We have just learned that the 70% of the Earth system that absorbs sunlight warms up as a result. This ~~at~~ extra heat is transferred ~~around on~~throughout the surface and atmosphere, ~~(for example, by winds and ocean currents),~~and ~~so~~ the parts of Earth that reflected sunlight warm as well. One of the biggest issues with this is that sunlight keeps coming in. ~~But notice next that the sunlight, of course, *keeps on coming in*.~~ Something else must happen, or else the Earth will~~ould~~ continue to warm, ~~and warm,~~ and ~~indeed~~ by all accounts ~~would have~~will continue to disintegrate.~~ed a long time ago.~~ To prevent this, much of the absorbed sunlight is ~~re-~~emitted back ~~out~~ into space.

We can see this phenomenon directly using a specialized camera on an orbiting satellite. From this perspective, the ~~In fact, with a specialized camera on an orbiting satellite, we can see this directly. The~~ Earth is actually glowing: it is emitting radiation (Earthlight) just like the S~~S~~un (Figure 2)![15] The big difference here is that the Earth, being much cooler than the S~~S~~un, emits much lower energy radiation, called **infrared radiation**, which is too weak to see with the unaided ~~eye (though you can feel this exact kind of radiation as heat just by standing under a heat lamp).~~eye.

Not all of the absorbed sunlight is re-~~We just said that *much* of the absorbed sunlight is reemitted back out – but not all of it! Here~~ emitted. ~~is where the atmosphere comes in.~~ After Earthlight is emitted to escape from the planet, some of it is intercepted by ~~the~~ greenhouse gases, which in turn emit even weaker radiation. ~~– in all directions.~~ While s~~S~~ome of this weaker radiation does ~~finally~~ make it ~~out~~ to space, ~~but~~ a lot ~~also~~ stays inside the Earth's climate system, making it permanently warmer. ~~than it would be if there were no atmosphere at all.~~ How much warmer? We discussed this above – 30°C of additional warming. ~~as compared to that frigid bare rock.~~

A good analogy for the natural greenhouse effect happens ~~any night~~ when we go to sleep in a cool room~~,~~ under a blanket. Let's say the ~~room temperature~~temperature of the room is 60°F and you are most comfortable at 70°F. You choose a ~~certain~~ blanket that absorbs some of the heat that your ~~98°F~~ body radiates out; t~~t. T~~he blanket re-radiates that heat back ~~down,~~in so the temperature underneath is 70°F, just the way~~as~~ you like it. This system – you, the room, and the blanket – is~~t – is~~ in an energy balance. The temperature under the blanket is warmer than the room, and it is not changing. ~~This is what is meant by a *balance*: given~~: given the thickness of the blanket and the temperature outside, ~~it,~~ a certain ~~constant~~ fraction of your body heat is radiated back to you, and a certain amount is lost to the room.

With the blanket you chose, the temperature underneath remains ~~at~~ 70°F. Similarly, if the "blanket" of greenhouse gases in the atmosphere were to remain constant, then ~~,~~ in the absence of any other human or natural perturbations, the average Earth surface temperature would also ~~not change~~remain constant ~~– it would stay constant at the present~~ at 59°F. The input energy from ~~sunlight~~ Sun would be balanced by the output energy ~~in the form of~~from Earthlight. ~~, and the temperature underneath the atmosphere then determined by how thick the greenhouse blanket is.~~

Now suppose you add another blanket to the bed. Your local system will adjust – more ~~st – more~~ of your escaping body heat will be radiated back ~~in~~ from the thicker blankets, and soon a new energy balance will be reached. ~~Now, however,~~However, the temperature under the blanket will be warmer – let's say ~~it is~~ 80°F. ~~It is starting to get uncomfortably~~With the increased temperature because of the extra blanket, ~~warm with the extra blanket, and so~~ we might want to ~~take~~ remove the blanket; ~~it back off.~~ i~~I~~n our bedroom, ~~,~~ this

[15] See https://www.wunderground.com/maps/satellite/regional-infrared for some IR images.

**Rachel Howe**
I would suggest maybe wording this as a question to your readers. This would keep your readers engaged as well as help with the cohesiveness of these sections. You could say, "So what happens to the 70% that is absorbed?"

**Rachel Howe**
I'm not sure what exactly it is that you are trying to say here.

**Rachel Howe**
I think that this seems alittle redundant and wordy. I think it would be much better if you were to make this more direct and to the point. Maybe just say "30 C – the missing piece of the puzzle."

**Rachel Howe**
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**Rachel Howe**
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from eating plants. This is the mirror image process to photosynthesis, known as **respiration**. A byproduct of photosynthesis is oxygen gas.~~s,~~ which has accumulated in the atmosphere to its present level of about 21%. Animals, including humans, breathe (*respire*) the oxygen, combining it with fixed carbon from eating~~g the~~ plants. This process essentially releases carbon dioxide while providing energy to the animal ~~cells~~.

Respiration dominates over photosynthesis ~~in the period~~ from November through May, when there is less vegetation in the Northern h~~h~~emisphere. ~~This accounts for the upward part of the Keeling curve. The~~ Unlike photosynthesis, the amount of respiration doesn't vary much throughout the year, so the up-and-down feature of the curve is controlled by how ~~much plant~~often photosynthesis ~~is going on~~occurs (Figure 6, left side). The ocean phytoplankton photosynthesize at the same rate year-round, and don't contribute to the seasonal variation.[21]

It is worth ~~pausing a moment to~~noting ~~note~~ that respiration is the same chemical process that occurs when gasoline is burned in an internal combustion engine. G~~e. G~~asoline contains larger carbon compounds, ~~just like~~similar to the fixed carbon ~~in the plant cell.~~found in plants. I~~I~~n the engine, these carbon compounds are combined with ~~the~~ oxygen in the air to ~~liberate~~ generate energy, which is then used to ~~that~~ powers the car, while producing carbon dioxide as a byproduct.[22]

Here, then, is the crux of the anthropogenic global warming problem: w~~.~~h~~W~~en we ~~are extracting~~extract fossil fuels from the deep underground, it isn't ~~not~~ from any part of Earth's surface climate system~~.~~, yet w~~W~~hen we burn those fuels, we are adding new carbon into the climate system in the form of carbon dioxide (Figure 6, right side). That carbon dioxide then ~~, of course,~~ enters the ~~cycle of~~ photosynthesis and respiration cycles ~~we've just described~~, ~~but the key point is that~~ and the total amount of carbon in the ~~five parts of~~ Earth's climate system ~~has now increased.~~increases. This explains why the Keeling C~~c~~urve trends upward from 1958 until today. Given this information, we can assert that~~It is beyond all doubt that~~ the increasing level of atmospheric carbon dioxide since the beginning of the Industrial Revolution is of human origin.[23]

*Carbon M~~m~~ovements through the L~~l~~and, O~~o~~cean, and A~~a~~tmosphere*

~~Let's next~~Next we will look at why the increase in the ~~the~~ rate of carbon dioxide buildup in the atmosphere ~~is so variable~~varies so much from year to year. Close study of ~~As mentioned above, looking closely at~~ the Keeling C~~c~~urve shows that in some years~~,~~ the levels of c~~c~~arbon dioxide ~~ppm number goes up~~increase much more than in others; t~~. T~~he easiest way to see this ~~in the curve~~ is to compare the levels of carbon dioxide ~~ppm levels~~ at their peaks in May of each year (Figure 5). For example, the ~~monthly average~~ average monthly levels of carbon dioxide ~~levels~~ at Mauna Loa increased by 3.6 ppm between May ~~of~~ 2015 and May ~~of~~ 2016. In ~~By~~ comparison, the ~~is~~ monthly average increased by only 1.4 ppm between May ~~of~~ 2017 and May ~~of~~ 2018. This may seem like a trivial detail, yet it amounts to a huge variation (~ ~~of~~ 250%).

[21] CB Field et al., *Primary P~~p~~roduction of the B~~b~~iosphere: I~~i~~ntegrating T~~t~~errestrial and O~~o~~ceanic C~~c~~omponents*, Science 281, 237-240 (1998), https://pubmed.ncbi.nlm.nih.gov/9657713/

[22] For an explanation of this chemistry, see https://www.khanacademy.org/science/biology/properties-of-carbon/carbon/a/carbon-and-hydrocarbons

[23] See C~~c~~hapter 2 for the explanation of why we are so certain about this.

**Rachel Howe**
Is this necessary for the rest of the paragraph? It seems kind of thrown in and not really used. I recommend deleting it and continuing with "A byproduct of photosynthesis is oxygen gas; animals, including humans, respire this oxygen, which combines with the fixed carbon obtained from eating the plants."

**Rachel Howe**
Maybe consider a different word such as "occurs more frequently than photosynthesis."

**Rachel Howe**
This seems out of place here. I would recommend deleting it.

**Rachel Howe**
While this is interesting information, I'm not sure if this paragraph is needed.

**Rachel Howe**
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**Box 3: Counting Carbon**

Just as Americans use a different temperature unit, ~~from the rest of the world,~~ we also use different units for length, mass, and volu~~units, mass units, and volume units~~me.~~.~~ ~~One mile is a little over 1.6 kilometers, for example, and one inch is 2.54 centimeters. Here again, we are the ones using ancient, confusing systems, while almost everybody else uses science-based scales that work in easy powers of ten. For example, there are 100 centimeters in one meter, and 1000 meters in one kilometer.~~

In order t~~T~~o count carbon ~~as scientists do~~, it ~~helps~~ is beneficial to be comfortable with the scientific notation for powers of ten. 100 (10 x 10) is written as $10^2$, and 1,000 (10 x 10 x 10) is $10^3$. When ~~you multiply~~multiplying these types of numbers, simply ~~he numbers,~~ add the exponents: 100 x 1,000 is $10^2$ x $10^3$, or $10^5$. ~~So there are $10^5$ centimeters in one kilometer. In contrast, there are 63,360 inches in one mile. Which system is easier?~~

Carbon counting is done in units of mass. One American pound equals 453 grams, the scientific unit for mass. There are 1,000 grams in 1 kilogram, so one pound equals 0.453 kilograms; l~~. L~~ooking at it the other way, there are 2.2 pounds in one kilogram (kilo).

Scientists often report amounts of carbon dioxide in the atmosphere, ~~or that are emitted from, say, an industrial process, but~~ other times they report only the mass of the carbon part of the molecule, ignoring the two oxygens. Fortunately, going between these is not difficult: a~~. A~~ carbon dioxide molecule is made of one carbon atom joined to two oxygen atoms (Figure 1-3). Chemists tell us that oxygen atoms are one and one-third times heavier than carbon atoms, or 4/3. So if a carbon atom weighs one unit, or 3/3, then a carbon dioxide ($CO_2$) molecule weighs 3/3 + 4/3 + 4/3 = 11/3.

If you are looking at data reporting the mass of carbon in the atmosphere, multiply by 11/3 (the ratio of carbon dioxide mass to carbon mass) and you will have the mass of carbon dioxide. Similarly, you can multiply the mass of carbon dioxide by 3/11 to get the mass of the carbon part of the molecule.

The most common units in carbon counting are megatons and gigatons. In the metric system, one ton is 1,000 kilograms, or $10^6$ grams. So one megaton, abbreviated Mt, is one million ($10^6$) metric tons, and ~~. And~~ one gigaton, abbreviated Gt, is one billion ($10^9$) metric tons.

It is also easy to convert parts per million (ppm) concentrations into masses. Emitting about 7.3 Gt of $CO_2$ to the atmosphere increases its concentration by 1 ppm, although about half of that would be taken up by the land and oceans, in the "fast" carbon cycle (see the text).

**Rachel Howe**
Please see comments on first Box 1, for general use questions. I'm not sure that this is the best title for this – it doesn't really encapsulate or summarize what is being talked about.