Carbon Implications of Building Materials Selection

Jim Bowyer
Dovetail Partners, Inc.
Minneapolis

Disclaimer: This presentation was developed by a third party and is not funded by WoodWorks or the Softwood Lumber Board.
Copyright Materials

This presentation is protected by US and International Copyright laws. Reproduction, distribution, display and use of the presentation without written permission of the speaker is prohibited.

© The Wood Products Council 2015
Course Description

Carbon emissions have come to the forefront of public discourse and increasingly, of public policy. This presentation will focus on the objective of minimizing carbon emissions associated with building construction and operation. The carbon implications of building material selection will be examined, using examples of real world projects and material comparisons to illustrate the extent to which a building’s carbon footprint is influenced by the construction materials used. Emissions linked to buildings will be discussed in the larger context of carbon and climate, with consideration of the current vs. historical situation, tools for assessing carbon liberation, carbon equivalency, fossil vs. atmospheric carbon, CO2 sequestration, and implications of potential carbon regulation for materials selection and building design.
Learning Objectives

• Define carbon issues, their importance in the context of climate change and how they relate to building products.

• Interpret calculation of a carbon footprint and CO2 equivalency.

• Recognize available tools for assessing carbon liberation in building construction.

• Determine how to minimize carbon and carbon dioxide emissions.
Carbon Implications of Building Materials Selection

• The Carbon Issue
• Carbon and the Built Environment
  - National and global trends and outlook
  - Progress in reducing operational energy
  - Embodied energy becomes more important
• Comparing Carbon Emissions for Various Building Materials and Assemblies
• Summary
The Carbon Issue
The Heat Trapping Efficiency of Various Greenhouse Gases is Not Equal

<table>
<thead>
<tr>
<th>Compound</th>
<th>Heat Trapping Efficiency Compared to Carbon Dioxide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide (CO₂)</td>
<td>1</td>
</tr>
<tr>
<td>Methane (CH₄)</td>
<td>25X</td>
</tr>
<tr>
<td>Nitrous oxide (N₂O)</td>
<td>296X</td>
</tr>
<tr>
<td>HFCs</td>
<td>120-12,000X</td>
</tr>
<tr>
<td>CFCs</td>
<td>5,700-11,900X</td>
</tr>
<tr>
<td>Sulfur hexafluoride</td>
<td>22,200X</td>
</tr>
</tbody>
</table>
Contributors to Global Warming

- Methane
- Chlorofluorocarbons
- Carbon Dioxide
- Nitrous Oxide
- Ozone

$\text{CO}_2\text{e}$
The Global Carbon Cycle

Basics – The Carbon Cycle

Source: IPCC Fifth Assessment Report (2013)
Line Widths proportional to amount of flow
Basics – The Carbon Cycle

“Emissions of CO$_2$ from fossil fuel combustion, with contributions from cement manufacture, are responsible for more than 75% of the increase in atmospheric CO$_2$ concentration since pre-industrial times.” (IPCC Fourth Assessment Report)

Atmosphere: 829 PgC, increasing by 4 PgC/yr.

Source: IPCC Fifth Assessment Report (2013)
Line Widths proportional to amount of flow
World Growth of Energy Consumption
1820-2010

Source: Our Finite World (2012)
(http://ourfiniteworld.com/2012/03/12/world-energy-consumption-since-1820-in-charts/)
Cumulative Atmospheric Carbon Added Through Human Activity, 1850-2012 (billions of metric tons)

- Fossil fuel consumption and cement production
- Land use change due primarily to deforestation and agriculture

Five largest emitters since 1850:
- US
- China
- Russia
- Germany
- UK

All other nations
Temperature of Lower Atmosphere
Last 400,000 Years
From Antarctica ice and air data

Source: (http://www.geocraft.com/WVFossils/last_400k_yrs.html)
Atmospheric CO$_2$ Concentrations Last 400,000 Years
From Antarctica ice and air data

Source: (http://www.geocraft.com/WVFossils/last_400k_yrs.html)
Temperature of Lower Atmosphere
Last 400,000 Years

Atmospheric CO₂ Concentrations
Last 400,000 Years
Sequestered Carbon

- **Fossil Fuels**
  - Petroleum
  - Coal
  - Natural gas
- **Limestone (CaCO₃)**
- **Peat**

- **Forests**
  - Trees
  - Litter
  - Forest soils
- **Other plants**
  - Shrubs, grass, ag. crops
  - Algae

Sequestered millions of years ago

Fossil Carbon

Sequestered, released, and re-sequestered as part of ongoing carbon cycle.

Biogenic Carbon
The Global Carbon Cycle

Carbon and the Built Environment
U.S. Energy Consumption by Sector, 2014

- Buildings 40.6%
- Industry 31.8%
- Transportation 27.6%

U.S. Energy Consumption by Sector, 2014

Industry 31.8%
Transportation 27.6%
Buildings 40.6%

CO₂ Emissions from U.S. Commercial and Residential Buildings, 1980-2010

Source: USDOE (2012). 2011 Buildings Energy Data Book, Section 1.4.1, March. (as reported by the Center for Energy and Climate Solutions).
U.S. Residential Energy Use, Energy Use Intensity, and Energy Use Factors

U.S. Outlook

• In 2030, about half the buildings in which Americans live, work, and shop will have been built since 2000.

• Between 2000 and 2030 the nation will need about 131 billion ft$^2$ of new built space and 82 billion ft$^2$ of replacement of existing space to accommodate growth projections.

• In 2030 over 60% of commercial/industrial space will be less than 30 years old.

World Energy Consumption by Sector, 2010

- Transportation: 30%
- Industry: 31%
- Buildings: 35%
- Other: 4%

1970-2010 Building energy consumption doubled.

Current Total World Building Stock

1.6 trillion ft\(^2\) - 75\% residential, 25\% commercial.

Anticipated Growth in Global Building Stocks, 2013-2030

• 38 billion ft\(^2\) of new building floor space annually.

• 21 billion ft\(^2\) of building floor space rebuilt annually.

• Over 850 billion ft\(^2\) will be built new and rebuilt in urban areas by 2030 – roughly equivalent to 60% of current total building stock in the world.

• 15% of building in N. America.

**Projected CO$_2$ Emissions from Buildings to 2030**

<table>
<thead>
<tr>
<th></th>
<th>High growth scenario</th>
<th>Low growth scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CO$_2$ emissions (GtCO$_2$)</strong></td>
<td>8.6 → 15.6</td>
<td>8.6 → 11.4</td>
</tr>
<tr>
<td><strong>Largest share from</strong></td>
<td>Developing Asia, Middle East/North Africa, Latin America, sub-Saharan Africa</td>
<td>North America and developing Asia</td>
</tr>
<tr>
<td><strong>Annual emissions growth rate (2004-2030)</strong></td>
<td>2.4%</td>
<td>1.5%</td>
</tr>
</tbody>
</table>

Source: IPCC (2007)

**IPCC projections suggest that CO$_2$ emissions from buildings will continue to account for one-third of global CO$_2$ emissions.**

“Much of the world is projected to be built and rebuilt over the next two decades, with the energy and emissions patterns of this construction locked in for decades.”

“This projection provides an unprecedented opportunity to reduce fossil fuel CO₂ emissions by setting the entire global building sector on a path to peak emissions quickly, and to completely phase out CO₂ emissions by about 2050.”

Projected U.S. Building Sector Operations 2005-2030

Projected U.S. Building Sector Operations 2005-2030


Embodied Energy

The raw resource extraction, manufacturing, transportation, construction, usage, and end-of-life stages of building products consume significant amounts of energy, each generating associated GHG emissions.

As buildings improve from an operational perspective, the embodied energy and emissions associated with building materials and construction will become more important.

Source: Architecture 2030: 2030 Challenge for Products.
Embodied Energy and Carbon Emissions in the Life Cycle of a Building
Embodied Energy (Typical Residence)

Source: Architecture 2030: 2030 Challenge for Products.
Studies of operational vs embodied energy of buildings have found:

• In inefficient buildings, embodied energy can equate to as little as 4-8 years (7-14%) of operational energy over a 50 year building life. (Pacheco-Torgal et al. 2009)

• Embodied energy in office buildings ranges between 13-19% of operational energy over a 50-year building life. (Dimoudi and Tompa 2008).

• Embodied energy was calculated to account for almost half (45%) of total energy consumption in a highly efficient apartment building located in Sweden. (Thormark 2002)
Studies of operational vs embodied energy of buildings have found:

• Use of renewable energy in a project can dramatically lower operating emissions – and simultaneously increase the significance of embodied energy. (Ayaz and Yang 2009)

• Demolishing a building prior to the end of its designed life (common in commercial buildings) substantially increases the portion of energy use attributable to embodied energy. (Ayaz and Yang 2009)
Embodied Energy

The embodied energy in building materials needs to be considered along with operating energy in order to reduce the total lifecycle energy use by buildings.

The replacement of materials that require significant amounts of energy to produce (such as concrete and steel) with materials requiring small amounts of energy to produce (such as wood products) will reduce the amount of energy embodied in buildings.

Comparing Carbon Emissions of Various Building Materials and Assemblies
## Fossil Carbon Emitted in Production

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Framing lumber</td>
<td>0.20*</td>
<td>0.12*</td>
</tr>
<tr>
<td>Concrete</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>Concrete block</td>
<td>0.13**</td>
<td>0.14**</td>
</tr>
<tr>
<td>Brick</td>
<td>0.24</td>
<td>0.32</td>
</tr>
<tr>
<td>Medium density fiberboard (MDF)</td>
<td>0.39*</td>
<td>0.32*</td>
</tr>
<tr>
<td>Recycled steel (avg recy content)</td>
<td>0.47</td>
<td>0.81</td>
</tr>
<tr>
<td>Glass (not including primary mfg.)</td>
<td>0.59</td>
<td>0.57</td>
</tr>
<tr>
<td>Cement (Portland, masonry)</td>
<td>0.95</td>
<td>0.97</td>
</tr>
<tr>
<td>Recycled aluminum (100% recycled content)</td>
<td>1.81</td>
<td>1.13</td>
</tr>
<tr>
<td>Vinyl</td>
<td>3.19</td>
<td>--</td>
</tr>
<tr>
<td>Steel (virgin)</td>
<td>2.89</td>
<td>2.55</td>
</tr>
<tr>
<td>Aluminum (virgin)</td>
<td>12.79</td>
<td>16.60</td>
</tr>
</tbody>
</table>

* There are also biogenic CO₂ emissions associated with prod. of these products.
** 10% increase in energy consumption assumed for production of concrete block.

1/ Values are based on life cycle assessment and include gathering and processing of raw materials, primary and secondary processing, and transportation. EPA values converted from tons C/ton of product to tons CO2e/ton of product.
# Fossil Carbon Emitted in Production

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Process Emissions (kg CO$_2$e/ kg of product)</td>
<td>Process Emissions (kg CO$_2$e/ kg of product)</td>
<td>Process Emissions Including Carbon Storage within Material (kg CO$_2$e/ kg of product)</td>
</tr>
<tr>
<td>Framing lumber</td>
<td>0.20</td>
<td>0.12*</td>
<td>-1.68</td>
</tr>
<tr>
<td>Concrete</td>
<td>0.12</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>Concrete block</td>
<td>0.13</td>
<td>0.14</td>
<td>0.14</td>
</tr>
<tr>
<td>Brick</td>
<td>0.24</td>
<td>0.32</td>
<td>0.32</td>
</tr>
<tr>
<td>Medium density fiberboard (MDF)</td>
<td>0.39</td>
<td>0.32</td>
<td>-1.47</td>
</tr>
<tr>
<td>Recycled steel (avg recy content)</td>
<td>0.47</td>
<td>0.81</td>
<td>0.81</td>
</tr>
<tr>
<td>Glass (not including primary mfg.)</td>
<td>0.59</td>
<td>0.57</td>
<td>0.57</td>
</tr>
<tr>
<td>Cement (Portland, masonry)</td>
<td>0.95</td>
<td>0.97</td>
<td>0.97</td>
</tr>
<tr>
<td>Recycled aluminum (100% recycled content)</td>
<td>1.81</td>
<td>1.13</td>
<td>1.13</td>
</tr>
<tr>
<td>Vinyl</td>
<td>3.19</td>
<td>1.13</td>
<td>1.00</td>
</tr>
<tr>
<td>Steel (virgin)</td>
<td>2.89</td>
<td>2.55</td>
<td>2.55</td>
</tr>
<tr>
<td>Aluminum (virgin)</td>
<td>12.79</td>
<td>16.60</td>
<td>16.60</td>
</tr>
</tbody>
</table>

Carbon content of 49% assumed for wood. (measured values range from about 47-52%)
Net Product Carbon Emissions: Wall Structure
(kgCO$_2$/ft.$^2$ of wall)

Net Product Carbon Emissions: Wall Structure
(kgCO₂/ft.² of wall)

-4 -2 0 2 4 6 8

Process Emissions Less Carbon Stored

Wood framing
OSB sheathing
Plywood sheathing
Concrete block
Concrete block/stucco
Steel framing
Concrete block/plywood/vinyl
Steel framing/OSB/vinyl
Steel framing/plywood/vinyl

In general, for every ton of wood used in place of potential alternative materials, emissions of 2.1 tons of carbon (or 7.7 tons of CO$_2$e) are avoided.
Harada Elementary School, Corona, CA

Two-story classroom building, administration building, kindergarten building, covered kindergarten play area, multipurpose building, cafeteria, media center, exercise courts, student gathering area, and outdoor classroom/amphitheater.
Harada Elementary School, Corona, CA

Construction: Wood-frame walls, roofs, and second-level floors

Features: include self-contained classrooms featuring nine-foot ceilings; pullout workrooms and other moveable elements.
Volume of wood used
4,012 m³

Carbon sequestered and stored (CO₂e)
3,493 metric tons

Avoided greenhouse gases (CO₂e)
7,431 metric tons

Total potential carbon benefit (CO₂e)
10,924 metric tons
Carbon savings from the choice of wood in this one project are equivalent to:

- 2,087 passenger vehicles off the road for a year
- Enough energy to operate a home for 929 years
Library Square, Kamloops, BC
Library Square, Kamloops, BC

Six story structure (Five stories of wood over podium slab). Combined residential/commercial.

• 140 condo units

• 14,000 ft² street level commercial

• 20,000 ft² library

• Underground parking
Library Square, Kamloops, BC

Volume of wood used 2,927 m³
Carbon sequestered and stored (CO₂e) 2,124 metric tons
Avoided greenhouse gases (CO₂e) 4,520 metric tons
Total potential carbon benefit (CO₂e) 6,645 metric tons
Time period needed for North American forests to replace the volume of wood used in this structure at current net growth rates:

8.6 minutes
Carbon management is important, and regulation of carbon is likely in our future.

Greater use of wood in construction can help to reduce carbon emissions, store carbon for long time periods, and reduce the rate of non-renewables depletion.
Forest Carbon Dynamics
Trends in U.S. Forestland Area
1630-2012

Source: USDA – Forest Service, 2013

Standing Timber Inventory – U.S.
1952-2012


U.S. Timber Growth and Removals,
1920 - 2011
Billions of cubic feet/ year

89% of harvest is from private forest lands


Carbon in Above-Ground Portion of Standing Trees, U.S. 1990-2011

Harvests in US forests increased 5.8 billion ft$^3$/year between 1952 and 2007.

U.S. Net Forest Growing Stock Volume 1952 and 2007 (billion ft$^3$)


GS volume increased by more than 50%!
Above-Ground Carbon in U.S. Forests 1990-2014

Total Forest Carbon Inventory, U.S. 1990-2014

Carbon in Wood Products in Use, U.S. 1990-2014

Summary

• Atmospheric carbon concentrations are clearly increasing and linked to fossil carbon emissions.

• Atmospheric carbon levels are higher than at any time in at least 800,000 years.

• 35-40% of human-caused carbon emissions are from building construction and operation.

• Over one-half of buildings that will exist in 2030 will have been built post 2010.

• Significant progress is being made in reducing consumption of operating energy.
Summary

• Embodied energy (and carbon) is becoming increasingly important.

• There are large differences in carbon emissions associated with various building materials.

• Use of wood building materials and assemblies result in far lower energy consumption and carbon emissions than other common building materials.

• Annual growth in U.S. forests far exceeds removals, resulting in increasing carbon storage.

• Wood construction creates new carbon pools that store carbon for long periods of time.
Questions?

This concludes The American Institute of Architects Continuing Education Systems Course

Wood Products Council  866.966.3448  info@woodworks.org
Dovetail Partners  612.333.0430  www.dovetailinc.org
Tracking Forest Carbon

When should we begin to count carbon?
Tracking Forest Carbon

What perspective should be used?
Depiction of a Sustainably Managed Forest at Stand, Parcel, and Landscape Levels

Source: Adapted from Colnes (2011)
Depiction of a Sustainably Managed Forest at Stand, Parcel, and Landscape Levels

Source: Adapted from Colnes (2011)
Depiction of a Sustainably Managed Forest at Stand, Parcel, and Landscape Levels

Source: Adapted from Colnes (2011)