Generic Concrete Paving

Product Selection and Description

Portland cement concrete, typically referred to as "concrete," is a mixture of portland cement (a fine powder), water, fine aggregate such as sand or finely crushed rock, and coarse aggregate such as gravel or crushed rock. The semi-fluid mixture forms a rock-like material when it hardens. Fly ash—a waste material—may be substituted for a portion of the portland cement in the concrete mix.

Concrete is specified for different building elements by its compressive strength measured 28 days after casting. Concretes with greater compressive strengths generally contain more cementitious materials. For the BEES concrete paving alternatives, a compressive strength of at least 24 MPa (3 500 lb/in^2) is used. The concrete paving systems all consist of a 15 cm (6 in) layer of concrete poured over a 20 cm (8 in) base layer of crushed stone or compacted sand. Paving installed in regions that experience freezing conditions have intentionally entrained air to the volume of 4 % to 6 % to improve its durability in these conditions.

For 0.09 m^2 (1 ft^2) of concrete paving, the 15 cm (6 in) thick concrete layer weighs 32.9 kg (72.5 lb) and the 20 cm (8 in) thick crushed stone base layer weighs 33.3 kg (73.3 lb). Fly ash, a waste material that results from burning coal to produce electricity, can be substituted in equal quantities by mass for various proportions of the cement.

Flow Diagram

The flow diagram below shows the major elements of the production of concrete paving for these products, as they are currently modeled for BEES.

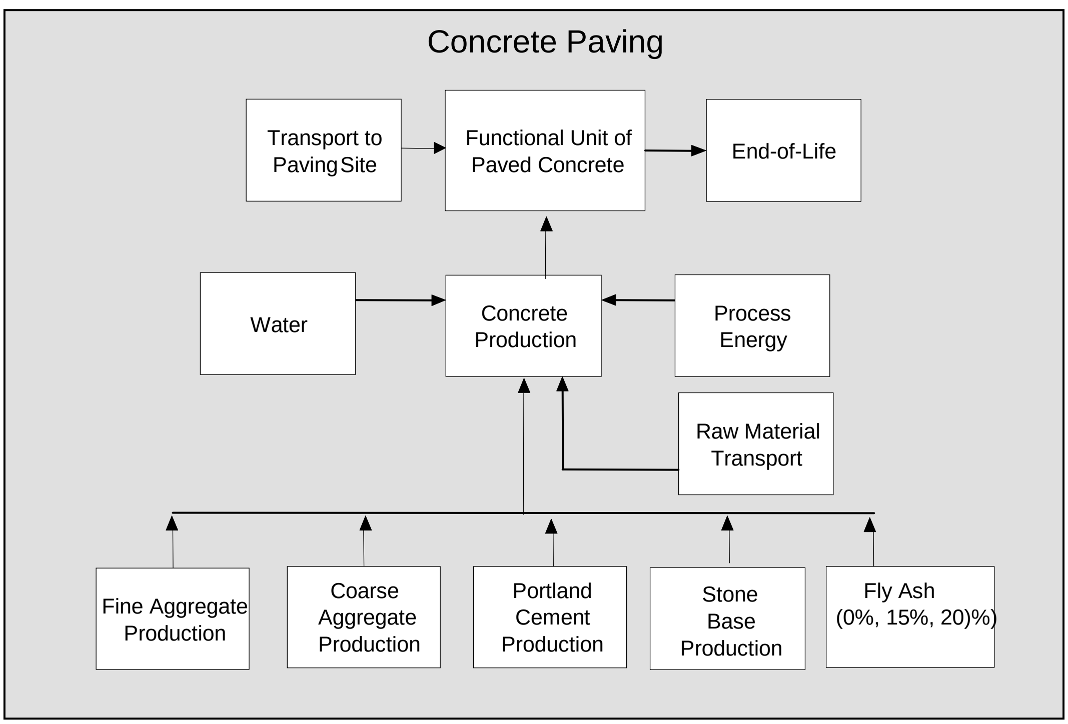

Figure 1: Concrete Paving System Boundaries

Raw Materials

The Table below shows concrete constituents and their quantities for the compressive strength of 24 MPa (3 500 lb/in^2).

Table 1: Concrete Constituents

Constituent	*Kg/m³ (lb/ yd³)*	*Mass Fraction*
Portland Cement and Fly Ash	265 (450)	12 %
Coarse Aggregate	1070 (1800)	42 %
Fine Aggregate	710 (1200)	38 %
Water	180 (300)	8 %

In LCA terms, fly ash is an environmental outflow of coal combustion, and an environmental inflow of concrete production. As such, this waste product is considered an environmentally "free" input material.[1] Transport of the fly ash to the ready mix plant, however, should be—and is—included in the BEES model.

A small amount of coarse aggregate and sand, assumed to be approximately 3 %, is recycled from unused returned concrete. Process water from concrete manufacturing (post-industrial) and in some cases post-consumer water also may be used as a component in concrete.

Manufacturing

Energy Requirements and Emissions. For concrete paving, about 20 % of the concrete is produced in central ready mix operations. Energy use in the batch plants includes electricity and fuel used for heating and mobile equipment.[2]

Table 2: Energy Requirements for Ready Mix Concrete Production

Energy Carrier	*MJ/m³ (MBtu/yd³)*	*MJ/kg (Btu/lb)*
Heavy Fuel Oil	124 (0.09)	0.05 (22)
Electricity	124 (0.09)	0.05 (22)
Total	**247 (0.179)**	**0.1 (43)**

Most concrete for paving applications (80 %) is produced in dry batch operations where the constituents are placed in a truck mixer. Concrete producers are located in all regions of the country since the product has to be placed within 1 h driving time from the production location. The trucks consume one gal of diesel fuel for every 5 km to 6 km (3 mi to 4 mi) traveled, and travel on average 64 km/h (40 mi/h) to reach the site. The fuel usage for mixing concrete in a truck mixer is estimated at 30 % of the total fuel used by mixer trucks.

Table 3: Energy Requirements for Dry Batch Concrete Production

Energy Carrier	*L/m³ (gal/yd³)*	*L/kg (gal/lb)*
Diesel Oil Total	7.07 (1.43)	0.00318 (0.00038)
Diesel Oil for Mixing (30 %)	2.12 (0.429)	0.00095 (0.00011)

Transportation. Concrete raw materials are transported to a plant where they are batched into either a plant mixer or a truck mixer. Round-trip distances by truck for the transport of the materials are assumed to be 97 km (60 mi) for portland cement and fly ash and 80 km (50 mi) for aggregate.

---

[1] The environmental burdens associated with the production of waste materials are typically allocated to the intended product(s) of the process from which the waste results.

[2] Nisbet, M., et al. "Environmental Life Cycle Inventory of Portland Cement Concrete." *PCA R&D Serial No. 2137a*(Skokie, IL: Portland Cement Association, 2002).

Waste. There is no manufacturing waste for either of the concrete manufacturing processes.

Transportation

The distance for transportation of concrete paving materials by heavy-duty truck to the building site is modeled as a variable of the BEES system.

Installation

The energy required for site preparation and placement of crushed stone is 7.5 MJ/m^2 (663 Btu/ft^2) of paving. The energy required for concrete placement is included in the energy requirements for the mixer truck that transports the concrete to the site.

About 3 % to 5 % of the total production of paving concrete is unused at the job site and returned to the concrete plant. Some of this material is recycled back into the product, and supplementary products also are developed. In some cases, the returned concrete is washed into pits and the settled solids are reused for other purposes or diverted to landfills. Landfill usage is minimized due to cost. For the purpose of this generic model of concrete paving, it is most representative of current practice to assume that 75 % of the leftover concrete is recycled back into the product as aggregate and 25 % is reused for other purposes. Industry practice varies based on local regulations, plant space, and company policy.

Installation of concrete paving *on roadways* requires heavy equipment using heavy fuel at 0.7 MJ (0.19 kWh) of fuel per ft^2 of paving; however, use of heavy equipment for installation may not be required for applications such as parking areas and sidewalks. Paving of larger parking areas like a mall area (generally totaling greater than 929 m^2, or 10 000 ft^2) requires some power-driven equipment with screeds[3] and ride-on finishing machines. The fuel used is some combination of diesel and gasoline, although only diesel fuel is assumed for modeling purposes. A rough estimate of fuel usage is about 20 % of that used for road paving. Smaller area placements (totaling less than 929 m^2, or 10 000 ft^2) are done manually with hand tools.

As noted above, unused concrete is usually returned to the concrete plant. About 1 % waste is generated on site as poured waste or spillage. This concrete is not returned to the mixer truck but is collected and hauled to the landfill with other construction debris.

Use

The design life for concrete pavement is typically 30 years, although longer life designs are now being promoted. Maintenance requirements are not intensive relative to life-cycle energy and other environmental burdens.

End of Life

At end of life, concrete parking lot paving is typically overlaid rather than replaced if the land is going to remain in use as a parking lot. The concrete is generally removed if the land is going to be used for a different purpose.

If the concrete paving is removed, the material can be crushed and reused on site or transported for use in another fill application. The decision to send crushed concrete to a landfill is a project decision. It is most representative of current practice to assume that removed concrete is managed by crushing and reusing or recycling in some manner other than landfilling.

---

[3] Screeds are used to level poured concrete surfaces.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Nisbet, M., et al. "Environmental Life Cycle Inventory of Portland Cement Concrete." *PCA R&D Serial No. 2137a*, (Skokie, IL: Portland Cement Association, 2002).

Industry Contacts

Colin Lobo, Ph.D., P.E, Vice President of Engineering, National Ready Mixed Concrete Association, September-October 2005.