Proceedings of US-Japan Workshop on
Life Cycle Assessment of Sustainable Infrastructure Materials
Sapporo, Japan, October 21-22, 2009

SUSTAINABLE INFRASTRUCTURE MATERIALS POLICY AT THE CITY-SCALE: DATA & INSTITUTIONAL NEEDS

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ABSTRACT

Developing sustainable materials policies at the city-scale requires data on material flow analysis (MFA), Life Cycle Assessment (LCA), and End of Life (EOL) assessment to quantitatively demonstrate sustainability benefits such as reductions in greenhouse gas emissions (GHG). Implementing such sustainable materials policies requires more holistic accounting of GHGs at the city scale, comparative analysis of sustainability benefits against alternative sustainability policies, as well as cross-scale, cross-sector institutions that enable and credit such policies. These data and institutional needs are exemplified via a case study of green concrete policies in Denver, CO. Preliminary data are also presented on translating the methodology to Delhi, India.

Keywords: green concrete, life cycle assessment (LCA), material flow analysis (MFA), greenhouse gases (GHG), end of life assessments (EOL).

1 INTRODUCTION

With more than half of the world's population presently living in cities versus rural areas [1], cities worldwide are functioning as vast global demand centers for both energy and materials. Energy use within cities includes use of electricity and natural gas in buildings and facilities, and use of petro-fuels (gasoline and diesel fuel) in the transport sector. Data on electricity and natural gas use can be obtained from the local energy utility, while data on transport fuel use, while more challenging, if often obtained via regional transportation models or by top-down estimation from regional fuel sales data [2], [3], and [4].

In contrast, materials use at the city scale is more challenging to quantify. Yet quantification of materials use in cities, particularly in urban infrastructure, is essential to motivate development of sustainable infrastructure materials policies. Recently, Ramaswami et al. [2] articulated four key urban materials necessary to sustain life in urban cities – the list of key urban materials included water, fuels, food and materials used for shelter such as cement. Cement emerges as an important urban material given that concrete is the second most widely used material on a per capita mass basis (after water), with nearly one ton of the material used annually for each person on the planet on average [5]. Further cement and concrete production also have important environmental consequences. Cement contributes globally to 7% of GHG emissions [6], while extraction of virgin aggregate for concrete production has numerous ecosystem impacts from transport of aggregates to urban centers from hinterland areas to alteration of river beds from aggregate mining operations. End of life disposal of concrete in urban areas also consumes landfill space that can be expensive.

Thus, numerous green concrete policies have been proposed in the literature that include recycling of urban concrete yielding recycled coarse aggregate and material substitutions for the cementitious component of typical concrete that uses Portland cement [e.g., 5, 6, 7]. However, the impact of material substitutions in concrete have rarely been quantified at the city-scale and compared with other GHG mitigation strategies, to justify city-scale green infrastructure materials policies. The purpose of this paper is to discuss key data needs and key institutional needs that can promote development of green infrastructure materials policies in cities.

The paper is organized around a case study of Denver, CO, which is the first US city to formally adopt a green concrete policy for all public sector infrastructure flatwork projects. For this pioneering effort, Denver in partnership with the University of Colorado Denver received EPA's award C^2P^2 award for pollution prevention via beneficial reuse of coal combustion by products.

In this paper we describe some of the data that were required for developing green infrastructure materials policy in Denver, CO, and we present some of the institutional needs and challenges encountered in implementing such a policy. The green infrastructure policy is presented in the context of the overall goal of reducing Denver's per capita GHG footprint by 10% over a 5 year time frame from 2007 to 2012.

2. DATA NEEDS FOR POLICYMAKING

The green concrete proposed for Denver included use of fly ash – a by-product of coal combustion, and recycled aggregates obtained from urban demolished concrete. The concrete was termed HPGC – high performance green concrete, to emphasize no loss of structural performance with incorporation of recycled materials that are often viewed to create an inferior product. Several types of data were required to develop a green concrete policy for Denver; the policy recommendations were first discussed by Greenprint Denver – a task force of about 40 citizens and experts assembled by Denver's Mayor, and then adopted by the Mayor as a daily operational practice in the Denver Public Works Department.

Both Greenprint Denver and the Public Works Department required the following types of data before the green concrete policy could be developed and adopted:

- Structural strength and durability data tested both in the lab and at field pilot test locations
- Environmental data showing anticipated GHG savings from the proposed policy.
- Environmental data showing end-of-life testing of the proposed green concrete.
- Economic data showing any potential monetary savings from the proposed policy.

Structural strength and durability data were obtained both in lab tests and at two field tests site locations. Various mixes of green concrete were tested with fly ash inclusions ranging from 10% to 40% and up to 50% recycled aggregate substitution for virgin aggregate. The results of strength and durability testing showed differences between Class C and Class F fly ash, with Class F performing superior to Class C fly ash; both types however, exceeded the strength specifications required for concrete use in pavements, and hence performed as well or better than ordinary Portland cement concrete (OPC). The strength and durability data are described elsewhere in Reiner [7] and Reiner and Rens [8].

In this paper, we describe the process of developing the environmental-economic data required for green concrete policy-making.

3. ENVIRONMENTAL-ECONOMIC ANALYSIS

GHG Savings: Quantifying the expected city-wide GHG savings from any proposed green materials policy requires a combination of material flow analysis (MFA) that estimates the material flows of infrastructure materials into the city, and, multiplies this tonnage by the expected life cycle GHG emissions savings comparing business as usual (BAU) infrastructure scenarios with the HPGC scenario [1, 7, 9].

3.1 Material Flow Analysis (MFA)

Estimating material flows of concrete in cities is challenging as concrete is used both in the private and the public-sector. Because private sector concrete consumption is not publicly reported in the US, city-wide monetary expenditure data on concrete products were obtained from the US Economic Census for the Denver-Aurora MSA level, and converted to mass consumption units. Monetary expenditures (NAICS code 3273) were converted to concrete mass flows utilizing local costs for concrete products obtained from the industry [7, 9]. Because there is a 10% seasonal variation and regional variation in the price of concrete, uncertainty is generated in the material flow estimate of concrete use in cities. However, this is at present the best available methodology because, while the US Portland Cement Association (PCA) reports total national cement consumption, it does not show regional and local variation in this number in the public domain.

In a few other countries, by contrast, the private sector reports the use of cement by region and even by city-location (in certain cases) in the public domain. For example, in translating this work to India, we have found that the Cement Manufacturers Association in India [10] reports cement use in individual cities such as Delhi. Per capita cement use in Denver, USA and Delhi, India are shown in Table 1, showing per capita cement consumption in Denver of the order of 0.4 metric tonnes, while that in India is 0.21 metric tonnes cement per person.

Table 1: Total and per capita cement use in Denver, USA and Delhi, India

City	Annual Cement Use Estimate (million mt.)	Data Source or Method	Pop. (millions)	Per cap cement use per year
Denver - Aurora	0.85 [5]	Econ. data on concrete purchase	2.24 [9]	0.38-0.46[9]
Delhi	3.52 [10]	Cement Assoc. Data	16.76[11]	0.21

3.2 Life Cycle Assessment (LCA)

Economic Input-Output LCA (EIO-LCA) was applied to compute the greenhouse gas (GHG) savings and monetary savings accrued comparing HPCG with 20% fly ash replacement and 50% recycled aggregate substitution, with BAU OPC concrete. The life cycle approach computed GHG savings from the following:

- Reduction in GHG from reduced cement use when substituted with fly ash. GHG from cement production is approximately 1 metric tonne CO2e per metric tonne cement.
- Reduction in GHG from use of local recycled aggregate compared to excavation and transport of virgin aggregates.
- Reduction in use of landfill operation when aggregate is recycled.
- While the fly ash is a waste material from power plants, it is considered to “environmentally free”, GHG emissions from transport of fly ash to Denver was incorporated.
- Both transport by rail and by truck were modeled.
- The energy required to crush and recycle urban demolished concrete was added, with data obtained from a local large scale recycling company.

The full methodology is described elsewhere [7] and [9]. The results showed a savings of 0.0454 mt CO2e (carbon dioxide equivalents) per metric tonne of HPGC concrete used (a 20% reduction), generating economic savings of $1.19 per metric tonne of HPGC [9] City-wide the benefits were more than 72,000 metric tonnes CO_2e saved and $2M in economic savings. Green concrete was the only GHG mitigation strategy that yielded immediate cost savings.

More than half of the GHG savings were associated with cement substitutions since life cycle inventory data show that one metric tonne of CO2e emissions associated with production of one metric tonne cement in the US [12], incorporating quarrying of lime stone, transport, calcining and energy use in wet or dry kiln process of cement manufacturing. The remaining savings, which were significant, were attributed to reductions in diesel use in truck transport of aggregates and avoided land-filling.

We are presently testing the same methodology for application to cities in India. Our preliminary analysis of cement manufacturing in India shows similar 1.08 metric tonnes of CO2e per tonne of cement manufactures in dry kiln process in India [13], in line with data reported for the US (NREL [12]). Truck transport, limestone quarrying, aggregate crushing and other data are presently being gathered in India

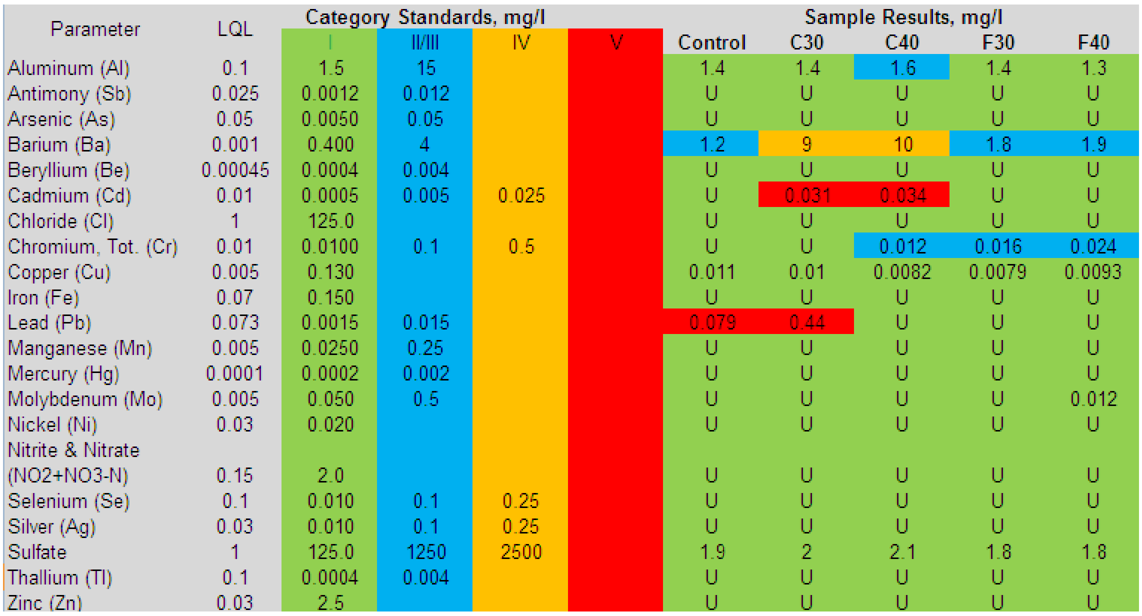
4. END-OF-LIFE ANALYSIS

Once the environmental and economic benefit of establishing HPGC is quantified, the end-of-life of HPGC is examined. What happens when the new material is disposed? Can HPGC concrete be safely recycled? To assess this question, HPGC samples were crushed to simulate their demolishing and crushing in a recycled materials factory. Since most of crushed concrete is returns to urban concrete urban infrastructure, which has been leach tested in numerous studies, here we studied end-of-life leaching of heavy metals from fine dust that is the 1% mass residue of concrete recycling operation (this represents a very stringent test on a small mass of fine residue). The fines were evaluated comparing HPGC with BAU-OPC concrete, using the State of Wisconsin’s guidelines for beneficial use of industrial by-products [14]

The results are shown in Table 2, and indicate that the HPGC residual fines performed the same or better than BAU-OPC residual fines from concrete recycling for a vast majority of chemicals of concern. HPGC fines met Category 3 standards (blue color) for beneficial re-use (Unconfined geotechnical fill), while both BAU-OPC fines and Class C HPGC fines indicated more study required for cadmium and lead [7] in disposal of fines from demolition operations.

Recognizing that the testing of fines from demolishing concrete was the most stringent test, given the benefits, HPGC was recommended by Denver’s Greenprint Council in 2005 and established as city government policy by Mayor;s decree in 2006 [15]. The precedent set by the Federal Highways Administration in establishing a 20% national minimum fly ash requirement in transportation concrete projects was an important consideration in policymaking.

Table 2: NR 538 Results for very fine dust residue from concrete demolition – ASTM D 3987 Water Leach Test[7]



Parameter	LQL	Category Standards, mg/l				Sample Results, mg/l				
		I	II/III	IV	V	Control	C30	C40	F30	F40
Aluminum (Al)	0.1	1.5	15			1.4	1.4	1.6	1.4	1.3
Antimony (Sb)	0.025	0.0012	0.012			U	U	U	U	U
Arsenic (As)	0.05	0.0050	0.05			U	U	U	U	U
Barium (Ba)	0.001	0.400	4			1.2	9	10	1.8	1.9
Beryllium (Be)	0.00045	0.0004	0.004			U	U	U	U	U
Cadmium (Cd)	0.01	0.0005	0.005	0.025		U	0.031	0.034	U	U
Chloride (Cl)	1	125.0				U	U	U	U	U
Chromium, Tot. (Cr)	0.01	0.0100	0.1	0.5		U	U	0.012	0.016	0.024
Copper (Cu)	0.005	0.130				0.011	0.01	0.0082	0.0079	0.0093
Iron (Fe)	0.07	0.150				U	U	U	U	U
Lead (Pb)	0.073	0.0015	0.015			0.079	0.44	U	U	U
Manganese (Mn)	0.005	0.0250	0.25			U	U	U	U	U
Mercury (Hg)	0.0001	0.0002	0.002			U	U	U	U	U
Molybdenum (Mo)	0.005	0.050	0.5			U	U	U	U	0.012
Nickel (Ni)	0.03	0.020				U	U	U	U	U
Nitrite & Nitrate (NO2+NO3-N)	0.15	2.0				U	U	U	U	U
Selenium (Se)	0.1	0.010	0.1	0.25		U	U	U	U	U
Silver (Ag)	0.03	0.010	0.1	0.25		U	U	U	U	U
Sulfate	1	125.0	1250	2500		1.9	2	2.1	1.8	1.8
Thallium (Tl)	0.1	0.0004	0.004			U	U	U	U	U
Zinc (Zn)	0.03	2.5				U	U	U	U	U

4. INSTITUTIONAL NEEDS

Although the HPGC policy is now institutionalized at the City and County of Denver, operationalizing this policy to gain GHG reduction credits requires overcoming various cultural and institutional challenges such as discussed below.

Contractor perceptions of “green concrete” and unfamiliarity with its different handling properties were often cited in interviews as barriers for rapid adoption of HPGC policies. Anecdotal information about field tests often add to reluctance to operationalize change. Continuous re-training of technical staff and open discussion of actual performance and monetary savings realized by the City are useful in operationalizing HPGC policies

Data Tracking – tracking the volume of green concrete applied and the tonnage of cement avoided is another useful strategy; however, this requires robust GIS-based databases for urban infrastructure improvement projects, with a specific field created for reporting on fly ash displacement of cement. Denver has recently incorporated this revision into their database.

Incorporating embodied energy of materials into standardized GHG reporting protocols: Standardized GHG reporting protocols for businesses [16, 17] and for cities [18] require reporting only of end uses of energy within the organization’s boundaries, i.e., use of electricity, natural gas and petro-fuels within urban boundaries – termed as Scope 1 and Scope 2 emissions. Although cities are large consumers of materials produced outside city boundaries, e.g., of transport fuels, treated water, food and cement, the embodied energy of these critical urban materials have not been incorporated into a city’s GHG footprint on a consistent basis – these inclusions are termed as optional Scope 3 items.

Different cities have on an ad hoc basis incorporated selected cross boundary Scope 3 embodied energy flows. For example, the city of Seattle included the impact of asphalt use, while select food and construction materials have been incorporated by cities such as Paris and New Delhi [19]. Recently, Ramaswami et al., developed a hybrid demand-centered life cycle based methodology for more holistic GHG accounting at the city-scale [2]. As seen in Figure 1, embodied energy of key urban materials contributed about 25% of the GHG footprint. Inclusion of a small number of most relevant Scope 3 items is strongly recommended by

EPA's Climate Leaders Program in developing a more holistic GHG account [17]. Inclusion of key cross boundary energy flows also created scale convergence on per capita GHG emissions from the city-scale to the national scale [2]. The contribution of cement use in cities alone contributed about 2% of Denver's GHG footprint - of the same order as all energy use in all city government buildings. Such visual demonstrations of the impact of infrastructure materials use were important in promoting green concrete policies.

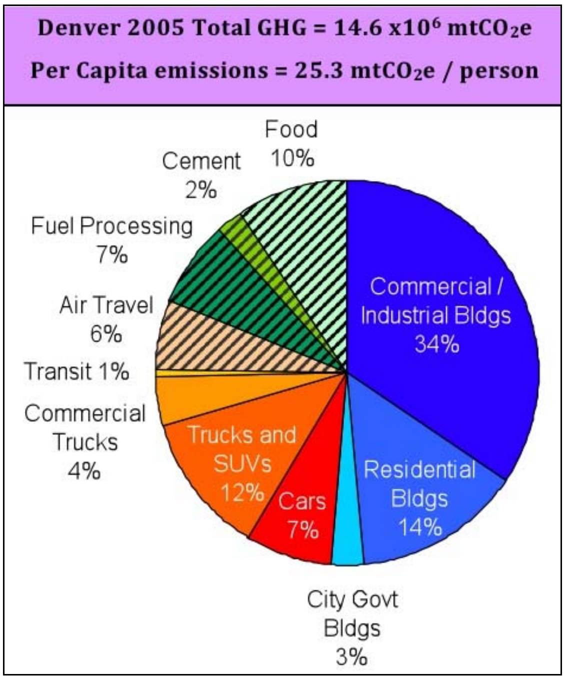


Figure 1: Denver's GHG emissions summary by activity in 2005 (From: [2]). The hatched regions show sectors and activities typically not included in conventional city-scale boundary-limited direct GHG emissions inventories.

The WRI is presently revising its GHG protocols to include important Scope 3 contributions. Given that cement contributes 5% to 7% of global GHG emissions, cement use is likely to be a high priority item in Scope 3 inclusions.

Carbon Trading: Incorporating key materials as a required inclusion in an entity's full Scope 1+2+3 GHG accounting can create the forum for carbon trading, generating win-win green infrastructure solutions. For example, at present credits for GHG emission reductions from waste recycling are awarded to the waste generator – thus green concrete credits would go to fly ash producers. This does not create an incentive for cities to invest in green concrete or green infrastructure policies and to track their GHG reductions, even when city-scale policies can create and unprecedented increase in demand fro recycled materials, thereby creating the condition of "additionality".

More sophisticated carbon trading guidelines are presently in discussion phase at the Colorado Carbon Fund and the Carbon Registry [20]. These rules may connect the supply side (supply of cement, waste fly ash, etc.) with the demand side (demand for HPGC in cities) creating balanced incentives in promoting HPGC and other green infrastructure policies in cities worldwide. Without larger scale institutions providing the institutional infrastructure to connect supply with demand for green infrastructures, such policies are not expected to be widely adopted. It is anticipated that entities such as the Carbon Fund will establish guidelines for green infrastructure materials policies in cities.

5 CONCLUSION & DISCUSSION

Data on environmental and economic performance of infrastructure materials have been shown to be essential in promoting sustainable infrastructure materials policies at the city scale. The data include MFA and LCA, the combination of which provides estimation of GHG reductions and any monetary savings at the city scale. End of Life environmental assessments are also essential in demonstrating the new infrastructure does not pose environmental concerns when compared with the BAU. The methodology outlined in this paper can be applied to quantitatively show environmental benefits from new green cements and polymer-incorporated concretes.

However, environmental and economic analytic data alone, while important in supporting sustainable materials policy development, are not sufficient to operationalize these policies. Engagement and education of technical personnel and contractors, incorporating embodied energy of materials in a city's GHG footprint, and, development of more sophisticated carbon credit sharing guidelines between infrastructure suppliers and users in cities is essential to widely disseminate sustainable infrastructure materials policies in cities worldwide.

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ACKNOWLEDGEMENT

This work was supported by grants from the SU Department of Education GAANN Program and the US National Science Foundation IGERT Program, and a sponsored project from the City & County of Denver.