ASHRAE2010–85081

Carbon neutrality based on native-site carbon storage

Michael Bendewald
Student Member ASHRAE

Victor Olgyay, AIA
Member ASHRAE

ABSTRACT

A certain amount of emphasis has been placed on carbon neutral design lately in the buildings industry. The emphasis has thus far been on building operation emissions and to a certain degree the embodied emissions of construction. In response to this increased interest in carbon neutrality, this paper discusses alternative approaches to carbon neutrality and introduces a new definition. There are three main components to the presented carbon neutrality computational model, which assesses the net carbon (C) flux from the Earth to atmosphere (or vice versa) as a result of a building project. The first is land use change, which accounts for the removal or addition of vegetation and other carbon storing elements to the project site. The amount of native-state C storage can be defined as the baseline C storage value for the building project. The second and third emissions sources in the model are from the embodied carbon emissions of construction and the building operation. Carbon neutrality is defined such that the embodied emissions of construction as well as operation are completely offset by the end of the building lifetime. Moreover, if the design state site C storage is less than the native state, than the net difference must be offset as well. As an example of the concept in practice, an institutional building in construction documentation phase in Lake Placid, Florida is examined. The introduced model allows for the assessment of buildings in a way that is arguably more helpful than calculating "net-zero" building operation emissions.

INTRODUCTION

Carbon-neutral design is gaining greater presence in the buildings industry. The Architecture 2030 Challenge has been and continues to be a highly influential driver of the industry toward carbon-neutral buildings. The American Institute of Architects and the Society for Building Science Educators have joint-initiated the Carbon Neutral Design Project to facilitate carbon neutral design practices.

With the emergence of carbon neutral design, there too emerges a discussion of calculating and defining carbon neutrality. What are the best emissions coefficients? For instance, time-dependent carbon accounting can yield far different emissions coefficients than annual averages (Mahone et al. 2009). What are the best data sources for embodied carbon emissions of buildings? What is the most appropriate boundary of analysis — should commuter transport be included?

Michael Bendewald is an analyst at Rocky Mountain Institute, Boulder, CO. **Victor Olgyay** is a principal at Rocky Mountain Institute, Boulder, CO.

Architecture 2030 has presented the most descriptive definition of carbon neutrality. The Architecture 2030 website states that carbon neutrality "may be accomplished by implementing innovative sustainable design strategies, generating on-site renewable power and/or purchasing (20% maximum) renewable energy and/or certified renewable energy credits." This definition is synonymous with ASHRAE's definition of "net zero energy emissions," which is the state when "the emissions that [are] produced by the energy needs of the building" are zero (ASHRAE 2008). The Carbon Neutral Design Project website explains that:

> The initial phase of the Carbon Neutral Design Project will focus on reducing the carbon emissions for the operating energy of the building. Operating energy has been selected over embodied energy as it represents the major contribution to the carbon emissions of a building, and is the focus of the 2030 Challenge. Practices, protocols and tools to reduce the carbon associated with embodied energy will form the focus of subsequent research associated with this project. (AIA/SBSE 2010)

The aforementioned descriptions show that carbon neutrality is commonly understood as the reduction of operational energy emissions to zero, and that embodied carbon emissions of buildings will be a future consideration. As new areas of consideration open up, it is worthwhile to step back and rethink our approach to carbon neutrality. Is a "net-zero" annual carbon emissions mindset, which has thus far been predominant, the correct one for carbon neutrality?

This paper will present an approach that is fundamentally different from a net-zero methodology. This new approach is more closely related to climate science methodology and better handles non-operational carbon emissions. The approach is "carbon neutrality based on native-site carbon storage."

CREATING CONTEXTUALIZED ENVIRONMENTAL GOALS

> *"The climate debate is a public issue in which the assets at risk are not specific resources, like oil, fish, or timber, but a life-supporting system."*
> – Natural Capitalism (1999)

> *"[Humans] must ever learn to dwell [or live in the world] and bring dwelling to the fullness of its nature [i.e., thriving] when they build out of dwelling."*
> - Martin Heidegger (1951)

As more realities of climate change emerge it is evident that our building industry can play a key role in preventing potentially catastrophic events. To meet this challenge, building designers need to approach old design problems in new ways, which include defining project goals that relate the individual building project to societal goals. As told in "The Tragedy of the Commons," living well is not solely determined by the individual experience but also the whole-society trajectory that eventually circles back around to the individual. By better understanding the societal relevance of a single design project, designers can help humans not only survive, but also thrive.

Designers need to use climate science methodology in order to develop building design goals that are more appropriate for contemporary society. How can this be done? Climate scientists first attempt to understand the historical carbon storage on the Earth and the atmospheric carbon dioxide equivalent (CO_2e) concentration, and then estimate a net change in these values (Barker et al., 2007). Building designers can use this same methodology for building assessment by narrowing the boundary of analysis from the entire Earth to the project site.

Competing environmental assessment methodologies

The widely recognized authority on climate change, the Intergovernmental Panel on Climate Change (IPCC), indicates a global carbon emissions limit and the consequences of exceeding this limit — known as an "integral of excess" methodology (Lowe 2006). The integral of excess methodology focuses "on the magnitude and duration of departure from sustainability" (Lowe 2006 p. 410). By contrast, a "static equilibrium" approach is concerning the sustainable rate at which carbon is emitted and not the consequences of exceedance (Lowe 2006). Each approach represents a viable option for building assessment and will be discussed below.

Ecological footprint assessment (EFA) is an example of a globally applied static equilibrium method. EFA assesses carbon emissions and regenerative resource consumption (such as food and fiber growth) by comparing the rate at which societies and the world as a whole consume to the rate at which resources and services can be provided.[1] By contrast to the integral of excess approach, there is no quantified indication of the long-term effects of exceeding the production rate.[2]

Another application of static equilibrium methodology is the "net-zero" approach for building assessment. It compares the annual carbon emissions for a building to zero. Like EFA, it only assesses a rate of consumption and does not quantify the effects of exceeding the limit.

Problems with static equilibrium for buildings. A net zero building definition becomes problematic when the boundary of analysis is expanded beyond operation. Consider a typical 40,000 sq. ft. office building constructed in Maine on a previously undeveloped 200,000 sq. ft. forested site. The annual building operational carbon emissions are 400 t CO_2e.[3] In order to become a "net-zero" building, these emissions would need to be reduced to zero through efficiency, on-site renewable energy, or annual carbon offsets[4] purchasing. However, a one-time release of 380 t CO_2e is emitted when the building project site is cleared. Add to this the 4,300 t CO_2e embodied in the building construction.[5] A major retrofit 25 years later will represent another significant spike in carbon emissions. In order

[1] For more information, see Wackernagel and Rees (1996) and the Global Footprint Network <http://www.footprintnetwork.org>

[2] EFA administrators indicate that ecosystem services (which provide us resources) are collapsing as a result of over consumption and will continue to do so until consumption is reduced; however, there is no EFA metric to present this information.

[3] Assuming 60 kBtu/sq. ft. electricity and 34 kBtu/sq. ft. natural gas use, and regional emissions coefficients.

[4] Green power or renewable energy credits represent other viable options in place of carbon offsets.

[5] These calculations were made using Rocky Mountain Institute's Green Footstep calculator <http://greenfootstep.org>

to maintain a net-zero annual emission, the building owner would need to purchase carbon offsets because neither efficient design nor renewable energy can immediately reduce to zero these one-time fluxes of carbon. This action seems unnecessary and arbitrary, but inherent to the net-zero approach.

Integral of excess for building assessment. Using an integral of excess approach, IPCC scientists assume that at some point in history the global carbon cycle was not significantly influenced by human society. Anthropogenic influence is commonly thought to have begun with the Industrial Revolution,[6] with studies indicating that land use change as well as the burning of fossil fuels were the first forms of impact (Pongratz, et al. 2009).[7]

Before industrial times (pre-1850), there were relatively equal rates of carbon flux between the Earth (soil, plants, animals, and the ocean) and atmosphere. During and after the Industrial Revolution, the carbon flux rate from the Earth to the atmosphere grew much larger than vice versa. The magnitude and duration of this exceedance is captured by the atmospheric parts-per-million (ppm) of carbon dioxide equivalent (CO_2e) metric. When the atmospheric ppm of CO_2e gets too large, we may experience potentially catastrophic climate change effects. (Barker et al., 2007)

An integral of excess approach for building assessment would allow greater flexibility than a static equilibrium (or net-zero) approach. It removes the somewhat arbitrary constraint that says a net-zero carbon flux should occur each year of the building lifetime. It allows for the spikes in building carbon emissions to be addressed in preceding or succeeding years through net-positive renewable energy generation or annual carbon offsets purchasing. This flexibility is critical in instances when owners, e.g., prefer to offset embodied carbon emissions by installing a larger photovoltaic system that exports energy to the grid. An integral of excess approach for building assessment is described in the following section.

Carbon neutrality based on native-site carbon storage

A building assessment method can make the following assumption regarding the building site, which is a corollary to a fundamental assumption of climate science: At some point in the past, the site contained a native (or natural) amount of vegetation and soil carbon storage that was undisturbed by human society. Carbon neutrality based on native-site carbon storage accounts for the change in site carbon storage relative to this native state. The IPCC provides the carbon storage data required for such a calculation.[8] In addition, any other carbon emissions that can be attributed to the site are also taken into account, such as the building operation and commuter transport emissions.

The method lends itself well to a bank account metaphor. The carbon storage on the project site in its native state is considered the amount of carbon the owner of

---

6 One study suggests that anthropogenic land cover change has affected the carbon cycle as early as the late medieval period (Pongratz, et al. 2009).

7 A later major emissions source is "agriculture and waste," which is the by-product of synthetic nitrogen fertilizer application, gasses produced from animal stock digestive processes and others. (Barker et al., 2007)

8 See IPCC "Guidelines for National Greenhouse Gas Inventories," Volume 4, Chapter 4, Table 4.53 and Chapter 6, Table 6.4. [accessed online] <http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html>. This data can also be accessed via the Green Footstep online tool at <http://greenfootstep.org>.

the facility has "in the bank." Carbon emissions reduce the amount in the bank and send the owner into a "carbon debt." [9] In order for a project to be "carbon neutral," this debt must be paid off by the end of the building lifetime and the original amount of carbon (equal in magnitude to the native state carbon storage) must be restored. It is worth noting here that, like a bank account, careful attention may result in an ecological profit. The net-zero framework could never capture such a positive concept.

A carbon debt directly relates to a net increase in the atmospheric ppm of CO_2e. Parametric equations have been derived to describe this relationship, accounting for the gradual decay of carbon emissions in the atmosphere due to plant photosynthesis and oceanic uptake.[10] Though not taken advantage for this study, the existence of such equations potentially enables the assessment of building performing using the ppm unit.

Potential impact of land use change. The major reason to include land use change in the calculation of carbon neutrality is to methodologically align with climate science. However, there is a not-insignificant amount of carbon emissions reduction at stake with increased native vegetation on building sites. A recent U.S. Geological Survey report indicates the potential for 3–7 gigatonnes (Gt) more carbon (C) stored in areas (including urban) deemed appropriate (Sundquist et al., 2009), which would reduce 5–12 ppm of CO_2e in the atmosphere.[11] Through the judicious planting of trees and other vegetation in and around buildings, a substantial amount of carbon can be sequestered. This fact should give rise to a new stewardship of the sequestration value of biomass, especially in carbon-intensive ecosystems such as tropical forests.

Emphasis on measured and verified building operation. Defining carbon neutrality based on the amount of carbon "in the bank" by the end of the building lifetime requires the designers and owner to be more concerned with the entire building life cycle. The owner or operator must ensure that the processes are in place to keep the building on the path to carbon neutrality. A carbon neutral building can only be verified at the end of its lifetime.

APPLICATION OF CARBON NEUTRALITY METHODOLOGY: ARCHBOLD BIOLOGICAL STATION

Archbold Biological Station (ABS) is an independent ecological research facility with a campus located inside a 5193-acre preserve of Florida scrub ecosystem. Sited in that campus, the Lodge and Learning Center (LLC) is intended to support the research and educational programs of the Station. The ecologically sensitive

---

[9] The term "carbon debt" has been used previously in various ways. Joseph Fargione uses the term to describe the carbon implications of biofuels (Fargione 2008). The term has been used to describe what developed nations owe to the developing nations. Finally, and most similar to the use in this paper, carbon debt has described the emissions from a single activity, <http://www.scientificamerican.com/podcast/episode.cfm?id=copenhagens-carbon-debt-09-12-18>.

[10] A commonly used equation can be found on the United Nations Framework Convention on Climate Change website at <http://unfccc.int/resource/brazil/carbon.html>, "CO2 Impulse Response Function…." (Flanner 2009)

[11] The decrease in ppm as a result of increase in net carbon storage can be calculated as follows. The mass of Earth's atmosphere is about 5.15E18 kg. Divide this by the mean molar mass of atmospheric molecules, 0.02884 kg/mole, to obtain 1.785E20 moles. One gigatonne of carbon corresponds to: 1E12 kg divided by 0.012 kg/mole, which equals 8.33E13 moles. And, 8.33E13 divided by 1.785E20 is about 4.7E-7, or 0.47ppm of C. Multiply 0.47 by 44/12 to obtain ppm of CO_2 per gigatonne C. (Flanner 2009)

location of the LLC and its educational intent drove the project team to pursue high goals including LEED Platinum and carbon neutrality. Carbon neutrality for the ABS project was based on native-site carbon storage.[12] This section will describe how the carbon neutrality assessment method was applied and how it informed design.

Establishing native- and design-site carbon storage

The 3.4-acre site of the LLC is on the northern edge of Archbold campus. Instead of using the more general carbon storage data from the IPCC, ABS provided carbon storage studies of the native-site ecosystem known as scrub oak. As shown in Figure 1, the stored carbon in the vegetation ebbs and flows with each natural burn and produces a small amount of charcoal that eventually disintegrates (Alexis et al. 2006). Assuming that the natural burn cycle is about 17 years (Swain 2008), the average carbon stored was 5.5 kg C/m^2 (1.9 kg CO2/ft^2). This estimate does not include underground biomass or carbon in the soil. In the case of Florida scrub oak, the underground biomass accounts for more than 80 percent of the total (Swain 2008). Therefore 5.5 kg C/m^2 is a major underestimate.

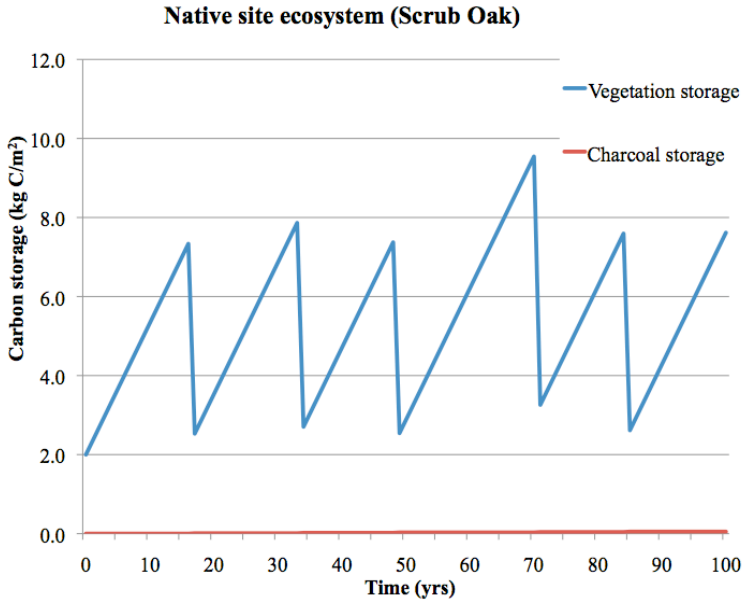

Figure 1 Graphic illustration of native site carbon storage (productivity) with average 17-year burn cycle, including some variation, over the course of 100 years. The average carbon stored is 5.5 kg C/m^2 (1.9 kg CO_2/ft^2).

The team carefully considered how it could increase the amount of native vegetation for carbon sequestration as well as biodiversity and water control. As a result, over 50 percent of the site is to be returned to the native ecosystem. As shown in Figure 2, the design-site carbon storage will be slightly more than half the native-site carbon storage after the vegetation is full grown. The 3.4-acre design site was modeled at 84,300 ft^2 scrub oak, 55,000 ft^2 nonporous surface, and 10,700 ft^2 building footprint.

[12] The authors and their colleague Erik Bonnett, an analyst at Rocky Mountain Institute, provided consulting on the project.

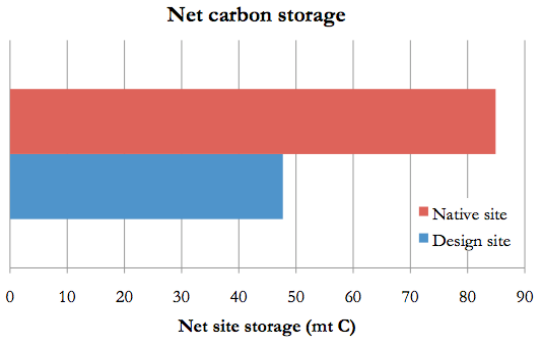

Figure 2 Metric tons (mt) of carbon stored on the 3.4-acre site.

Embodied Carbon Emissions

The embodied carbon emissions of the new construction of this facility were estimated using an online tool from Rocky Mountain Institute.[13] The estimate is a national average and does not account for the efforts made by the ABS design team to reduce embodied carbon emissions, which included some materials reuse.

Table 1. Embodied carbon emissions of Archbold Biological Station LLC

National average carbon intensity (kg CO_2e/ft^2)	Area of building (ft^2)	Total carbon emissions (metric tons CO_2e)
107	10,500	1100

Operational Carbon Emissions

The operational carbon emissions were calculated using GHG Protocol standards. The electricity emissions coefficient is the U.S. Environmental Protection Agency's eGRID emissions coefficient for the Florida region (FRCC), 0.60 kg CO_2e per kWh. The natural gas coefficient is from the Department of Energy's Energy Information Administration website, 0.053 kg CO_2e per kBtu. Extensive daylighting, lighting controls, and a variable-refrigerant-volume cooling system all contribute to the reduction of operational carbon emissions, modeled to be around 40 percent (Ellis 2010).[14]

Calculating Carbon Neutrality

The native-site carbon storage and sources of carbon emissions are all plotted over the anticipated lifetime of the building (100 years in this case) in Figure 3. As noted above, the native-site carbon storage can be thought of as the carbon "in the bank." As the project design decisions are made, the trajectory of carbon emissions illuminates for designers the amount of incurred "carbon debt" (or carbon surplus) by the end of the building lifetime. It is important to note that neither embodied carbon of building retrofits nor other sources of operational emissions such as refrigerant leak and commuter transport are included in the ABS LLC life-

[13] Green Footstep <http://greenfootstep.org> also provides life-cycle carbon impact assessment and goal setting.
[14] Baseline is ASHRAE 90.1 2007.

cycle carbon emissions estimate. It also does not account for future changes to the electricity emissions coefficient.

The design team and owner used this life-cycle carbon emissions perspective when evaluating design decisions. From the outset, as shown in Figure 3, it was clear that achieving the Architecture 2030 Challenge would result in an unacceptable carbon debt (assuming no major future renovations that meet the Challenge). The ABS team used this framework to quantify how far the building will be from carbon neutrality by the end of building lifetime and after a certain number of years (such as up to the point of the first anticipated major retrofit).

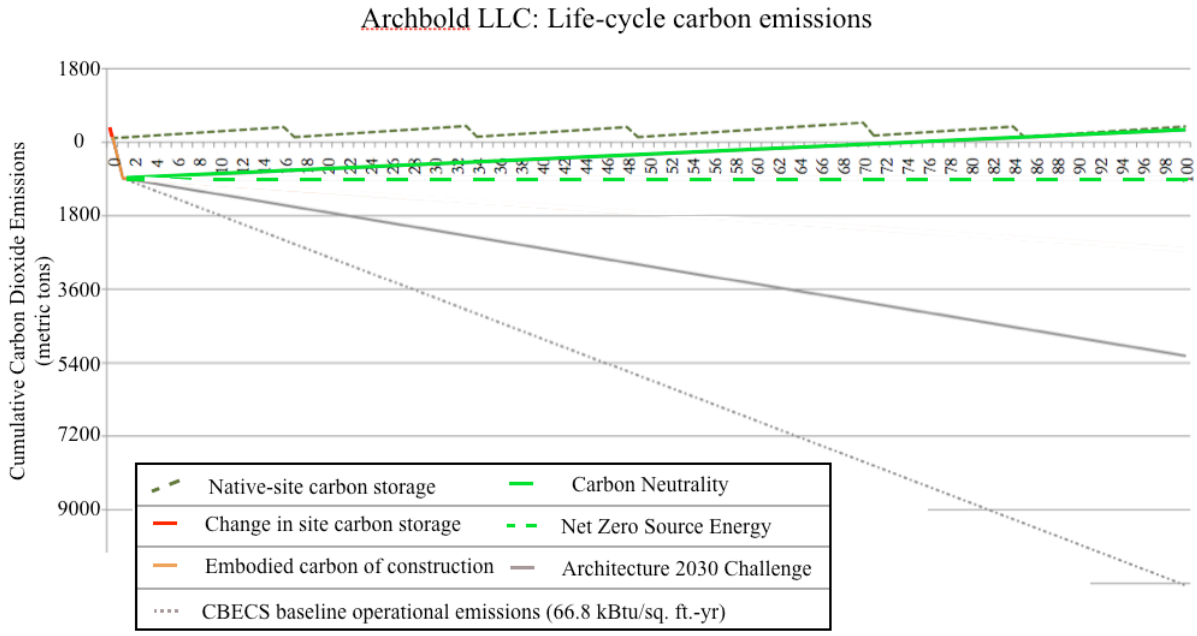

Figure 3 Archbold Biological Station LLC life-cycle carbon emissions. The CBECS baseline was determined using the EPA's Target Finder. The energy use intensity is a mix of 32% natural gas and 68% electricity. The Architecture 2030 Challenge is a 60% savings of operational source energy from the CBECS baseline.

CONCLUSION

Carbon neutrality is emerging in the 2010s as a predominant goal within the buildings industry. With this new concept come questions about its definition and use as such. This paper has shown how carbon neutrality based on native-site carbon storage is both unique from and has certain benefits over a "net-zero" approach. The presented method removes arbitrary restrictions as to when carbon emissions are addressed and places greater emphasis on the measurement and verification of carbon emissions performance. It also gives rise to a new stewardship of carbon sequestration by biomass on a building site. Finally, the approach shares its methodology with climate science and helps the designers relate their building projects to societal goals regarding climate change.

The Archbold Biological Station project was presented to illustrate how the carbon neutrality calculations are made and how they can inform design decision-making. As shown in the case study, teams can use this methodology to target carbon neutrality, report life-cycle carbon emissions, and estimate carbon debt.

REFERENCES

American Institute of Architects and Society for Building Science Educators. 2010 "Carbon Neutral Design Project," http://www.architecture.uwaterloo.ca/faculty_projects/terri/carbon-aia/introduction.html

Alexis, M.A., D.P. Rasse, C. Rumpel, G. Bardoux, N. Péchot, P. Schmalzer, B. Drake, A. Mariotti. 2006 "Fire impact on C and N losses and charcoal production in a scrub oak ecosystem" *Biogeochemistry*

ASHRAE 2020 Ad Hoc Committee. 2008. ASHRAE Vision 2020: Producing Net Zero Energy Buildings.

Barker T., I. Bashmakov, L. Bernstein, J. E. Bogner, P. R. Bosch, R. Dave, O. R. Davidson, B. S. Fisher, S. Gupta, K. Halsnaes, G.J. Heij, S. Kahn Ribeiro, S. Kobayashi, M. D. Levine, D. L. Martino, O. Masera, B. Metz, L. A. Meyer, G.-J. Nabuurs, A. Najam, N. Nakicenovic, H. -H. Rogner, J. Roy, J. Sathaye, R. Schock, P. Shukla, R. E. H. Sims, P. Smith, D. A. Tirpak, D. Urge-Vorsatz, D. Zhou, 2007: Technical Summary. In: *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [B. Metz, O. R. Davidson, P. R. Bosch, R. Dave, L. A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Ellis, Lawrin. 2010. TLC Engineering for Architecture. Personal communication.

Hawken, Paul, Lovins, Amory L., Lovins, L. Hunter. 1999. *Natural Capitalism*, New York: Little, Brown and Company

Heidegger, Martin. 1982. *Poetry, Language, Thought*. New York: Harper Collins

Fargione, Joseph, Jason Hill, David Tilman, Stephen Polasky, and Peter Hawthorne. 2008. "Land Clearing and the Biofuel Carbon Debt," *Science,* 319: 1235.

Flanner, Mark. 2009. National Center for Atmospheric Research. Personal communication.

Lowe, Robert. 2006. "Defining absolute environmental limits for the built environment," *Building Research & Information*, 34:4, 405 - 415

Mahone, Amber, Snuller Price, William Morrow. 2009. "Developing a Greenhouse Gas Tool for Buildings in California: Methodology and User's Manual v.2." [Accessed online] http://www.ethree.com/E3_Public_Docs.html

Olgyay, Victor and Julee Herdt 2004. "The application of ecosystems services criteria for green building assessment," Solar Energy, 77, 389–398

Sundquist, Eric T., Katherine V. Ackerman, Norman B. Bliss, Josef M. Kellndorfer, Matt C. Reeves, and Matthew G. Rollins. 2009. "Rapid Assessment of U.S. Forest and Soil Organic Carbon Storage and Forest Biomass Carbon Sequestration Capacity." U.S. Geological Survey, Reston, Virginia.

Swain, Hilary. 2008. Director, Archbold Biological Station. Personal communication

Wackernagel, Mathis and William Rees. 1996. *Our Ecological Footprint*, Gabriola Island, B.C.: New Society

