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MATERIAL NATURE VERSUS STRUCTURAL NURTURE: THE EMBODIED CARBON OF FUNDAMENTAL STRUCTURAL ELEMENTS

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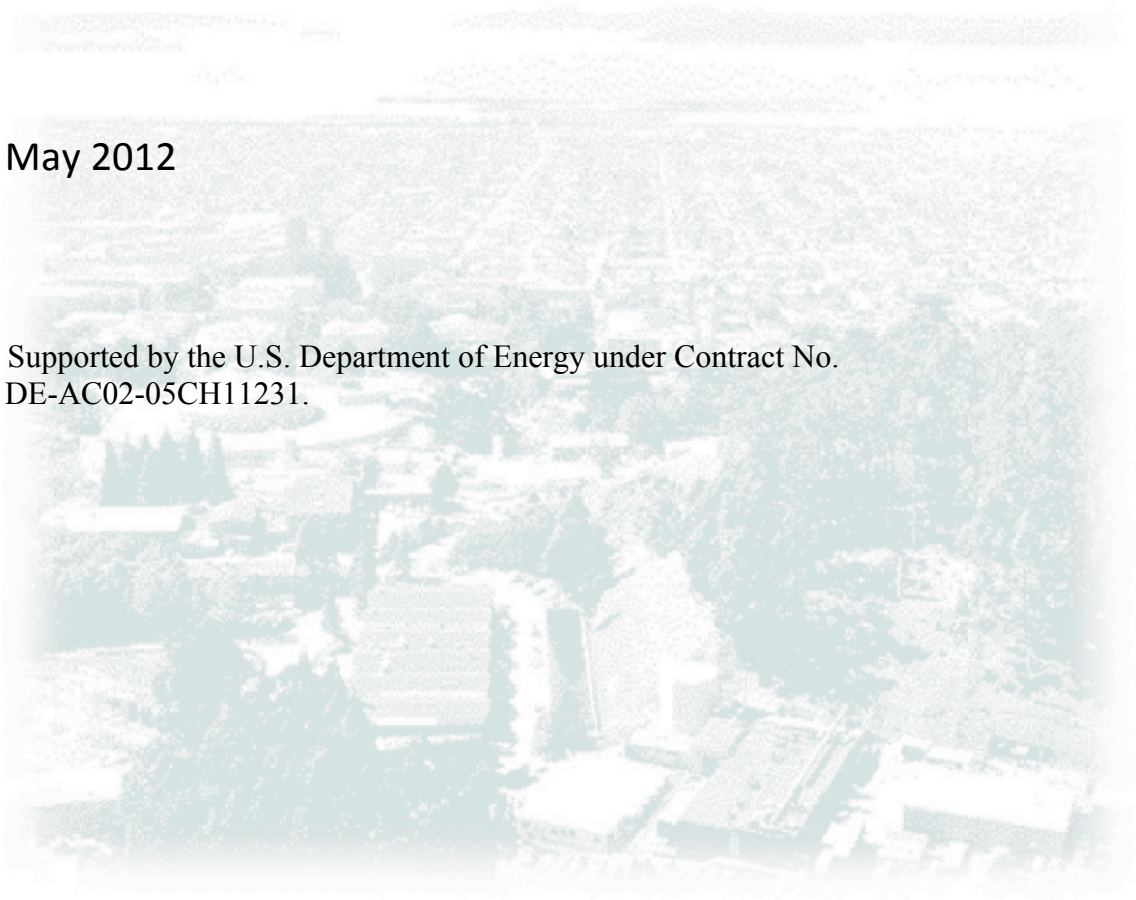

Comment on "Material Nature versus Structural Nurture: The Embodied Carbon of Fundamental Structural Elements"

In an article recently published in *ES&T*, Purnell [1] purports that previous studies of embodied carbon (EC) of structural materials are flawed because they are "based either on subjective narrative arguments, or values of embodied CO_2 per unit volume or mass." Purnell then compares "cradle to site" carbon emissions of simple beams and columns made of different materials, and concludes that there is "no such thing as a green structural material." We agree with Purnell that different structural applications may have different solutions for minimizing environmental impact, but we argue that his review of prior literature in the field is incomplete, and that his analytical approach is overly simplistic and uses inappropriate functional units and system boundaries that do not provide an adequate comparison of the life-cycle climate impacts of different materials.

Defining a functional unit, or the objective basis for comparing different systems, is an essential step in life-cycle assessment (LCA). Purnell uses structural performance of materials as a functional unit, which he considers to be a significant advance over the use of material volume or mass. Indeed it is, but the field of building materials LCA has progressed well beyond uni-dimensional functional units such as volume, mass, or isolated structural characteristics. In focusing exclusively on structural performance, Purnell has overlooked a rich literature base discussing appropriate methods of modeling the life-cycle environmental impacts of building materials (e.g. [2,3]). Buildings are complex systems of multiple components and functions, thus Purnell's comparison of materials solely on the basis of structural characteristics is inadequate for all but the most simple of structures.

A particular material often fulfills more than one function (e.g. structural support and thermal insulation), and a given building function may be fulfilled by a combination of materials. Changing one material may impact different functions in various ways, for example sound transmission, fire protection, and the overall weight of the building and the required foundation design. Purnell acknowledges the dominance of operational energy use in a conventional building life-cycle, but does not consider how material function (e.g. providing greater spans for more efficient use of daylight and interior space) and properties (e.g. thermal inertia and insulation effects) might affect the greater building system. Robust LCAs must ensure that these complex interactions between multiple system elements are accounted for within the functional unit. This is commonly done by comparing functionally equivalent versions of complete buildings made with different material mixes. A building is more than a collection of structural elements, and Purnell's narrow focus on simple beams and columns does not consider this complexity.

System boundaries of an LCA must be broad enough to include all significant impacts. The "cradle to site" boundaries defined by Purnell exclude two essential system elements: the end-of-life management of the materials, and the biogenic carbon in wood materials. He erroneously states that end-of-life considerations "generally impact metrics other than EC and are thus not of primary interest here." In fact, post-use management strongly affects the carbon balance of materials, especially wood [4,5]. Because half of the dry weight of wood is carbon, an EC analysis of wood products is incomplete without considering the life-cycle biogenic carbon

flows, i.e. the source and fate of the carbon stored in the wood [6]. Purnell cryptically states that EC calculations of wood products are sensitive to whether a "sequestration argument" is accepted, apparently referring to whether an analysis accounts for the biological carbon making up the wood. We submit that there is no "sequestration argument." Instead, there is either full accounting of the life-cycle carbon flows associated with a product (resulting in accurate representation of climate impacts), or there is incomplete carbon accounting. Purnell mentions the important issue of deforestation, but his narrow system boundaries are incapable of identifying changes in forest carbon stock. His approach does not capture the fundamental difference between the one-way flows of fossil carbon associated with manufacturing steel and concrete, and the cyclical life-cycle flows of biogenic carbon associated with wood products from sustainably managed forests [7].

Increasingly, progressive materials management systems consider post-use materials as resources rather than wastes. Post-use wood products can be used, as Purnell notes, in "particleboard, animal bedding, or biofuel." In the latter case the wood often replaces a fossil fuel, in which case the stored biogenic carbon is released to the atmosphere while fossil emissions are avoided. Alternately, if post-use wood is landfilled, some biogenic carbon may be sequestered indefinitely in the landfill but other carbon may be released as methane with more severe climate impacts [8]. In Purnell's study "no account is taken of decommissioning regimes, since these cannot be reliably specified in general for each material or component," thus he implicitly assumes zero impact from all forms of post-use material management. This simplification is unfortunate, because LCA can be a valuable tool for understanding how our current and future actions affect the environment, allowing us to make better decisions with fewer negative impacts. However, this requires modeling a range of potential actions and impacts, which Purnell's restricted "cradle to site" system boundaries do not allow.

In general, the importance that Purnell credits to his analysis is based largely on his spurious claims about the status quo of the field of building materials LCA. Many of the methodological shortcomings he points to were overcome long ago, or are inaccurate portrayals of how LCA is used to make robust decisions. Worryingly, Purnell states that "the purpose of this paper is categorically not to propose which of the major structural materials is the greenest, but to demonstrate that such questions are nonsensical by presenting a more appropriate approach to analysis." On the contrary, we argue that the question of climate impacts of construction materials is not nonsensical, and can be understood through detailed system analysis in a life-cycle perspective. Purnell's study in fact suggests that which material is greenest may depend on the application, and that detailed life-cycle assessment should reveal these differences. He says his analysis "is only intended to provide a basis for more complex studies in which the interaction between structural elements (systems of beams, columns, frames, foundations, etc.) is explicitly taken into account," but then goes on to offer general design rules of thumb based on his simplified analysis. In fact, the complex studies that Purnell calls for have already been carried out by others (see [8,9]), who based their analyses on complete building functional units that considered interactions not only between structural elements but also essential non-structural building components, and that accounted for full life-cycle carbon flows. A general conclusion of these studies is that wood products from sustainably managed forests have the potential to produce less life-cycle climate impact than other common building materials [7,8,9]. Purnell's

analysis, with its inappropriate functional unit and incomplete system boundaries, does not alter this conclusion.

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