

# Today I Learned About Materials

## Description:

Our modern world uses many different materials, often complexly constructed and difficult to recycle. Students investigate the elements in a smartphone and innovations in cement and steel. They also consider the challenge of communicating about large and complex numbers.

## Skills & Objectives

### SWBAT

- Understand that materials science can help reduce the carbon dioxide and other polluting outputs from industrial processes.
- Explain why cement and steel are key to reducing carbon dioxide from industry.
- Give one example of a technique to describe a large number to the general public.

### Skills

- Communication
- Reading scientific news articles

### Students Should Already Know That

- Everyday materials are made from elements, minerals, chemicals, and other materials that must be mined, sourced, produced, and processed.

### Standards Alignment:

HS-PS2-6 Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

HS-ESS3-2 Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources.

RST.11-12.2 Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.

SL.11-12.5 Make strategic use of digital media in presentations to enhance understanding of findings, reasoning, and evidence and to add interest.

### Disciplinary Core Ideas:

ESS3.A Natural Resources

ESS3.C Human Impacts on Earth Systems

ESS3.D Global Climate Change

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 and dark band across the top are intended for educators. Simpler pages without the dark band across the top are meant for students.

Each of the included activities is designed to be used as a standalone, in sequence, or integrated within other curriculum needs. A detailed table of contents, on the next page, explains what students will do in each activity.

## A Note About Printing

All student pages are designed to be printable in grayscale. Larger copies of the infographics on page 2 are included. A few copies of this page could be printed color for students to share, or the image projected in the classroom.

The worksheets do not leave space for students to answer questions. Students may answer these questions in whatever form is the norm for your classroom – a notebook, online form, or something else. This allows you, the teacher, to define what you consider a complete answer.

**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. One way to do this is to encourage your students to create their own podcasts - they're 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](mailto:tilclimate@mit.edu), Tweet us @tilclimate, or tag us on Facebook @climateMIT.



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## Detailed Table of Contents

Page	Title	Description	Time (min)
	Podcast Episode	Students listen to TILclimate: TIL about materials, either as pre-class work at home or in the classroom. <a href="https://climate.mit.edu/podcasts/e3-til-about-materials">https://climate.mit.edu/podcasts/e3-til-about-materials</a>	10-15
1-2	Periodic Table in Your Pocket	Students explore some of the elements involved in a smartphone and explore which elements are most easily recycled.	15-20
3-5	Steel and Cement (internet required to access articles)	Steel and cement are some of the most carbon-intensive parts of industry. Students investigate innovations in steel and cement production and use. In small groups, they discuss their innovations and their application.	20-45
6-7	Data Communication	One challenge for science communicators is that large numbers are hard to comprehend. Students practice some techniques to make large data more understandable to the general public.	20-45

## Research Resources

On page 1, students are encouraged to investigate programs that are increasing e-waste harvest safety and fully recyclable devices. In the US, e-waste recyclers can gain certification from two approved organizations, e-Stewards and SERI (R2). Students can find local certified e-waste recycling facilities at:

- <https://e-stewards.org/find-a-recycler/>
- <https://sustainableelectronics.org/find-an-r2-certified-facility/>

Development of fully-recyclable electronic devices is ongoing. Internet search terms such as “recyclable phone” or “recyclable laptop” will show the most up-to-date innovations.

For ratings on the repairability of popular smartphones, visit <https://www.ifixit.com/smartphone-repairability>



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## Materials: Sources, Innovations, and Communication

This Educator Guide includes a reading, a group research project, and a communication challenge. 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:

- Physical science: Innovations in materials science. Periodic table of the elements.
- Life/environmental science: Impacts of materials use on climate change and environmental and human health.
- History/social science: History of technological innovations.
- ELA/nonfiction: Communicating large numbers and other complex scientific data.

## 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/>
  - Chapter 02 The greenhouse effect and us
  - Chapter 07 Understanding risk
  - Chapter 10 What can we do?
- MIT Climate Portal Explainers are one-page articles describing a variety of climate topics. New Explainers are added each month. <https://climate.mit.edu/explainers>
  - Concrete
  - Mining and Metals
  - Greenhouse Gases



# Today I Learned About Materials

## Wrap-Up Discussion Questions

- We often focus on recycling as an eco-friendly action and forget that 'reduce' and 'reuse' come before 'recycle.' In the case of one of the materials you studied, what would 'reduce' and 'reuse' look like?
- What innovations in materials use are the most exciting to you? Which do you think you will see in use soonest?
- Many science communicators focus on talking about impacts and solutions instead of showing graphs, figures, and numbers. How could you reframe the fact(s) you chose above to remove the numbers altogether? What is your goal in sharing this information?
- Have you seen scientific data presented in a way that resonated with you? What did you like about how the communicator(s) chose to present the material?
- Why is it important to communicate about science in a way that is accessible and understandable to everyone?

## Climate Solutions

Climate solutions can be thought of as falling into four categories outlined below. Across all categories, solutions at the community, state or federal level are generally more impactful than individual actions. For example, policies that increase the nuclear, solar and wind mix in the electric grid are generally more effective at reducing climate pollution than 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?

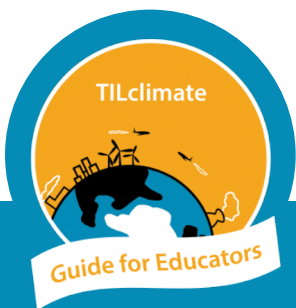
### • Adaptation

How can cities and towns adapt to the impacts of climate change?

### • 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?

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](mailto:tilclimate@mit.edu), Tweet us @tilclimate, or tag us on Facebook @climateMIT.



# Today I Learned About Materials

“As technology has become amazing and advanced, we increasingly make things more complicated, meaning more elements ... which makes it more difficult to manage at end of [the product's] life. We sometimes make the joke that you carry the periodic table in your pocket.”

*Professor Elsa Olivetti, MIT Department of Materials Science & Engineering  
TILclimate podcast: Today I Learned About Materials*

## The Periodic Table in Your Pocket

The average smartphone contains more than 30 separate chemical elements (more than a quarter of the periodic table) in many combinations.<sup>1</sup> While this makes the device the technological wonder that it is, it also makes it difficult to separate those elements for recycling after a user upgrades to a new phone. US *e-waste* (cell phones, computers, wearables, etc.) is often sent overseas to be recycled. There are many materials in e-waste that then affect human and environmental health in these countries.

What if we could better separate and handle the materials in our e-waste? According to the United Nations (UN), “industrial and consumer products containing [chemical elements] have often been regarded as waste material rather than as ‘surface mines’ waiting to be exploited. This is a nearsighted and unfortunate view... [W]e limit our technological future by using these resources once and then discarding them through neglect, poor product design, or poor planning.”<sup>2</sup>

## What is Recyclable, What is Recycled?

On the next page, find infographics that describe some of the elements that go into a smartphone, and the average recycling rates for those elements worldwide.

1. What do you notice? Does anything surprise you?
2. We often focus on recycling as an eco-friendly action and forget that ‘reduce’ and ‘reuse’ come before ‘recycle.’ In the case of the materials in electronic devices, what would ‘reduce’ and ‘reuse’ look like?
3. What did the UN report mean that products containing these elements could be seen as ‘surface mines’? Research programs or organizations that are working to increase the safe harvesting of e-waste materials.
4. Engineers and designers are working to develop electronic devices that are more fully recyclable, so that their materials can be reused again and again. Research one of these projects – how are they thinking about materials use?

<sup>1</sup> The Chemical Elements of a Smartphone <https://www.compoundchem.com/2014/02/19/the-chemical-elements-of-a-smartphone/>

<sup>2</sup> United Nations Environment Programme, Recycling Rates of Metals, 2011

[https://wedocs.unep.org/bitstream/handle/20.500.11822/8702/Recycling\\_Metals.pdf](https://wedocs.unep.org/bitstream/handle/20.500.11822/8702/Recycling_Metals.pdf)

# Today I Learned About Materials

## ELEMENTS OF A SMARTPHONE

ELEMENTS COLOUR KEY: ● ALKALI METAL ● ALKALINE EARTH METAL ● TRANSITION METAL ● GROUP 13 ● GROUP 14 ● GROUP 15 ● GROUP 16 ● HALOGEN ● LANTHANIDE

### SCREEN

**Indium tin oxide** is a mixture of indium oxide and tin oxide, used in a transparent film in the screen that conducts electricity. This allows the screen to function as a touch screen.

The glass used on the majority of smartphones is an aluminosilicate glass, composed of a mix of alumina (Al<sub>2</sub>O<sub>3</sub>) and silica (SiO<sub>2</sub>). This glass also contains potassium ions, which help to strengthen it.

A variety of Rare Earth Element compounds are used in small quantities to produce the colours in the smartphone's screen. Some compounds are also used to reduce UV light penetration into the phone.

### BATTERY

The majority of phones use lithium ion batteries, which are composed of lithium cobalt oxide as a positive electrode and graphite (carbon) as the negative electrode. Some batteries use other metals, such as manganese, in place of cobalt. The battery's casing is made of aluminium.

### ELECTRONICS

Copper is used for wiring in the phone, whilst copper, gold and silver are the major metals from which microelectrical components are fashioned. Tantalum is the major component of micro-capacitors.

Nickel is used in the microphone as well as for other electrical connections. Alloys including the elements praseodymium, gadolinium and neodymium are used in the magnets in the speaker and microphone. Neodymium, terbium and dysprosium are used in the vibration unit.

Pure silicon is used to manufacture the chip in the phone. It is oxidised to produce non-conducting regions, then other elements are added in order to allow the chip to conduct electricity.

Tin & lead are used to solder electronics in the phone. Newer lead-free solders use a mix of tin, copper and silver.

**Cu** Copper  
**Ag** Silver  
**Au** Gold  
**Ta** Tantalum

**Ni** Nickel  
**Dy** Dysprosium  
**Pr** Praseodymium  
**Tb** Terbium  
**Nd** Neodymium  
**Gd** Gadolinium

**Si** Silicon  
**O** Oxygen  
**Sb** Antimony  
**As** Arsenic  
**P** Phosphorus  
**Ga** Gallium

**Sn** Tin  
**Pb** Lead

### BATTERY

**Li** Lithium  
**Co** Cobalt  
**C** Carbon  
**Al** Aluminium  
**O** Oxygen

### CASING

Magnesium compounds are alloyed to make some phone cases, whilst many are made of plastics. Plastics will also include flame retardant compounds, some of which contain bromine, whilst nickel can be included to reduce electromagnetic interference.

**C** Carbon  
**Mg** Magnesium  
**Br** Bromine  
**Ni** Nickel

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## RECYCLING RATES OF SMARTPHONE METALS

COLOUR KEY: ● < 1% RECYCLE RATE ● 1-10% RECYCLE RATE ● 10-25% RECYCLE RATE ● 25-50% RECYCLE RATE ● > 50% RECYCLE RATE ● NON-METAL (OR RECYCLE RATE UNKNOWN)

### SCREEN

**TOUCH: INDIUM TIN OXIDE**  
Used in a transparent film over the phone's screen that conducts electricity. This allows the screen to function as a touch screen. This is the major use of indium.

**GLASS: ALUMINA & SILICA**  
On most phones the glass is aluminosilicate glass, a mix of aluminium oxide & silicon dioxide. It also contains potassium ions which help strengthen it.

**COLOURS: RARE EARTH METALS**  
A variety of rare earth metal-containing compounds are used to help to produce the colours in a smartphone's screen. Some of these compounds are also used to help reduce light penetration into the phone. Many of the 'rare earths' occur commonly in the Earth's crust, but often at levels too low to be economically extracted.

### BATTERY

Most phones use lithium ion batteries, composed of lithium cobalt oxide as a positive electrode and graphite (carbon) as the negative electrode. Sometimes other metals, such as manganese, are used in place of cobalt. The battery casing is often made of aluminium.

### ELECTRONICS

**WIRING & MICROELECTRONICS**  
Copper is used for wiring, and for micro-electrical components along with gold and silver. Tantalum is the major component in micro-capacitors.

**MICROPHONES & VIBRATIONS**  
Nickel is used in the microphone and for electrical connections. Rare earth element alloys are used in magnets in the speaker and microphone, and the vibration unit.

**THE SILICON CHIP**  
Pure silicon is used to manufacture the chip, which is then oxidised to produce non-conducting regions. Other elements are added to allow the chip to conduct electricity.

**CONNECTING ELECTRONICS**  
Tin & lead were used in older solders; newer, lead-free solders use a mix of tin, copper & silver.

**Cu** Copper  
**Ag** Silver  
**Au** Gold  
**Ta** Tantalum

**Ni** Nickel  
**Dy** Dysprosium  
**Pr** Praseodymium  
**Tb** Terbium  
**Nd** Neodymium  
**Gd** Gadolinium

**Si** Silicon  
**O** Oxygen  
**Sb** Antimony  
**As** Arsenic  
**P** Phosphorus  
**Ga** Gallium

**Sn** Tin  
**Pb** Lead

### BATTERY

**Li** Lithium  
**Co** Cobalt  
**C** Carbon  
**Al** Aluminium  
**O** Oxygen

Magnesium alloy is used to make some phone cases, whilst many others are made of plastics, which are carbon-based. Plastics will also include flame retardant compounds, some of which contain bromine, whilst nickel can be included to reduce electromagnetic interference.

**C** Carbon  
**Mg** Magnesium  
**Br** Bromine  
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### SCREEN

**In** 49 Indium  
**Sn** 50 Tin  
**O** 8 Oxygen

Indium tin oxide is a mixture of indium oxide and tin oxide, used in a transparent film in the screen that conducts electricity. This allows the screen to function as a touch screen.

**Al** 13 Aluminium  
**Si** 14 Silicon  
**O** 8 Oxygen  
**K** 19 Potassium

The glass used on the majority of smartphones is an aluminosilicate glass, composed of a mix of alumina (Al<sub>2</sub>O<sub>3</sub>) and silica (SiO<sub>2</sub>). This glass also contains potassium ions, which help to strengthen it.

**Y** 39 Yttrium  
**La** 57 Lanthanum  
**Pr** 59 Praseodymium  
**Eu** 63 Europium  
**Dy** 66 Dysprosium  
**Tb** 65 Terbium  
**Gd** 64 Gadolinium

A variety of Rare Earth Element compounds are used in small quantities to produce the colours in the smartphone's screen. Some compounds are also used to reduce UV light penetration into the phone.

### ELECTRONICS

**Cu** 29 Copper  
**Au** 79 Gold  
**Ag** 47 Silver  
**Ta** 73 Tantalum

Copper is used for wiring in the phone, whilst copper, gold and silver are the major metals from which microelectrical components are fashioned. Tantalum is the major component of micro-capacitors.

**Ni** 28 Nickel  
**Tb** 65 Terbium  
**Dy** 66 Dysprosium  
**Nd** 60 Neodymium  
**Pr** 59 Praseodymium  
**Gd** 64 Gadolinium

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**Si** 14 Silicon  
**O** 8 Oxygen  
**Sb** 51 Antimony

Pure silicon is used to manufacture the chip in the phone. It is oxidised to produce non-conducting regions, then other elements are added in order to allow the chip to conduct electricity.

**Sn** 50 Tin  
**Pb** 82 Lead

Tin & lead are used to solder electronics in the phone. Newer lead-free solders use a mix of tin, copper and silver.

### BATTERY

**Li** 3 Lithium  
**Co** 27 Cobalt  
**C** 6 Carbon  
**Al** 13 Aluminium  
**O** 8 Oxygen

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**Mg** 12 Magnesium  
**C** 6 Carbon  
**Br** 35 Bromine

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### CASING

**C** 6 Carbon  
**Mg** 12 Magnesium  
**Br** 35 Bromine  
**Ni** 28 Nickel

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### CASING



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“The majority of [CO<sub>2</sub> emissions from materials and manufacturing] is steel and cement. Aluminum and paper and plastic are all about five to ten percent... Focusing on innovations in steel and cement are always useful.”

*Professor Elsa Olivetti, MIT Department of Materials Science & Engineering*  
TILclimate podcast: Today I Learned About Materials

## Steel



If a new building is going up in your neighborhood (especially a very tall one) chances are the structure is made of steel. Steel is used in cars, bridges, and buildings all over the world. Steel is iron with other added elements to improve its strength and flexibility.

Steel begins its life as iron ore, mined out of the ground. From there, it is processed, melted, mixed, and reformed into the many shapes and types of steel needed. Almost every step of the steel process requires large amounts of heat. Most steel plants use coal or other fossil fuels as their primary heat source. Burning fossil fuels releases carbon dioxide (CO<sub>2</sub>).

## Cement and Concrete

Walk down a sidewalk. Look at the foundation (basement) of a building. Concrete is all around us – it is the second-most used material on the planet, after water.<sup>1</sup> We rarely think about how it is made, or what it is made of.



As Prof. Olivetti mentioned in the podcast episode, concrete is made of a mixture of water, sand and gravel, chemical additives, and cement. Cement is the glue that holds the other materials together and gives the concrete its strength. Cement is like the flour, while concrete is like the bread that is made with the flour.

Most cement is made from heated limestone and is a major source of CO<sub>2</sub> around the world. Its production emits CO<sub>2</sub> in two main ways: As *clinker* forms in a heated kiln, CO<sub>2</sub> is released directly from the chemical reaction. To heat the kiln to the necessary 2600 °F, most cement factories burn fossil fuels, which also release CO<sub>2</sub>.

## A Warming Planet

In the atmosphere, CO<sub>2</sub> acts like a blanket, trapping heat. This trapped heat is warming our Earth, ocean, and air and causing dramatic changes to weather and climate patterns all over the world.

Globally, cement accounts for around 7% of all heat-trapping gas emissions<sup>1</sup> while steel emits another 7% or more<sup>2</sup>.

<sup>1</sup> MIT Explainer: Concrete <https://climate-dev.mit.edu/explainers/concrete>

<sup>2</sup> IEA (2020), Iron and Steel Technology Roadmap, IEA, Paris <https://www.iea.org/reports/iron-and-steel-technology-roadmap>

Images from Pixabay

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## Each One, Teach One

Each member of your group will choose one of the following articles about an innovation that is reducing the CO<sub>2</sub> emissions of steel or concrete.

### As you read:

1. In your own words, summarize the innovation – is a new manufacturing process, material, method of construction, energy source, something else?
2. What do you find the most interesting about this innovation?
3. How does this innovation reduce CO<sub>2</sub> emissions?

### After you read:

1. Each member of the group teaches the others about their article.
2. Discuss similarities and differences among these innovations.
3. Imagine your group was in charge of building a new youth center in your community. One key goal is for the building to meet your community's needs while emitting as little CO<sub>2</sub> as possible in its materials, construction, and use. Which of these new innovations might you use in constructing the building? What other methods, materials, or ideas have you heard about that could decrease the CO<sub>2</sub> emissions of the building?
4. Some innovations are 'multisolving' – that is, they solve more than one challenge. How do some of the solutions you learned about solve multiple problems at once?

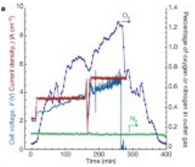


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## Innovations: Steel



Reducing industrial carbon emissions <https://news.mit.edu/2021/reducing-emissions-decarbonizing-industry-0721>



One order of steel; hold the greenhouse gases  
<https://news.mit.edu/2013/steel-without-greenhouse-gas-emissions-0508>

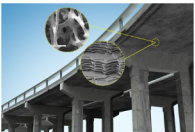


Taking the carbon out of construction with engineered wood  
<https://news.mit.edu/2019/taking-carbon-out-construction-with-engineered-wood-1211>

## Innovations: Cement



New approach suggests path to emissions-free cement  
<https://news.mit.edu/2019/carbon-dioxide-emissions-free-cement-0916>



Finding a new formula for concrete  
<https://news.mit.edu/2016/finding-new-formula-for-concrete-0526>



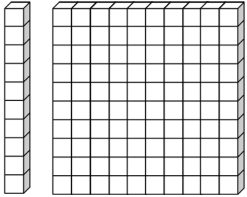
How to make stronger, "greener" cement  
<https://news.mit.edu/2014/stronger-greener-cement-0925>

# Today I Learned About Materials

“[W]hat’s tricky about any of these conversations around CO<sub>2</sub> or materials use is that the numbers are huge. [H]ow do you relate them to anything that feels more concrete to us?”

*Professor Elsa Olivetti, MIT Department of Materials Science & Engineering  
TILclimate podcast: Today I Learned About Materials*

## Numbers are Hard: Science Communication



The human brain finds very large numbers difficult to comprehend. We can easily imagine 10 of something and can probably roughly estimate that we are looking at 100 of something. Once numbers get much larger than that, however, they start to be difficult to imagine, compare, and understand.

In the modern world, we are often faced with extremely large numbers: trillions of dollars in government budgets, billions of dollars owned by single individuals, millions of people in one city. When discussing climate change, we hear about millions of metric tons of carbon dioxide emissions – but what is a metric ton, and what is a million?

People who make big numbers make sense in an everyday context often use some of the following techniques:

## Data Communication Tips



**Make it Smaller:** For example, if a building is going to cost \$10 million to build, and will take two years to build, that is \$416,666 per month. While this is still a large number, it is closer to the average cost of a house in the US.



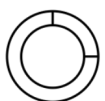
**Change the Unit:** The Mariana Trench (the deepest known part of the ocean) is over 36,000 feet deep. Most people cannot imagine this. Convert it to 6.8 miles and it becomes more understandable.



**Divide it Up:** It may be too much to imagine one million people – but how many times would you need to fill your local football stadium to fit one million? It may be easier to imagine 15 football stadiums of people.

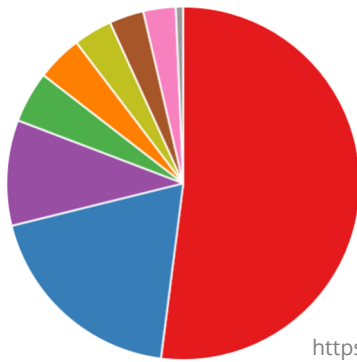


**Convert to Time:** Another way to imagine one million people is in interactions. If you spoke to each person for one minute, eight hours a day, every day, it would take 5.7 years to meet each person.



**Visualize It:** Numbers are often easier to compare if they are represented in a graph, chart, graphics, or video. However, it is important that your graphics are accurate in terms of area or length.

# Today I Learned About Materials



US Heat-Trapping Gas Emissions from Industry, 2019

- Fossil fuel combustion: 52%
- Natural gas & petroleum systems: 19.1%
- Other industrial categories: 9.7%
- Chemical production & use: 4.7%
- Mineral products: 4.2%
- Coal mining: 3.5%
- Production & use of fluorinated gases: 3.1%
- Metal production: 3%

<https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks>

## Data Communication Practice

Take one or more of the following data points from the US Environmental Protection Agency (EPA.) Reframe it to make more sense to the general public, using one or more of the tips on the previous page. All data points are US measurements from 2019, listed in million metric tons (mmt) of carbon dioxide equivalents (CO<sub>2</sub>e – a method of combining data for all heat-trapping gases.)

Total: 6,588mmt

Total industrial use: 1,504.83mmt

Industrial fossil fuel use: 782.82mmt

Iron and steel production: 41.32mmt

Cement production: 40.90mmt

Lime production: 12.11mmt

For more data points, or data from other years, visit

<https://cfpub.epa.gov/ghgdata/inventoryexplorer/index.html>

To convert metric tons of CO<sub>2</sub> to passenger cars, homes, smartphones, and more, visit

<https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator>

## Questions

1. Why do you think it is so hard to talk about very large numbers?
2. Many science communicators focus on talking about impacts and solutions instead of showing graphs, figures, and numbers. How could you reframe the fact(s) you chose above to remove the numbers altogether? What is your goal in sharing this information?
3. Have you seen scientific data presented in a way that resonated with you? What did you like about how the communicator(s) chose to present the material?

All data from EPA "Greenhouse Gas Inventory Data Explorer" <https://cfpub.epa.gov/ghgdata/inventoryexplorer/index.html>