ENVIRON, Life Cycle Greenhouse Gas Emissions from Building Materials

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Contents

Acronyms

AP-42	Compilation of Air Pollutant Emission Factors
$CaCO_3$	limestone
CaO	calcium oxide
CCAR	California Climate Action Registry
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
DOE	Department of Energy
EERE	Energy Efficiency and Renewable Energy
EIA	Energy Information Administration
ENVIRON	ENVIRON International Corporation
ft^2	square feet
GHG	greenhouse gas
GRP	General Reporting Protocol
kWh/m^2	kilowatt hour per square meter
LCA	life cycle analyses
VC	Vista Canyon
MMBTU	million British thermal units

EXECUTIVE SUMMARY

This report evaluates the life cycle greenhouse gas (GHG) emissions associated with the building materials used in the construction of the Vista Canyon (VC) development. The life cycle GHG emissions include the embodied energy from the materials manufacture and the energy used to transport those materials to the site. This report then compares the life cycle GHG emissions to the overall annual operational emissions of VC. The materials analyzed in this report include materials for 1) residential and non-residential buildings and 2) site infrastructure. This report calculates the overall life cycle emissions from construction materials to be 46 to 87 tonnes per year, or 0.29% to 0.54% of the overall VC project emissions.

ENVIRON estimated the life cycle GHG emissions for buildings by conducting an analysis of available literature on life cycle analyses (LCA) for buildings. According to these studies, approximately 75 - 97% of GHG emissions from buildings are associated with energy usage during the operational phase; the other 3 - 25% of the GHG emissions are due to material manufacture and transport. Using the GHG emissions from the operation of VC buildings, 3% to 25% corresponds to 6 to 46 tonnes CO_2 per year or 0.03 – 0.29% of VC project emissions.

ENVIRON calculated the life cycle GHG emissions for infrastructure (roads, storm drains, utilities, gas, electricity, cable) to be equal to a one time emission of 1,616 tonnes CO_2. This analysis considered the manufacture and transport of concrete and asphalt. Based on this analysis, the manufacture of the materials leads to 1,053 tonnes of emissions, and the transport of the materials leads to 563 tonnes of CO_2 emissions. Although VC estimates the need for volume of asphalt approximately three times higher than that of concrete, the majority of the emissions for infrastructure result from the manufacture of concrete because of the higher CO_2 emission factor associated with this process. If a 40-year lifespan of the infrastructure is assumed, the total annualized emissions are 40 tonnes per year or 0.25% of VC project emissions.

The overall life cycle emissions from embodied energy in VC building materials, annualized by 40 years, are 46 to 87 tonnes CO_2 per year. This represents 0.29% to 0.54% of the annualized GHG emissions from the VC project. The bulk of these emissions are based on general life cycle analysis studies and do not reflect the design features of VC. Aspects of the project will tend to drive the life cycle emissions towards the lower end of the range; one example is the emphasis on the use of local construction materials.

1 Introduction

This report evaluates the life cycle greenhouse gas (GHG) emissions associated with the building materials used in the construction of the VC development. The life cycle GHG emissions include the embodied energy from the materials manufacture and the energy used to transport those materials to the site. This report then compares the life cycle GHG emissions to the overall annual operational emissions of VC. The materials analyzed in this report include materials for 1) residential and non-residential buildings and 2) site infrastructure.

1.1 Background on Life Cycle Analysis

LCA is a method developed to evaluate the mass balance of inputs and outputs of systems and to organize and convert those inputs and outputs into environmental themes or categories. In this case, the LCA is related to GHG emissions associated with the different stages of a life cycle. The LCA field is still relatively new, and while there are general standards for goals and general practices for LCAs[1] the specific methodologies and, in particular, the boundaries chosen for the LCA makes inter-comparison of various studies difficult. Simple choices such as the useful life of a building or road, for example, can change the LCA outcome substantially. Additionally, the geographic location, climatic zone and building type significantly influence patterns of energy consumption (and energy efficiency) and therefore determine life cycle GHG emissions, which makes comparisons among different studies difficult.

The calculations and results presented in this report are estimates and should be used only for a general comparison to the overall GHG emissions estimated in the Climate Change Section of the Draft EIR for VC. LCA emissions vary based on input assumptions and assessment boundaries (e.g., how far back to trace the origin of a material). Assumptions made in this report are generally conservative. However, due to the open-ended nature of LCAs, the analysis is not exact and may be highly uncertain.

2 Emissions Estimates

2.1 Life Cycle GHG Emissions from Building Materials

ENVIRON estimated the life cycle GHG emissions for building materials by conducting an analysis of available literature on life cycle analyses (LCA) for buildings. According to these studies, approximately 75 - 97% of GHG emissions from buildings are associated with energy usage during the operational phase; the other 3 - 25% of the GHG emissions are due to building material manufacture and transport. Based on the GHG emissions from the operation of VC buildings[2], 3% to 25% corresponds to 221 to 1,845 tonnes CO_2 per year, as shown in Table 1. The specific LCA studies used are discussed in the next section.

[1] ISO 14044 and ISO 14040

[2] Climate Change Technical Report: Vista Canyon. January 2010.

With the current energy generation mix in the US which relies heavily on fossil fuel based sources, focusing on energy efficiency measures (which ultimately reduces lifetime GHG emissions) is more effective in reducing the overall GHG footprint than focusing on materials with low embodied energy. As the energy generation measures reduce their GHG intensity (shift away from fossil fuel to renewable fuels), material selection will be a more critical factor in a building's GHG emissions over its life cycle.

2.1.1 LCA Studies for Buildings

The LCA literature studies tend to compare the energy used to make and transport building materials, or the embodied energy, with the operational energy use. In this manner, the relative importance of the embodied energy can be assessed. ENVIRON discusses several studies that compare the embodied energy and the operational energy.

A life cycle assessment of a 66,000 ft^2 sustainably-designed university building[3] in the US Mid-west[4] estimated that the GHG emissions associated with its energy use over a 100-year time horizon to be 135,000 metric tonnes of carbon dioxide equivalent (CO_2e), 96.5% of which result from operations phase activities, 3% from material production (of which ⅓ is cement production) and 0.5% from transportation and decommissioning combined. The study also notes that the GHG emissions closely matches the distribution of life cycle energy distributions, indicating that operational energy requirements are the key factor determining overall GHG emissions, especially when considering fossil fuel based energy generation. This building has a longer estimated life than VC buildings, which would lead to a lower comparison of embodied energy to operational energy.

A study of single-family homes in the US Mid-west,[5] one built using standard construction techniques and the second incorporating energy efficiency measures, reached similar conclusions. Over the life cycle of the homes (assumed to be 50 years), the conventional home uses 15,000 MMBTU and the energy efficient configuration uses 6,000 MMBTU of energy, representing a 60% reduction in overall energy. As GHG emissions closely match the distribution of life cycle energy distributions, the energy efficient variant resulted in 63% fewer emissions. Of the total energy use over the structure's life cycle, 91% of the conventional house total energy results from energy consumed in the use stage (e.g., operating energy). This value drops to 74% in the energy efficient home as the energy embodied in the building materials stays the same or is slightly higher than that in the conventional home and operating energy is reduced.

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[3] Includes 4 floors of classroom and open-plan offices and 3 floors of hotel rooms, in this evaluation used as a surrogate for a generic commercial structure.

[4] Scheuer, C., G.A. Keoleian, and P. Reppe. (2003) Life cycle energy and environmental performance of a new university building: Modeling challenges and design implications. *Energy and Buildings*, **35**(10): p. 1049.

[5] Keoleian, G.A., S. Blanchard, and P. Reppe. (2000) Life-cycle energy, costs, and strategies for improving a single-family house. *Journal of Industrial Ecology*, **4**(2): p. 135.

Similarly, a review of 60 case studies of homes from nine European countries in a variety of climates[6] indicated that operating energy represents the largest part of energy demand by a building during its life cycle. In one evaluation the operating energy is reported as between 92 - 95% for conventional construction and 72 - 90% for low-energy buildings[7] (which are also consistent with other literature references[8]). Sartori and Hestnes[6] also note that buildings constructed with energy efficiency measures may have a higher energy (and concomitant GHG emissions) embodied by the materials used in construction (e.g., more insulation, higher thermal mass), but over the lifespan of the building the overall energy use (operating and embodied energy) is dramatically lower due to the large reductions in operating energy. As an example, the embodied energy was estimated to be 1171 kWh/m^2 for a conventional house and 1391 kWh/m^2 for a passive, energy efficient home, an increase of 220 kWh/m^2 or 19%. Over the lifetime of the building, however, the total energy (operating and embodied) of the conventional house was approximately 22,500 kWh/m^2, while the passive house was roughly 5,500 kWh/m^2, a four-fold decrease in the total energy over an assumed 80 year life cycle.

2.1.2 Energy Efficiency vs. Embodied Energy in Buildings

From our analysis of these assessments, we note the following major conclusions:

- To minimize GHG lifetime emissions, optimization of energy efficiency (both thermal and electrical) for the operational phase of a building should be the primary emphasis for design, especially when the energy supplied is generated from fossil fuel sources.
- Passive design measures such as the orientation of structure to maximize solar heating and daylighting as well as natural ventilation; heavy construction to increase the thermal mass of the structure with materials that have a high capacity for absorbing heat and change temperature slowly; and solar control like window shading[9] should be emphasized[10,11,12] as they have a negligible increase in embodied energy (GHG emissions from material production) and can reduce total energy substantially.[13]
- Active energy efficiency measures (e.g., mechanical ventilation, artificial cooling, free cooling) may as much as double the embodied energy of the structure, but can halve overall energy usage.

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[6] Sartori, I. and A.G. Hestnes. (2007) Energy use in the life cycle of conventional and low-energy buildings: A review article. *Energy and Buildings*, **39**(3): p. 249.

[7] Winther, B.N. and A.G. Hestnes. (1999) Solar versus green: The analysis of a Norwegian row house. *Solar Energy*, **66**(6): p. 387.

[8] Adalberth, K., A. Almgren, and E.H. Petersen. (2001) Life Cycle Assessment of Four Multi-Family Buildings. *International Journal of Low Energy and Sustainable Buildings*, **2**.

[9] United Nations Environment Program 2007 Buildings and Climate Change report whole-house system measures are recommended for the Mediterranean and desert climate zones.

[10] Browning, W.D. and J.J. Romm. (1998) *Greening the Building and the Bottom Line*. Snowmass, Colorado: Rocky Mountain Institute.

[11] United Nations Environment Program. (2007) *Buildings and Climate Change: Status, Challenges and Opportunities.*

[12] US Department of Energy Building Technologies Program. (2007) www.eere.energy.gov/buildings/. October.

[13] Sartori, I. and A.G. Hestnes. (2007) Energy use in the life cycle of conventional and low-energy buildings: A review article. *Energy and Buildings*, **39**(3): p. 249.

- With the current energy generation mix in the US which relies heavily on fossil fuel based sources, focusing on energy efficiency measures (which ultimately reduces lifetime GHG emissions) is more effective in reducing the overall GHG footprint than focusing on materials with low embodied energy. As the energy generation measures reduce their GHG intensity (shift away from fossil fuel to renewable), material selection will be a more critical factor in a building's GHG emissions over its life cycle.

One cannot evaluate the life cycle emissions of a building product independent of the impact that the building product has on energy use. For example, studies that evaluate the relative embodied energy and GHG emissions associated with the production of structural materials such as steel, concrete or wood generally indicate that the wood products have the lowest GHG emissions as it is produced from a renewable resource that may actually remove CO_2 during its production phase and sequester it during its use phase.[14,15] However, these studies do not account for the effect of the material on overall building energy efficiency, which is often heavily dependent on the climate in which the building is located. In desert climates, the thermal mass of the structure is important for energy savings, as the thermal mass cools at night and keep the house cool during the day during hot weather and conversely heats during the day keeps the house warm during the evening during cool weather. To increase thermal mass, concrete is much more effective than wood. In other types of climates (cooler with less solar heating), wood with insulation has a greater impact at improving overall building efficiency.

For some building products or systems, the net energy savings during the operational portion of the building's life cycle are comparable. If this is the case, then the alternative with the lowest embodied GHG emissions will result in the lowest life cycle GHG emissions.

Building materials with high replacement rates, like carpeting and wiring, can often have a high contribution to the overall GHG emissions as their impact is dependent on renovation schedules. For example, if two building materials have the same embodied energy but one is replaced every 5 years and the second is replaced every 25 years then the first will have five times the embodied energy over the lifetime of the building. As such Scheuer et al.[16] indicate that "[d]esign strategies that maximize the service life of building materials should be maximized." These strategies include designing the structure for minimal material use and choosing materials with low embodied energy, high recycled content, and long life spans.

From our analysis of these product or system specific assessments, we note the following major conclusions:

- Products or systems which have the greatest impact in improving overall building energy efficiency over the building's life cycle should be selected to minimize life cycle GHG

[14] Borjesson, P. and L. Gustavsson. (2000) Greenhouse gas balances in building construction: Wood versus concrete from life-cycle and forest land-use perspectives. *Energy Policy*, **28**(9): p. 575.

[15] Lenzen, M. and G. Treloar. (2002) Embodied energy in buildings: Wood versus concrete - Reply to Borjesson and Gustavsson. *Energy Policy*, **30**(3): p. 249.

[16] Scheuer, C., G.A. Keoleian, and P. Reppe. (2003) Life cycle energy and environmental performance of a new university building: Modeling challenges and design implications. *Energy and Buildings*, **35**(10): p. 1049.

emissions. These alternatives may not necessarily have the lowest embodied GHG emissions.

- When evaluating products or systems that have similar impacts on overall building energy efficiency, alternatives with the lowest embodied GHG emissions should be selected to minimize GHG emissions.
- Materials with high replacement rates (e.g., carpeting, wiring) tend to have higher embodied energy due to their short life cycle, therefore minimizing embodied GHG emissions is most critical for these types of products or systems to minimize overall GHG emissions. Materials with low replacement rates (e.g., piping, air ducts) tend to have lower embodied energy over the life cycle of the building, therefore differences in overall GHG emissions between several alternatives are likely to be small.

2.2 GHG Emissions from Manufacture of Infrastructure Materials

ENVIRON evaluated the embodied energies of materials likely to be found in the infrastructure (roads, storm drains, utilities, gas, electricity, cable) of the VC development. The embodied energies of different materials vary based upon the transportation distance and manufacturing processes. A material that is locally-sourced may require a large amount of energy to be produced and, on the contrary, a material with a relatively low energy intensity may be sourced from farther away. ENVIRON assumed that concrete and asphalt will be among the dominant materials used in the infrastructure and estimated the embodied energies of these two materials. The manufacture of these materials results in overall CO_2 emissions of 1,053 tonnes. Although asphalt is predicted to be used in higher quantities than concrete, almost 78% of these emissions (818 tonnes) result from the manufacture of concrete because the CO_2 emission factor of concrete is over fifty times that of asphalt.

2.2.1 Embodied Energy in Concrete Production

Concrete is composed primarily of cement, water, and aggregate such as sand and gravel, with small amounts of chemical admixtures. A typical concrete mix contains approximately 15% cement by volume.[17] Because the remaining 85% of concrete is composed of water and aggregate, ENVIRON assumed that all of the manufacture-related embodied energy in concrete stems from the production of cement.

There are two main sources of CO_2 emissions from the production of cement: “calcining” emissions and fossil fuel combustion emissions. Calcining emissions result from the chemical conversion of limestone ($CaCO_3$) to calcium oxide (CaO) and carbon dioxide (CO_2). CaO is a precursor to cement and CO_2 is released to the atmosphere. The emissions from fossil fuel combustion vary based on fuel type, but in general slightly more than half of the emissions

[17] Portland Cement Association. Cement and Concrete Basics. http://www.cement.org/basics/concretebasics_concretebasics.asp

associated with cement production are attributed to calcining emissions and the remainder result from fossil fuel combustion.[18]

ENVIRON used three sources to estimate CO_2 emission factors for the production of cement. The Energy Information Administration (EIA)[19] and AP-42[20] estimate that 0.5 tonnes of CO_2 are emitted from the calcining process for every 1 tonne of cement produced. AP-42 also provides a range (0.75 – 1.19 tonnes CO_2 / tonne cement) of total CO_2 emission factors (including calcining emissions and fossil fuel combustion emissions). The consulting group Battelle[21] estimates a total CO_2 emission factor for cement production in North America of 0.99 tonnes CO_2 / tonne cement. These emission factors are presented in Table 2.

2.2.2 Embodied Energy in Asphalt Production

The manufacture of asphalt is less energy intensive than the manufacture of cement. Asphalt is composed of asphalt cement and aggregate; the aggregate typically constitutes 92% by weight of the asphalt mixture.[22] AP-42 estimates CO_2 emission factors for batch mix (37 pounds CO_2 / short ton asphalt) and drum mix (33 pounds CO_2 / short ton asphalt) hot mix asphalt plants based on fuel usage within the plants.[23] ENVIRON used the average of these two values to represent the embodied energy of asphalt for VC infrastructure.

2.2.3 Embodied Energy in Infrastructure

ENVIRON used the CO_2 emission factors from cement and asphalt to estimate the embodied energy of the infrastructure materials in the VC development. ENVIRON estimated the projected volumes of virgin concrete and asphalt per acre of development based on past projects and engineering judgment, resulting in the predicted material amounts shown in Table 3. The estimated emissions from the manufacture of the infrastructure materials are presented in Table 4. Because concrete is 15% cement by volume,[24] the total volume of concrete in Table 3 is multiplied by 15% to yield the volume of cement presented in Table 4. The emissions from the cement manufacture are assumed to be equal to the emissions from concrete manufacture. One-time emissions from concrete and asphalt manufacture for infrastructure materials are estimated to be 818 and 235 tonnes CO_2, respectively.

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[18] USGS 2005 Minerals Yearbook: Cement. February 2007. pg 16.1-16.2. http://minerals.usgs.gov/minerals/pubs/commodity/cement/cemenmyb05.pdf

[19] EIA Energy Market and Economic Impacts of S.280, the Climate Stewardship and Innovation Act of 2007. August 2007. http://www.eia.doe.gov/oiaf/servicerpt/csia/special_topics.html

[20] EPA AP42 Section 11.6: Portland Cement Manufacturing. http://www.epa.gov/ttn/chief/ap42/ch11/final/c11s06.pdf

[21] Battelle. Humphreys, K. and Mahasenan, M. Climate Change: Toward a Sustainable Cement Industry. March 2002.

[22] EPA AP42 section 11.1: Hot Mix Asphalt Plants. pg 11.1-1. http://www.epa.gov/ttn/chief/ap42/ch11/final/c11s01.pdf

[23] EPA AP42 section 11.1: Hot Mix Asphalt Plants. Tables 11.1-5 and 11.1-7. http://www.epa.gov/ttn/chief/ap42/ch11/final/c11s01.pdf

[24] Portland Cement Association. Cement and Concrete Basics. http://www.cement.org/basics/concretebasics_concretebasics.asp

2.3 Transportation of Materials for Infrastructure

ENVIRON estimated the emissions from the transportation of the infrastructure. ENVIRON selected distances based on an expected trip distance of local manufacturers of cement and asphalt to the VC development.[25] Using the infrastructure material quantities specified in Table 3, ENVIRON estimated emissions of 563 tonnes CO_2 from the transportation of the concrete and asphalt in the infrastructure.[26] Details of the calculations are outlined in Table 5.

2.3.1 Calculation of Emissions from Transportation of Materials for Buildings

Although each particular shipper operates with greater or lesser efficiencies, ENVIRON assumed an average GHG emission rate per tonne-mile[27] for each mode of transportation. Although it is likely that more dense material has a slightly lower GHG shipping intensity than does less dense material, this analysis developed a single emission factor per tonne-mile of material moved, regardless of density, for each mode of transportation.

2.3.1.1 Emissions associated with transporting the material

Emission factors were calculated from DOE EERE energy intensity indicators.[28] EERE data is presented in terms of energy per mile traveled. These were converted using AP-42 conversion factors[29] for energy in different types of fuel, and California Climate Action Registry (CCAR) General Reporting Protocol (GRP)[30] emission factors for mass of CO_2 emitted per gallon of fuel. Trains and trucks are assumed to run on diesel. These emission factors are listed in Table 5. The emission factors developed above were multiplied by the distances traveled by each type of transportation.

2.4 Summary of Emissions from Buildings and Infrastructure

Table 6 presents the summary of the life cycle greenhouse gas (GHG) emissions associated with the building materials used in the construction of the VC development. The life cycle GHG emissions include the embodied energy from the materials manufacture and the energy used to transport those materials to the site. The materials analyzed include materials for 1) residential and non-residential buildings and 2) site infrastructure. This report calculates the overall life cycle emissions from construction materials to be 46 to 87 tonnes per year, or 0.29 to 0.54% of the overall VC project emissions. Aspects of this project such as the emphasis on the use of local construction materials are expected to drive the life cycle emissions toward the lower end of the range.

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[25] The distance for concrete and asphalt assumes the use of a local source 100 miles from Vista Canyon.

[26] For the estimates of emissions from material transportation, ENVIRON conservatively assumed that the entire concrete mix, not just cement, is transported from the source locations to the development site.

[27] A tonne-mile refers to the amount of material (in tonnes) moved a distance of one mile.

[28] Grams CO_2 per tonne-mile. See http://intensityindicators.pnl.gov/trend_data.stm Transportation sector data.

[29] AP-42 conversions available at http://www.epa.gov/ttn/chief/ap42/appendix/appa.pdf

[30] The GRP is available online at http://www.climateregistry.org/resources/docs/protocols/grp/GRP_3.1_January2009.pdf