ATMOSPHERIC CARBON DIOXIDE

AND

CARBON STORAGE IN URBAN WOOD PRODUCTS

Prepared by Sam Sherrill, Ph.D.
Presentation Based on Two Research Projects Conducted by Sam Sherrill and Steve Bratkovich in 2011 and 2018.

*Carbon and Carbon Dioxide Equivalent Sequestration in Urban Forest Products, July, 2011* (technical report)

*Carbon Sequestration in Solid Wood Products from Urban Forests, July 19, 2011* (public report)

*Estimates of Carbon Dioxide Withheld from the Atmosphere by Urban Hardwood Products, March, 2018*

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Additional Acknowledgements:

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David Richardson, Ph.D., Professor of Aerospace Engineering (retired), University of Cincinnati.

Jessica Tierney, Ph.D., Associate Professor, Department of Geosciences, University of Arizona, Tucson, AZ.
Why do this research?

Because two of the three common uses for fallen urban trees are as products, fuel, and mulch. When used as fuel and mulch, C is released into the atmosphere:

- Quickly, when burned as fuel,
- Or, a bit more slowly as mulch.

Either way, C combines with $O_2$ ($C + O_2 \rightarrow CO_2$) to form carbon dioxide, a major greenhouse gas.
By contrast, solid wood products made from urban trees continue to retain C just as the trees did.

We will get to the importance of this later. But first:
Quick overview of the greenhouse effect of CO$_2$ on the Earth’s atmosphere.
Electromagnetic Spectrum
Infrared Radiation Key to Understanding How CO₂ Works as GH Gas

Infrared extends from about 700+ nm to 1 millimeter (or, 1,000,000 nm).
“In your eyes
The light, the heat”
Peter Gabriel, *In Your Eyes*

Unaided humans can’t see but do feel the heat from infrared radiation.

Human visibility on spectrum ranges from about 380 to about 750 nanometers.

Infrared starts just above 750 nanometers and goes to about 1 millimeter.
Start with actual greenhouse
1. Sunlight easily penetrates glass walls and ceiling and heats plants & soil.
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2. Plants & soil absorb some light energy and re-radiates rest as infrared energy (can feel the heat).
1. Sunlight easily penetrates glass walls and ceiling and heats plants & soil which plants needs for photosynthesis.

2. Plants & soil absorb light energy and re-radiates rest as infrared energy (heat).

3. Since infrared radiation has a longer wavelength than sunlight it does not easily penetrate glass from the inside.

Odd fact: bed bugs, pit vipers, goldfish, salmon, and frogs can see in infrared.
1. Sunlight easily penetrates glass walls and ceiling and heats plants & soil.

2. Plants, floor, & soil absorb light energy and re-radiates it as heat which heats air inside greenhouse.

3. Heat mostly trapped in greenhouse by glass.

4. Convection moves warm and cool air from floor to ceiling keeping the greenhouse temperature even.
1. Sunlight easily penetrates glass walls and ceiling and heats plants & soil.

2. Plants, floor, & soil absorb light energy and re-radiates it as heat which heats air inside greenhouse.

3. Since infrared radiation has a longer wavelength than sunlight it does not easily penetrate glass from the inside.

4. Convection moves warm and cool air from floor to ceiling keeping the greenhouse temperature even.

5. And warmer than outside air.
Small Scale Greenhouse Effect: Why Never Leave Children or Pets in Cars Even For Short Periods of Time in Mild Weather.

1. Sunlight energy absorbed by dashboard, seats, steering wheel, and carpet.
Small Scale Greenhouse Effect: Why Never Leave Children or Pets in Cars Even For Short Periods of Time in Mild Weather.

1. Sunlight energy absorbed by dashboard, seats, steering wheel, and carpet.

2. Infrared energy from all four heats air inside car.
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1. Sunlight energy absorbed by dashboard, seats, steering wheel, and carpet.
2. Infrared energy from all four heats air inside car.
3. Windows trap infrared heat just as they do in greenhouse.

Small Scale Greenhouse Effect: Never Leave Children or Pets in Cars Even For Short Periods of Time in Mild Weather.

1. Sunlight energy absorbed by dashboard, seats, steering wheel, and carpet.
2. Energy from all four rather quickly heats air inside car.
3. Windows trap heat just as they do in greenhouse.
4. Temperature in car above eventually peaks at ~ 140°F.

How Does CO₂ Raise the Temperature of the Atmosphere?

Complete answer is complex. Really short version:

1. In 1827, French mathematician Jos. Fourier realized an atmospheric process acted like a blanket retaining heat energy from Sun. In mid-19th century, John Tyndall discovered CO₂ is effective absorber/emitter of infrared. Calculated that without this process Earth’s temperature would be ~0°F instead of ~60 °F.
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2. Equivalent to windows in greenhouses and cars, atmospheric CO$_2$ is transparent to incoming short-wave sunlight.
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3. Earth’s surface both absorbs sunlight energy and re-radiates some of that energy as invisible infrared waves.
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3. Earth’s surface both absorbs sunlight energy and re-radiates some of that energy as invisible infrared waves.

4. CO₂ molecules are so excited by infrared radiation they do a frantic molecular dance in all directions. The extra heat energy generated by this dance is trapped by CO₂ molecules (as the glass does in greenhouses and cars).
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2. Like greenhouse and car windows, atmospheric CO₂ is transparent to incoming short-wave sunlight.

3. The earth’s surface both absorbs sunlight energy and re-radiates some of that energy as invisible infrared waves.

4. CO₂ molecules are so excited by infrared radiation they do a frantic molecular dance in all directions. The extra heat energy generated by this dance is trapped by CO₂ molecules (as the glass does in greenhouses and cars).

5. Heats up the atmosphere on a global scale. Heat distributed by moving air masses, water vapor, and ocean currents.
Is the Amount of CO$_2$ in Earth’s Atmosphere Increasing?

Charles Keeling began measuring atmospheric CO$_2$ in 1958 on Mauna Loa volcano in Hawaii.

Keeling Curve shows growing concentration of CO$_2$ in Earth’s atmosphere.

His graph credited with bringing attention to rapidly rising level of CO$_2$ in the atmosphere.

316 ppm in 1958

~410 ppm in May, 2018
1. In the 60 years since 1958, CO₂ has increased about 30 percent, from 316 ppm to 410 ppm (from 0.0316% to 0.0410% of atmosphere).
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2. Fossil fuels are the source of additional CO$_2$. Much of this CO$_2$ has unique and identifiable “fingerprint” of long dead and decayed trees which eventually became coal.
1. In the 60 years since 1958, CO₂ has increased about 30 percent, from **316 ppm** to **410 ppm** (from 0.0316% to 0.0410% of atmosphere).

2. Fossil fuels are the source of additional CO₂. Much of this CO₂ has the unique and identifiable “fingerprint” of long dead and decayed trees which eventually becomes coal.

3. CO₂ will remain in atmosphere for hundreds or even thousands of years. In terms of multiple human life spans, this problem is not going to go away anytime soon.
1. These graphs show concentrations of carbon dioxide in the atmosphere from 800,000 years ago through 2015, measured in parts per million (ppm).

2. The data come from a variety of historical ice core studies and recent air monitoring sites around the world. Compilation of 10 underlying datasets.
Is the Earth Getting Warmer?

From 1880 through 2016, surface temperature has risen 1.7°F.
https://www.ncdc.noaa.gov/sotc/summary-info/global/201612

International Panel on Climate Change’s low range estimate is another 1.4°F increase by 2050.
If your body temperature rose by 1.7°F, from 98.6 to 100.3°F, you would have a low-grade fever.

If your body temperature rose another 1.4°F, you would have a fever of ~102°F.
One More Point About the Impact of CO$_2$

Earth’s atmosphere consists of about 78% nitrogen, 21% oxygen, and 0.9% argon.

Remaining 0.1% are trace gases: carbon dioxide, methane, neon, helium, nitrous oxide, and ozone.
How Can So Little CO$_2$ (0.41%) Raise the Temperature of Earth’s Atmosphere??

Quick answer from toxicology where it is said that,

“it’s the dose that makes the poison”.

CO$_2$’s cousin, carbon monoxide (CO), provides a well-known example.

CO is incapacitating at 800 ppm (0.08%) in a closed space such as a bedroom or garage,

and fatal within two hours when it reaches 1,600 ppm or 0.16 %.
Okay, one more point on CO₂.

Some CO₂ is good – keeps the Earth habitable.

Without GH gases trapping re-emitted radiation, Earth’s temperature ~ 0°F instead of ~60°F.

Then is more better? Not likely.

Then way too much can’t be just right. Right?

Look at Venus as an example of way too much.
Venus: The Goddess of Heat

CO$_2$ is 96.5% of the Venusian atmosphere.

Making Venus is the hottest world in the solar system.

Temperatures on the planet reach 870 °F, more than hot enough to melt lead.

Although Venus is not the planet closest to the sun, its dense atmosphere traps heat in a runaway version of the same greenhouse effect that warms Earth.
So, What is the Connection Between Atmospheric Carbon Dioxide and Carbon Storage in Urban Wood Products?

Facts:

Trees are between 48% and 52% carbon.
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Trees are between 48% and 52% carbon.

When burned or used as mulch carbon is released immediately or in a very short time.

When used to make wood products carbon remains captured in the products as long as they exist.
For every pound of C captured in one of your urban wood products, 3⅓ pounds of CO₂ would have been created had that same pound of C been released by burning the wood or grinding it into mulch.

Where does 3⅓ pounds of CO₂ come from? Based on ratio of molar mass of CO₂ to the molar mass of C (measured in grams/mole).

\[
\text{C} @ 1 \times 12 \text{ g/mole} + \text{O}_2 @ 2 \times 16 \text{ g/mole} = 44 \text{ g/mole}:
\]

\[
44 \text{ g/mole} \div 12 \text{ g/mole of C} = 3.6667 \text{ or } 3\frac{2}{3} \text{ CO}_2 \text{ to } 1 \text{ C}.
\]

By definition, one mole is the number of atoms in precisely 12 thousandths of a kilogram (0.012 kg) of C-12, the most common naturally occurring isotope of the element carbon. Carbon-12 has an atomic mass of 12 (six neutrons and six protons). Oxygen, O, has 16 grams (eight neutrons and eight protons). The O molecule consists of pair of O atoms. Hence, \( \text{O}_2 \) has 2 x 16 grams or 32 g/mole.
Worth Repeating:

For every pound of C captured in one of your urban wood products, 3¾ pounds of CO₂ would have been created had that same pound of C been released by burning the wood or grinding it into mulch.

The CO₂ not formed is referred to as CO₂e or carbon dioxide equivalent.
In forestry,

the CO$_2$ that would have formed when C released by fuel and mulch hooks up with O$_2$ but instead remains in urban wood products.

In the climate sciences,

CO$_2$e (aka, CO$_2$-eq) refers to using CO$_2$ as an equivalent measure of all greenhouse gases.

For example, 1 ton of methane (CH$_4$) is the equivalent to 25 tons of CO$_2$ (CH$_4$ breaks down into CO$_2$ in ~ 12 years).
So far, looked at carbon in 3 different ways:

1. atmospheric carbon dioxide, \( \text{CO}_2 \);

2. carbon, \( \text{C} \), as an element that makes up about half of all trees; and

3. carbon dioxide equivalent, \( \text{CO}_2e \) -- the \( \text{CO}_2 \) that would have formed when \( \text{C} \) released by fuel and mulch hooks up with \( \text{O}_2 \) but instead remains in urban wood products.
So far, looked at carbon in 3 different ways:

1. atmospheric carbon dioxide, CO$_2$;

2. carbon, C, as an element that makes up about half of all trees; and

3. carbon dioxide equivalent, CO$_2$e -- CO$_2$ that would have been formed had urban wood products been burned and/or ground into mulch.

4. Now, the 4$^{th}$ way: CO$_2$e measured in lbs./bd. ft. for common urban hardwood and softwood species.

Example: the CO$_2$e for green ash made into a product (versus fuel and mulch) is 5.0956 lbs./bd. ft.
## Amounts of CO$_2$e Measured in Pounds per Board Foot for Common Urban Hardwood Trees

<table>
<thead>
<tr>
<th>Species by Common Name</th>
<th>CO$_2$e Measured in Pounds per Board Foot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alder</td>
<td>3.6087</td>
</tr>
<tr>
<td>Ash, White</td>
<td>5.2969</td>
</tr>
<tr>
<td>Ash, Black</td>
<td>4.3831</td>
</tr>
<tr>
<td><strong>Ash, Green</strong></td>
<td><strong>5.0956</strong></td>
</tr>
<tr>
<td>Aspen, Quaking</td>
<td>3.3609</td>
</tr>
<tr>
<td>Balsam</td>
<td>3.4074</td>
</tr>
<tr>
<td>Basswood</td>
<td>3.3609</td>
</tr>
<tr>
<td>Beech</td>
<td>5.8081</td>
</tr>
<tr>
<td>Birch, Paper</td>
<td>4.8943</td>
</tr>
<tr>
<td>Birch, Yellow</td>
<td>5.6841</td>
</tr>
<tr>
<td>Cherry, Black</td>
<td>4.5380</td>
</tr>
<tr>
<td>Chestnut</td>
<td>3.8720</td>
</tr>
<tr>
<td>Cottonwood, Black</td>
<td>3.0976</td>
</tr>
<tr>
<td>Cypress, Southern</td>
<td>4.1818</td>
</tr>
<tr>
<td>Elm, Rock</td>
<td>5.6841</td>
</tr>
<tr>
<td>Elm, American</td>
<td>4.5225</td>
</tr>
<tr>
<td>Gum, Black</td>
<td>4.5225</td>
</tr>
</tbody>
</table>
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<tr>
<td>Hackberry</td>
<td>4.7703</td>
</tr>
<tr>
<td>Hickory</td>
<td>6.5825</td>
</tr>
<tr>
<td>Hickory, Pecan</td>
<td>6.0714</td>
</tr>
<tr>
<td>Locust, Black</td>
<td>6.3501</td>
</tr>
<tr>
<td>Magnolia, Southern</td>
<td>4.5225</td>
</tr>
<tr>
<td>Maple, Sugar</td>
<td>5.6841</td>
</tr>
<tr>
<td>Maple Red</td>
<td>4.9562</td>
</tr>
<tr>
<td>Maple, Silver</td>
<td>3.4848</td>
</tr>
<tr>
<td>Oak, Red</td>
<td>5.6841</td>
</tr>
<tr>
<td><strong>Oak, White</strong></td>
<td><strong>6.0714</strong></td>
</tr>
<tr>
<td>Sweet gum</td>
<td>4.3831</td>
</tr>
<tr>
<td>Tupelo, Black</td>
<td>4.5225</td>
</tr>
<tr>
<td>Tupelo, Water</td>
<td>4.5225</td>
</tr>
<tr>
<td>Poplar,</td>
<td></td>
</tr>
<tr>
<td>Yellow (tulip)</td>
<td>3.6397</td>
</tr>
<tr>
<td>Sycamore</td>
<td>4.3831</td>
</tr>
<tr>
<td>Walnut, Black</td>
<td>4.9097</td>
</tr>
</tbody>
</table>
Knowing CO$_2$e by weight per board foot by species, we can easily calculate CO$_2$e per Product

Knowing CO$_2$e weights in lbs. per bd. ft. by species allows you to easily compute CO$_2$e for each of your products.

EXAMPLE: the table and ten chairs shown below contain about 120 bd. ft. of white oak.
As given in the table above, the CO$_2$e weight per bd. ft. for white oak is 6.0714 lbs.

6.0714 lbs. CO$_2$e/bd. ft. $\times$ 120 bd. ft. $\approx$ 730 lbs. CO$_2$e.*

Therefore, the table and chairs will withhold 730 lbs. of potential CO$_2$ from the atmosphere as long as they exist.

* To be clear, this is not the weight of the table and chairs. That would be for white oak @ 12% MC: 47 lbs./ft.$^3$ $\div$ 12 bd. ft./ft.$^3$ = 4 lbs./bd. ft. $\times$ 120 bd. ft. = 480 lbs.
According to the EPA, 88 lbs. of CO₂ are emitted annually by a typical four-stroke gas-powered lawn mower.

730 lbs. CO₂e ÷ 88 lbs. CO₂ annually per mower = 8.3 years.

That is, the oak table and chairs will offset potential CO₂ emissions from 8 mowers for 1 year (or 1 mower for 8 years).
Another Example:

Research partner, Steve Bratkovich, had 140 sq. ft. of urban green ash flooring installed in his home. Boards are ¾ inch thick.

140 sq. ft. x ¾ inch = 105 bd. ft. x 5.0956 lbs. CO₂e /bd. ft. = 535 lbs. of CO₂e.

535 lbs. CO₂e ÷ 88 lbs. of mower CO₂ emissions = 6 mowers for 1 year (or 1 mower for 6 years).
### Amounts of CO$_2$e Measured in Pounds per Board Foot
**For Selected Urban Softwood Trees**

<table>
<thead>
<tr>
<th>Species by Common Name</th>
<th>Amount CO$_2$e by Weight in lbs. per bd. ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cedar, Red Western</td>
<td>3.1545</td>
</tr>
<tr>
<td>Fir, Douglas, Coastal</td>
<td>4.7451</td>
</tr>
<tr>
<td>Hemlock, Western</td>
<td>4.4296</td>
</tr>
<tr>
<td>Larch, Western</td>
<td>5.1142</td>
</tr>
<tr>
<td>Pine, Ponderosa</td>
<td>3.9363</td>
</tr>
<tr>
<td>Redwood, 2nd Growth</td>
<td>3.4631</td>
</tr>
<tr>
<td>Spruce, Sitka</td>
<td>3.8793</td>
</tr>
</tbody>
</table>

Source: WOODWEB-Lumber Weight. [http://www.woodweb.com/cgi-bin/calculators/calc.pl](http://www.woodweb.com/cgi-bin/calculators/calc.pl). Note: I do not recommend using the weight calculator at this site. Answers are not accurate.
Softwood Example: Redwood Table by Evan Shively, Aborica

Estimate this redwood table top to be 1 ft. by 3 ft. by 20 ft. long.
The top contains about 720 bd. ft. of redwood which will prevent the formation of almost 2,500 lbs. of CO$_2$.

3.4631 lbs. CO$_2$e /bd. ft. x 720 bd. ft. = 2,493 lbs. CO$_2$e

Also equals CO$_2$ emissions of 28 lawn mowers in 1 year (or 1 mower for 28 years – who keeps a mower for 28 years?).
CO$_2$e by UFP Businesses

You can also calculate the **annual** CO$_2$e weights for all your products by species and bd. ft. totals.

For example, my small (former) business in Ohio in one (really good) year used about **10,000** bd. ft. of oak, ash, cherry, and walnut.

Held another **5,000** bd. ft. in inventory (same species/proportions).
CO$_2$e by UFP Businesses

You can also calculate the **annual total** CO$_2$e weights for all your products by species.

For example, my small (former) business in Ohio in one year used about **10,000** bd. ft. of oak, ash, cherry, and walnut.

Held another **5,000** bd. ft. in inventory (same species/proportions).

**Total for given year** = **15,000** bd. ft.

Equally weighted CO$_2$e proportions for four hardwood species @ **5.2** CO$_2$e lbs./bd. ft.

5.2 CO$_2$e lbs./bd. ft. x 15,000 bd. ft. = **78,000** CO$_2$e lbs.

78,000 CO$_2$e lbs. ÷ 2,000 lbs./ton = **39** tons CO$_2$e
According to the EPA, a typical passenger car emits about 5.1 (U.S.) tons of CO$_2$ per year.

Thus, my small business in one year offsets CO$_2$ emissions of about 7 ½ cars (or one car for 7 ½ years).
For Your Customers, Addresses Thinking Globally, Acting Locally.

CO$_2$e numbers by product and annually for your business are especially important to your customers interested in buying environmentally responsible products.
Thinking globally, acting locally.

CO$_2$e numbers by product and annually by your business are important to your customers interested in buying environmentally responsible products, especially in CA.

Your customers will know that the urban wood products they’re buying in some small way will contribute to the reduction of a major greenhouse gas.
Thinking globally, acting locally.

CO$_2$e numbers by product and annually by your business are important to your customers interested in buying environmentally responsible products, especially in CA.

Your customers will know that the urban wood products they’re buying in some small way will contribute to the reduction of a major greenhouse gas.

In addition, they will also know that they’re purchasing products that utilize the nation’s urban wood at its highest economic value.
Looked at Carbon Sequestration in Individual Products and UFP Companies

Now Look at Nation as a Whole
Both the 2011 and the 2018 reports are based on an Excel model that calculates CO$_2$e over a 30 year period for hardwood products.

In 2011 report, model only estimated tons of CO$_2$e.

The baseline estimate = 124.1 million tons of CO$_2$e for 30 years.

Estimate based on five conservative assumptions:

1. No growth in capacity of urban forest to sequester C.
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1. No growth in capacity of urban forest to sequester C.

2. Annual tree removal rate of 1% from urban forest.
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Estimate based on five conservative assumptions:

1. No growth in capacity of urban forest to sequester C.
2. Annual tree removal rate of 1% from urban forest.
3. 10% utilization of the 1% removed.
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4. Very conservative estimates of how many years urban wood products will last.
Both the 2011 and the 2018 reports are based on Excel model that calculates CO$_2$e for a 30 year period for hardwood products.

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Estimate based on five conservative assumptions:

1. No growth in capacity of urban forest to sequester C.
2. Annual tree removal rate of 1% from urban forest.
3. 10% utilization of the 1% removed.
4. Very conservative estimates of how many years urban wood products will last.
5. Urban hardwood lumber meets restrictive National Hardwood Lumber (NHLA) standards.
That typical passenger car emits about 5.1 (U.S.) tons of 
CO$_2$ per year.

124.1 million tons CO$_2$ withheld from atmosphere for 30 years = removal of CO$_2$ emissions of $\approx 811,000$ cars each year.*

*124.1 million tons CO$_2$ $\div$ 5.1 tons CO$_2$/car/year) $\div$ 30 years
How many bd. ft. in urban hardwood products are required to withhold 124.1 million tons of CO$_2$ from atmosphere for 30 years?

Updated version of Excel model calculates total bd. ft. of hardwood required.

Answer: 53 billion bd. ft. for thirty years, or average of 1.8 billion bd. ft./year for 30 years.

Is this annual amount feasible?
Yes.

Amount of urban hardwood available is between 3 billion and 4 billion bd. ft. per year.

Based on two different estimates made by Steve Bratkovich and David MacFarlane.*

So, 1.8 billion very feasible with plenty left over for UFP industry growth.


1. Increasing utilization from 10% of annual removals (still 1%) to 20% raises 30 year total to 105 billion bd. ft. (CO$_2$e = 248.1 million tons)

2. Averages = 3.5 billion bd. ft./year.

3. Within annual 3 to 4 billion bd. ft. range.
From list of five conservative assumptions for Excel model, look again at last two:

4. Very conservative estimates of how many years urban wood products will last.

Estimates come from forest product industry where 1/3 of wood products are discarded after 1st year.
Urban forest products have much longer life because they have:

- history,
- specific provenance,
- figure, color, dimensions, and personal and community meaning.

Often one-of-a-kind and heirloom quality.
Example: A trestle table made from century-old Cucumber Magnolia from Biltmore Estate in Asheville, NC. And white ash.

Both create standards that allow sales of large quantities of homogeneous dimensional lumber.

What urban forest product businesses sell and wood artisans use would be rejected under either standard.

Examples:

Studio of George/Mira Nakashima

See 100 examples from WM at https://www.youtube.com/watch?v=RbA1beXE7r0

Sculptor Emilie Brzensinski, age 85, utilizes discarded tree trunks as material for her wood sculptures shaping them with chain saws.

By late John Metzler, Urban Tree, Pittsburgh, PA.
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8. UFP businesses and wood artisans use far more of urban wood because they are not bound by NHLA/ASL PS20 standards.
Additional Observations

1. For more research, need data directly from urban forest product businesses.

Now all comes from forest products industry which isn’t always directly relevant for urban forest products.

For example, life of wood products way low for urban wood products & use of hardwood/softwood standards ignores more extensive use of urban trees.
2. Need census of urban forest product businesses to learn basic stuff like:

size of businesses,
species of wood used,
range of products,
types of customers, and
business problems.
Have to appreciate the irony of newly deceased urban trees being used to make products that will to some degree offset the CO$_2$ from the really old dead trees that are the source of CO$_2$ emissions from coal-fired power plants.
Questions?
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