# Today I Learned About Removing $CO_2$ from the Atmosphere

## Description

Carbon dioxide is increasing in Earth's atmosphere as we burn fossil fuels like coal, oil, and natural gas. While technology that can remove $CO_2$ from the air is growing, it is an engineering challenge. Students model the challenge of carbon capture and graph the historic rise in carbon dioxide as observed at Mauna Loa, Hawai'i.

## Skills & Objectives

SWBAT:

- Briefly explain some reasons for increases in atmospheric carbon dioxide
- Understand that carbon capture technology is difficult to develop in part because the concentration of atmospheric carbon dioxide is very low.
- Demonstrate that carbon dioxide has been rising in Earth's atmosphere since at least the 1950s.

Skills

- Create and/or interpret data via a line graph
- Communicate scientific information

Students Should Already Know That:

- Carbon dioxide in the atmosphere acts like a heat-trapping blanket.
- Burning fossil fuels releases excess carbon dioxide into the atmosphere.

**Standards Alignment:**
HS-ETS1-3 Evaluate a solution to a complex real-world problem.
CCSS.ELA-LITERACY.SL Speaking & Listening
CCSS.ELA-LITERACY.RST Science & Technical Subjects
CCSS.MATH.CONTENT.HSS.ID.A Summarize, represent, and interpret data
**Disciplinary Core Ideas:**
ESS2.D Weather and Climate
ESS3.C Human Impacts on Earth Systems
ETS1.A Defining and Delimiting an Engineering Problem

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## How to Use These Activities

Pages with the circular "TILclimate Guide for Educators" logo are intended for educators. Simpler pages without the dark band across the top are meant for students.

A detailed table of contents on the next page describes what students will do during each activity. All activities are designed to be done as standalones, in sequence, or as part of a larger curriculum effort.

The podcast episode, bead model (p. 1-2) and graphing activity (p. 4) all take similar amounts of time. They could be set up as rotating stations.

Projects for the "Each One Teach One" activity can be as simple or as complex as is appropriate for your class.

## A Note About Materials

- Standard pony beads come in a variety of colors. A 1lb bag costs around $12 or less from various online suppliers.
- For this model, one could use a mixed-color bag and decide on a single color that represents carbon dioxide, or a single-color bag with a very small number of a contrasting color representing carbon dioxide.
- Dry beans, dry rice, or other small items could also be used.
- Students who have challenges differentiating colors can take the "Input" or "Timer" role. However, they may be able to agree with their teammates on a bead color that they are able to easily discern.

**Podcasts in the Classroom:** Throughout these Guides for Educators, we invite students to think about how they would share their learning with family and friends. Student-created podcasts are shareable, creative, and have multiple options for embedded assessment. We would love to hear any podcasts or see any other projects you or your students create! Email us at tilclimate@mit.edu, Tweet us @tilclimate, or tag us on Facebook @climateMIT.

TILclimate Guide for Educators

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## Detailed Table of Contents

# Today I Learned About Removing $CO_2$ from the Atmosphere

## Removing $CO_2$ from the Atmosphere

This Educator Guide includes a demonstration, discussion, math extensions, graphing activity, and a creative communication project. Educators may pick and choose among the pieces of the Guide, as suits their class needs.

Parts of this Guide may align with the following topics:

- Mathematics: Graphing datasets with a single line (annual mean data) or with multiple lines (monthly mean data.) Interpreting graphs. Arithmetic with scientific notation.
- Physical science: Atmospheric composition and changes over time. Measuring very small concentrations.
- Life/environmental science: History of the development of Earth's atmosphere. Carbon cycle changes.
- History/social science: Choices about technology use. The Industrial Revolution.
- ELA/literature: Science fiction or other texts with future technology.
- ELA/nonfiction: Interpreting and communicating scientific information.
- Extension: Print or otherwise represent 1 million of something (there are documents available online to print 1 million dots) and color them to represent the atmosphere and/or to demonstrate change in $CO_2$ concentration over time.

## MIT Resources

We recommend the following as resources for your own better understanding of climate change or as depth for student investigations. Specific sections are listed below:

- Climate Science, Risk & Solutions, an interactive introduction to the basics of climate change. https://climateprimer.mit.edu/
    - 02: The greenhouse effect and us
    - 05: How much of the $CO_2$ increase is natural?
    - 09: How long can we wait to act?
    - 10: What can we do?
- MIT Climate Portal Explainers are one-page articles describing a variety of climate topics. https://climate.mit.edu/explainers
    - Greenhouse Gases
    - Carbon Capture
    - Renewable Energy

# Today I Learned About Removing $CO_2$ from the Atmosphere

## Discussion Questions

- We measure carbon dioxide at very low levels, hundreds of parts per million. What are some other important things that might be measured at this level? (Examples: lead in drinking water should not rise above 15 parts per billion (ppb); ground-level ozone affects air quality at 70 ppb.)
- Do you think engineers and inventors should keep developing carbon capture technology? Why or why not?
- What other ways do we know of to reduce the carbon dioxide in the atmosphere?
- We are adding carbon dioxide to the atmosphere every day. A metaphor some people use is that the atmosphere is a bathtub, being filled from a faucet of carbon dioxide. If a bathtub is close to overflowing, you should turn the faucet off before you start emptying the tub. How are communities, governments, and organizations reducing the amount of carbon dioxide we release into the atmosphere?

## Climate Solutions

Climate solutions can be thought of as falling into four co-equal categories. Across all categories, a focus on community-level solutions leads to more effective action. Community-level solutions change decision-making so that the default option for individuals is the one that has the best result for the climate. For example, policies that increase the solar and wind mix in the electric grid, instead of asking homeowners to install solar panels. For more on talking about climate change in the classroom, see “How to Use This Guide”

- **Energy Shift**
  How do decision-makers make the switch from carbon-producing energy to carbon-neutral and carbon-negative energy?
- **Energy Efficiency**
  What products and technologies exist to increase energy efficiency, especially in heating and cooling buildings?
- **Adaptation**
  How can we adapt buildings to keep people safe from heat and cold?
- **Talk About It**
  Talking about climate change with friends and family can feel overwhelming. What is one thing you have learned that you could share to start a conversation?

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What solutions are the most exciting in your classes? We would love to hear from you or your students! Images, video, or audio of student projects or questions are always welcome. Email us at tilclimate@mit.edu, Tweet us @tilclimate, or tag us on Facebook @climateMIT.

# Today I Learned About Removing $CO_2$ from the Atmosphere

## Math Challenge Answer

According to NASA, Earth's atmosphere weighs $5.1 \times 10^{15}$ metric tons (MT).

As of June 2021, carbon dioxide measured 417ppm in the atmosphere.

For most of human history, we have had between 250-350ppm $CO_2$ in the atmosphere.

1. How many metric tons (MT) of $CO_2$ is in the atmosphere now? (417 ppm is .000417)

$$\mathbf{0.000417 \cdot (5.1 \times 10^{15}) = 2{,}127{,}600{,}000{,}000 = (2.1267 \times 10^{12})}$$

If we wanted to lower $CO_2$ to 350ppm, how many MT $CO_2$ would we have to remove?

$$\mathbf{0.00035 \cdot (5.1 \times 10^{15}) = 1{,}785{,}000{,}000{,}000 = (1.785 \times 10^{12})}$$

$$\mathbf{(2.1267 \times 10^{12}) - (1.785 \times 10^{12}) = 341{,}700{,}000{,}000 = (3.417 \times 10^{11})}$$

Mount Everest is estimated to weigh $1.619 \times 10^{11}$ metric tons. How many Mount Everests would it take to make up the number of metric tons of $CO_2$ we would have to remove to get back to 350ppm?

$$\mathbf{(3.417 \times 10^{11}) / (1.619 \times 10^{11}) = 2.11}$$

**We would have to remove more than two Mount Everests' worth of**

**$CO_2$ from the atmosphere to reduce from 417ppm to 350ppm.**

*Unfamiliar with scientific notation? These calculations can be done on Wolfram Alpha https://www.wolframalpha.com/. $5.1 \times 10^{15}$ is written 5.1x10^15.*

## Bead Weighing Example

| | | |
|---|---|---|
| 1. Count out and weigh 100 beads in grams. | A: **25** grams | Taking a sample is easier than counting all the beads. |
| 2. Weigh all beads in grams. | B: **454** grams | Make sure to zero the scale (tare) with your container on it first. |
| 3. Divide B / A | C: **18** | How many sets of 100 beads do you have? |
| 4. Multiply C * 100 | D: **1,800** beads | How many beads do you have? |

For this example, we rounded all answers to estimate the number of beads.

| **1,800** | | **0.0004** | | **.72** |
|---|---|---|---|---|
| number of beads total | x | 400 parts per million | = | carbon dioxide beads |

**A perfectly accurate model would have less than one $CO_2$ bead.**

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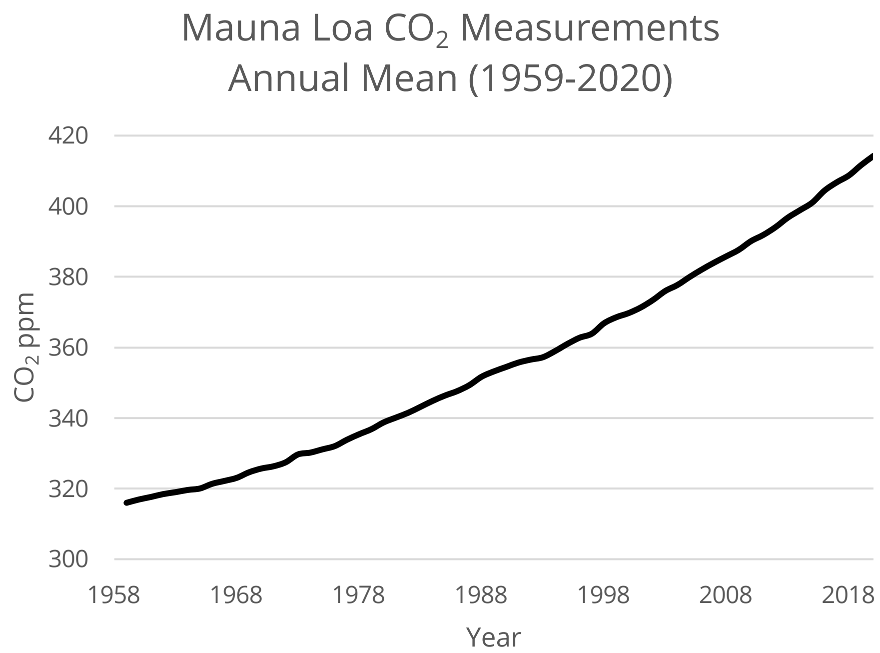
ENVIRONMENTAL SOLUTIONS INITIATIVE

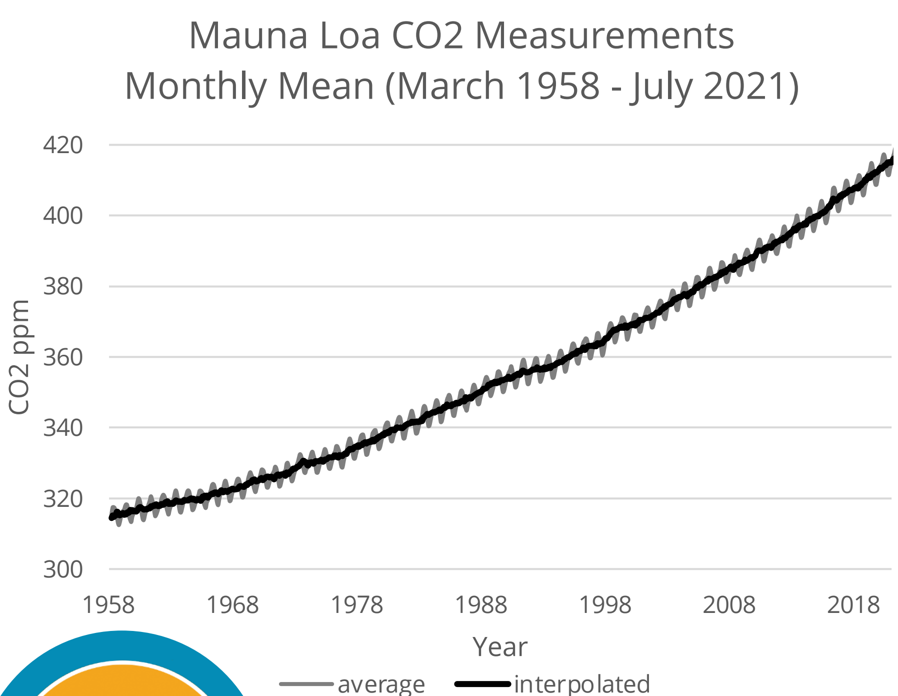
# Today I Learned About Removing $CO_2$ from the Atmosphere

## Mauna Loa Annual Mean Graph Example

This example graph was created in Microsoft Excel. Other graphing programs such as Google Sheets or OpenOffice will produce similar, if slightly different, results. For this smaller dataset, students could also plot data points by hand on graph paper. In this case, the chart type is XY Scatter with Smooth Lines.




## Mauna Loa Monthly Mean Graph Example




This example graph was also created in Microsoft Excel as an XY Scatter with Smooth Lines chart. The Interpolated line is smoothed to erase seasonal variability, and is almost identical to the Annual Mean line, above. In the interactive graph on NOAA's website, this is called the trend line. Atmospheric $CO_2$ rises during the Northern Hemisphere's winter when trees are dormant and falls when they are active.

https://gml.noaa.gov/ccgg/trends/data.html

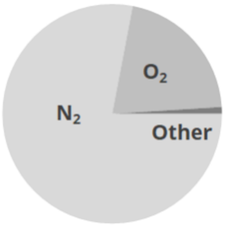
TILclimate Guide for Educators

ENVIRONMENTAL SOLUTIONS INITIATIVE

# Today I Learned About Removing $CO_2$ from the Atmosphere

"For every million tons of $CO_2$ that you want to recover from the atmosphere … you have to physically move between 5 and 7 billion - with a B - tons of air, and a ton of air is as heavy as a ton of rock."
*Niall Mac Dowell, Imperial College London*
*TILclimate podcast: Today I Learned About Removing $CO_2$ from the Atmosphere*

## Earth's Atmosphere




Earth's atmosphere contains about 78% Nitrogen ($N_2$) and 21% Oxygen ($O_2$). The remaining 1% is a mix of non-reactive gases (Argon, Neon, Helium, etc.) and gases that change over time and location, such as carbon dioxide ($CO_2$), water vapor ($H_2O$), methane ($CH_4$), sulfur dioxide ($SO_2$), and ozone ($O_3$).

## Carbon Dioxide

As we burn fossil fuels like coal, oil, and natural gas, we release carbon dioxide into the atmosphere. This carbon dioxide acts like a blanket around Earth, trapping heat and warming our ocean and air. Warmer ocean and air temperatures lead to more extreme weather, sea level rise, and other impacts.

Even at extremely low concentrations, carbon dioxide has a huge impact on Earth's climate. We measure carbon dioxide at parts per million (ppm) instead of percent (%.)
In 2013, $CO_2$ reached 400ppm for the first time in millions of years.

400ppm
= 0.04%

## Check Your Model

Today we will be modeling the atmosphere with beads. The actual concentration of $CO_2$ in the atmosphere is very low, so your model will have more "carbon dioxide" beads than the actual atmosphere. Make sure you know which color of bead is representing carbon dioxide in your model.

If you have time, you can calculate how many carbon dioxide beads would be accurate in your model. If you know how many beads you have total, multiply

____________ x ____________ = ____________

number of beads total x 400 parts per million = carbon dioxide beads

If you do not know how many beads you have total, there is a chart to help on page 3.

# Today I Learned About Removing $CO_2$ from the Atmosphere

## Setup

Make sure to read through all instructions before you begin.

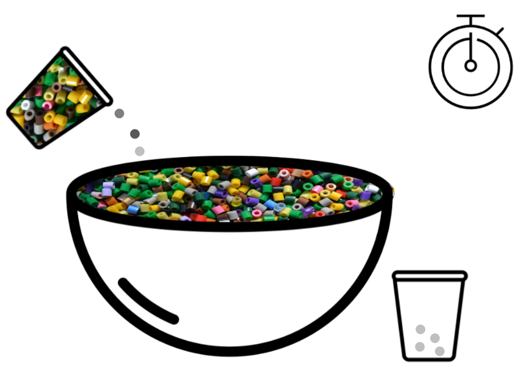
**Materials:**

- One larger container mixed-color beads
- One cup mixed-color beads
- One empty cup
- One timer

**Before You Begin:**

1. If there are no beads in the cup, scoop some out of the larger container.
2. Choose roles: 1 Timer, 1-2 Input, everyone else is Carbon Capture.
3. Make sure everyone in the Carbon Capture group agrees on which color bead represents carbon dioxide.

## Do The Activity



All these steps happen at the same time:

1. Timer begins 1 minute countdown.
2. Input team steadily adds beads to the large container a few at a time.
3. Carbon Capture team digs through beads, finding and removing carbon dioxide beads and adding them to the empty cup.
4. When 1 minute is up, everyone stops.
5. Reset the activity by pouring all beads into the bowl, mixing, and scooping out one cup.

## Discuss

- How many carbon dioxide beads did you get?
- Do you think you were able to get them all?
- Was it easy to find the right beads in among all the others?
- How many new carbon dioxide beads do you think were added during the activity?

Cup by Ahargun Ahduy, bowl by priiyanka from the Noun Project. Beads by Innviertlerin from Pixabay.

# Today I Learned About Removing $CO_2$ from the Atmosphere

## Discussion

- Was this an accurate model of carbon capture technology? Why or why not?
- We measure carbon dioxide at very low levels, hundreds of parts per million. What are some other important things that might be measured at this level? (Think about testing drinking water, medicines, or other places that might affect human health.)
- Do you think engineers and inventors should keep developing carbon capture technology? Why or why not?
- What other ways do we know of to reduce the carbon dioxide in the atmosphere?

## Math Extension

According to NASA[a], Earth's atmosphere weighs $5.1 \times 10^{15}$ metric tons (MT).

As of June 2021[b], carbon dioxide measured 417ppm in the atmosphere.

For most of human history, we have had between 250-350ppm $CO_2$ in the atmosphere[c].

1. How many metric tons (MT) of $CO_2$ is in the atmosphere now? (417 ppm is .000417)
2. If we wanted to lower $CO_2$ to 350ppm, how many MT $CO_2$ would we have to remove?
3. Mount Everest is estimated to weigh $1.619 \times 10^{11}$ metric tons[d]. How many Mount Everests would it take to make up the number of metric tons of $CO_2$ we would have to remove to get back to 350ppm?

## Check Your Model

| | | |
|---|---|---|
| 1. Count out and weigh 100 beads in grams. | A: _________ grams | Taking a sample is easier than counting all the beads. |
| 2. Weigh all beads in grams. | B: _________ grams | Make sure to tare the weight of the container. |
| 3. Divide B / A | C: __________ | How many sets of 100 beads do you have? |
| 4. Multiply C * 100 | D: __________ beads | How many beads do you have? |

a NASA Earth Fact Sheet https://nssdc.gsfc.nasa.gov/planetary/factsheet/earthfact.html
b NASA Global Climate Change Vital Signs https://climate.nasa.gov/vital-signs/carbon-dioxide/
c Ask MIT Climate "What is the ideal level of carbon dioxide in the atmosphere for human life?" https://climate.mit.edu/ask-mit-climate
d How Much Does Mount Everest Weigh? https://weightofstuff.com/how-much-does-mount-everest-weigh/



ENVIRONMENTAL SOLUTIONS INITIATIVE

# Today I Learned About Removing $CO_2$ from the Atmosphere

> "We are at, I think, the very early days of developing direct air capture technology. You know, the basic science is sort of there, right? We know how to capture the $CO_2$. The problem is that what we need to do is be actively removing lots of $CO_2$ at the million tons per year scale minimum. It's a bit maybe like saying we need to be able to break the sound barrier and Orville and Wilbur Wright now just managed to get … the first plane flying for 10 meters.
>
> *Niall Mac Dowell, Imperial College London*
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## A Warming Planet

As we burn fossil fuels like coal, oil, and natural gas, we release carbon dioxide into the atmosphere. Carbon dioxide ($CO_2$) acts like a blanket, trapping heat. We need regular amounts of $CO_2$ for life on Earth. We are seeing rampant $CO_2$ now, and the blanket is trapping extra heat, warming our Earth and ocean. This leads to impacts such as extreme weather and sea level rise around the world.

## How Do We Know?

The Mauna Loa Observatory in Hawai'i has been measuring $CO_2$ in the atmosphere since 1958[1]. This is one of the best sets of data showing direct measurement of carbon dioxide. For measurements before 1958, scientists use gas trapped in ice and other places.

## What Does It Show Us?

1. Visit https://gml.noaa.gov/ccgg/trends/graph.html. Make sure **Mauna Loa, Hawaii** and **Interactive Plots** are selected.
2. The first measurements were taken in March 1958. What was the level of $CO_2$ in the atmosphere at that time? What is it now?
3. What do you notice about this graph?
4. What do you wonder?
5. There are two lines on the graph — $CO_2$ and trend. Why are both lines needed? What do they tell us?
6. At the bottom of the graph, there is a slider that allows you to focus on a section of time. Slide the bars to show just the decade 1960-1969, and then the decade 2010-2020. What do you notice about the shape of the $CO_2$ line?
7. What other questions could you ask and answer with this tool?

1 NOAA Global Monitoring Laboratory: Trends in Atmospheric Carbon Dioxide https://gml.noaa.gov/ccgg/trends/

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## What Does It Show Us?

1. Visit https://gml.noaa.gov/ccgg/trends/data.html. Make sure **Mauna Loa, Hawaii** and **Data** are selected.
2. Download the data file **Mauna Loa $CO_2$ annual mean data**. Depending on how you will be graphing, you may want the .txt file or the CSV file, which is in parenthesis.
3. Graph Annual Mean $CO_2$ as a function of year.
4. The first measurements were taken in 1959. What was the level of $CO_2$ in the atmosphere at that time? What is it now?
5. What do you notice about this graph?
6. What do you wonder?
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## What Does It Show Us?

1. Visit https://gml.noaa.gov/ccgg/trends/data.html. Make sure **Mauna Loa, Hawaii** and **Data** are selected.
2. Download the data file **Mauna Loa $CO_2$ monthly mean data**. Depending on how you will be graphing, you may want the .txt file or the CSV file, which is in parenthesis.
3. Graph Monthly Mean $CO_2$ and the Interpolated column as a function of decimal date.
4. The first measurements were taken in 1959. What was the level of $CO_2$ in the atmosphere at that time? What is it now?
5. What do you notice about this graph?
6. What do you wonder?
7. There are two lines on the graph – average and interpolated. Why are both lines needed? What do they tell us?
8. What other questions could you ask and answer with this tool?

1 NOAA Global Monitoring Laboratory: Trends in Atmospheric Carbon Dioxide https://gml.noaa.gov/ccgg/trends/

# Today I Learned About Removing $CO_2$ from the Atmosphere

> "We will need everything. We need renewable energy. We need fuel switching. We need nuclear power. We need demand reduction. We need carbon capture and storage, and we will need all forms of greenhouse gas removal as and when they get going."
>
> *Niall Mac Dowell, Imperial College London*
>
> *TILclimate podcast: Today I Learned About Removing $CO_2$ from the Atmosphere*

## We Need Everything

Carbon capture technology is very promising, but even its biggest supporters agree that it will not be ready for widespread use for years or even decades. In the meantime, we know that we need to be adding less carbon dioxide to the atmosphere. If a bathtub is about to overflow, the best thing to do is turn the faucet off before you start trying to empty the tub.

## Each One, Teach One

1. Visit https://climate.mit.edu/explainers. Each member of your group will read a different one of the articles listed below.
2. Briefly describe what you learned to your teammates.
3. As a team, decide on three key messages you want to share with your classmates, friends, and family.
4. Create! How will you share what you have learned? You could create a podcast episode, a video, a painting or mural…

Keep In Mind:

- Talking about climate change can feel scary. This is OK – you don't need to be complete expert. If you don't know the answer to a question, you can give people resources to find out their own answers.
- Choose your key messages with your audience in mind. Does your audience need convincing about climate change, or do they just want to know what to do about it?
- Make it real. You don't need a lot of graphs and figures. People respond to metaphors, stories, and your passion for the topic.
- Think about solutions on a community scale. The biggest change happens when policies, laws, and programs make it easier for everyone to use renewable energy, switch fuel types, and reduce their energy use.

Suggested MIT Explainers:

- Renewable Energy, Greenhouse Gases, Carbon Capture, Soil-Based Carbon Sequestration, Forests and Climate Change, Concrete, Nuclear Energy, Food Systems and Agriculture, Energy Storage