging and other films (including bags, such as trash bags or other household bags) and coatings. LDPE resin is made by polymerising ethylene in high-pressure reactors using catalysts or initiators. Post-consumer recycling of LDPE products in the USA is near zero (less than 2%), although internal industrial recycling is included in the process inventory table. The system contains data for the manufacture of PE film products at 0 percent recycling and 100 percent recycling. This allows the user to weight these two systems to a specific percent of recycling.

1. Subsystems

In addition to the fuels and electricity subsystems, the following subsystems are included in the data reported in the table.

- Crude oil production
- Petroleum refining (desalting, distillation and hydrotreating)
- Natural gas production
- Natural gas processing
- Olefins manufacture (propylene and ethylene)
- LDPE resin manufacture
- Product manufacture
- Product disposal

2. Other Information

For all other fields, the general descriptions apply. References are found in the source list.

1.1.8 High Density Polyethylene Products

Description:

Over two-thirds of the USA plastics packaging and disposable market is polyethylene products, and about one-fourth of that market is high density polyethylene (HDPE). It is used in a variety of blow moulded, injection moulded and film products, as well as in coatings. An important product is the blow moulded containers used for milk and a variety of other fluids. HDPE resin is made by polymerising ethylene either in a slurry process or in a gas phase process. About 30% of the post-consumer HDPE milk bottles are recovered for recycling, but the recycled content of the milk bottles is near zero. About 50% of HDPE basecups on PET bottles are recovered, and pigmented HDPE bottles are recovered at about 20%. Recovery of other HDPE products occurs at lower rates. Overall, about 10% of HDPE products are recovered for recycling, giving it the second highest recycling rate among plastic resins behind the 21% overall rate for PET. Internal industrial recycling is included in the process inventory table. Two systems are included: a virgin system and a 100% recycled system for the manufacture of blow moulded bottles. This allows the user to weight these two systems to a specific percent of recycling.

1. Subsystems

In addition to the fuels and electricity subsystems, the following subsystems are included in the data reported in the table.

- Crude oil production
- Petroleum refining (desalting, distillation and hydrotreating)
- Natural gas production
- Natural gas processing
- Olefins manufacture (propylene and ethylene)
- HDPE resin manufacture
- Product manufacture
- Product disposal

2. Other Information

For all other fields, the general descriptions apply. References are found in the source list.

1.1.9 Linear Low Density Polyethylene Products

Description:

Linear low density polyethylene (LLDPE) is an intermediate polymer that shares characteristics with both LDPE and HDPE. LLDPE is made in the same type of reactors as HDPE. The difference is that a different olefin composition is used. In addition to ethene (ethylene), butene and hexene are mixed in to serve as co-monomers. When the polymerisation occurs, the LLDPE achieves longer branching chains, resulting in a lower density than HDPE. LLDPE dominates the 700 million kilogram USA trash bag market, and is also widely used as a stretch film. Recycling of LLDPE is negligible. However, both a virgin system and 100 percent recycling are included. The system is for a film product.

1. Subsystems

The same subsystems are used for HDPE and LDPE.

2. Other Information

For all other fields, the general descriptions apply. References are found in the source list.

1.1.10 Polypropylene Products

Description:

Polypropylene (PP) products account for about 10% of the plastics used in USA packaging and disposable product markets. It is used widely as a packaging film (including extruded drinking straws), injection moulded products (such as bottle caps, margarine and yoghurt tubs), and blow moulded bottles. In this model, the PP resin is manufactured by the polymerisation of propylene using Ziegler-Natta catalysts, and the following mix of processes: gas, 8%; slurry, 11%; and liquid, 81%. Post-consumer recycling of all PP products in the USA is at a low level, about 5%, most of which are automobile battery casings. The remainder is food tubs and cups (margarine and yoghurt) collected in a few curbside programs. Internal industrial recycling is included in the process inventory table. Two PP models are included, both for the manufacture of injection moulded bottle caps. One is for virgin material manufacture, and the other is for 100% recovered material manufacture, using a generic plastics recovery and processing module.

1. Subsystems

In addition to the fuels and electricity subsystems, the following subsystems are included in the data reported in the table.

- Crude oil production
- Petroleum refining (desalting, distillation and hydrotreating)
- Natural gas production
- Natural gas processing
- Olefins manufacture (propylene and ethylene)
- Polypropylene resin manufacture
- Product manufacture
- Product disposal

2. Other Information

For all other fields, the general descriptions apply. References are found in the source list.

1.1.11 Polyethylene Terephthalate (PET) Products

Description:

Less than 10% of USA plastics packaging and disposable market is PET products. It is used widely for soft drink bottles, with significant markets for other fluid products. PET resin has a very complex production matrix, requiring a variety of chemical feedstocks, and ending with a melt phase polymerisation followed with a solid state polymerisation. Polymerisation occurs from either esterification of purified terephthalic acid (PTA) or by trans-esterification of dimethyl terephthalate (DMT) with ethylene glycol. The PTA route is assumed to be used for 65% of the resin, and the DMT used for 35% of the resin. The bottle fabrication is also complex, with a two stage process of first making an intermediate "parison" which then is stretched to orient the polymer before final blowing and shaping of the bottle. PET bottles enjoy the highest recovery rate for recycling of any plastic product. The recovery rate has been between 40% and 50% since 1994. However, the recovered PET is not presently being recycled back into bottles, so the recycled content of bottles is zero. Both a virgin system and a 100 percent mechanical recycling system are included in the library.

1. Subsystems

In addition to the fuels and electricity subsystems, the following subsystems are included in the data reported in the table.

- Crude oil production
- Petroleum refining (desalting, distillation and hydrotreating)
- Natural gas production
- Natural gas processing
- Olefins manufacture (propylene and ethylene)
- Methanol manufacture
- Acetic acid manufacture
- Mixed xylenes production
- Paraxylene extraction
- Ethylene oxide manufacture
- Terephthalic acid (TPA) manufacture
- Dimethyl terephthalate (DMT) manufacture
- Purified terephthalic acid (PTA) manufacture
- Ethylene glycol manufacture
- Polymerisation from DMT
- Polymerisation from PTA
- Product manufacture
- Product disposal

2. Other Information

For all other fields, the general descriptions apply. References are found in the source list.

1.1.12 General Purpose Polystyrene Products

Description:

Polystyrene (PS) is manufactured by combining ethylene with benzene to form ethyl benzene. This molecule is then cracked to form styrene, which is polymerised to form PS. PS products account for about 10% of all plastics products made in the USA. About two-thirds of this is used in packaging applications and disposable consumer products, with the remainder being used in the manufacture of durable goods, such as furniture. About one-fourth of the PS is used in packaging and disposable products, with the other three-fourths being general purpose PS. General purpose PS has exceptional clarity, forms attractive glossy surfaces and has excellent printability which makes it suitable for display and/or transparent applications, such as retail displays, clear or pigmented drink cups and windows for envelopes or blister packs. It is also used as a surface film on co-extruded films because of it glossy appearance. Its use as a single material film is hampered by poor structural properties. Many disposable food service products are general purpose PS. The product described by the data in this model is for a clear disposable drink cup. Recycling occurs at very low levels for PS products, with an overall recovery rate of 1.5%. The recycled content is assumed to be 0%. Both a virgin system and a 100 percent mechanical recycling system are included in the library.

1. Subsystems

In addition to the fuels and electricity subsystems, the following subsystems are included in the data reported in the table.

- Natural gas production
- Natural gas processing
- Olefins manufacture (ethylene)
- Crude oil production
- Petroleum refining (desalting, distillation, hydrotreating)
- Naphtha reforming
- Benzene manufacture (aromatic extraction and toluene dealkylation)
- Ethyl benzene manufacture
- Styrene manufacture
- PS resin manufacture
- Product manufacture
- Product disposal

2. Other Information

For all other fields, the general descriptions apply. References are found in the source list.

1.1.13 Expanded Polystyrene Products

Description:

Expanded polystyrene (EPS) is made from general purpose PS by introducing a foaming chemical, known as a blowing agent. These are liquids with boiling temperatures at approximately the softening point of PS. Typically, these blowing agents are hydrocarbons, with isopentane being selected for this model. The liquid is incorporated into the plastic, and when the PS is extruded, the liquid will boil, forming gas cells that create the plastic foam. The liquid can also be incorporated into resin granules that will expand when heated during thermoforming processes. PS foams have excellent insulating properties and are widely used in food packaging and food service, as well as for building insulation. A popular application of EPS is as a cushioning agent in product packaging, especially electronic and furniture packaging, either in thermoformed rigid shapes or as loose fill. For this model, the product selected is a retail food service container. Perhaps as much as 5% of the EPS used in food service and packaging is recovered and recycled. Most of this being recovered is thermoformed packaging shapes. The recycled content is assumed to be 0%. Both a virgin system and a 100 percent mechanical recycling system are included in the library.

1. Subsystems

In addition to the fuels and electricity subsystems, the following subsystems are included in the data reported in the table. This set of subsystems is identical to those for solid general purpose PS with the addition of the manufacture of the blowing agent.

- Natural gas production
- Natural gas processing
- Blowing agent (isopentane) production
- Olefins manufacture (ethylene)
- Crude oil production
- Petroleum refining (desalting, distillation, hydrotreating)
- Naphtha reforming
- Benzene manufacture (aromatic extraction and toluene dealkylation)
- Ethyl benzene manufacture
- Styrene manufacture
- PS resin manufacture
- Product manufacture

- Product disposal

2. Other Information

For all other fields, the general descriptions apply. References are found in the source list.

1.1.14 High Impact Polystyrene Products

Description:

High impact polystyrene (HIPS) is manufactured in the same way as general purpose PS, except elastomers are incorporated in the polymerisation stage to reduce brittleness and increase impact resistance. For this model, the HIPS is approximately 10% polybutadiene, and 3% mineral oil is added as a plasticizer. HIPS does not possess the exceptional optical properties of general purpose PS. It is used for translucent or pigmented applications. Many disposable food service products are HIPS. The product described by the data in this model is a disposable drink cup. Recycling occurs at very low levels for PS products, with an overall recovery rate of 1.5%. Both a virgin system and a 100 percent mechanical recycling system are included in the library.

1. Subsystems

In addition to the fuels and electricity subsystems, the following subsystems are included in the data reported in the table.

- Natural gas production
- Natural gas processing
- Olefins manufacture (ethylene)
- 1,3 – butadiene manufacture
- Polybutadiene manufacture
- Crude oil production
- Petroleum refining (desalting, distillation, hydrotreating)
- Mineral oil production
- Naphtha reforming
- Benzene manufacture (aromatic extraction and toluene dealkylation)
- Ethyl benzene manufacture
- Styrene manufacture
- PS resin manufacture
- Product manufacture
- Product disposal

2. Other Information

For all other fields, the general descriptions apply. References are found in the source list.

1.1.15 Polyvinyl Chloride Products

Description:

Polyvinyl chloride (PVC) is chemically quite similar to polyethylene up to a point, where one atom of hydrogen on ethylene is replaced with one chlorine atom. PVC has excellent clarity, stiffness and resistance to oils and alcohols, leading to its common use in food packaging. PVC film clings quite well, enhancing its desirability in food packaging. Common packaging products are films, bottles and blister

packs. Common non-packaging applications are automobile parts and building products. PVC by itself is a difficult plastic to process, so that additives and plasticizers make up a significant fraction of PVC products. A wide range of plasticizers is used, but the plasticizer used in this model is diethylhexyl phthalate, also known as dioctyl phthalate. This chemical accounts for about 50% of all PVC plasticizer use and is generally considered the industry standard. The product chosen for this model is a fluid container. There is virtually no post-consumer recycling of this plastic.

1. Subsystems

In addition to the fuels and electricity subsystems, the following subsystems are included in the data reported in the table.

- Crude oil production
- Petroleum refining (desalting, distillation and hydrotreating)
- Natural gas production
- Natural gas processing
- Olefins manufacture (propylene and ethylene)
- Salt mining
- Chlorine manufacture
- Ethylene dichloride manufacture
- Vinyl chloride manufacture
- Plasticizer manufacture
- PVC manufacture
- Product manufacture
- Product disposal

2. Other Information

For all other fields, the general descriptions apply. References are found in the source list.

1.1.16 SBR Rubber Products

Description:

Styrene-butadiene rubber (SBR) is the primary component of rubber tires and many other synthetic rubber products such as footwear, flooring and conveyor belts. It also is used as an elastomer in plastics to impart toughness and flexibility. It is made by combining 1,3 butadiene and styrene in a cold polymerisation reaction, which produces the polymer in an emulsion. Automobile and truck tires are the predominant rubber products, making up about one-half of all rubber products. They are virtually the only rubber product recovered for recycling, with about 19% being diverted from solid waste for recycling. A small but growing amount of tires are being collected separately from other waste and incinerated for energy recovery. This system includes only the preparation of a natural rubber crumb, which can be used as an additive for plastic products or for tires.

1. Subsystems

In addition to the fuels and electricity subsystems, the following subsystems are included in the data reported in the table.

- Crude oil production
- Petroleum refining (desalting, distillation and hydrotreating)
- Natural gas production

- Natural gas processing
- Olefins manufacture (1,3 butadiene and ethylene)
- Mixed xylenes production
- Benzene production
- Ethylbenzene/styrene manufacture
- SBR polymerisation (crumb production)
- Product disposal

2. Other Information

For all other fields, the general descriptions apply. References are found in the source list.

1.1.17 Natural Rubber Additive

Description:

Natural rubber starts as an agricultural product of tropical countries, especially in the Far East. Chemically, it is a polyisoprene found as a component of the sap of many trees. On rubber plantations, trees with high concentrations of polyisoprene are tapped to produce latex. The dilute water emulsion is coagulated with the addition of acetic or formic acid, and then dried to a concentrate. The concentrate has sufficient dryness that it can be made into sheets and further dried or formed into a dry crumb concentrate. The dried latex is processed into a variety of products, such as a tire component, gloves, adhesives, foam carpet backing and thread. This system includes only the preparation of a natural rubber crumb additive for plastic products or for tires.

1. Subsystems

In addition to the fuels and electricity subsystems, the following subsystems are included in the data reported in the table.

- Natural rubber growing and tapping
- Centrifugation
- Coagulation
- Rubber crumb production
- Product disposal

2. Other Information

For all other fields, the general descriptions apply. References are found in the source list.

1.1.18 Newsprint

Description:

Newsprint is manufactured from a variety of virgin and recycled paper pulps. In the USA, the statistical average for the newsprint industry is 38% recycled pulp primarily manufactured from post-consumer recovered newspapers, with some old magazines and other miscellaneous deinking grades of waste paper. The remaining 62% is virgin pulp which is statistically 37% groundwood, 51% thermomechanical pulp (TMP), and 12% bleached Kraft pulp. It is assumed for these calculations that only old newspapers are used for the recycled pulp.

1. Subsystems

In addition to the fuels and electricity subsystems, the following subsystems are included in the data reported in the table.

- Wood harvesting
- Production of wood residues by forest products manufacturers
- Sodium sulphate production
- Soda ash (sodium carbonate) production
- Limestone mining
- Lime production
- Sulphur production
- Sulphuric acid manufacture
- Salt mining
- Sodium hydroxide manufacture
- Sodium chlorate production
- Chlorine production
- Chlorine dioxide production
- Stone groundwood pulp production
- Thermomechanical pulp production
- Bleached Kraft paperboard manufacture
- Recovery and recycling of newspapers
- Deinked pulp manufacture
- Solvent-based ink manufacture
- Newsprint production
- Product disposal

2. Other Information

For all other fields, the general descriptions apply. References are found in the source list.

1.1.19 Bleached Kraft Paper And Paperboard Products

Description:

The system describes an uncoated bleached paper or paperboard system that could serve as printing paper or as the basic paperboard material for a rigid fluid container such as a polyethylene coated milk container. However, this system does not include the plastic coating. This is a virgin fibre system that has no recycled content and the product is disposed of in a municipal solid waste system, by landfilling 78% of the containers and incinerating the remaining 22%.

1. Subsystems

In addition to the fuels and electricity subsystems, the following subsystems are included in the data reported in the table.

- Wood harvesting
- Production of wood residues by forest products manufacturers
- Limestone mining
- Lime production
- Sulphur production
- Sulphuric acid manufacture
- Salt mining

- Sodium hydroxide manufacture
- Chlorine manufacture
- Sodium chlorate manufacture
- Hydrogen production
- Hydrochloric acid manufacture
- Oxygen production
- Fertiliser production
- Corn growing and harvesting
- Cornstarch production
- Virgin Kraft bleached paper and paperboard production
- Product disposal

2. Other Information

For all other fields, the general descriptions apply. References are found in the source list.

1.1.20 Tissue Paper Products

Description:

The system is similar to other paper systems. The product is tissue paper that is used in commercial and consumer products, such as paper towels or other liquid-absorbing papers. The model system is primarily a virgin system that uses bleached Kraft pulp, sulphite pulp and chemi-thermo-mechanical pulp (CTMP). In addition, recycled pulp from both industrial/commercial and post-consumer sources is included. For this model, both virgin towels and 100 percent recycled content towels are included in the library. These products are not recovered for recycling, although there is a 6% solid waste disposal credit for the recovered post-consumer content of the recycled pulp.

1. Subsystems

In addition to the fuels and electricity subsystems, the following subsystems are included in the data reported in the table.

- Wood harvesting
- Production of wood residues by forest products manufacturers
- Limestone mining
- Lime production
- Salt mining
- Sodium hydroxide manufacture
- Chlorine manufacture
- Sodium chlorate manufacture
- Sodium sulphite production
- Hydrogen production
- Hydrochloric acid manufacture
- Hydrogen peroxide production
- Oxygen production
- CTMP pulp production
- Bleached Kraft pulp production
- Recovery and repulping of paper
- Deinking
- Crude oil production
- Petroleum refining (distillation, desalting, and hydrotreating)

- Processing aid manufacture
- Natural gas production
- Natural gas processing
- Olefins manufacture (ethylene)
- Ethylene oxide production
- Coconut growing and harvesting
- Copra production
- Crude coconut oil production
- Coconut fatty acid production
- Absorbency control additive manufacture
- Paper towel production
- Paper towel converting
- Product disposal

2. Other Information

For all other fields, the general descriptions apply. References are found in the source list.

1.1.21 Unbleached Kraft Paper And Paperboard Products

Description:

The system describes an unbleached Kraft paperboard system. Products include the brown inner and outer faces of corrugated boxes, and brown paper bags for both consumer and industrial use. It is quite similar to the bleached Kraft system except that the species of trees that are the source of the fibre differ, and the bleaching steps are omitted. The product chosen for this model is linerboard (for the facings of corrugated boxes). However, this same system can be used for paper bags. This is a virgin fibre system that has no recycled content. About 67% of corrugated boxes are recovered for recycling, and 13% of brown paper bags.

1. Subsystems

In addition to the fuels and electricity subsystems, the following subsystems are included in the data reported in the table.

- Wood harvesting
- Production of wood residues by forest products manufacturers
- Limestone mining
- Lime production
- Sulphur production
- Sulphuric acid manufacture
- Salt mining
- Sodium hydroxide manufacture
- Fertiliser production
- Corn growing and harvesting
- Cornstarch production
- Virgin Kraft unbleached paperboard production
- Product disposal

2. Other Information

For all other fields, the general descriptions apply. References are found in the source list.

1.1.22 Semichemical Paperboard Products

Description:
The system describes the manufacture of semichemical paperboard. The predominant use is the fluted interior layer of the three layers of corrugated boxes. It is called corrugating medium. This is a paperboard fibre product that customarily is a blend of virgin semichemical fibre and recycled fibre. Semichemical pulp manufacture is similar to that other chemical wood pulps, where wood chips are heated in a digester along with chemicals to form the pulp. This model uses the neutral sulphite semichemical (NSSC) pulping process. The NSSC process is less complete than Kraft processes and leaves more of the wood chemicals in the pulp. The recycled content used in this model is the USA average of 35%, of which almost all is post-consumer recovered old corrugated containers. The recovery rate of semichemical medium is 67% (the same as for corrugated containers).

1. Subsystems
In addition to the fuels and electricity subsystems, the following subsystems are included in the data reported in the table.

- Wood harvesting
- Production of wood residues by forest products manufacturers
- Salt mining
- Sodium hydroxide production
- Soda ash production
- Sodium sulphite manufacture
- NSSC (semichemical) paperboard production
- Product fabrication
- Product disposal

2. Other Information
For all other fields, the general descriptions apply. References are found in the source list.

1.1.23 Corrugated Containers

Description:
Corrugated containers (boxes) are fabricated from a “sandwich” of three primary paperboard structural components: outer liner, corrugating medium, and an inner liner. The liners are virgin and recycled unbleached Kraft paperboard. The medium is semichemical paperboard, also with virgin and recycled content. The system used in this model is a typical USA average box that contains 39% post-consumer recycled content, and 6% industrial scrap, for a total recycled content of 45%. These containers experience a 67% recovery rate for recycling after use. The post-consumer content is recovered old corrugated containers, and the industrial scrap is primarily “cuttings” from box plants where corrugated containers are manufactured. The cuttings are recovered and returned to paper manufacturers.

1. Subsystems
In addition to the fuels and electricity subsystems, the following subsystems are included in the data reported in the table.

- Wood harvesting
- Production of wood residues by forest products manufacturers
- Sodium sulphite production
- Soda ash (sodium carbonate) production
- Limestone mining
- Lime production
- Sulphur production
- Sulphuric acid manufacture
- Salt mining
- Sodium hydroxide manufacture
- Fertiliser production
- Corn growing and harvesting
- Cornstarch production
- Starch adhesive manufacture
- Unbleached Kraft paperboard manufacture
- Semichemical medium manufacture
- Recovery and recycling of paperboard
- Box manufacturing
- Product disposal

2. Other Information

For all other fields, the general descriptions apply. References are found in the source list.

1.1.24 Recycled Paperboard Products

Description:

This system describes a 100% recycled paperboard product, such as a "combination box board" container. These are the widely used grey boxes that are used in a variety of consumer and industrial applications. Common consumer applications are dry food boxes and shoe boxes. The raw materials include old corrugated boxes, mixed waste papers, newspapers and high-grade "pulp substitute" waste paper. The grey colour comes from the ink on printed papers that are used without de-inking. Some de-inking may occur for a white outer layer used to enhance appearance and provide a printing surface. While the recycled content is 100% post-consumer paper, the product itself is not recovered because it is not generally considered suitable for recycling in the USA.

1. Subsystems

In addition to the fuels and electricity subsystems, the following subsystems are included in the data reported in the table.

- Recovery of various grades of wastepaper
- Wastepaper processing
- Repulping of wastepaper and manufacture of recycled paperboard
- Box manufacturing
- Product disposal

2. Other Information

For all other fields, the general descriptions apply. References are found in the source list.

1.1.25 Glass Containers

Description:

Glass bottles are used to package beer, soft drinks, a variety of other fluids and a variety of foods. Glass is manufactured by melting a high-purity sand with other minerals, including limestone, soda ash (sodium carbonate), feldspar and post-consumer glass cullet. The mixture is melted, refined and fabricated into bottles in an integrated operation. Other glass products account for only 15% of total glass production. Those products are primarily windows, light bulbs and various ornamental goods. Post-consumer recovered glass typically makes up 27% of the raw materials for new glass containers in the USA. This is virtually a closed loop recycling system, with glass containers being recovered and recycled back into glass containers. About 15% of glass manufactured becomes internal industrial scrap, and that recycling is included in the process inventory table. Both virgin and 100% recycled systems are included.

1. Subsystems

In addition to the fuels and electricity subsystems, the following subsystems are included in the data reported in the table.

- Limestone mining
- Glass sand mining
- Sodium carbonate (soda ash) mining
- Feldspar mining
- Post-consumer cullet (glass) recovery and processing
- Glass container manufacture and product fabrication
- Product disposal

2. Other Information

For all other fields, the general descriptions apply. References are found in the source list.

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