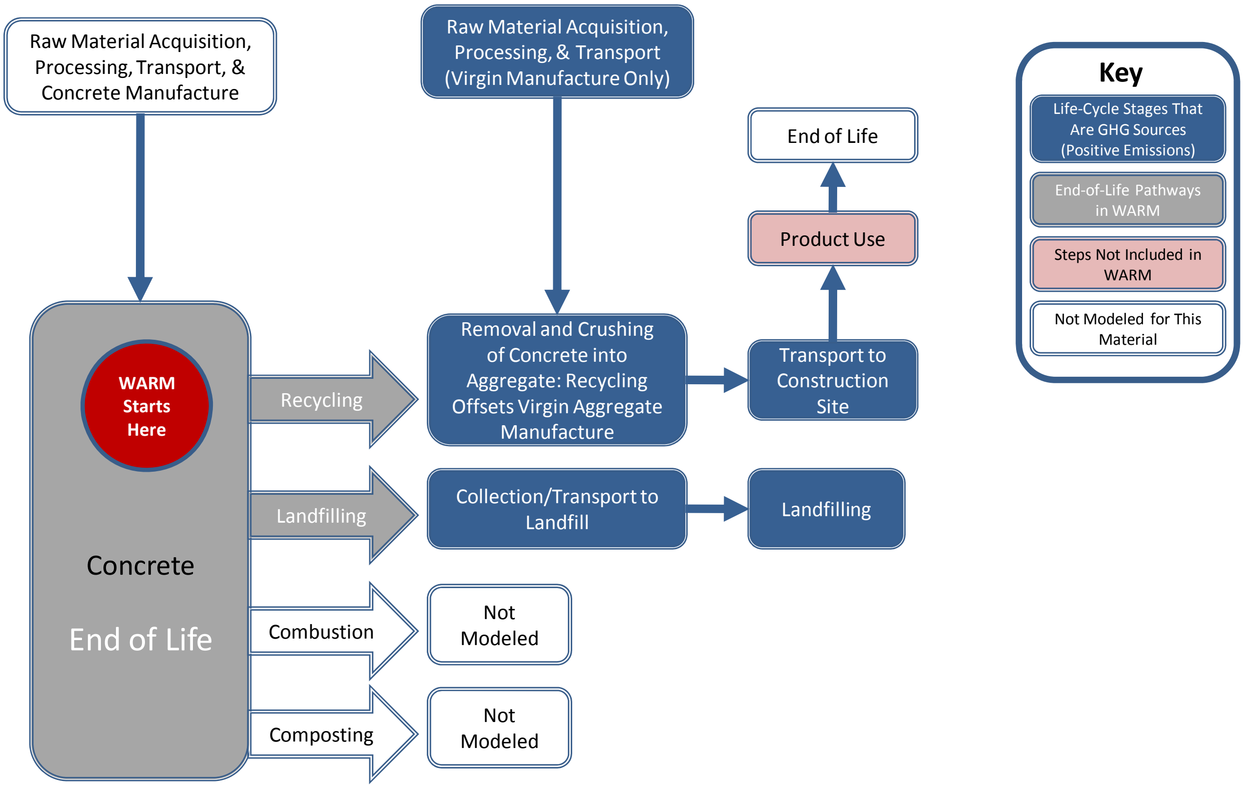
CONCRETE

1. INTRODUCTION TO WARM AND CONCRETE

This chapter describes the methodology used in EPA's Waste Reduction Model (WARM) to estimate streamlined life-cycle greenhouse gas (GHG) emission factors for concrete beginning at the point of waste generation. The WARM GHG emission factors are used to compare the net emissions associated with concrete in the following two waste management alternatives: recycling and landfilling. Exhibit 1 shows the general outline of materials management pathways for concrete in WARM. For background information on the general purpose and function of WARM emission factors, see the Introduction & Overview chapter. For more information on Recycling and Landfilling, see the chapters devoted to these processes. WARM also allows users to calculate results in terms of energy, rather than GHGs. The energy results are calculated using the same methodology described here but with slight adjustments, as explained in the Energy Impacts chapter.

Exhibit 1: Life-cycle of Concrete in WARM



Concrete is a high-volume, low-cost building material produced by mixing cement, water and coarse and fine aggregates. Its use is nearly universal in modern construction, as it is an essential component of roads, foundations, high-rises, dams and other staples of the developed landscape. Approximately 919 million tons of concrete[1] were produced in 2007 and approximately 200 million tons of waste concrete are generated annually from construction and demolition (C&D) and public works

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[1] The total consumption of cement in 2007 was 114,800,000 tons (USGS, 2009). It was assumed that 100 percent of this cement was used to make concrete and the concrete contained 12.5 percent cement by weight (Collins 2002), resulting in a calculated concrete production of about 919 million tons.

projects (Turley, 2002; Wilburn and Goonan, 1998). According to Turley (2002) and Wilburn and Goonan (1998), an estimated 50 to 60 percent of waste concrete is recycled, while the remainder is landfilled.

2. LIFE-CYCLE ASSESSMENT AND EMISSION FACTOR RESULTS

The streamlined life-cycle GHG analysis in WARM focuses on the waste generation point, or the moment a material is discarded, as the reference point and only considers upstream GHG emissions when the production of new materials is affected by materials management decisions.[2]

As Exhibit 2 illustrates, most of the GHG sources relevant to concrete in this analysis are contained in the raw materials acquisition and manufacturing and end of life sections of the life cycle assessment. WARM does not consider source reduction, composting or combustion as life-cycle pathways for concrete. Of note, the recycling emission factor represents the GHG impacts of manufacturing concrete using recycled concrete in place of the virgin aggregate component. The landfilling emission factor reflects the GHG impacts of disposing of concrete in a landfill. Because concrete does not generate methane in a landfill, the emission factor is the emissions from transporting the concrete to the landfill and operating the landfill equipment.

Exhibit 2: Concrete GHG Sources and Sinks from Relevant Materials Management Pathways

MSW Management Strategies for Concrete	GHG Sources and Sinks Relevant to Concrete		
	Process and Transportation GHGs from Raw Materials Acquisition and Manufacturing	**Changes in Forest or Soil Carbon Storage**	**End of Life**
Source Reduction	Not modeled in WARM		
Recycling	**Offsets** • Transport of raw materials and products • Virgin aggregate mining and production process energy	NA	**Emissions** • Collection and transportation to processing facility • Sorting and processing energy
Composting	Not applicable because concrete cannot be composted		
Combustion	Not applicable because concrete cannot be combusted		
Landfilling	NA	NA	**Emissions** • Transport to landfill • Landfilling machinery

NA = Not applicable.

WARM analyzes all of the GHG sources and sinks outlined in Exhibit 2 and calculates net GHG emissions per short ton of concrete inputs for each materials management alternative (see Exhibit 3). For additional discussion on the detailed methodology used to develop these emission factors, please see sections 3 and 4 on individual waste management strategies.

Exhibit 3: Net Emissions for Concrete under Each Materials Management Option (MTCO$_2$E/Short Ton)

Material	Net Source Reduction (Reuse) Emissions for Current Mix of Inputs[a]	Net Recycling Emissions	Net Composting Emissions	Net Combustion Emissions	Net Landfilling Emissions
Concrete	NA	-0.01	NA	NA	0.04

NA = Not applicable.

[a] The current mix of inputs for carpet is considered to be 100% virgin material.

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[2] The analysis is streamlined in the sense that it examines GHG emissions only and is not a comprehensive environmental analysis of all emissions from materials management.

3. RAW MATERIALS ACQUISITION AND MANUFACTURING

In general, GHG emissions associated with raw materials acquisition and manufacturing (RMAM) are (1) GHG emissions from energy used during the acquisition and manufacturing processes, (2) GHG emissions from energy used to transport raw materials, and (3) non-energy GHG emissions resulting from manufacturing processes.[3] For the recycling emission factor, WARM compares the impact of producing aggregate from recycled concrete to the impact of producing virgin aggregate. In WARM, concrete is considered to be essentially a byproduct of the demolition of buildings and other concrete structures. Since the structures were created for themselves, and not for the purpose of being turned into aggregate, WARM considers that there are no manufacturing or combustion emissions associated with concrete before end of life. Hence, no RMAM emissions are considered in the life-cycle analysis of concrete in WARM. However, we do note that the production of concrete is a greenhouse-gas- and energy-intensive process.

4. MATERIALS MANAGEMENT METHODOLOGIES

WARM analyzes all of the GHG sources and sinks outlined in Exhibit 2 and calculates net GHG emissions per short ton of concrete. This analysis considers recycling and landfilling as possible materials management options for concrete. Recycling of concrete leads to reductions in GHG emissions since it avoids manufacture of virgin aggregate. Landfilling has a slightly positive emission factor due to the emissions from landfill operation equipment.

4.1 SOURCE REDUCTION

When a material is source reduced (i.e., less of the material is made), GHG emissions associated with making the material and managing the postconsumer waste are avoided. Although concrete may be reused or used in ways that could reduce the overall demand for new concrete structures, the benefits of this type of activity have not yet been quantified. Therefore, WARM does not include an emission factor for source reduction.

For more information on this topic, please see the chapter on Source Reduction.

4.2 RECYCLING

When a material is recycled, it is used in place of virgin inputs in the manufacturing process, rather than being disposed of and managed as waste. The Construction Materials Recycling Association (CMRA, 2010) indicates that approximately 140 million tons of concrete are recycled annually in the United States. WARM investigates the GHG impacts associated with reusing crushed concrete in place of virgin aggregate, an open-loop recycling process.[4] Virgin aggregates, which include crushed stone, gravel and sand, are used in a wide variety of construction applications, such as road base and fill, and as an ingredient in concrete and asphalt pavement. When structures are demolished, the waste concrete can be crushed and reused in place of virgin aggregate, reducing the GHG emissions associated with producing concrete using virgin aggregate material. Therefore, the GHG benefit of using recycled

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[3] Process non-energy GHG emissions are emissions that occur during the manufacture of certain materials and are not associated with energy consumption.

[4] Concrete may be recycled in a “closed-loop” by being crushed and reused as aggregate in new concrete. The recycling process is believed to rehydrate some cement in the used concrete, thus reducing the need for cement in the new concrete, resulting in additional GHG benefits. However, sufficient data to quantify this additional benefit are not available at this point.

concrete results from the avoided emissions associated with mining and processing aggregate that concrete is replacing.[5]

More than 2 billion tons of aggregates are consumed each year in the United States, with an estimated 5 percent coming from recycled sources such as asphalt pavement and concrete (USGS, 2000). The U.S. Geological Survey (USGS) estimates that, of the concrete recycled in 1997, at least 83 percent was used in applications that typically employ virgin aggregate: 68 percent of all recycled product was used as road base, 9 percent in asphalt hot mixes, and 6 percent in new concrete mixes. Non-aggregate uses of recycled concrete included 7 percent as general fill, 3 percent as high-value riprap, and 7 percent as other (USGS, 2000.) As tipping fees at landfills increase in many urban areas and recycling techniques continue to improve, concrete recycling is expected to become even more popular.

The calculation of the concrete emission factor involves estimating the emissions associated with production and transportation of one ton of virgin input (aggregate) versus one ton of recycled input (i.e., crushed concrete) individually, and then determining the difference in emissions between recycled and virgin production. The GHG emissions associated with these steps result from the consumption of fossil fuels used in the production and transport of aggregate (combustion energy), as well as the upstream energy (pre-combustion energy) required to obtain these fuels. The concrete recycling emission factor is made up of two components: process energy and transportation energy. No process non-energy emissions occur. Exhibit 4 presents a summary of these components. The following sections contain descriptions of how each component is calculated.

Exhibit 4: Recycling Emission Factor for Concrete ($MTCO_2E$/Short Ton)

Material/ Product	Raw Material Acquisition and Manufacturing (Current Mix of Inputs)	Materials Management Emissions	Recycled Input Credit[a] Process Energy	Recycled Input Credit[a] – Transportation Energy	Recycled Input Credit[a] – Process Non-Energy	Forest Carbon Sequestration	Net Emissions (Post-Consumer)
Concrete	–	–	0.00	-0.01	–	–	-0.01

NA = Not applicable.

– = Zero emissions.

[a] Includes emissions from the initial production of the material being managed.

4.2.1 Developing the Emission Factor for Recycling Concrete

EPA calculates the benefits of recycling by comparing the difference between the emissions associated with producing one short ton of recycled concrete aggregate and the emissions from producing one short ton of virgin aggregate. This recycled input credit is composed of GHG emissions from process energy, transportation energy and process non-energy. Since process non-energy emissions for production of both virgin aggregate and recycled concrete are considered to be zero, this component is not considered in the discussion below.

To calculate the benefit of recycling concrete to displace virgin aggregate, EPA follows three steps, described here in detail.

Step 1. *Calculate emissions from virgin production of aggregate.* GHG emissions from the combustion of fossil fuels are attributed to both process energy (required to extract and process raw

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[5] There is evidence that recycled concrete would also have the benefit of increased carbon storage. Studies have shown that, over time, the cement portion of concrete can absorb CO_2. Factors such as age, cement content, and the amount of exposed surface area affect the rate of carbon absorption. While it is likely that the increase in surface area due to crushing would increase the rate of CO_2 absorption, insufficient data exist at this time to quantify this benefit (Gadja, 2001).

materials such as coarse aggregate and sand) and transportation energy (required to transport virgin aggregate to the job site where it is used.) Emissions associated with transporting the virgin or recycled materials to the consumer, in the case of aggregates, are a driving factor in the GHG impacts of end-of-life concrete management options. EPA estimates the total energy required to produce one short ton of aggregate as 0.0429 million Btu.[6] WARM applies fuel-specific carbon content and fugitive CH_4 emissions coefficients to the energy data for production of (one ton of) virgin aggregate, in order to obtain total process energy GHG emissions, including CO_2 and CH_4. This estimate is then summed with the emissions from transportation energy to calculate the total emissions from virgin production of aggregate. Both process and transportation energy estimates for virgin aggregate production were calculated from data in U.S. Census Bureau (1997), as detailed in EPA (2003).

Step 2. *Calculate GHG emissions from production of recycled aggregate (i.e., crushed concrete).* Recycling of concrete involves crushing, sizing and blending to provide suitable aggregates for various purposes. Concrete may also contain metals (such as rebar) and waste materials that need to be removed. As above, WARM calculates emissions from both process and transportation energy by applying fuel-specific carbon and fugitive CH_4 emissions coefficients to energy data for recycled aggregate production and transportation. Both process and transportation energy estimates for recycled aggregate production were taken from Wilburn and Goonan (1998).

Exhibit 5 and Exhibit 6 present the process and transportation energy and associated emissions for virgin and recycled manufacture of aggregate.

Exhibit 5: Process Energy GHG Emission Calculations for Concrete

Material/Product	Process Energy per Short Ton Aggregate (Million Btu)	Process Energy GHG Emissions ($MTCO_2E$/Short Ton)
Virgin Aggregate	0.05	0.00
Recycled Aggregate (Crushed Concrete)	0.04	0.00

Exhibit 6: Transportation Energy GHG Emission Calculations for Concrete

Material/Product	Transportation Energy per Short Ton Aggregate (Million Btu)	Transportation Energy GHG Emissions ($MTCO_2E$/Short Ton)
Virgin Aggregate	0.19	0.01
Recycled Aggregate (Crushed Concrete)	0.09	0.01

Note: The transportation energy and emissions in this exhibit do not include retail transportation.

Step 3. *Calculate the difference in emissions between virgin and recycled aggregate production.* We then subtract the recycled product emissions (Step 2) from the virgin product emissions (Step 1) to get the GHG savings for using recycled concrete in place of virgin aggregate. These results are shown in Exhibit 7.

Exhibit 7: Differences in Emissions between Recycled and Virgin Concrete Manufacture ($MTCO_2E$/Short Ton)

(a) Material/Product	(b) Process Energy	(c) Transportation Energy	(d) Total (d = b + c)
Recycled Aggregate (Crushed Concrete)	0.00	0.01	0.01
Virgin Aggregate	0.00	0.01	0.02
Total (Recycled - Virgin)	0.00	-0.01	-0.01

Note: Negative values denote net GHG emission reductions or carbon storage from a materials management practice.

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[6] This total represents the sum of pre-combustion and combustion process energy. Please refer to Appendix B of EPA 2003 for more details on how the total energy per ton of aggregate was calculated.

Since no material losses occur during the recovery and manufacturing stages of recycling concrete, the recycling factor obtained above does not need to be adjusted for loss rates. For more information on this topic, please see the chapter on Recycling. For more information about all of these calculations, please refer to the *Background Document for Life-Cycle Greenhouse Gas Emission Factors Clay Brick Reuse and Concrete Recycling* (EPA, 2003).

4.3 COMPOSTING

Concrete is not subject to aerobic bacterial degradation and cannot be composted. Consequently, WARM does not include an emission factor for the composting of concrete.

4.4 COMBUSTION

Concrete cannot be combusted; therefore, WARM does not include an emission factor for combustion.

4.5 LANDFILLING

In general, GHG emissions from landfilling consist of landfill CH_4; CO_2 emissions from transportation and landfill equipment operation; landfill carbon storage; and avoided utility emissions that are offset by landfill gas energy recovery. However, since concrete is not subject to aerobic bacterial degradation and does not degrade in landfills, it does not produce any CH_4 emissions associated with landfilling concrete. Studies have indicated that, over time, the cement portion of concrete is capable of absorbing CO_2 (Gadja, 2001). The amount of carbon stored is affected by age, cement content and the amount of exposed surface area. While this effect would represent landfill carbon storage when concrete is deposited in a landfill, the results of this with respect to the emission factor are difficult to quantify and are considered to be beyond the scope of WARM. Therefore, WARM only counts transportation emissions: transportation of concrete to a landfill and operation of landfill equipment result in anthropogenic CO_2 emissions due to the combustion of fossil fuels in the vehicles used to haul and move the wastes. This information is summarized in Exhibit 8. For more information on this topic, please see the chapter on Landfilling.

Exhibit 8: Landfilling Emission Factor for Concrete ($MTCO_2E$/Short Ton)

Material/ Product	Raw Material Acquisition and Manufacturing (Current Mix of Inputs)	Transportation to Landfill	Landfill CH_4	Avoided CO_2 Emissions from Energy Recovery	Landfill Carbon Sequestration	Net Emissions (Post-Consumer)
Concrete	–	0.04	–	–	–	0.04

– = Zero emissions.

5. LIMITATIONS

Although this analysis is based upon the best available life-cycle data, uncertainties do exist in the final emission factors. This life cycle assessment has the following limitations:

- Landfill carbon storage by the cement component of concrete deposited in a landfill is difficult to quantify and considered to be beyond the scope of WARM. Better data and more information on this storage process would help enhance the landfill emission factor.
- There is a current lack of sufficient data to quantify the GHG benefits of "closed-loop" recycling of concrete. Concrete may be recycled and reused as aggregate in new concrete such that it rehydrates some cement in the used concrete, thus reducing the need for cement in the new concrete, and resulting in additional GHG benefits. More information related to a decrease in

need for virgin cement due to this kind of recycling would help improve the recycling emission factor.

If updated information could be obtained to address these limitations, the life-cycle emission factor for concrete could be further refined. It is important that we continue to assess the assumptions and data used to develop the emission factors. As the combustion processes, manufacturing processes and recycling processes change in the future, these changes will be incorporated into revised emission factors. In addition, it should be noted that these results are designed to represent national average data. The actual GHG impacts of recycling or landfilling concrete will vary, depending on individual circumstances.

6. REFERENCES

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