Note to peer reviewer - This is a script for a video essay I've already recorded, but it still needs to be edited. Some of the bulleted points in the script were skipped for the sake of the flow of the video. Also, I'm sorry if this is hard to read!

Hook:

- I want to tell a quick story to get us started, and it's one that many people watching this have probably heard already.
- The story takes place in the 1800s in Victorian-era England and focuses on the likes of a species of moth, the peppered moth. The story goes that before the industrial revolution, peppered moths were mostly white with black spots and usually lived on birch trees where they were camouflaged against predators like birds. As the industrial revolution kicked off, the moths gradually turned from being mostly white with black spots to mostly black with white spots. The British peppered moth story is one of the most commonly used examples of natural selection in evolution (True).
- But, instead of talking about evolution and natural selection, I want to talk about why these peppered moths had to undergo their change in color - the industrial revolution and the start of humanity's influence on the amount of pollution in the air.
- The same pollution in the air from the peppered moth story ,soot- but specifically CO_2, may have some drastic consequences on our planet Earth.
- The CO_2 levels have gradually been on the rise, and the natural systems the interact with CO_2 might be in danger.

Background:

- Much like the water cycle that most of you, the people watching this video, probably learned in middle school, there is also a carbon cycle. This carbon cycle works a little bit like the water cycle, but not entirely. Instead of water evaporating from the oceans, CO_2 is released from the oceans and into the atmosphere, and vice versa. CO_2 is also used by plants in photosynthesis, then released back into the atmosphere when the plants decompose. This cycle has been active for a very long time.

possibly rephrase for old-to-new?

- Ice cores from Antarctica can tell us a lot about the history of the carbon cycle.
- Cores reach back as far as 800,000 years from Antarctica (Bauska), but the data examined only considered the last 420,000 years in observing the carbon cycle (Falkowski).
- What scientists determined was that the carbon cycle historically operates in 100,000-year intervals, between 180ppm or 280ppm CO_2 in the air. Right now, there is over 400ppm CO_2, according to NASA.

old-to-new

- It's important also to mention the ocean, by which the cycle is also regulated; the ocean contains as much as fifty times the carbon than the atmosphere does. This means that the ocean acts as a sort of buffer.
- However, while the ocean is more impactful on the levels of carbon in the atmosphere than regular land carbon sequestration, this video review is going to focus on more land-based methods of removing carbon from the atmosphere.

- Switching from ppm to gigatons, which is arguably easier to measure, let's put the current carbon cycle into perspective.
- Right now, human activity outputs about 40gt of carbon a year, and natural systems like photosynthesis and the ocean sequester about 23 gt - leaving a 17 gt imbalance as of 2019 (Hepburn). How can that 17gt imbalance be fixed?

Topic introduction/ honorable mentions:

- For this 17gt imbalance of CO_2, there are several methods that are currently being developed or improved.
- One of the overarching methods, and one that I believe most people first think of when discussing carbon sequestration is photosynthesis.
- Photosynthesis, in carbon sequestration, is used in several different ways, and photosynthesis will be the focus of this video because it is easier to digest and understand than some of the other methods.
- But, for honorable mentions of sequestering carbon, we have research focused on using the building blocks of CO_2 to create usable fuel. NASA is working on developing CO_2-to-fuel technology that works sort of like a solar panel (NASA).
- There is a company from Iceland that converts CO_2 to methanol, or usable fuel, which has actually been in operation since 2012 (Carbon Recycling International).
- There is a method for using CO_2 to extract oil called enhanced oil recovery, which is where CO_2 is pumped into the ground to force tight oil, or oil trapped in shale, into oil pumps (Energy.gov).
- Using alternative methods of producing concrete, specific alternatives to portland cement, the most common cement which has a high carbon cost (Singh).
- My point in bringing up these topics is that photosynthesis is not the only way to take carbon out of the atmosphere; there are many ways it can be done.

Main Topic:

- So photosynthesis is an integral part of the carbon cycle, and it removes massive amounts of carbon from the atmosphere every year.
- Humans introduce about 40 gt of CO_2 into the atmosphere every year, according to the International Panel on Climate Change, but photosynthesis removes over ten times that amount, around 440gt of carbon, from the atmosphere every year (IPCC 2014).

Since you are repeating a fact, (40gt/year) it might help your reader make connections if you explicitly point out that this is a repeat (i.e. "remember, humans introduce about...")

- So what’s the problem? Again, its in a cycle, 97-98% of the CO_2 used in photosynthesis is released back into the atmosphere as plants breathe, die and decompose.
- Research is focused on doing something with the carbon that comes from plants undergoing photosynthesis before the plants decompose and release the carbon back into the air.

RuBisCo:

- But, all of this talk about photosynthesis has probably got someone wondering, how does it even work?
- The long story short, Photosynthesis is how plants use sunlight, water, and atmospheric CO_2 to create energy. Diving a little deeper, plants use photons from sunlight to excite electrons from water in their chloroplasts, the functional photosynthesis part of their cells. This helps them undergo energetically unfavorable reactions, which they can use to produce ATP, or energy. Plants also need to store this energy, and one of the ways they do this is via the Calvin cycle, where they pull CO_2 out of the air and use energy derived from the sun to make energy-containing molecules, like starch!
- The Protein that uses the CO_2 and energy to make the energy-containing molecules is called Ribulose-1,5-bisphosphate carboxylase/oxygenase, or RuBisCO. RuBisCo is arguably the most important and one of the most abundant proteins in existence, it is the protein that supplies the world with food (Erb).
    - Rubisco is also a comparatively slow enzyme, it makes the oxygen mistake 20-40% of the time and uses about 30% of the energy created to fix the oxygen mistake (Erb). What is the "oxygen mistake"

    - Hopefully, this shows a little bit about why RuBisCo has problems, and it should also give some context for the next part.

Making RuBisCo more efficient:

- With all of the problems surrounding RuBisCO, there is research devoted to making the enzyme more efficient, which could help plants sequester more carbon.
- One of the current research focuses on making RuBisCO more efficient is using a structure from certain bacteria called a carboxysome (Chen). One of the core problems with RuBisCO is that it makes the mistake of accidentally using oxygen instead of CO_2, and certain photosynthetic bacteria have found a way sort of around that. What these bacteria have done is concentrate CO_2 around RuBisCO molecules using a certain protein complex called a carboxysome. A carboxysome is almost like a big ball that has RuBisCO inside of it, and the carboxysome uses a chemical reaction to concentrate CO_2 inside of itself so that RuBisCO doesn't make the oxygen mistake as often.

Ok, this is the oxygen mistake. I'm sure you're aware of this while editing, but just to do my due diligence as a reviewer, make sure you fix the order of these two mentions

- What researchers have been doing is proving that carboxysomes can be synthesized and constructed independently of bacteria and that they can still make RuBisCo more efficient. Turns out that this is possible and that future research can be focused on creating plants that have the carboxysome complex so that the plants can fix carbon more efficiently.
- Another interesting RuBisCO improvement being studied has to do with using ancestral RuBisCos.
- This probably happened because the enzyme is thought to have evolved before there was as much oxygen in the atmosphere, and it has slowed down its catalytic activity in order to make fewer mistakes, which still happens.
- Since RuBisCO likely evolved before the first large oxygenation event, older ancestral RuBisCO should be better equipped to fix carbon faster (Lin). - Remember that modern RuBisCO works at a slower rate so that it doesn't accidentally use oxygen instead of CO_2. Ancient RuBisCO didn't really have to worry about oxygen because there wasn't much of it so it can work faster.

- Since humanity has gone through the industrial revolution, there is much more CO2 in the air than most modern plants are used to.
- What some researchers are doing is trying to predict what the ancient RuBisCO looked like, synthesize it, and then genetically engineer other plants to use the ancient, more CO2-oriented RuBisCO.
- There has actually been some success, where scientists have found that the predicted ancient RuBisCO is actually kinetically faster than modern rubisco, which could make the plant grow much faster and sequester more carbon.

Forestry/actual photosynthesis

- So we have some methods for improving RuBisCO, the main mechanism of photosynthesis, but there are also methods using normal photosynthesis for carbon sequestration that are being developed.
- One idea that is fairly common is using forests to try to store more carbon.
- Sustainable forest carbon pools typically operate in 45-year time frames, which is perfect because trees stop absorbing as much carbon when they turn about 100 years old (Lippke).
- The idea is that as long as forests are harvested sustainability, the carbon sequestered in wood can be kept out of the atmosphere as long as the wood doesn't rot. Meaning that if more wood is sold and not allowed to rot, more carbon will actually be kept out of the atmosphere.
- Additionally, much of the waste produced from foresty, like the crown, root, and any extra part of the tree not usually marketed, can be used as an alternative energy source. The idea is that since the forestry waste would decompose and return to the atmosphere anyways, it would be more sustainable to collect the waste and create usable fuel from it. By substituting fossil fuels with wood products, less carbon is introduced to the carbon cycle from beneath the biosphere.

- If these sustainable forestry techniques were implemented, much more carbon could be either sequestered or kept from entering the cycle. \

Microalgae:

- I have one more idea for carbon sequestration that I want to bring up, and it has to do with algae.
- Algae, or more specifically microalgae and phytoplankton, are a huge contributor of photosynthetic carbon sequestration, where its estimated that the microorganisms keep around 150ppm of CO_2 out of the atmosphere (**Falkowski).** Some Microalgaes are able to photosynthesize and grow at rates 40-50% faster than most other plants.
- However, there is an issue with using microalgae for carbon sequestration; the organism requires a ton of nutrients and water to grow, so it wouldn't really be commercialize or worth-it to traditionally farm the algae for its carbon sequestration abilities (Shahid).
- But the algae can help us solve another problem that we have created, how we treat our wastewater.
- Wastewater can be difficult and expensive to treat. Often, wastewater pollutants like nitrogen, phosphorous, metals, and other environmental hazards make it down the watershed and into the ocean where eutrophication, or algal blooms, can happen, which damage ecosystems.
- So, researchers are developing methods where microalgae can be used in our wastewater treatment.
- If Microalgae is used to treat wastewater, some of the limitations of traditional wastewater treatment may be mitigated. The algae would be able to subsist on the excess nitrogen, phosphorous, and other natural wastes. It also would have the freshwater real estate it needs to grow.
- Additionally, there are commercialized by-products of algal wastewater treatment like certain pigments, fatty acids, and sugars. The algae could be harvested for biofuels, and

since some microalgae produce fatty acids high in tri-glycerols, certain strains could be used to produce biodiesels.

- The use of microalgae in waste-water treatment is an exciting idea but one that needs more research and testing before it can be implemented.

Conclusion:

- To wrap everything up, the carbon cycle is complex, and right now, there is more carbon in the atmosphere than there probably should be.
- But now is not the time to give up; there are exciting new methods and research devoted to pulling carbon out of the atmosphere. Some seem out of science fiction, like the RuBisCO carboxysomes or Jurrasic park-esk ancestral RuBisCO; some is not so science fiction, forestry techniques are already implemented and microalgae could feasibly be used to suck up carbon while purifying out wastewaters.
- There is so much more research that I don't have time to go into, and there will be so much more in the close future, but what matters is that some of the research is actually used and implemented so that we may leave behind a world that others would want to live in.
- Thank you for watching or listening, I hope that I have inspired someone or at least made someone wonder what to do next. For our future on this Earth!

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