Re-Examining The Life Cycle Energy of Residences: Functional Unit, Technological Dynamics and Scaling

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SETTING

Energy use in the housing sector is responsible for 21.4% of U.S. carbon emissions. Through Life Cycle Assessment (LCA) tools, we take up the question of how materials, size and form of housing are related to life cycle energy use and greenhouse gas (GHG) emissions.

Objective: To provide policy makers and planners better information for energy efficient and low-carbon residential communities in the U.S. by:

- Re-defining the functional units for buildings in LCA
- Accounting for technological changes in LCA

SINGLE FAMILY DETACHED DWELLINGS

We simulated a scenario that represents typical housing units in low-density subdivision developments in the Phoenix metropolitan area. It includes one-story and two-stories dwellings ranging from 1,500 to 3,500 square feet of livable space. The dwelling characteristics are:

- average construction quality
- no basement
- cement slab foundation
- basic architectural components
- cement tiled roof
- stucco exterior walls on wood frame

HYBRID EIOLCA MODEL

Combination of Process-sum and Economic Input-Output LCA: an additive hybrid method in which economic data is identified and used to cover processes where materials data are unavailable and associated with sectors in an EIO model.[(1)]

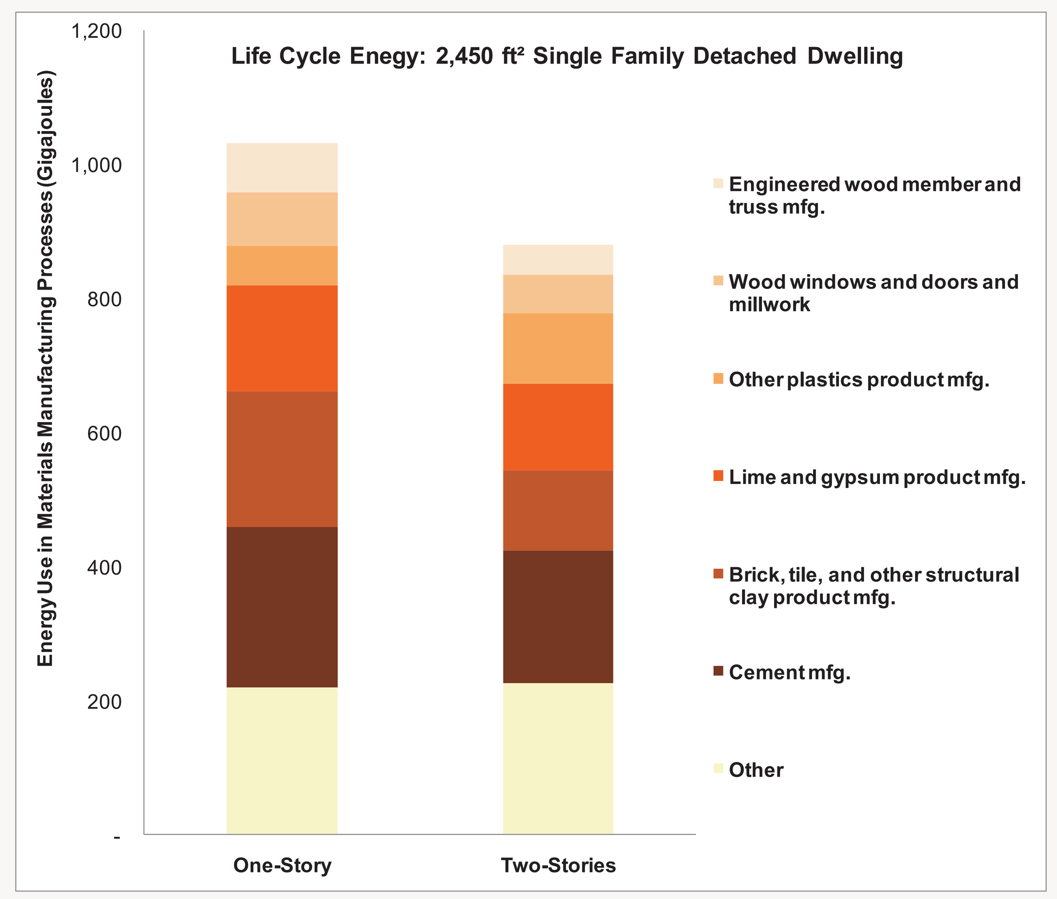
Model elements:

- functional unit defined as a climate controlled space over the assumed lifespan of the dwelling (50 years)
- life cycle energy and carbon emissions associated with materials, construction, operation and associated equipment of dwellings built in 2002
- technological progress in HVAC technology from 2002-2051 integrated into estimation of life cycle energy

Data Sources:

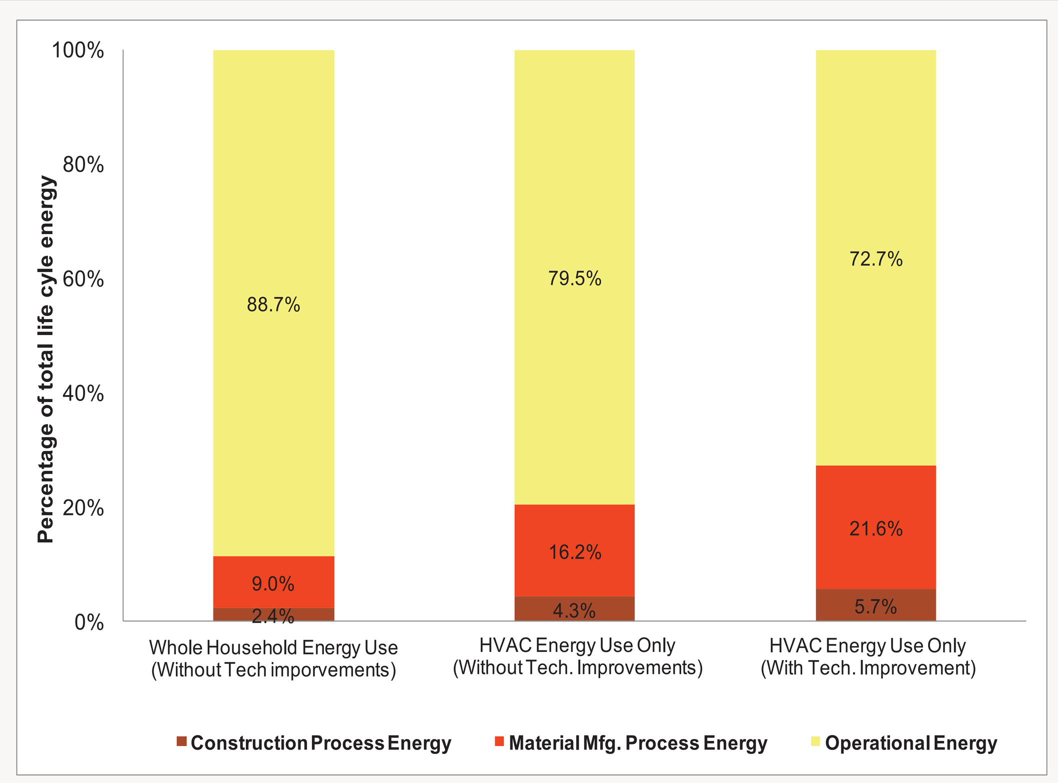
- RS Means for construction materials, labor, quantities and costs
- 2002 Economic Census for construction energy used [(2)]
- U.S. Dept. of Energy Home Energy Saver model for space cooling and heating primary energy use [(3)]
- Carnegie Mellon Economic Input-Output life cycle assessment for supply chain energy use intensity matrix (MJ/$) [(4)]

RESULTS: ENERGY



Two-story dwellings require between **10-15%** less energy (primary) than one-story dwellings of equal livable space and materials composition.

Results were achieved by comparing the total life cycle energy embedded in materials manufacturing processes required to build one and two-story dwellings.



The combined share of construction and materials manufacturing processes accounts for **27%** of the total life cycle embedded primary energy.

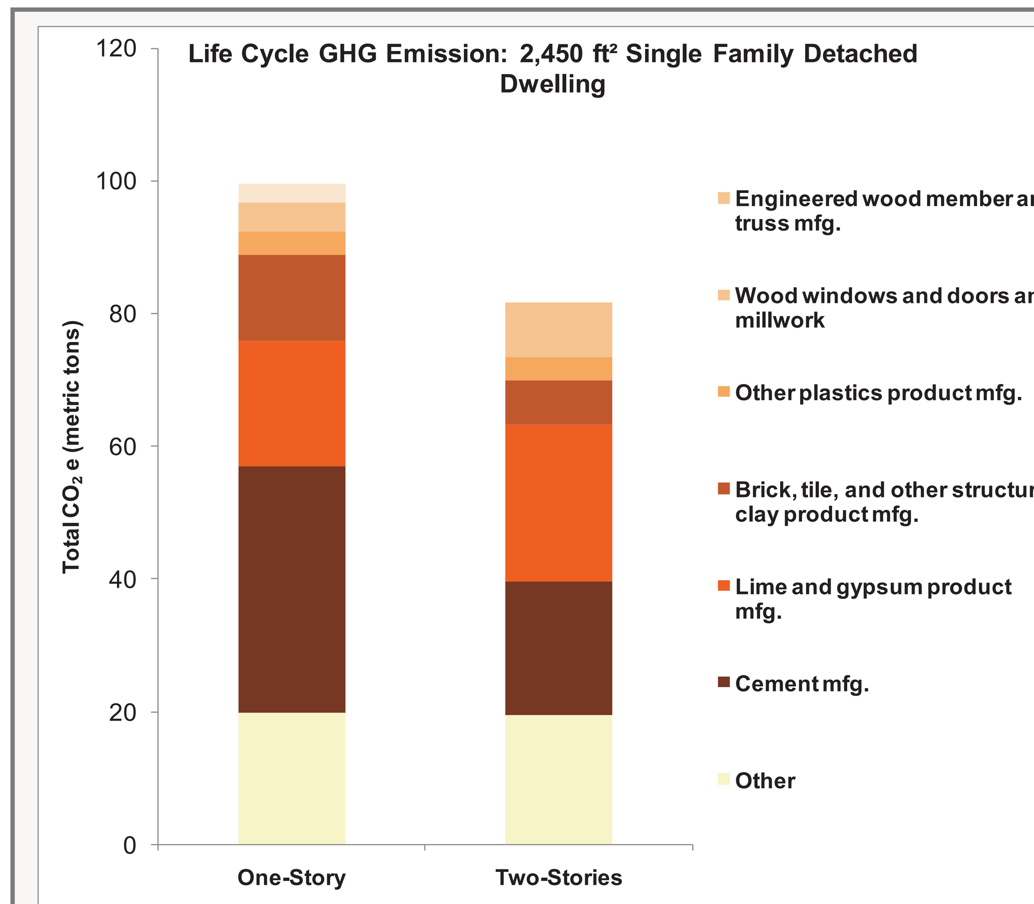
The variation of the relative contributions of construction, materials manufacturing and operational processes to total life cycle embedded primary energy is due to different definitions of functional units.

We define the functional unit as a climate controlled (only) space for which technological improvements in equipment efficiency and electricity production are accounted for in the LCA.

Size	N° Story	Construction Process (GJ)	Material Mfg. Process (GJ)	Total (GJ)	Energy Intensity (GJ/m²)
1500	1	197.3	730.8	898.9	6.45
	2	181.7	655.8	837.5	5.80
2000	1	240.6	910.4	1,118.9	6.02
	2	214.0	779.9	993.9	5.18
2450	1	283.6	1,068.4	1,315.5	5.78
	2	250.7	917.0	1,167.7	4.97
3000	1	329.9	1,257.0	1,543.1	5.54
	2	315.5	1,150.8	1,466.2	5.10
3500	1	366.5	1,419.4	1,734.8	5.34
	2	319.6	1,208.0	1,527.6	4.54

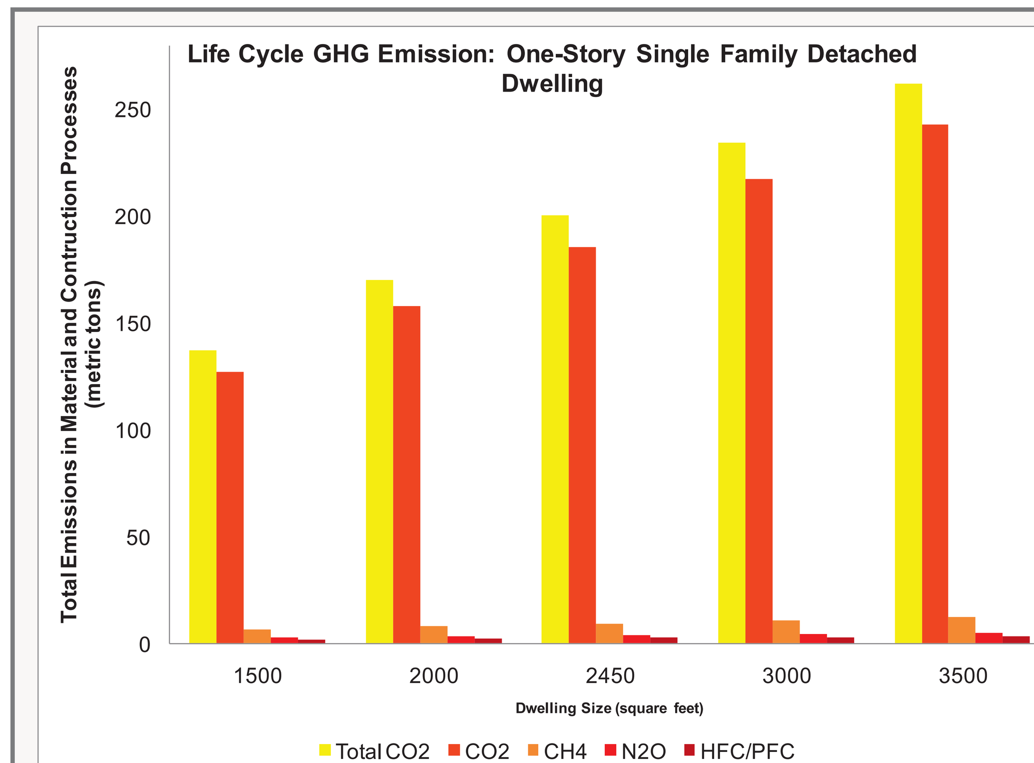
The table shows total life cycle energy, intensity and scaling of construction and materials manufacturing processes as a function of dwelling size and number of stories.

RESULTS: GHG EMISSIONS



Two-story dwellings produce between **8-15%** less CO_2e than one-story dwellings.

Results were achieved by comparing total life cycle GHG emissions associated with the materials manufacturing processes required to build one and two-story dwellings. Construction processes account for ~**50%** of total CO_2e.



The data show that 0.07 tons CO_2e are emitted for each square foot of livable space built.

To the left we illustrate the relationship between dwelling size and GHG emissions from construction and materials manufacturing processes.

TAKEAWAY POINTS

- Prior LCA studies have defined the operational phase as all energy use within a residence. We argue that only the **delivery of heating and cooling energy should be used as a functional unit** for life cycle building assessments;
- We argue that the amount of energy embedded in the material and construction processes is not trivial: ~ 27%;
- Construction type, stories, and materials affects the total life cycle energy and emissions. Some impacts scale proportionally to size, others scale as a function of perimeter and volume; and
- Careful consideration of the type of construction material and form used could achieve significant savings in energy and GHG emissions.

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