EMBODIED CARBON IN BUILDINGS
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The BSA Embodied Carbon in Buildings advisory group

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EMBODIED CARBON IN BUILDINGS
EMBODIED CARBON IN BUILDINGS

Session 1: Embodied Carbon 101

Marc Rosenbaum PE
South Mountain Company

Greg Norris
International Living Future Institute

Kate Simonen AIA
Carbon Leadership Forum

Maggie Wildnauer
thinkstep
Inform, Inspire and Enable Low Carbon Construction

CARBON LEADERSHIP FORUM
 Industry sponsored
 Ten year track record
 Academic research collaborative
 Focused on embodied carbon

Values:
Transparency,
Open source data
Collaboration
Impact

www.carbonleadershipforum.org
Operating vs Embodied Carbon

Understanding Carbon

Embodied Carbon
Manufacture, transport and installation of construction materials

Operational Carbon
Building Energy Consumption
Net Zero = Zero Carbon??
Buildings: Total Lifetime Energy Use

Typical Building
Typical Carbon Grid
Longer Lifespan

High Performance
Low Carbon Grid
Shorter Lifespan
Carbon Smart Building Strategies

How the building sector meets global climate targets

1. New Buildings to Zero Net Operating Carbon by 2030
2. Existing Buildings to Zero Net Operating Carbon by 2050
3. Integrate Buildings into an Optimized Energy Grid
4. Eliminating Embodied Carbon in Buildings
5. Measure & Improve Health & Equity

http://carbonsmartbuilding.org/declaration
Life Cycle Assessment: Life Cycle Scopes

**Cradle-to-Gate**
- Material extraction
- Manufacturing + Production

**Gate-to-Gate**
- Construction
- Use
- End of life
  - refurbish
  - reuse
  - recycle
Life Cycle Assessment: Embodied Carbon

Emissions due to:
- Material extraction
- Transportation
- Manufacturing

Life Cycle Assessment (LCA) is a method used to calculate embodied carbon.
Embodied Carbon Market Drivers

Rating Systems/Challenges
• LEED v4
• 2030 Challenge for Products
• ILFI: Materials petal/zero carbon certification

Industry
• SE 2050
• AIA Materials Pledge

Policy
• Buy Clean
• Low Carbon Concrete Codes
• Vancouver Embodied Carbon Targets

COMMON THEMES:
DISCLOSURE & OPTIMIZATION
EPDs Enable Embodied Carbon Transparency

Environmental Product Declarations

Nutrition Facts
Serving Size 2/3 cup (55g)
Servings Per Container About 8

<table>
<thead>
<tr>
<th>Amount Per Serving</th>
<th>% Daily Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calories 230</td>
<td>12%</td>
</tr>
<tr>
<td>Calories from Fat 40</td>
<td></td>
</tr>
<tr>
<td>Total Fat 8g</td>
<td>12%</td>
</tr>
<tr>
<td>Saturated Fat 1g</td>
<td>5%</td>
</tr>
<tr>
<td>Trans Fat 0g</td>
<td></td>
</tr>
<tr>
<td>Cholesterol 0mg</td>
<td>0%</td>
</tr>
<tr>
<td>Sodium 160mg</td>
<td>7%</td>
</tr>
<tr>
<td>Total Carbohydrate 37g</td>
<td>12%</td>
</tr>
<tr>
<td>Dietary Fiber 4g</td>
<td>16%</td>
</tr>
<tr>
<td>Sugars 1g</td>
<td></td>
</tr>
<tr>
<td>Protein 3g</td>
<td></td>
</tr>
</tbody>
</table>

Life Cycle Impact Results (per m²)
Declared Unit: 1 m² of 10,000 psi concrete at 28 days

OPERATIONAL IMPACTS
PerformX™ 
PECC10K
- Plant Operating Energy (MJ) 38.6
- On-Site Plant Fuel Consumption (MJ) 11.1
- Concrete Batch Water (m³) 1.6E-01
- Concrete Wash Water (m³) 1.91E-02
- On-Site Waste Disposal (kg) 0.0

ENVIRONMENTAL IMPACTS
- Total Primary-Energy (MJ) 3.017
- Climate Change (kg CO₂ eq) 445
- Ozone Depletion (kg CFC 11 eq) 1.31E-08
- Acidification Air (kg SO₂ eq) 2.96
- Eutrophication (kg N eq) 0.99
- Photochemical Ozone Creation (kg O₃ eq) 0.61
EPDs Enable Embodied Carbon Transparency

Environmental Product Declarations

EPD Results are like MPG
- Estimates based on standard assumptions (PCR)
- Known variability
- Directionally accurate
## LCA: Materials/Processes to Impacts

### Inventory

Estimate of quantities of materials or processes.

- **E.g. 100kg steel**
  - 0.43 kg CO2e /kg steel
- **E.g. 50kg glass**
  - 1.064 kg CO2e /kg steel
- **Etc.**

### Impacts

Estimate of environmental impacts for each unit process.

### Total

Estimate of total environmental impact of building materials.

- **43 kg CO2e**
- **53.2 kg CO2e**
- **Etc.**

**Sum Total Impact**
<table>
<thead>
<tr>
<th>Carbon Leadership Forum: Research to Outreach</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Carbon Smart Building</strong></td>
</tr>
<tr>
<td><strong>Model LCA Specs</strong></td>
</tr>
<tr>
<td><strong>Concrete PCR</strong></td>
</tr>
<tr>
<td><strong>LCA of MEP Systems</strong></td>
</tr>
</tbody>
</table>
Embodied Carbon Benchmarking Study

- Over 1,000 building entries
- 12 Building Categories
- Open Source Database
- Phase 1 of Larger LCA Practice Guide Funded Project

CONTRIBUTORS

Sponsors

CLF Embodied Carbon Benchmarking Study
EC3: Embodied Carbon Calculator for Construction
RECOMMENDED ACTIONS (Practitioners)
• Act NOW on Embodied Carbon
• Demand embodied carbon transparency via EPDs.
• Start making purchasing based on Embodied Carbon
• Learn more: Become and embodied carbon leader!

IN ORDER TO:
• Incentivize low carbon material/products
• Help drive market innovation and investment
• Drive better quality data and tools
EMBODIED CARBON IN BUILDINGS
Embodied Carbon 101: Data in LCA

Embodied Carbon in Buildings

Maggie Wildnauer
Consulting Team Lead, Americas
thinkstep, Inc.

May 31, 2019
An LCA is only as good as the data that comprises it:

- **Primary data:**
  - BOM
  - Material details: source, technology, recycled content, etc.

- **Secondary data:**
  - LCI databases
  - EPDs
ISO 14040/44 includes the following topics in the required data quality assessment:

- time-related coverage
- geographical coverage
- technology coverage
- precision (e.g. variance)
- **completeness**
- **representativeness**
- consistency (of methodology)
- reproducibility (of LCA)
- sources of the data
- uncertainty of the information
Selecting a dataset requires consideration of representativeness

- Geographic
- Temporal
- Technological

And completeness, which can be confirmed by using

- A reputable source (for background data as well as LCA)
- Available documentation
Data source:

- Facility-level information for specified product
- Company-level information for specified product
- Industry-average data (typ. regional)
- Global or different regional data
Data Sources

- Building LCA Tools
  - tally
  - Athena Impact Estimator for Buildings

- Databases
  - GaBi Databases
  - European Commission - Joint Research Centre

- Industrial data
  - EUROFER The European Steel Association
  - European Federation of Corrugated Board Manufacturers
  - worldsteel ASSOCIATION
  - Zinc essential for life
  - International Aluminium Institute

& more
**Geographical Relevance:** United States

**Temporal Relevance:** 2018

**System Boundary:** Manufacturing (A1-A3), Inbound transport to site (A4), transport to EoL treatment (C2), EoL treatment (C3-C4), credits or burdens beyond the system boundary, e.g., recycling potential (D)

**Impact Categories**
- Global Warming Potential, incl. biogenic carbon  
  TRACI 2.1
- Global Warming Potential, excl. biogenic carbon  
  TRACI 2.1
- Acidification Potential  
  TRACI 2.1
- Eutrophication Potential  
  TRACI 2.1
- Ozone Depletion Potential  
  TRACI 2.1
- Smog Formation Potential  
  TRACI 2.1
- Primary Energy Demand  
  Inventory indicator
Making a Tally Entry

Window

Glass (double-paned, low-e coating)
- US: Double glazing unit (2013)
- US: Flat glass (2013)

Aluminum frame
- NA: Aluminum ingot (2012)
- GLO: Metal extrusion process (2012)
- GLO: Aluminum extrusion (2012)
- NA: Aluminum extrusion (2007)

Which dataset is most appropriate:
- What region are we representing?
- What technology?
- What year?

What is the correct ratio of glass to frame?
free, transparent, download-able composition

components + residuals and contaminants
0.01 % disclosure (100 ppm)

health hazard screening

pharos screening (60+ lists)
human health hazards (13)

life cycle assessment

Cradle-to-gate + EoL
TRACI 2.1 impact indicators (4) + IPCC AR5
GWP + PED
**Geographical Relevance:** United States

**Temporal Relevance:** 2015

**System Boundary:** Cradle-to-Gate + EoL

- Installation/use included only when some fraction of their product composition (excluding water) is released during installation or use as a direct emission. Includes:
  - products with blowing agents
  - wet-applied products

**Impact Categories**

- Global Warming Potential, incl. biogenic carbon
- Acidification Potential
- Eutrophication Potential
- Ozone Depletion Potential
- Smog Formation Potential
- Primary Energy Demand

IPCC AR5
TRACI 2.1
Inventory indicator
Making a Quartz Entry

COMMON PRODUCT

thinkstep GaBi

cradle-to-gate:
composition + manufacturing

industry average dataset + end-of-life

eO L
Data needs to be representative of what you’re trying to model

Accuracy is the goal in LCA, not necessarily precision

Compromises will likely need to be made when selecting data (geographical, technical, and temporal accuracy)
EMBODIED CARBON IN BUILDINGS
• Towards Zero, over what scope?
• Beyond Zero
TWO NORTH AMERICAN RATING SYSTEMS:
ILFI’S LBC AND USGBC’S LEED
• LEED
  • Building Life Cycle Impact Reduction
  • Building Product Disclosure and Optimization: EPDs
  • BPD&O: Sourcing of Raw Materials
  • BPD&O: Material Ingredients

• LEED ZERO
  • Carbon
  • Energy
  • Water
  • Waste
LEED BUILDING LIFE CYCLE IMPACT REDUCTION

- Option 1: Historic building reuse
- Option 2: Renovate abandoned or blighted building
- Option 3: Building and material reuse
- Option 4: Whole-building life cycle assessment
  - LCA of structure and enclosure
  - Demonstrate at least 10% reduction vs. baseline, in at least 3 of 6 impact categories, one of which must be GHGs
  - No impact category can increase by more than 5%
LEED ZERO CARBON

• Operational Phase Only (Currently)
• Carbon Caused – Carbon Avoided
• Caused
  • Energy consumption
  • Transportation to site
  • Water in development
  • Waste in development
  • Embodied Carbon in development
• Avoided
  • Onsite electricity to grid
  • Offsite renewable added to grid, including carbon offsets
ENERGY
Relying on Renewable Resources

I-07 ENERGY + CARBON REDUCTION
I-08 NET POSITIVE CARBON
The intent of this imperative is to treat energy as a precious resource and minimize energy-related carbon emissions that contribute to climate change.

All projects must achieve a reduction in total net annual energy consumption (after accounting for on-site renewable power), as compared to a typical existing building with comparable climate, size, use and occupancy, and combustion must be limited as follows:

<table>
<thead>
<tr>
<th>ENERGY PERFORMANCE REQUIREMENT</th>
<th>NEW BUILDING</th>
<th>EXISTING BUILDING</th>
<th>INTERIOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>70% reduction from an equivalent building baseline</td>
<td>50% reduction from an equivalent building baseline</td>
<td>35% reduction from an equivalent building baseline</td>
<td></td>
</tr>
<tr>
<td>COMBUSTION LIMITS*</td>
<td>Not Allowed (except through existing exceptions)</td>
<td>Allowed for HVAC systems that are not in project scope. Phase out plan and advocacy are required.</td>
<td></td>
</tr>
<tr>
<td>RENEWABLES</td>
<td>Must be on-site to count towards the efficiencies above.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

All projects must meter energy used by the project.

New or Existing Building projects must demonstrate a twenty percent reduction in the embodied carbon of primary materials compared to an equivalent baseline. Existing Buildings may count in-situ materials against the required twenty percent.

All projects (except Landscape + Infrastructure) must select interior materials with lower than industry average carbon footprint for product categories for which embodied carbon data is readily available.

All projects must be “zero ready” through strategies such as designating area(s) and/or pre-installing wiring and connections for both electric vehicle charging and future installation of renewable energy systems.

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19 Projects must establish their baseline through using tools such as Zero Tool, World Bank EDGE or other approved tools.
20 The allowance for Existing Buildings & Interiors is only for Imperative 07, Energy + Carbon Reduction. Combustion is not allowed, except through an exception, for Imperative 08, Net Positive Carbon.
21 Refer to the v4.0 Energy Petal Handbook for recommended tools to establish a baseline.
22 Refer to the v4.0 Energy Petal Handbook for relevant interior product categories and industries averages.
The intent of this Imperative is to foster the development and use of carbon-free renewable energy resources while avoiding the negative impacts of fossil fuel use, primarily the emissions that contribute to global climate change.

All projects must supply one hundred and five percent of their project’s energy needs through on-site renewable energy on a net annual basis, without the use of combustion.\textsuperscript{23}

All projects (except single-family residential) must sub-meter major energy end uses.

All single-family residential projects must develop a method to understand and trouble-shoot energy use.

All projects must account for the total embodied carbon emissions (tCO2e) from its construction (including the energy consumed during construction) through the utilization of carbon-sequestering materials and/or through a one-time carbon offset purchase through an ILFI-approved carbon offset provider.\textsuperscript{24}

All projects must develop and incorporate a resilience strategy to allow the building to be habitable for one week, or otherwise participate in support for the local community in a disaster, through the use of batteries, storage etc.

\textsuperscript{23} Refer to the v4.0 Energy Petal Handbook for a list of renewable energy systems, clarifications, and exceptions, including sub-metering requirements. Energy consumed during construction must be accounted for with either a carbon offset or renewable energy on site.

\textsuperscript{24} Refer to the v4.0 Energy Petal Handbook for approved carbon offset programs, clarifications, and exceptions.
ASSESSING IMPACTS OF LIVING BUILDINGS

96 Projects included

LBC versions 1.3 through 3.1

Five impact categories for each of up to 5 project attributes, plus ecosystem benefits of FSC

<table>
<thead>
<tr>
<th>Project Attributes Assessed</th>
<th>Impact Types Assessed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Climate</td>
</tr>
<tr>
<td>Embodied</td>
<td></td>
</tr>
<tr>
<td>Energy Supply</td>
<td></td>
</tr>
<tr>
<td>Water Supply</td>
<td></td>
</tr>
<tr>
<td>Sanitation</td>
<td></td>
</tr>
<tr>
<td>Special: LES</td>
<td></td>
</tr>
<tr>
<td>Special: FSC</td>
<td></td>
</tr>
</tbody>
</table>
**METHOD OF ASSESSMENT**

<table>
<thead>
<tr>
<th>Project Attributes Assessed</th>
<th>Climate</th>
<th>Water</th>
<th>Energy</th>
<th>Health</th>
<th>Ecosystem</th>
</tr>
</thead>
<tbody>
<tr>
<td>Embodied</td>
<td>Embodied Impact Calculator (Input/Output LCA)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy Supply</td>
<td>Energy System Impact Calculator (Process LCA)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water Supply</td>
<td>Water Supply Impact Calculator (Process LCA)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sanitation</td>
<td>Sanitation System Impact Calculator (Process LCA)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Special: LES</td>
<td>Inbound Transport Impact Calculator (Input/Output LCA)</td>
<td>(I/O LCA)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Special: FSC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Life cycle assessment (LCA) of conventional vs. LBC
- Developed system-specific calculators, for use by future project teams, ILFI staff, and others to assess benefits of Living Building
We studied energy, water, and sanitation attribute impacts for all relevant projects.

We performed two case studies of embodied impacts—This data is also used to assess benefits of FSC.

<table>
<thead>
<tr>
<th>Project Attributes Assessed</th>
<th>Impact Types Assessed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Embodied</td>
<td>2 Projects</td>
</tr>
<tr>
<td>Energy Supply</td>
<td>70 Projects</td>
</tr>
<tr>
<td>Water Supply</td>
<td>23 Projects</td>
</tr>
<tr>
<td>Sanitation</td>
<td>23 Projects</td>
</tr>
<tr>
<td>Special: LES</td>
<td>38 Projects</td>
</tr>
<tr>
<td>Special: FSC</td>
<td>2 Projects</td>
</tr>
</tbody>
</table>
## ANNUAL BENEFITS OF LBC: ENERGY SYSTEMS

<table>
<thead>
<tr>
<th></th>
<th>Climate kg CO2e</th>
<th>Water m3</th>
<th>Energy kg oil eq</th>
<th>Health DALYs</th>
<th>Ecosystem species-yrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net vs. conventional</td>
<td>8,688,804</td>
<td>26,283,978</td>
<td>2,478,486</td>
<td>23.3</td>
<td>0.08</td>
</tr>
<tr>
<td>Benefit of excess elect</td>
<td>716,119</td>
<td>2,922,592</td>
<td>191,417</td>
<td>2.13</td>
<td>0.001</td>
</tr>
<tr>
<td>Total benefit</td>
<td>9,404,923</td>
<td>29,206,570</td>
<td>2,669,903</td>
<td>25.43</td>
<td>0.08</td>
</tr>
</tbody>
</table>
Imagine if 1% of new US construction across 3 building sectors were Living Buildings. In just one year...

- **5.7 Million tons of CO₂ avoided**
  - Educational: 886,845
  - Commercial: 865,662
  - Single Family: 3.9 Million

- **13.8 Billion cubic meters of water saved**
  - Educational: 2.4 Billion
  - Commercial: 2.5 Billion
  - Single Family: 8.9 Billion

- **14,007 life years saved**
  - Educational: 2,236
  - Commercial: 2,341
  - Single Family: 9,431

We would prevent the emissions of 5.7 million tons of CO₂ and save 14,000 years of human life.
EXTENSIONS

• We estimated benefits of LBC vs. conventional per sqft, and per $, for three building types
  – Commercial
  – Educational
  – Single Family Residential

• These can be used to estimate benefit potential for any city or state or the US, or the effects of other policies or scales of Living Building
SURPRISES AND KEY FINDINGS

• Impacts of construction itself have been ignored
• They are 20-25% of total embodied impacts!
• Even if embodied impacts of LBC were not offset, climate/water/health payback: 4-11 years
• FSC is key for reducing ecosystem impacts
### Figure 6: Contractors’ Influence on Activities Resulting in GHG Emissions

<table>
<thead>
<tr>
<th>Most Influence</th>
<th>Some Influence Possible</th>
<th>Little Influence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel selection</td>
<td>Equipment idling</td>
<td>Electricity use</td>
</tr>
<tr>
<td>Equipment maintenance</td>
<td>Equipment selection</td>
<td>Materials recycling</td>
</tr>
<tr>
<td>Materials selection</td>
<td>Employee commuting</td>
<td></td>
</tr>
<tr>
<td>Materials shipment</td>
<td>Vegetation removal</td>
<td></td>
</tr>
<tr>
<td>Site selection</td>
<td>Structure design and performance</td>
<td></td>
</tr>
</tbody>
</table>
• Towards Zero, over what scope?
• Beyond Zero
Every Product Has Many Footprints
Footprints are True. But Footprints are not the whole story.
Can we give more than we take?
What we “Take”: Our Footprints:

• The Negative Impacts of Production and Consumption
• My Footprints: My shares of the total mess, for each mess
• The Burdens or Costs of our Presence/Existence
Handprints: Definition:
- Positive impacts that we cause (change), relative to business as usual. Including:
  - Reductions we create in the human footprint
    - Our own footprint
    - The footprints of others
  - Beneficial impacts we cause which are measurable in footprint units.
Handprints

- For every impact category on which we have footprints, we can also have handprints.

- Carbon Footprint
- Water Footprint
- Health Footprint
- Biodiversity Footprint
- Slavery Footprint
- Poverty Footprint

- Carbon Handprint
- Water Handprint
- Health Handprint
- Biodiversity Handprint
- Slavery Handprint
- Poverty Handprint
JUNE 19 - 20, 2019
NET POSITIVE SYMPOSIUM
FOR HIGHER EDUCATION
R.W. Kern Center
Amherst, MA

OCTOBER 8 - 10, 2019
Music City Center
Nashville, TN

NOVEMBER 7 - 8, 2019
BUILDING RESILIENCE
Cleveland, OH