Environmental Impacts of Recycled Plastic Concrete

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This report discusses the potential reductions in carbon footprint and embodied energy for recycled plastic concrete. Two cases are investigated in a comparative life cycle assessment (LCA) study, following the principles and framework outlined in ISO 14040 (ISO, 2006).

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1. Goal and scope definition

1.1. *Goal of the study*

The goal of this study is to investigate the life cycle impacts of 15% recycled plastic concrete compared to the current practice of disposing of excess concrete. The results from this study are intended to inform Caltrans in proposing the establishment of protocols and specifications for the reuse of fresh, reclaimed plastic concrete.

The intended audience for this study is the Caltrans Rock Products Committee, Concrete Materials & QA Sub Task Group. Comparative assertions are for internal use only and are not intended for public disclosure.

1.2. *Scope of the study*

The product system to be studied is the manufacturing of minor concrete with and without recycling of returned plastic concrete. The functional unit is *10 cyd of minor concrete and 1.5 cyd of excess plastic concrete, either disposed or recycled.*

As this is a comparative LCA, the system boundary includes only those life cycle stages that differ between the two cases (**Figure 1**):

- pre-use phase
  - raw material extraction
  - upstream material processing
  - concrete manufacturing
- end-of-life phase
  - end of life (excess concrete)

Data sources and calculation methods for the cradle-to-gate impacts of concrete manufacturing follow those outlined in the Central Concrete EPD (Betita, 2013) which has been independently verified by Athena Sustainable Materials Institute; the concrete mix investigated in this study (D33SL9EA, San Jose service area) was not included in the original set of mixes initially verified in the EPD, but will be included in the next update.

The upstream impacts of the excess concrete are not included as they would be the same for both cases. Excess concrete disposal impacts are from the Ecoinvent database (Ecoinvent Centre, 2007).

Manufacturing impacts at the plant are allocated based on total sales volume.

The impact categories calculated in this report are *global warming potential* (GWP) and *total primary energy consumption* (TPE).

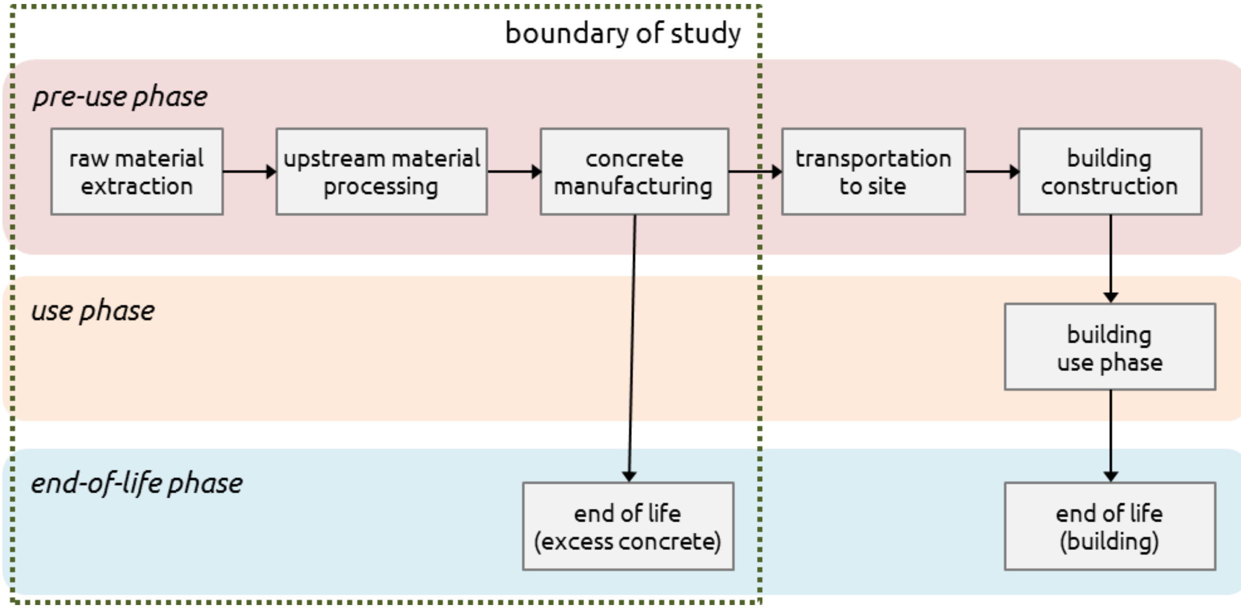

Figure 1. System boundary of the current study.

1.2.1. Cases

The two cases being compared are summarized in **Table 1**. For both cases, it is assumed that 1.5 cyd of excess concrete has been returned in plastic state and 10 cyd of minor concrete is to be manufactured, with the choice of disposing of (Case 1) or recycling (Case 2) the excess concrete. The minor concrete mix is Central Concrete mix D33SL9EA, produced in the San Jose service area.

Table 1: Case comparison

	concrete manufacturing (10 cyd)	excess plastic concrete (1.5 cyd)	additional admixture	end-of-life impacts
Case 1 (no recycling)	10 cyd of virgin concrete	not recycled	n/a	disposal of 1.5 cyd of concrete
Case 2 (recycled plastic concrete)	8.5 cyd of virgin concrete (on top of 1.5 cyd recycled concrete)	recycled in plastic state (displacing virgin concrete)	40 oz retarding admixture per cyd of recycled concrete	n/a

2. Life cycle inventory analysis

Life cycle inventory (LCI) analysis involves the data collection and calculation procedures to quantify the relevant inputs and outputs of the product system being studied.

2.1. LCI of concrete manufacturing

The LCI of concrete manufacturing is based on both the mix design (specifying the amount of component material per cyd of concrete) and service area. It encompasses three life cycle stages:

- **A1**: raw material supply *(based on mix design)*
- **A2**: transportation from supplier to plant *(based on mix design and service area)*
- **A3**: manufacturing *(based on service area)*

While the specific mix investigated in this study (D33SL9EA, San Jose) was not included in the initial set of mixes included in the externally-verified Central Concrete EPD, the underlying data and calculation methods are the same, with the only difference being the material quantities given by the mix design.

For Case 1, 10 cyd of virgin concrete are manufactured. For Case 2, 8.5 cyd of virgin concrete are needed in addition to the 1.5 cyd of recycled plastic concrete.

2.2. LCI of additional admixture

For Case 2, 40 oz of retarding admixture (Delvo Stabilizer, COMMAND code XUT12) is added to stabilize each cyd of recycled concrete. The LCI of this additional admixture is compiled according to the Central Concrete EPD, including material and energy inputs and outputs from raw material processing (EFCA, 2006) and transportation from supplier to plant (Khan, 2012).

2.3. LCI of end-of-life phase

Only the end-of-life impacts of excess concrete are included in the present study. The source for the LCI of concrete disposal is the Ecoinvent database (Ecoinvent Centre, 2007). For Case 1, 1.5 cyd of excess concrete is disposed.

3. Life cycle impact assessment

The life cycle impact assessment (LCIA) phase translates the LCI results into environmental impacts. The two impact categories included in this study are global warming potential (GWP) measured in kilograms of carbon dioxide equivalent (kg CO_2e), and total primary energy consumption (TPE) measured in megajoules of primary energy (MJ). The impact assessment methods used are TRACI 2.0 and Cumulative Energy Demand, respectively; both are included in SimaPro LCA software.

3.1. LCIA of concrete manufacturing

Impacts per cyd of virgin concrete manufacturing for Central Concrete mix code D33SL9EA, produced in the San Jose service area, are shown in **Table 2** (GWP) and **Table 3** (TPE).

Table 2: GWP impacts of 1 cyd of virgin concrete (D33SL9EA, San Jose)

		Impacts (kg CO_2e/cyd)			
Material (unit)	Amount (unit/cyd)	*A1 (material)*	*A2 (transportation)*	*A3 (manufacturing)*	TOTAL
Portland cement (lb)	379	168.29	0.68		168.98
Fly ash (lb)	126	0.00	0.13		0.13
Natural aggregate (lb)	1459	2.79	26.03		28.82
Crushed aggregate (lb)	1740.24	4.99	3.81		8.80
Air-entraining admixture (oz)	2.53	0.03	0.02		0.04
Batch water (gal)	34	0.00	0.00		0.00
manufacturing				2.48	2.48
TOTAL		176.09	30.68	2.48	**209.25**

Table 3: TPE impacts of 1 cyd of virgin concrete (D33SL9EA, San Jose)

Material (unit)	Amount (unit/cyd)	Impacts (MJ/cyd)			
		A1 (material)	*A2 (transportation)*	*A3 (manufacturing)*	TOTAL
Portland cement (lb)	379	1015.6	9.4		1025.0
Fly ash (lb)	126	0.0	1.9		1.9
Natural aggregate (lb)	1459	37.4	354.8		392.1
Crushed aggregate (lb)	1740.24	103.3	52.3		155.6
Air-entraining admixture (oz)	2.53	0.2	0.2		0.4
Batch water (gal)	34	0.0	0.0		0.0
manufacturing				132.5	132.5
TOTAL		1156.4	418.5	132.5	**1707.3**

3.2. LCIA of additional admixture

Table 4 gives the GWP and TPE impacts per cyd of recycled plastic concrete due to the addition of 40 oz of Delvo stabilizer.

Table 4: GWP and TPE impacts of additional admixture for 1 cyd of recycled concrete

Material (unit)	Amount (unit/cyd)	Impact (unit)	*A1 (material)*	*A2 (transportation)*	TOTAL
Retarding admixture (oz)	40	**GWP** (kg CO_2e/cyd)	1.79	0.24	**2.03**
		TPE (MJ/cyd)	21.8	3.3	**25.0**

3.3. LCIA of end-of-life phase

The end-of-life impacts of concrete disposal for 1 cyd of concrete are:

- **GWP**: 7.64 kg CO_2e
- **TPE**: 187.3 MJ

3.4. Total impacts

The total impacts for each case are presented in **Table 5** (GWP) and **Table 6** (TPE).

Table 5: Total GWP impacts for each case

	Impacts (kg CO_2e/cyd)			
	concrete manufacturing	*additional admixture*	*end-of-life phase*	*TOTAL*
Case 1 (no recycling)	2092.5	0.0	11.5	**2103.9**
Case 2 (recycled plastic concrete)	1778.6	3.0	0.0	**1781.6**

Table 6: Total TPE impacts for each case

	Impacts (MJ/cyd)			
	concrete manufacturing	*additional admixture*	*end-of-life phase*	*TOTAL*
Case 1 (no recycling)	17,073	0	281	**17,354**
Case 2 (recycled plastic concrete)	14,512	38	0	**14,550**

The recycling of plastic concrete results in a **15.3% reduction in carbon footprint** and **16.2% reduction in embodied energy**.

4. Interpretation

The reuse of fresh, returned plastic concrete offers the opportunity to directly reuse the water, cement, and aggregate used in the production of concrete. The impacts due to manufacturing and transportation of additional admixture to stabilize recycled concrete are offset by the avoided impacts of concrete disposal, and pale in comparison to the impact reduction from the displacement of virgin concrete production.

The carbon and energy savings of recycled concrete in Case 2 mirror the 15% recycled content in (1.5 cyd/10 cyd), with additional savings resulting from the diversion of excess concrete from the waste stream. Because the impacts of virgin concrete manufacturing far outweigh the impacts of both additional admixture and concrete disposal, the impact reductions are approximately equal to the percentage of recycled concrete. Thus, a batch of concrete containing x% recycled content will result in carbon and energy savings of at least x% when compared to the production a virgin concrete batch with the excess sent to disposal.

The apparent carbon and energy benefits of recycled plastic concrete warrant further investigation into the feasibility of allowing for returned plastic concrete in Caltrans projects. As a large consumer of concrete products, Caltrans has the opportunity to drastically reduce greenhouse gas emissions and total primary energy consumption through the adoption of plastic concrete recycling protocols.

References

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