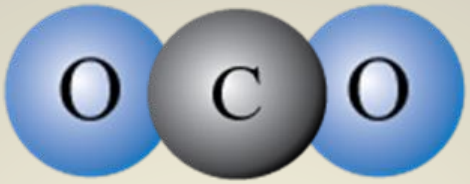
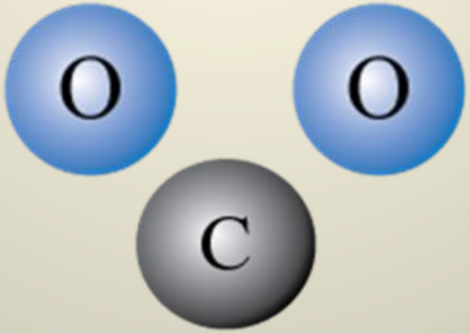
ATMOSPHERIC CARBON DIOXIDE



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

Both funded by the Wood Education and Resource Center (WERC), USDA Forest Service, Morgantown, WV

Research conducted through Dovetail Partners, Inc., Minneapolis, MN (www.dovetailinc.org)

Additional Acknowledgements:

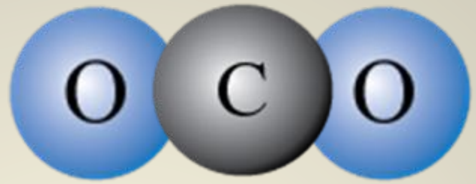
Steve Bratkovich, Ph.D., USDA Forest Service (retired).

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

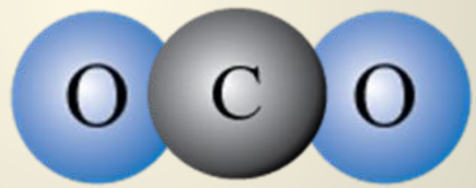
Jessica Tierney, Ph.D., Associate Professor, Department of Geosciences, University of Arizona, Tucson, AZ.

Why do this research?

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



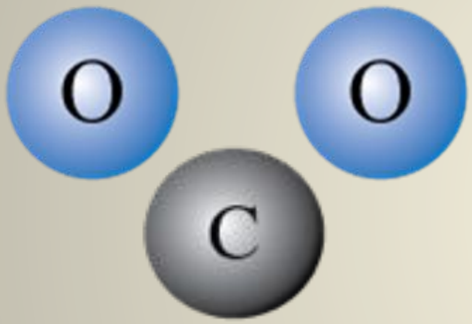
quickly, when burned as fuel,



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.

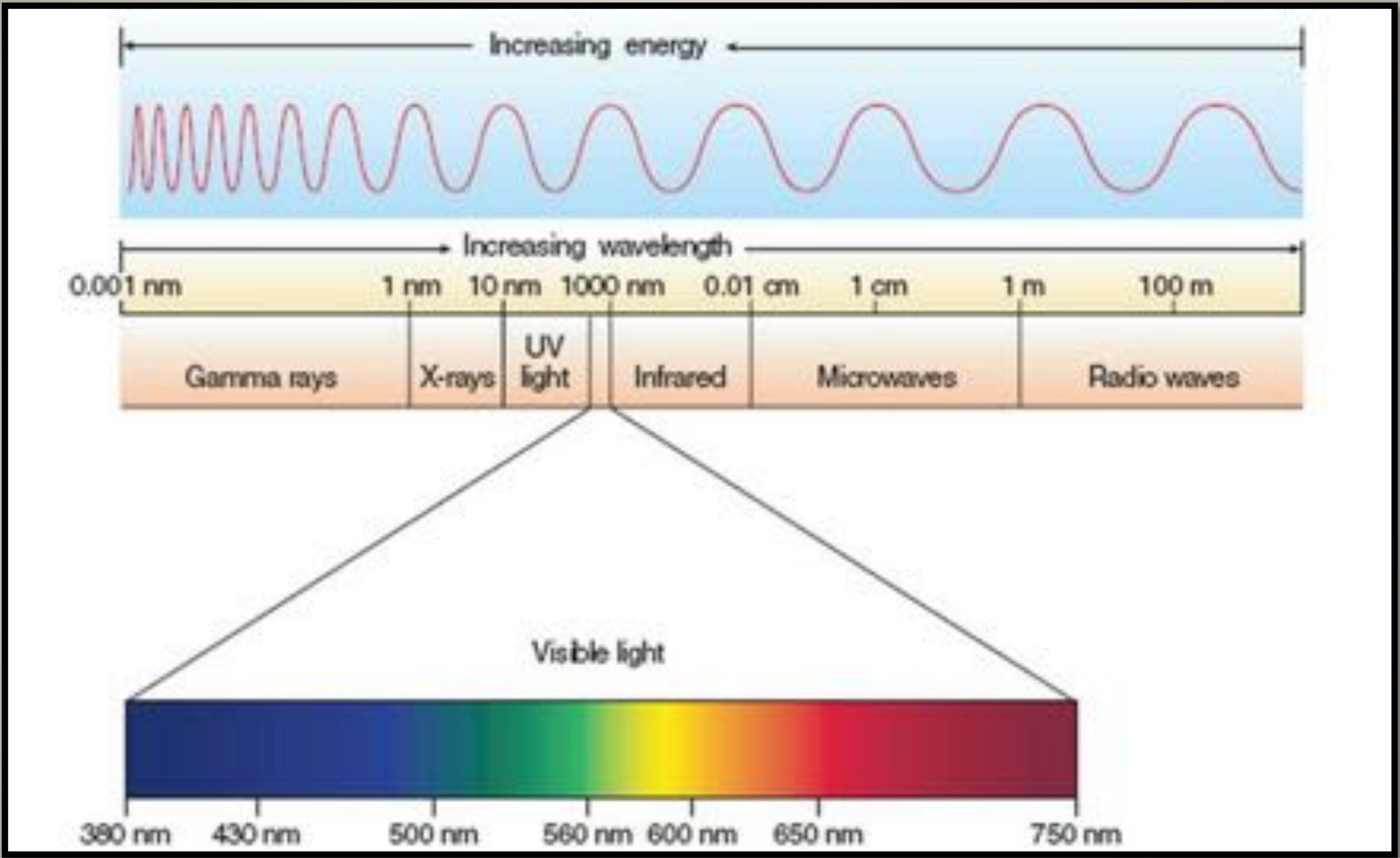


We will get to the importance of this later.
But first:

Quick overview of the greenhouse effect of CO_2 on the Earth's atmosphere.

Electromagnetic Spectrum

Infrared Radiation Key to Understanding How CO_2 Works as GH Gas



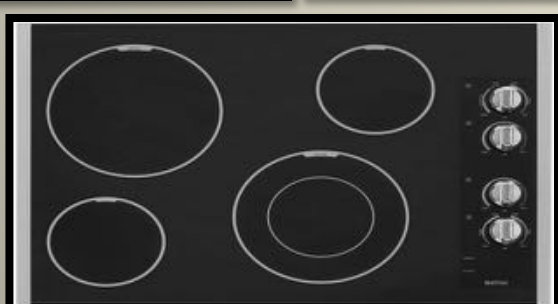
Infrared extends from about 700+ nm to 1 millimeter (or, 1,000,000 nm).

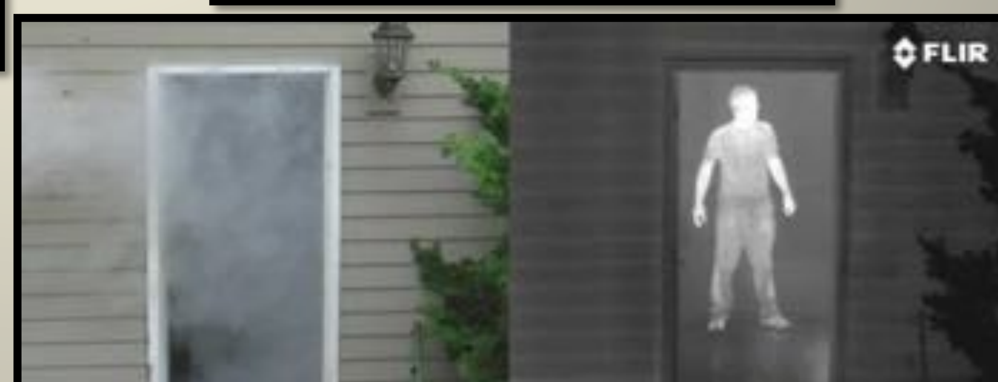
“In your eyes
The light, the heat”
Peter Grabriel, *In Your Eyes*

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

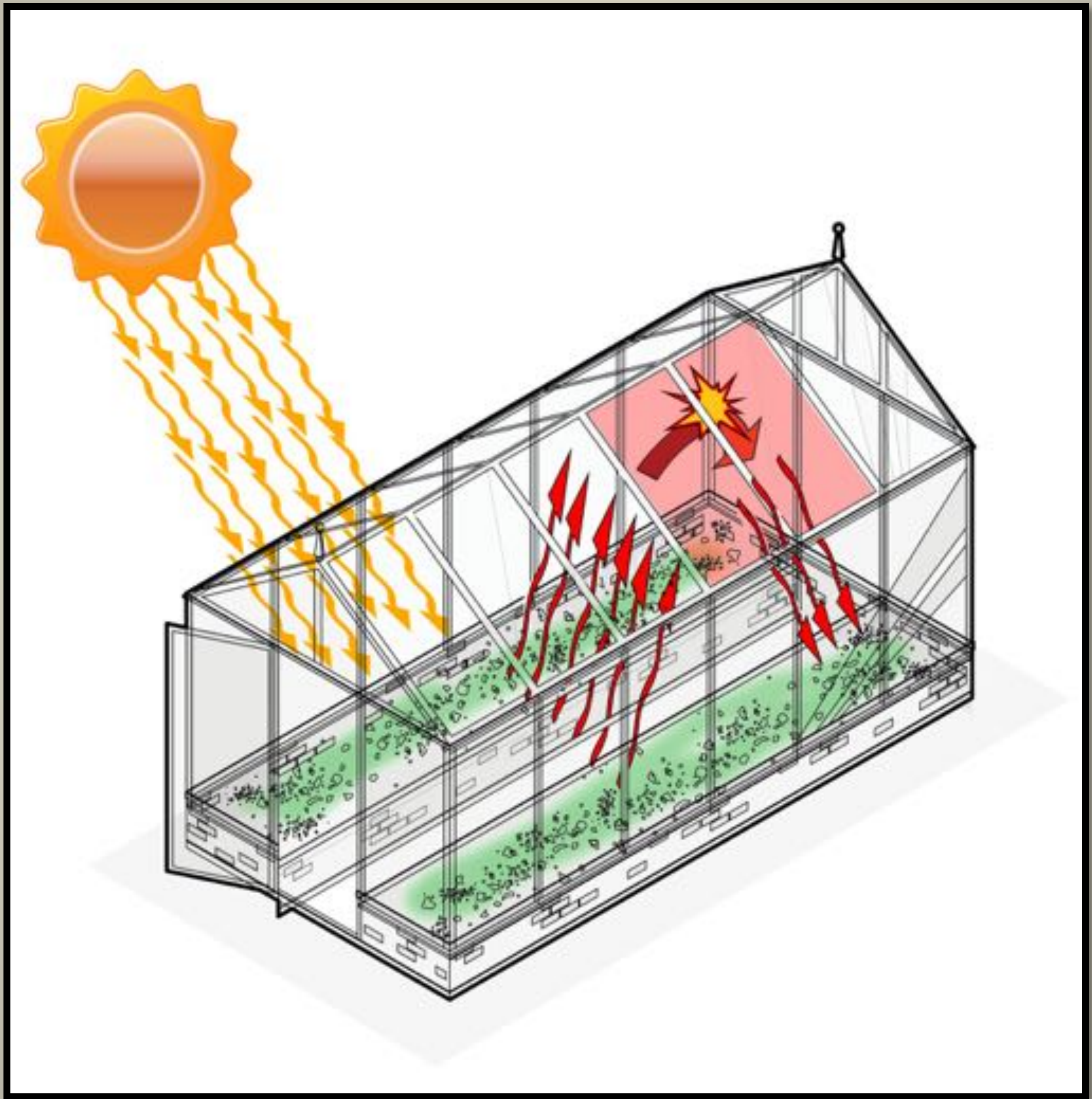
Human visibility on spectrum ranges from about 380 to about 750 nanometers.

Infrared starts just above 750 nanometers and goes to about 1 millimeter.

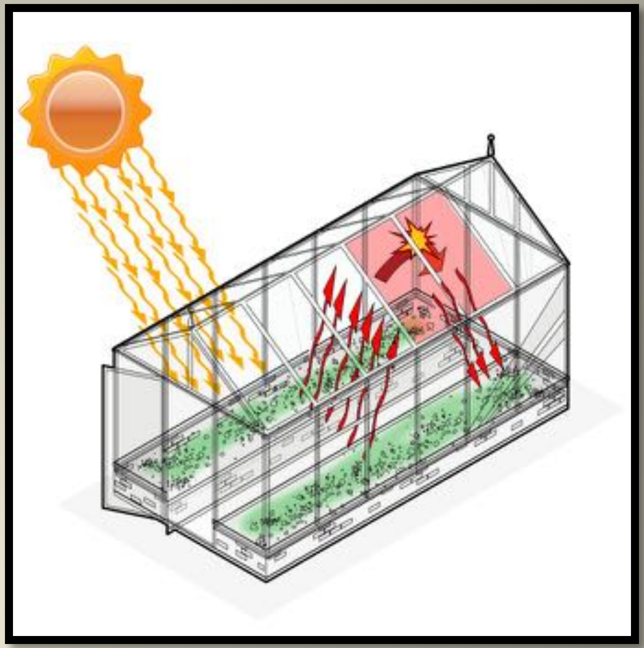




Start with actual greenhouse

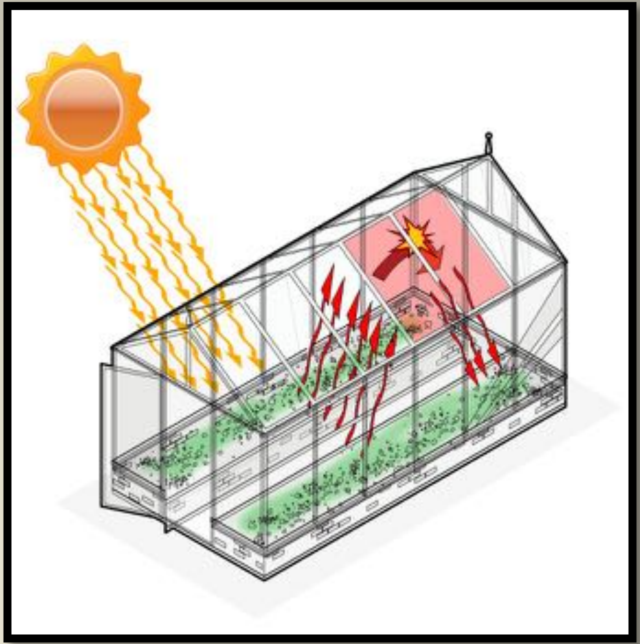


1. Sunlight easily penetrates glass walls and ceiling and heats plants & soil.



1. Sunlight easily penetrates glass walls and ceiling and heats plants & soil which plants needs for photosynthesis.

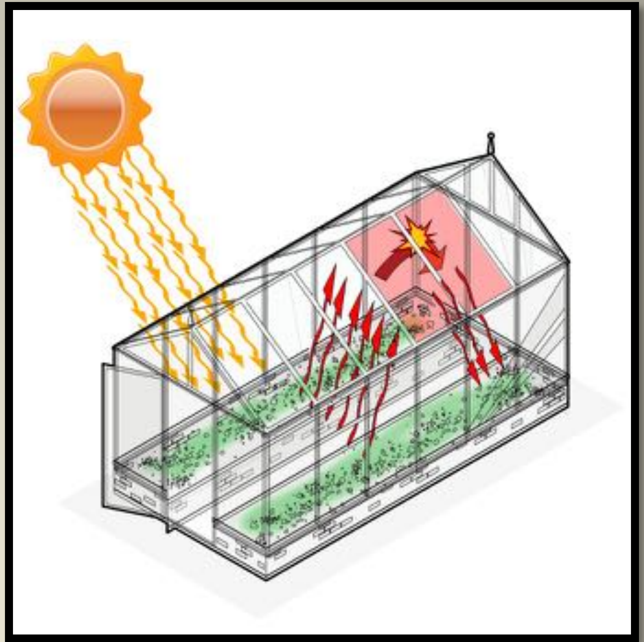
2. Plants & soil absorb some light energy and re-radiates rest as infrared energy (can feel the heat).



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.



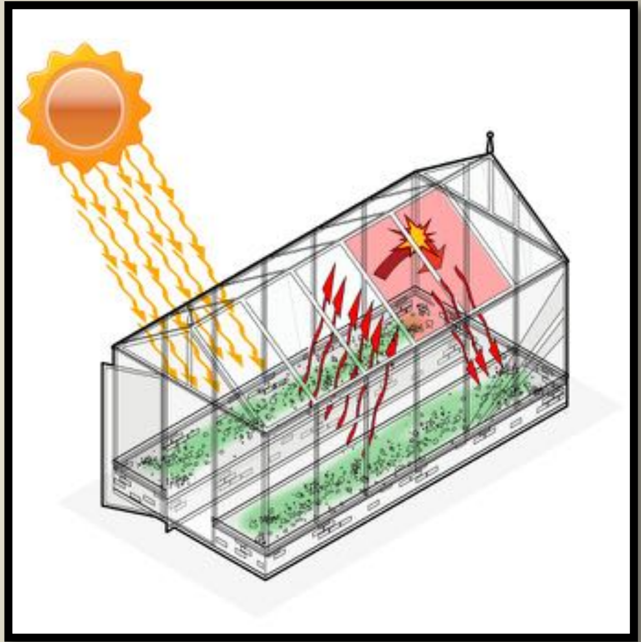
Odd fact: bed bugs, pit vipers, goldfish, salmon, and frogs can see in infrared.

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.



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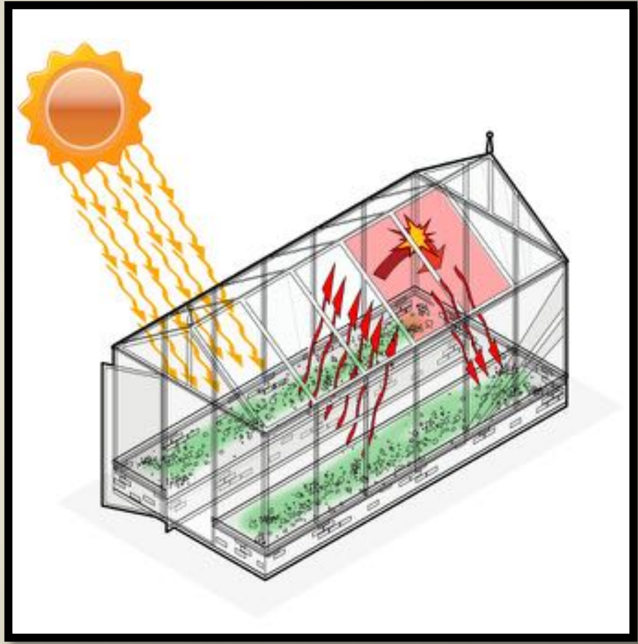
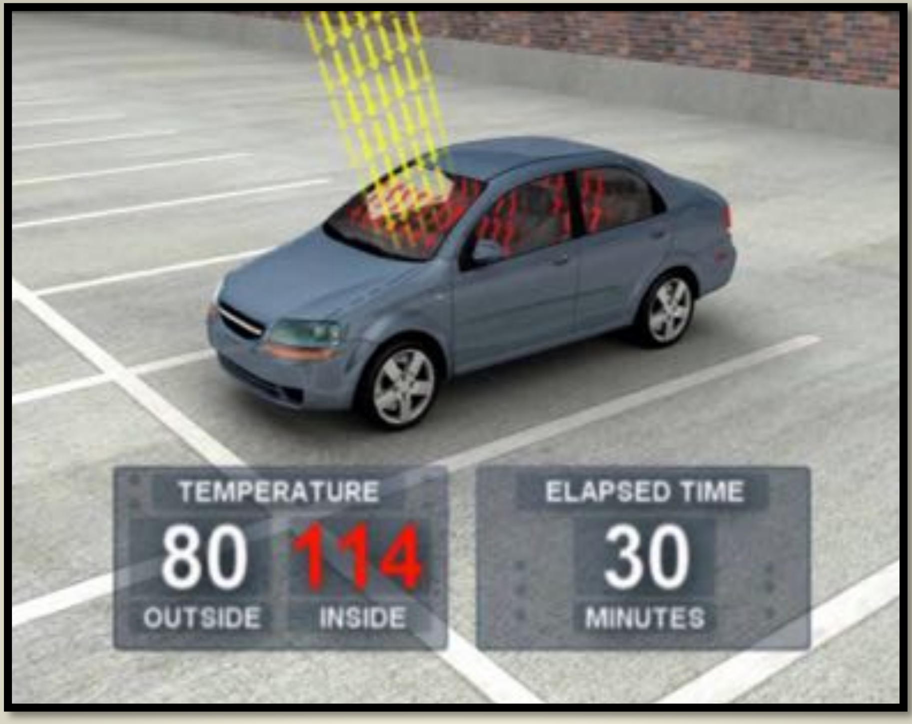
5. And warmer than outside air.



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.**

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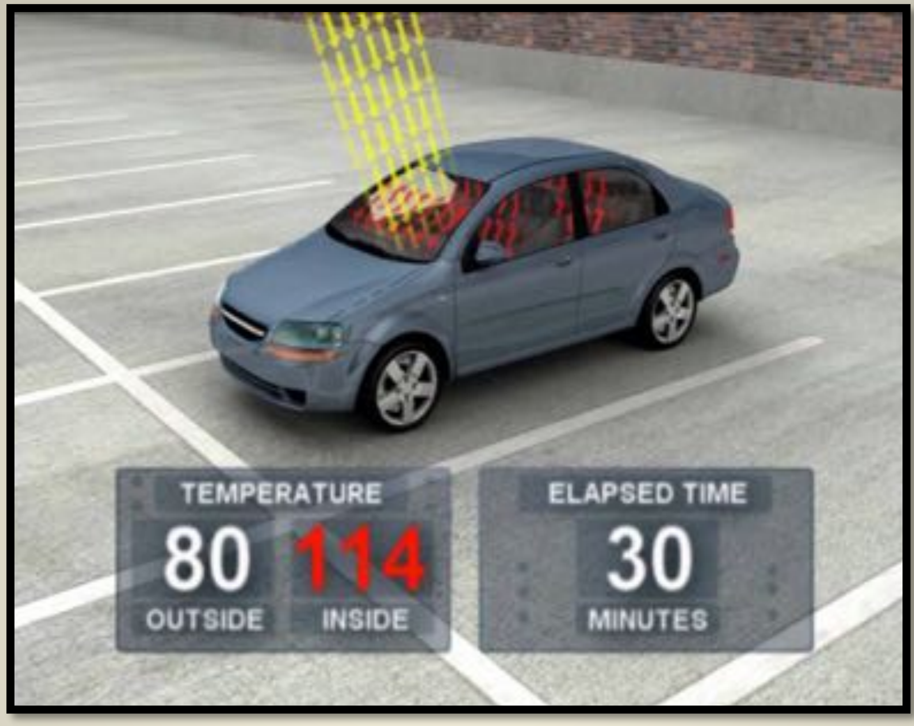

1. Sunlight energy absorbed by dashboard, seats, steering wheel, and carpet.

2. **Infrared energy from all four heats air inside car.**

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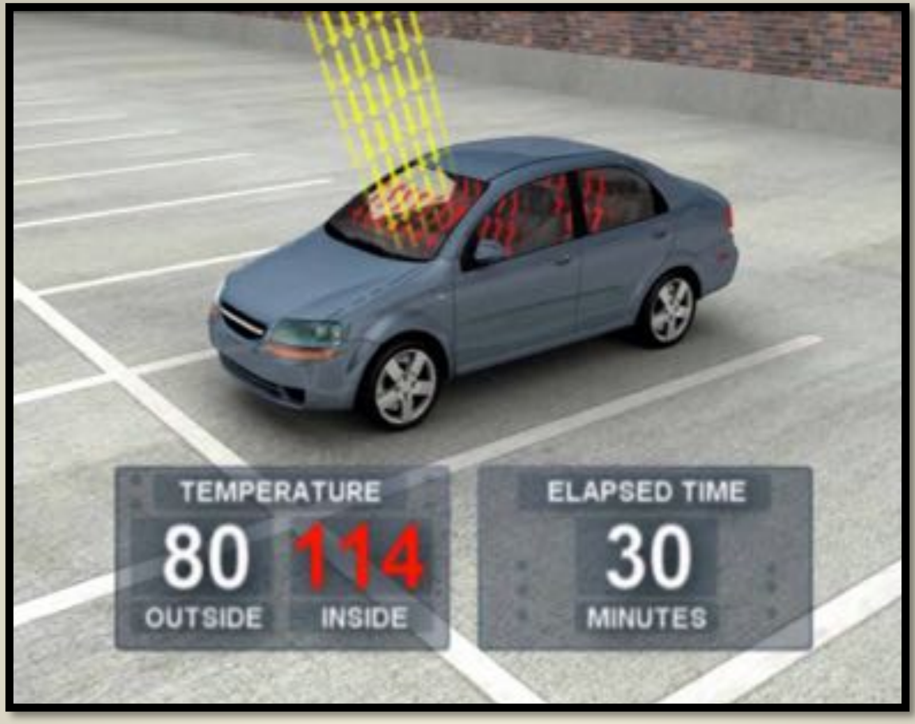

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2. Infrared energy from all four heats air inside car.

3. **Windows trap infrared heat just as they do in greenhouse.**

*Eighty percent of the temperature rise occurs within the first half-hour. McLaren, Catherine, Jan Null, James Quinn. July, 2005. *Heat Stress From Enclosed Vehicles: Moderate Ambient Temperatures Cause Significant Temperature Rise in Enclosed Vehicles.* Pediatrics, vol.116, no.1.

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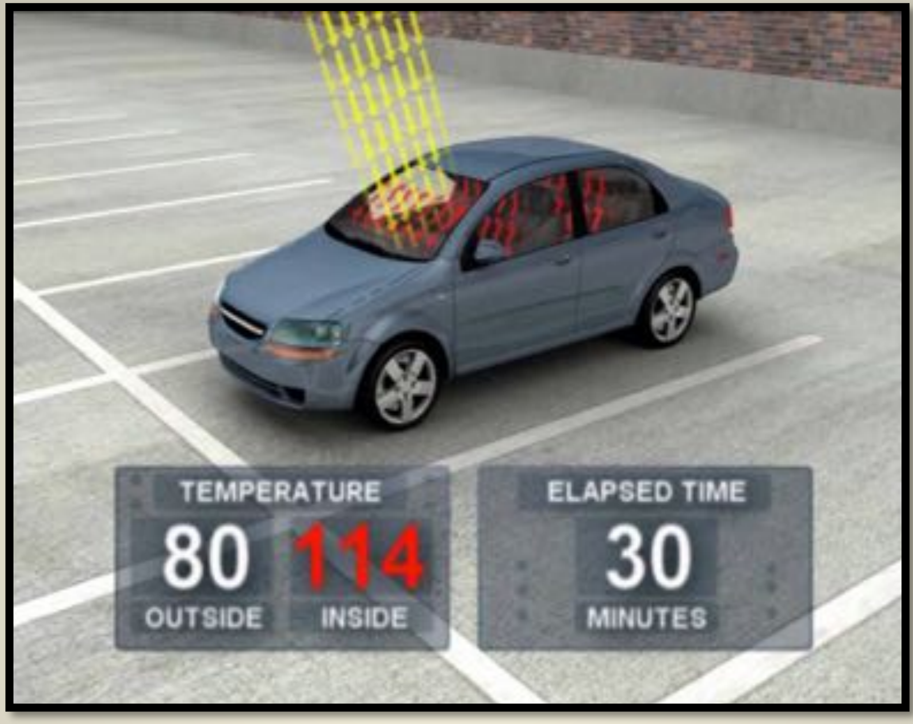

1. Sunlight energy absorbed by dashboard, seats, steering wheel, and carpet.
2. Energy from all four rather quickly heats air inside car.
3. Windows trap heat just as they do in greenhouse.
4. **Temperature in car above eventually peaks at ~ 140°F.**

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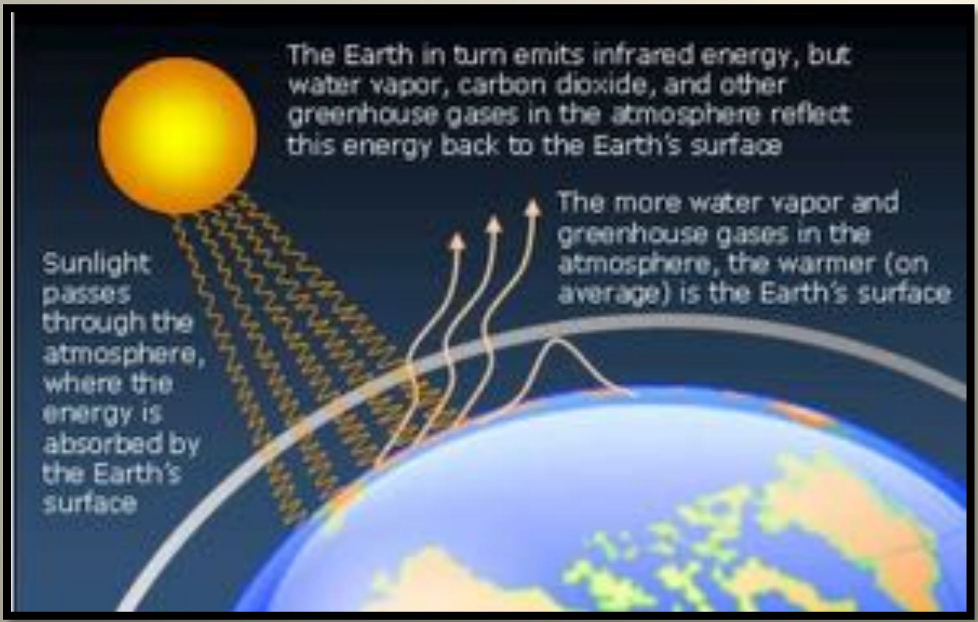
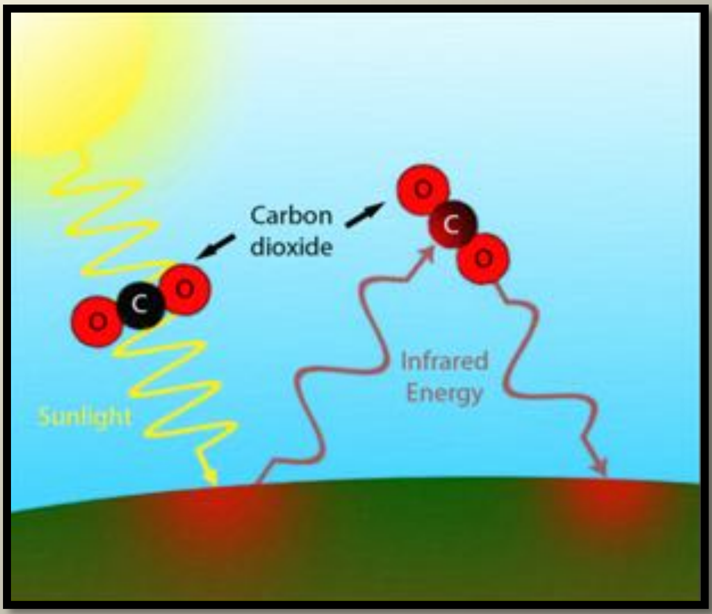
How Does CO_2 Raise the Temperature of the Atmosphere?

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 CO_2 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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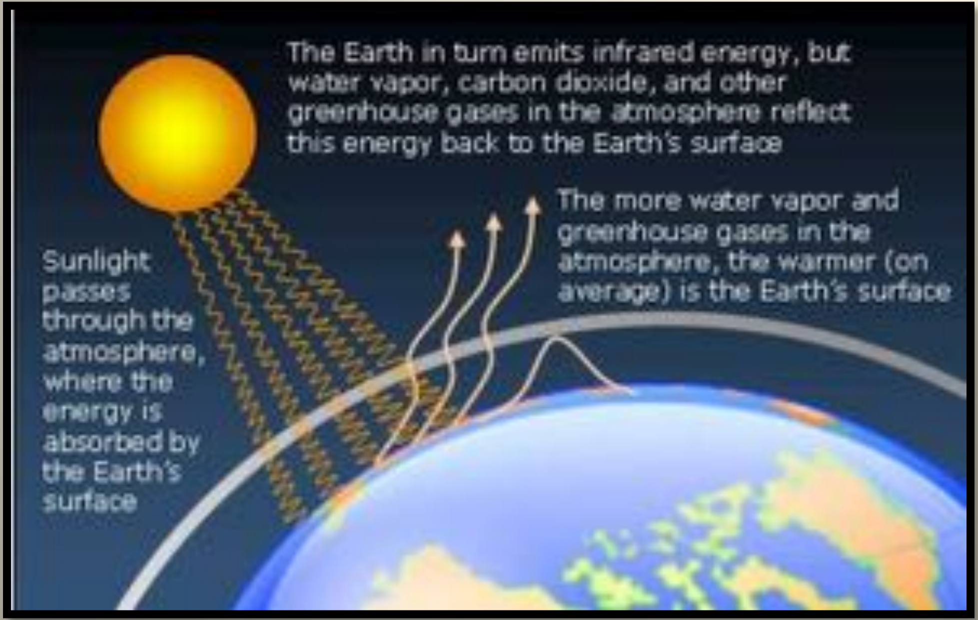

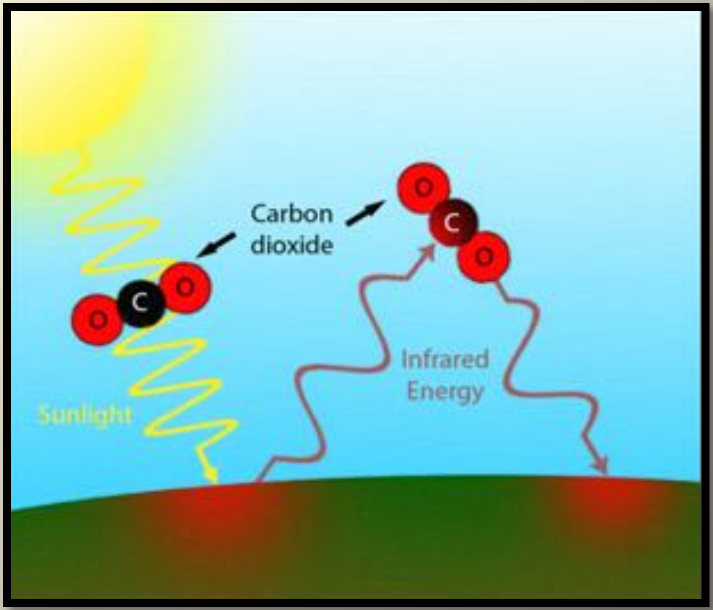

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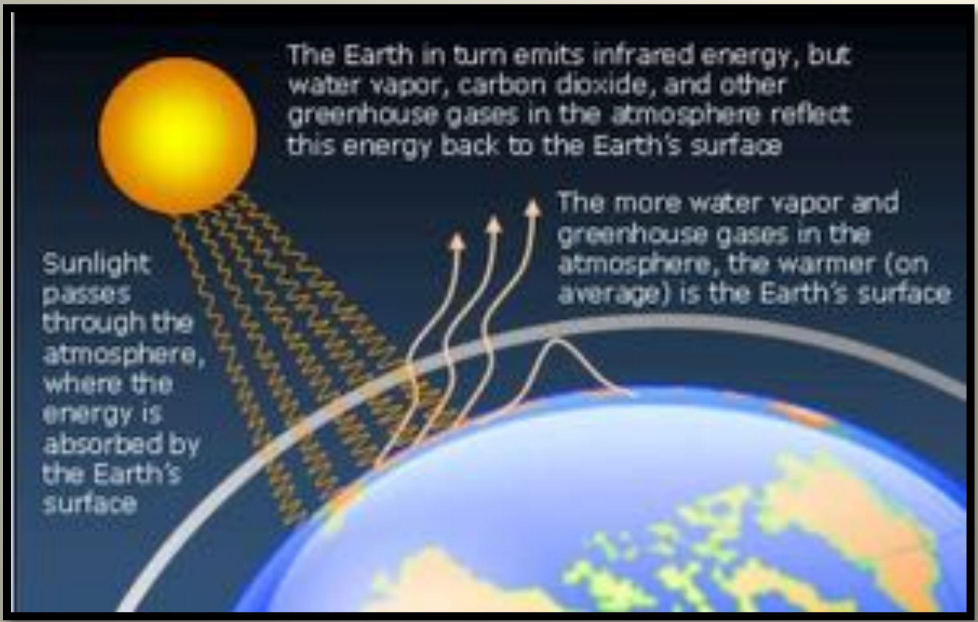

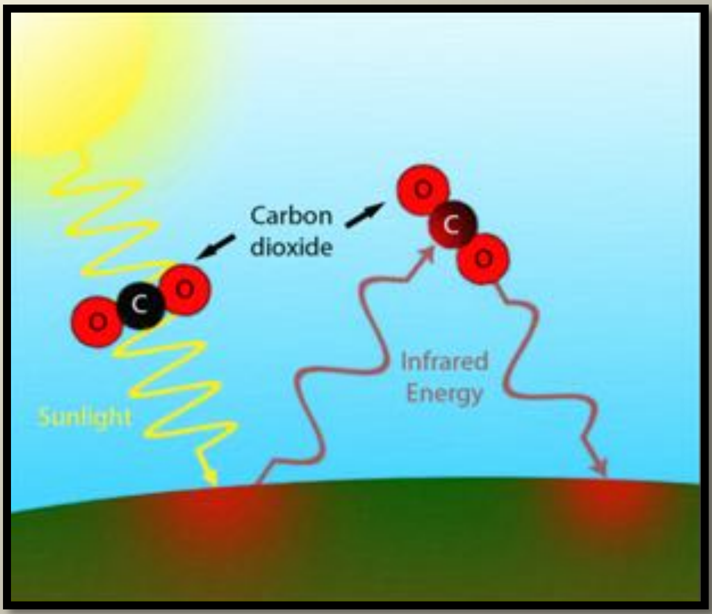

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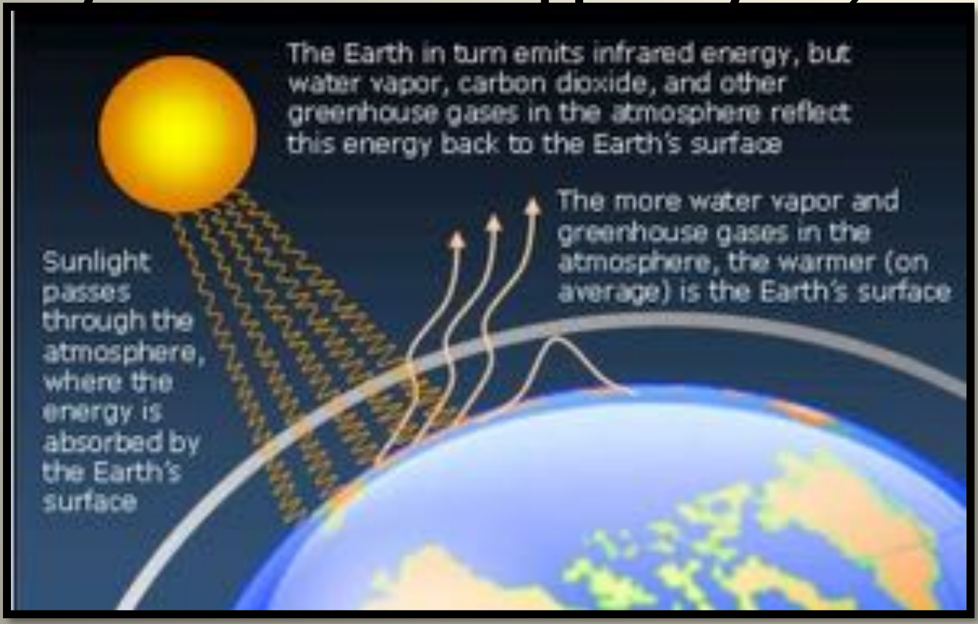
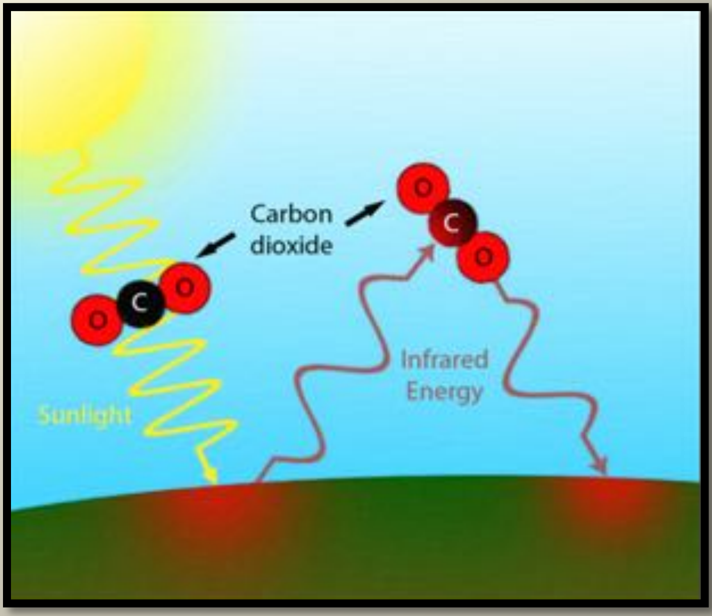
4. CO_2 molecules are so excited by infrared radiation they do a frantic molecular dance in all directions. The extra heat energy generated by this dance is trapped by CO_2 molecules (as the glass does in





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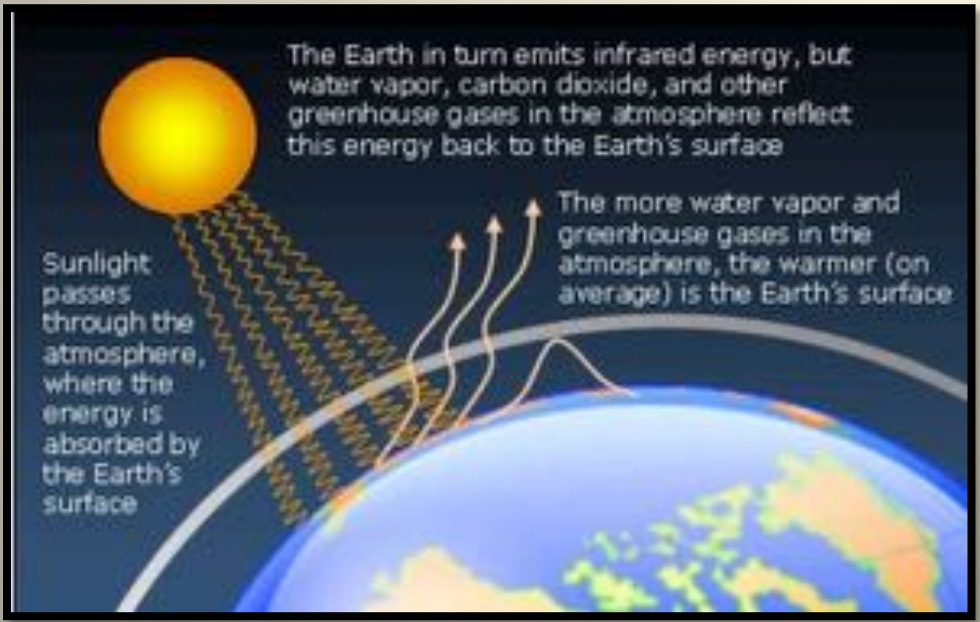
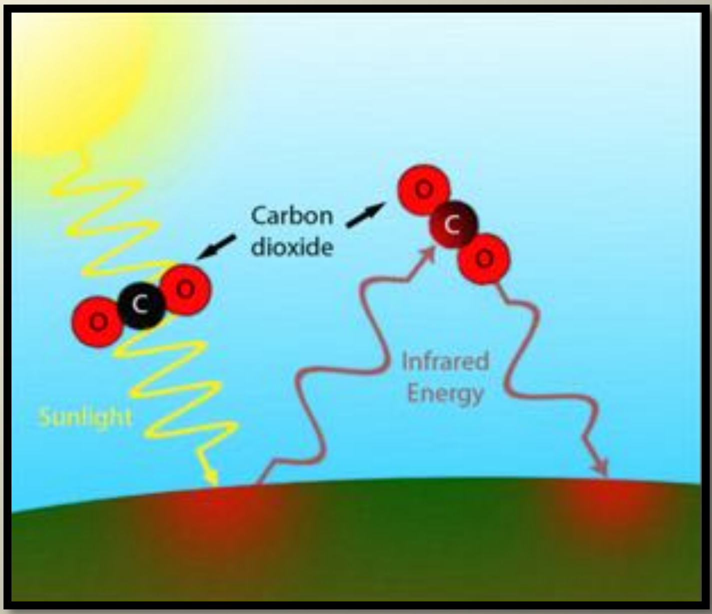
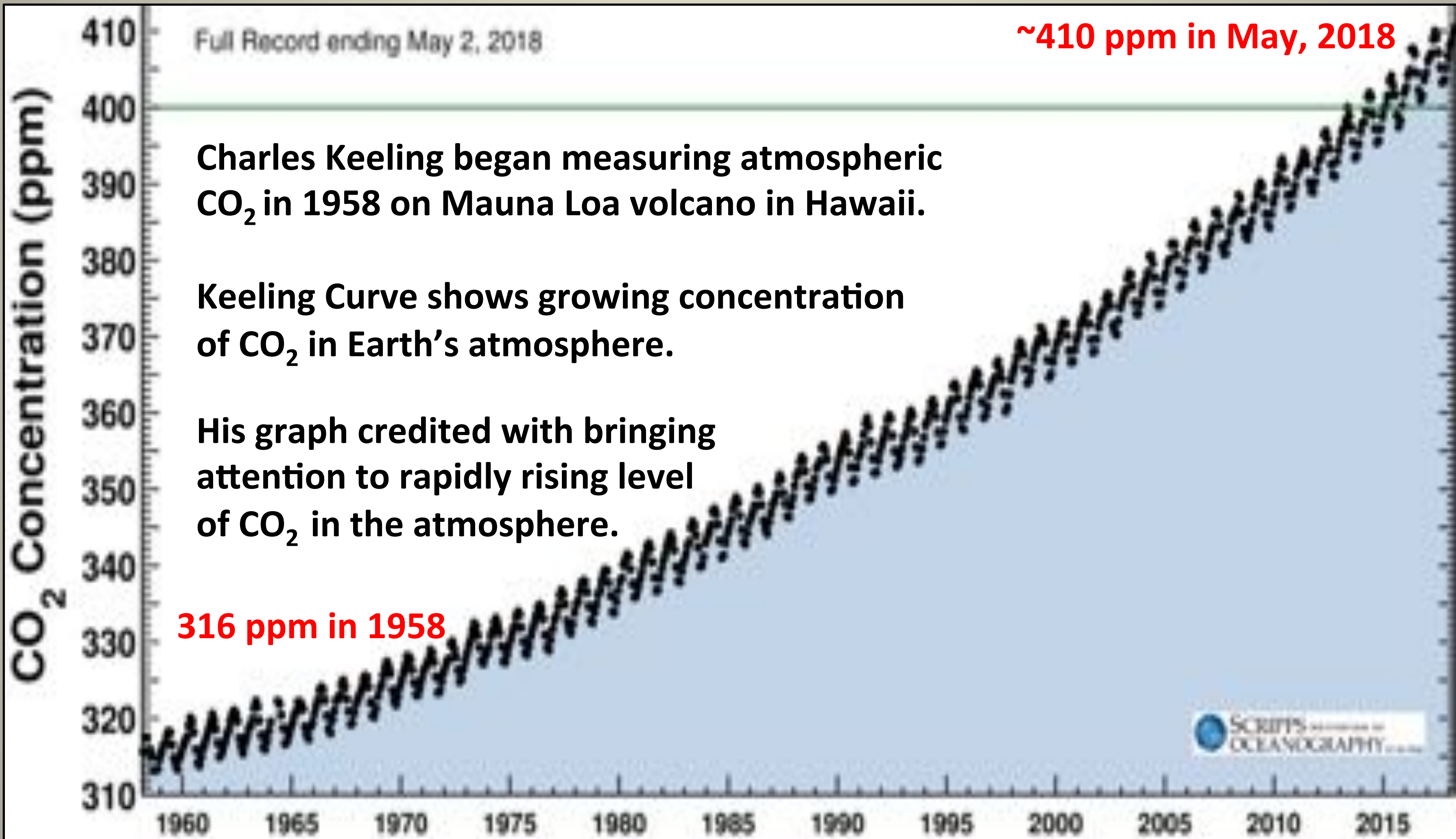
4. CO_2 molecules are so excited by infrared radiation they do a frantic molecular dance in all directions. The extra heat energy generated by this dance is trapped by CO_2 molecules (as the glass does in greenhouses and cars).

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?



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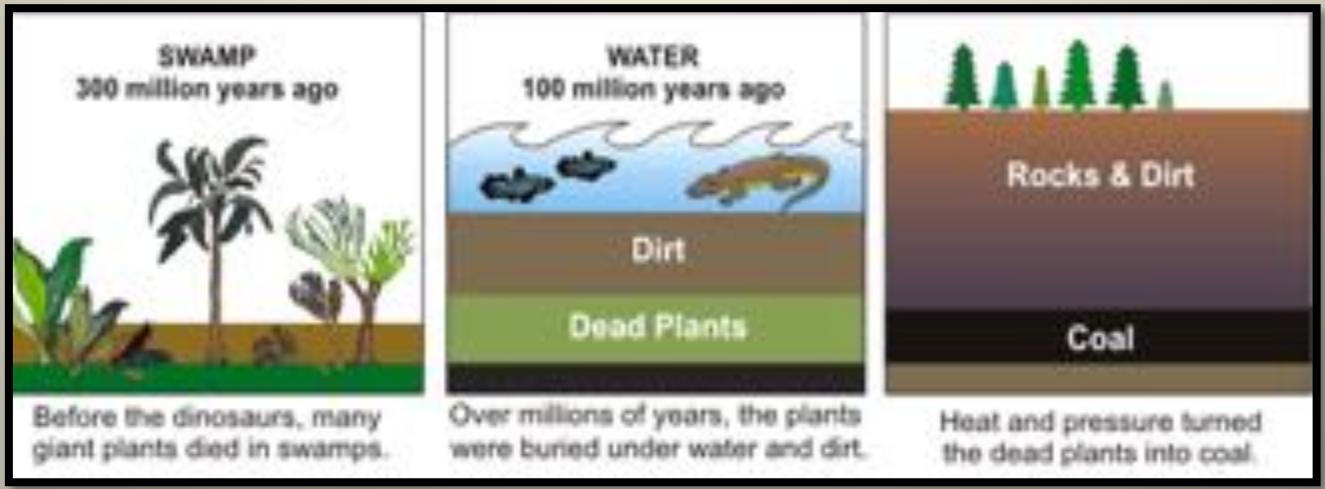
2. Fossil fuels are the source of additional CO_2.

Much of this CO_2 has unique and identifiable "fingerprint" of long dead and decayed trees which eventually became coal.



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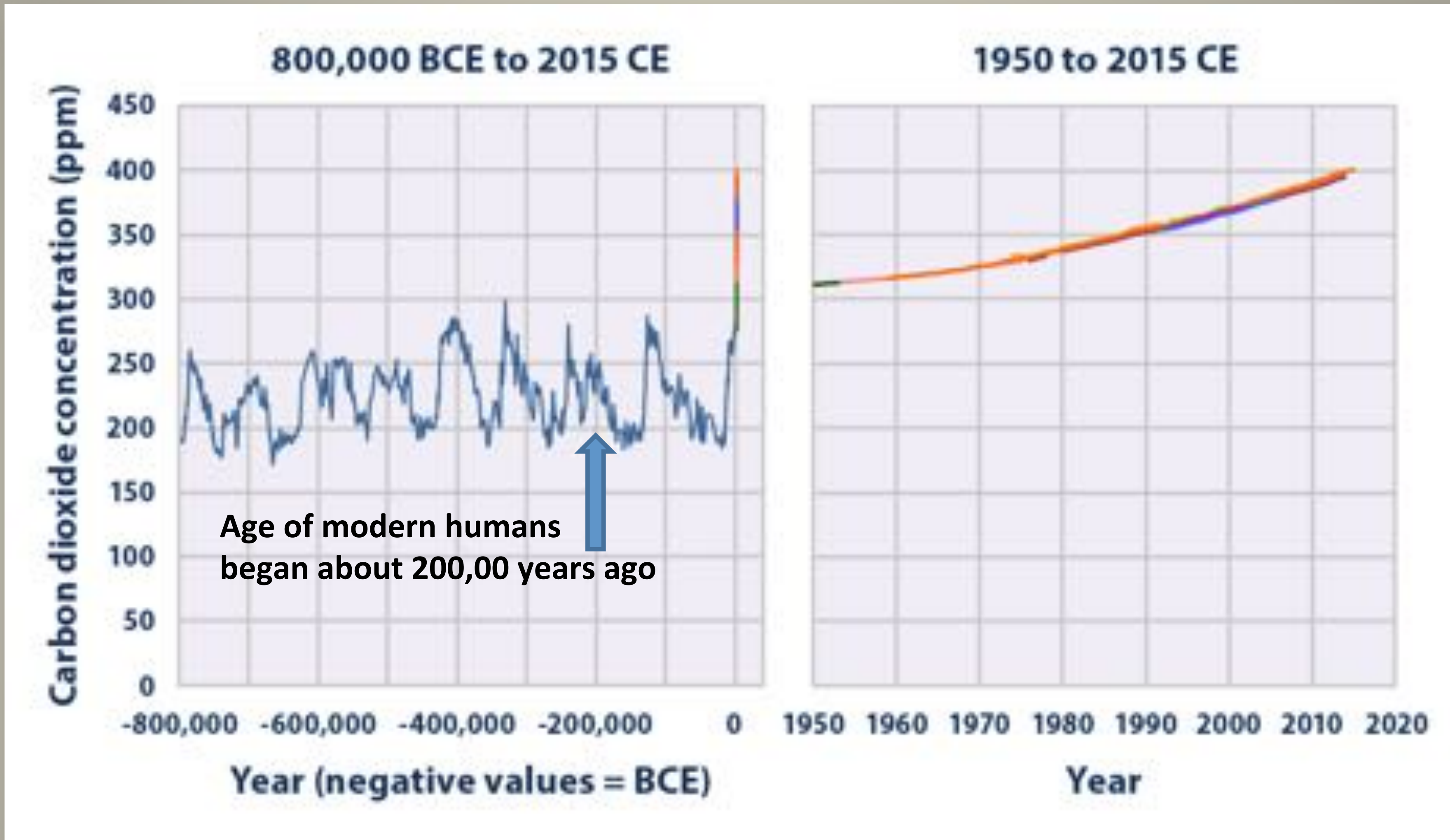
3. **CO_2 will remain in atmosphere for hundreds or even thousands of years.**

In terms of multiple human life spans, this problem is not going to go away anytime soon.

Global Atmospheric Concentrations of Carbon Dioxide Over Time

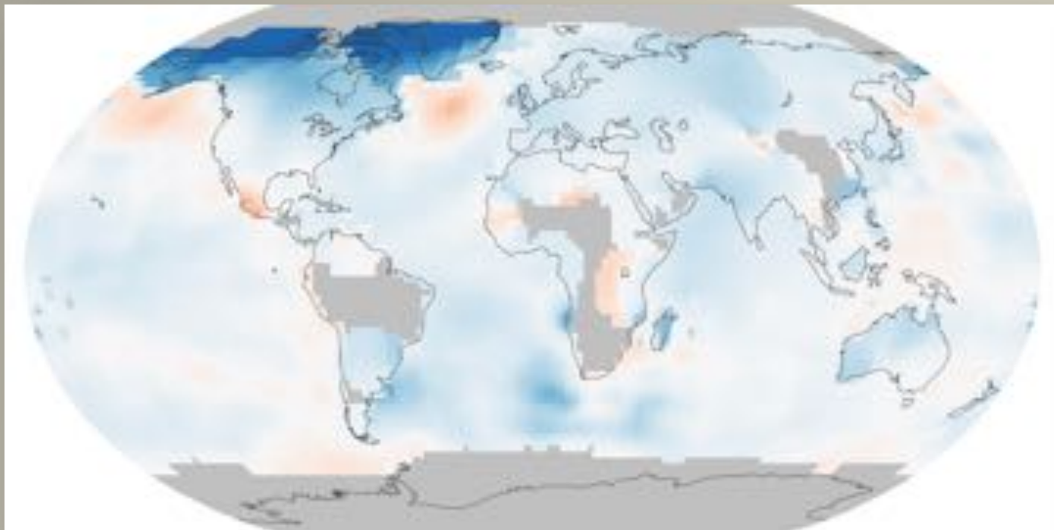


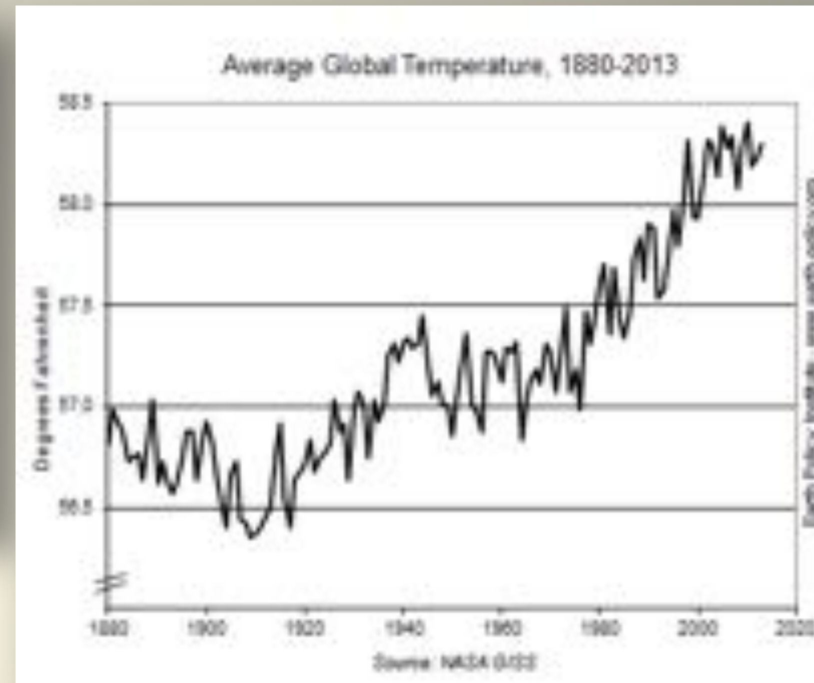
1. These graphs show concentrations of carbon dioxide in the atmosphere from 800,000 years ago through 2015, measured in parts per million (ppm).

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.

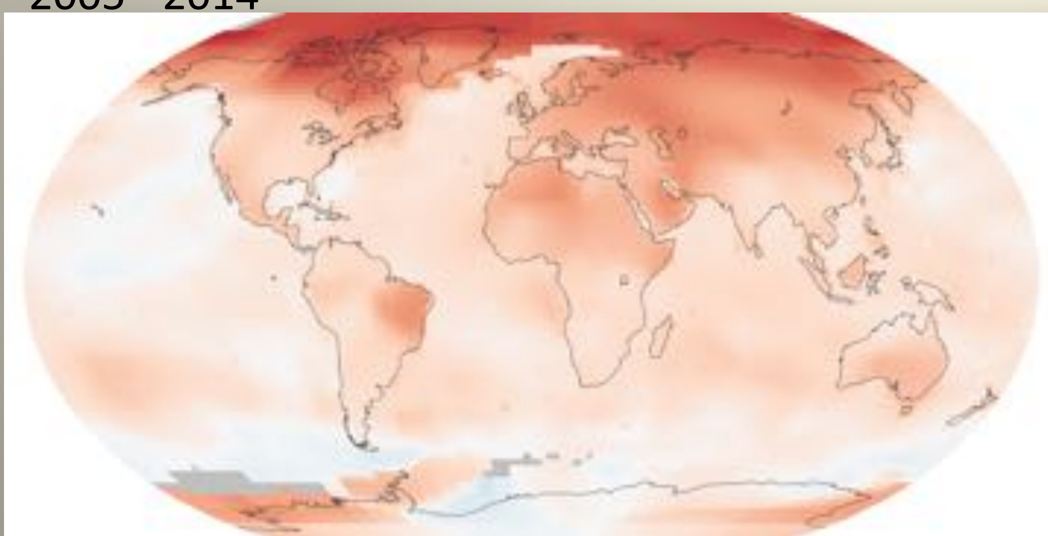
Is the Earth Getting Warmer?

1885 - 1894





2005 - 2014



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.

http://www.ipcc.ch/ipccreports/tar/wg2/index.php?idp=29

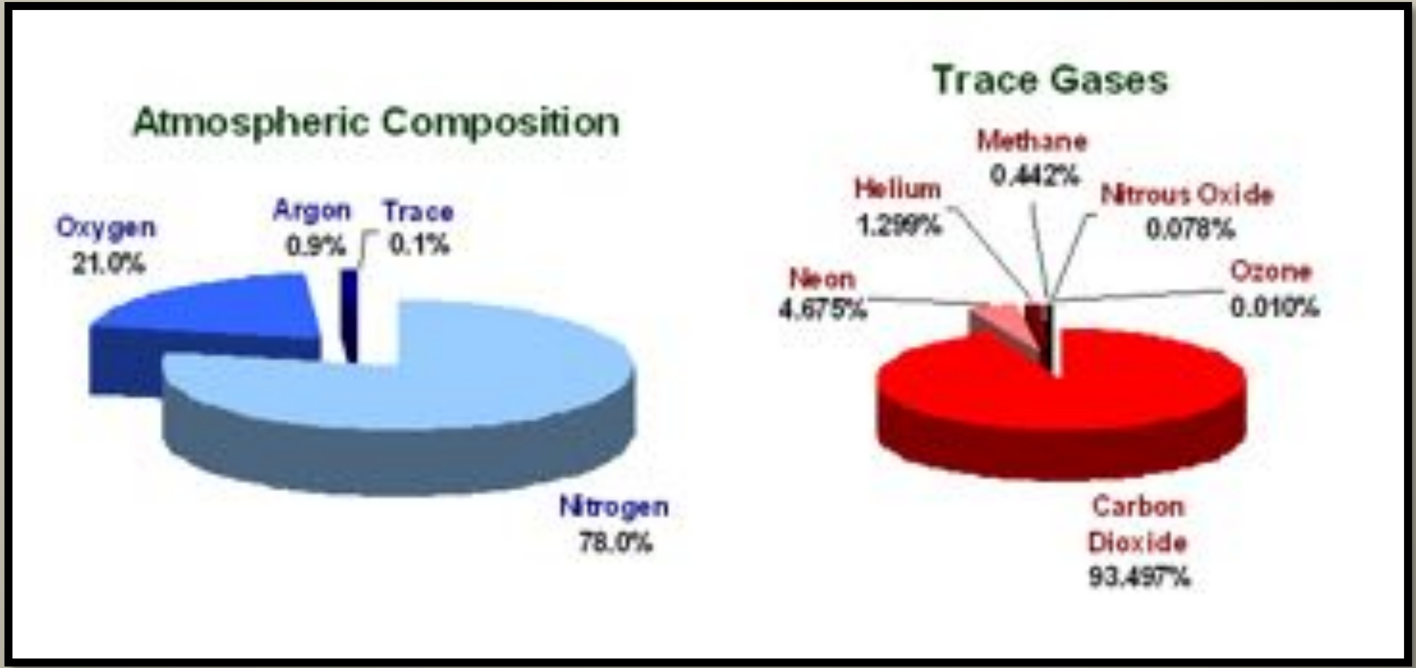
If your body temperature rose by 1.7°F, from 98.6 to 100.3°F, you would have a low-grade fever.

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 CO_2.

Some CO_2 is good – keeps the Earth habitable.

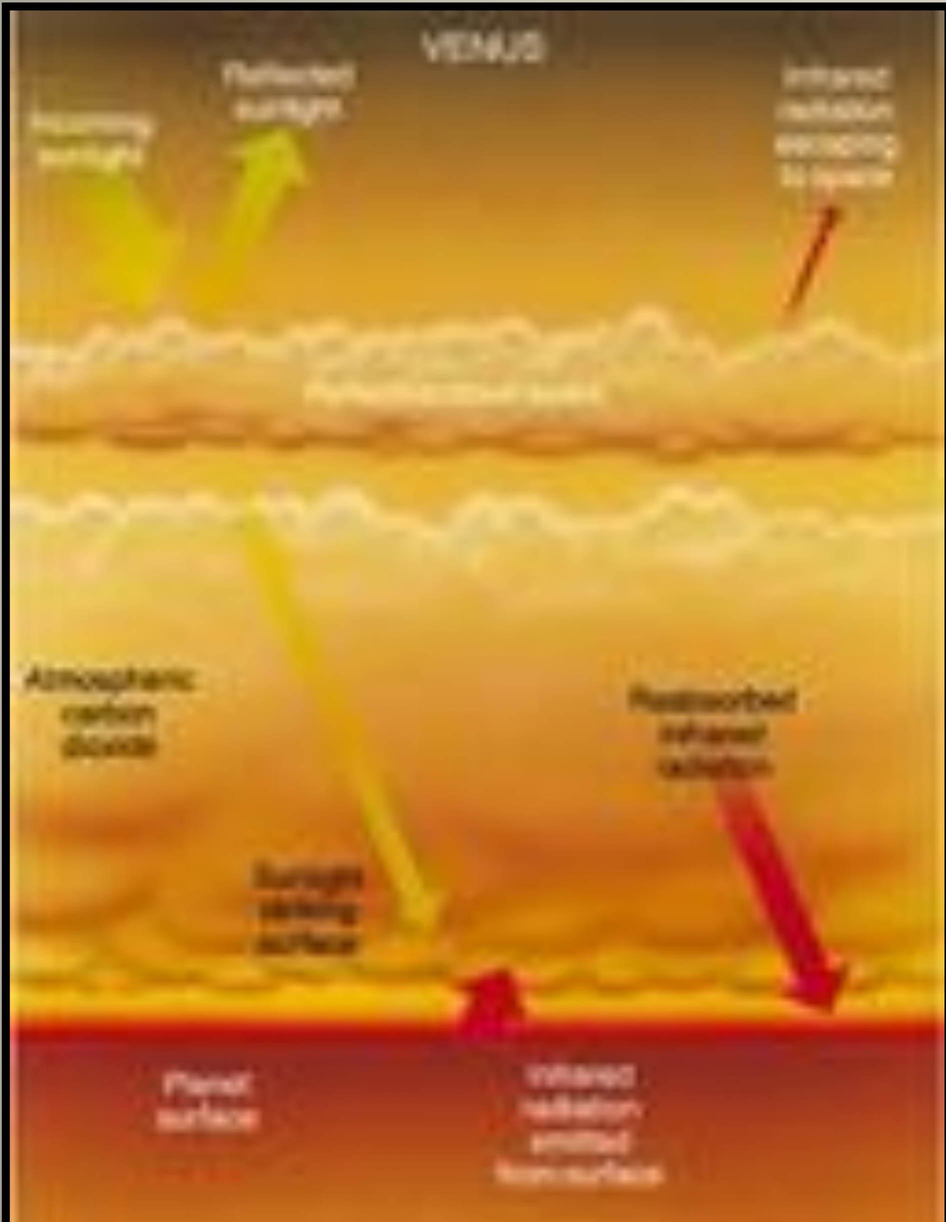
Without GH gases trapping re-emitted radiation, Earth's temperature ~ 0°F instead of ~60°F.

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

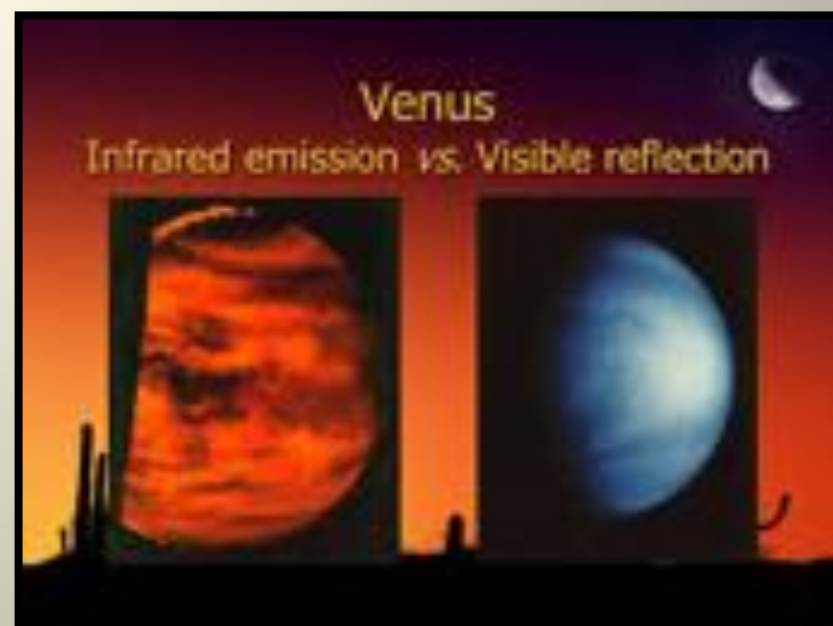


CO_2 is 96.5% of the Venusian atmosphere.

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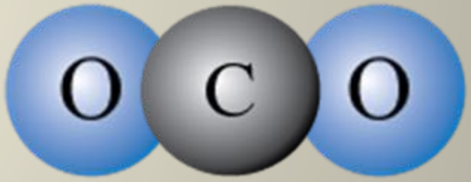
When burned or used as mulch carbon is released immediately or in a very short time.



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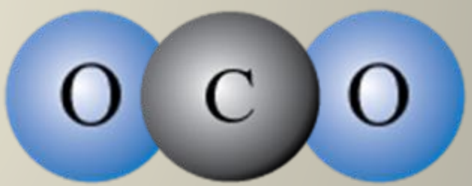
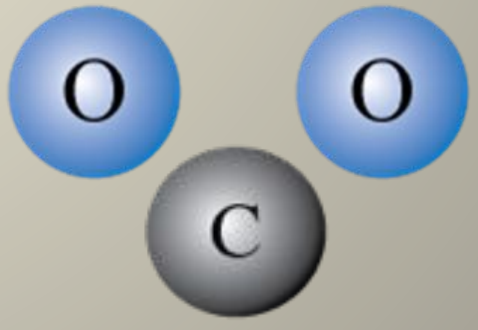


When used to make wood products carbon remains captured in the products as long as they exist.



For every pound of C captured in one of your urban wood products, 3⅔ pounds of CO_2 would have been created had that same pound of C been released by burning the wood or grinding it into mulch.

Where does 3⅔ pounds of CO_2 come from? Based on ratio of molar mass of CO_2 to the molar mass of C (measured in grams/mole).

C @ 1 x 12 g/mole + O_2 @ 2 x 16 g/mole = 44 g/mole:

44 g/mole ÷ 12 g/mole of C = 3.6667 or 3⅔ CO_2 to 1 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, 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, 3⅔ pounds of CO_2 would have been created had that same pound of C been released by burning the wood or grinding it into mulch.

The CO_2 not formed is referred to as <u>CO_2e</u> or <u>carbon dioxide equivalent</u>.

Meaning of CO_2e: 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_2e (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, CO_2;**

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

3. **carbon dioxide equivalent, CO_2e -- 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.**

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2. carbon, C, as an element that makes up about half of all trees; and
3. carbon dioxide equivalent, CO_2e -- CO_2 that would have been formed had urban wood products been burned and/or ground into mulch.

4. Now, the 4th way: CO_2e measured in lbs./bd. ft. for common urban hardwood and softwood species.

Example: the CO_2e for green ash made into a product (versus fuel and mulch) is 5.0956 lbs./bd. ft.

Amounts of CO_2e Measured in Pounds per Board Foot For Common Urban Hardwood Trees

Species by Common Name	*CO_2e Measured in Pounds per Board Foot*
Alder	3.6087
Ash, White	5.2969
Ash, Black	4.3831
Ash, Green	5.0956
Aspen, Quaking	3.3609
Balsam	3.4074
Basswood	3.3609
Beech	5.8081
Birch, Paper	4.8943
Birch, Yellow	5.6841
Cherry, Black	4.5380
Chestnut	3.8720
Cottonwood, Black	3.0976
Cypress, Southern	4.1818
Elm, Rock	5.6841
Elm, American	4.5225
Gum, Black	4.5225

Amounts of CO_2e Measured in Pounds per Board Foot For Common Urban Hardwood Trees

Species by Common Name	*CO_2e Measured in Pounds per Board Foot*
Hackberry	4.7703
Hickory	6.5825
Hickory, Pecan	6.0714
Locust, Black	6.3501
Magnolia, Southern	4.5225
Maple, Sugar	5.6841
Maple Red	4.9562
Maple, Silver	3.4848
Oak, Red	5.6841
Oak, White	6.0714
Sweet gum	4.3831
Tupelo, Black	4.5225
Tupelo, Water	4.5225
Poplar, Yellow (tulip)	3.6397
Sycamore	4.3831
Walnut, Black	4.9097

Knowing CO_2e by weight per board foot by species, we can easily calculate CO_2e per Product

Knowing CO_2e weights in lbs. per bd. ft. by species allows you to easily compute CO_2e 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_2e weight per bd. ft. for white oak is 6.0714 lbs.

6.0714 lbs. CO_2e/bd. ft. x 120 bd. ft. ≈ 730 lbs. CO_2e.*

Therefore, the table and chairs will withhold <u>730 lbs.</u> of potential CO_2 from the atmosphere as long as they exist.

***To be clear, this is <u>not</u> the weight of the table and chairs. That would be for white oak @ 12% MC: 47 lbs./ft.^{3} ÷ 12 bd. ft./ft.^{3} = 4 lbs./bd. ft. x 120 bd. ft. = <u>480 lbs</u>.**

According to the EPA, 88 lbs. of CO_2 are emitted annually by a typical four-stroke gas-powered lawn mower.

730 lbs. CO_2e ÷ 88 lbs. CO_2 annually per mower = <u>8.3 years.</u>

That is, the oak table and chairs will offset potential CO_2 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. CO_2e /bd. ft. = 535 lbs. of CO_2e.

535 lbs. CO_2e ÷ 88 lbs. of mower CO_2 emissions = 6 mowers for 1 year (or 1 mower for 6 years).

=

Amounts of CO_2e Measured in Pounds per Board Foot For Selected Urban Softwood Trees

Species by Common Name	Amount CO_2e by Weight in lbs. per bd. ft.
Cedar, Red Western	3.1545
Fir, Douglas, Coastal	4.7451
Hemlock, Western	4.4296
Larch, Western	5.1142
Pine, Ponderosa	3.9363
Redwood, 2nd Growth	3.4631
Spruce, Sitka	3.8793

Source: WOODWEB-Lumber Weight. 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_2e /bd. ft. x 720 bd. ft. = 2,493 lbs. CO_2e

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_2e by UFP Businesses

You can also calculate the annual CO_2e 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_2e by UFP Businesses

You can also calculate the annual total CO_2e 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_2e proportions for four hardwood species @ 5.2 CO_2e lbs./bd. ft.

5.2 CO_2e lbs./bd. ft. x 15,000 bd. ft. = 78,000 CO_2e lbs.

78,000 CO_2e lbs. ÷ 2,000 lbs./ton = 39 tons CO_2e

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_2e 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_2e 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_2e numbers by product and annually by your business are important to your customers interested in buying environmentally responsible products, <u>especially in CA.</u>

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_2e over a 30 year period for hardwood products.

In 2011 report, model only estimated tons of CO_2e.

The baseline estimate = <u>124.1 million tons of CO_2e</u> for 30 years.

Estimate based on five conservative assumptions:

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

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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 ≈ 811,000 cars each year.*

*124.1 million tons CO_2 ÷ 5.1 tons CO_2/car/year) ÷ 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.

***Bratkovich, Stephen. October, 2001. *Utilizing Municipal Trees: Ideas from Across the Country*. https://www.fs.usda.gov/naspf/publications/utilizing-municipal-trees-ideas-across-country. pgs. 1 – 3.**

MacFarlane, David W. 2009. *Potential Availability of Urban Wood Biomass in Michigan: Implications for Energy Production, Carbon Sequestration and Sustainable Forest Management in the U.S.A.* Biomass and Bioenergy, 33. 628 – 634. Scaled up to the nation as a whole and calculated in board feet from data in Table 1 (pg. 631).

1. **Increasing utilization from 10% of annual removals (still 1%) to 20% raises 30 year total to <u>105 billion bd. ft.</u> (CO_2e = 248.1 million tons)**

2. **Averages = <u>3.5 billion bd. ft./year</u>.**

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.

5. Urban lumber: impact of restrictive National Hardwood Lumber and American Softwood Lumber PS 20 standards.

By late John Metzler, Urban Tree, Pittsburgh, PA.

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.

Major Conclusions:

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6. Even more so when urban softwoods are added.
7. Urban wood products will remain in use longer than commercial counterparts.

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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