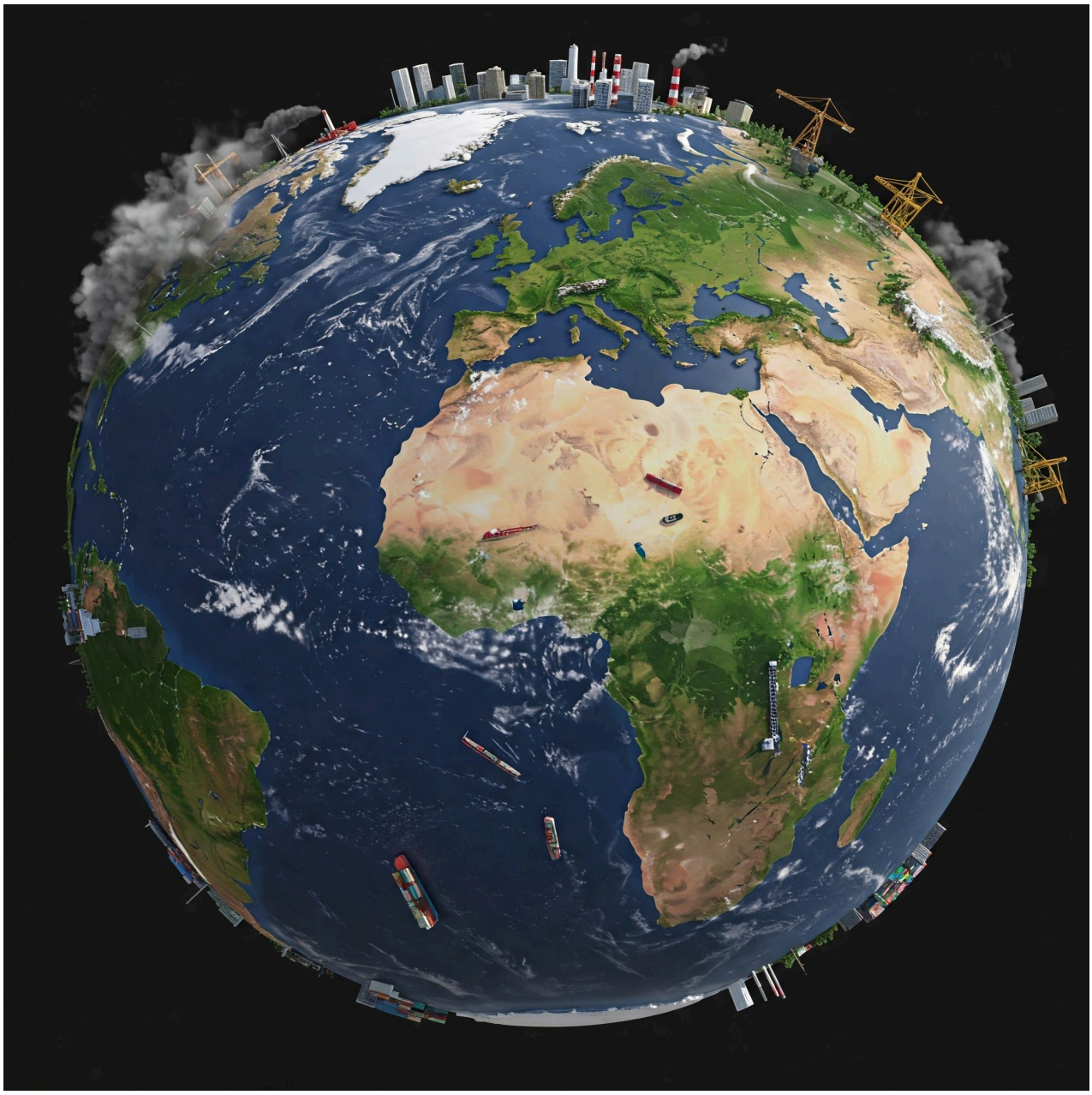
Solutions for a Sustainable Future - Student Materials

Unit 6	Earth and Space Science



Student Materials Table of Contents

Performance Task Organizer

Unit 6 Solutions for a Sustainable Future	Earth and Space Science
Student Name:	

Tell the Story

Directions:

1. Silently read or watch the “texts” provided to you.
2. Record or annotate three details that are most important to the phenomenon being described for each text.
3. Share with your group. Each person should identify the details that they circled.
4. Discuss as a group, and determine the overall story. What is the phenomenon?

Text 1: World Health Organization Video

Important Details

1. _____

2. _____

3. _____

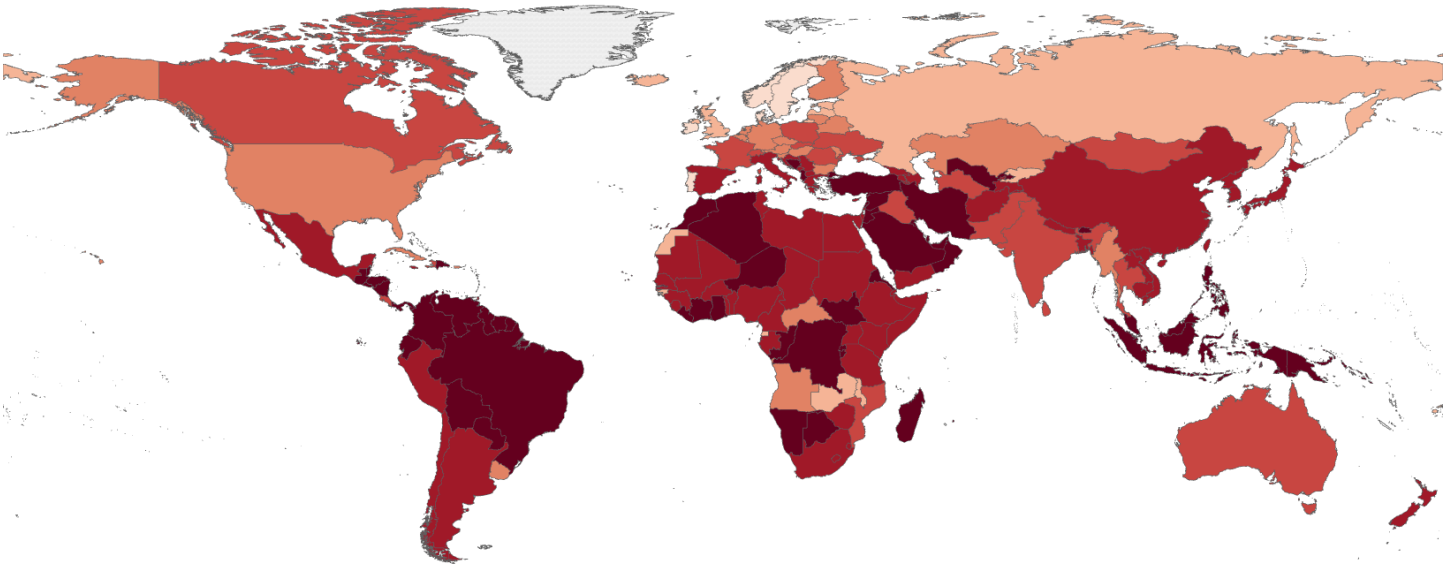
Text 2: Heat Related Mortality

Percent change in annual heat-related deaths of adults over 65 years old in 1990-1999 compared to 2014-2023

Compares with counterfactual scenario in which temperatures are unchanged from baseline values

Estimated change in heat-related mortality | Expected change if no temperature change

Percent change in annual deaths: -50% 0% 50% 100% 200%



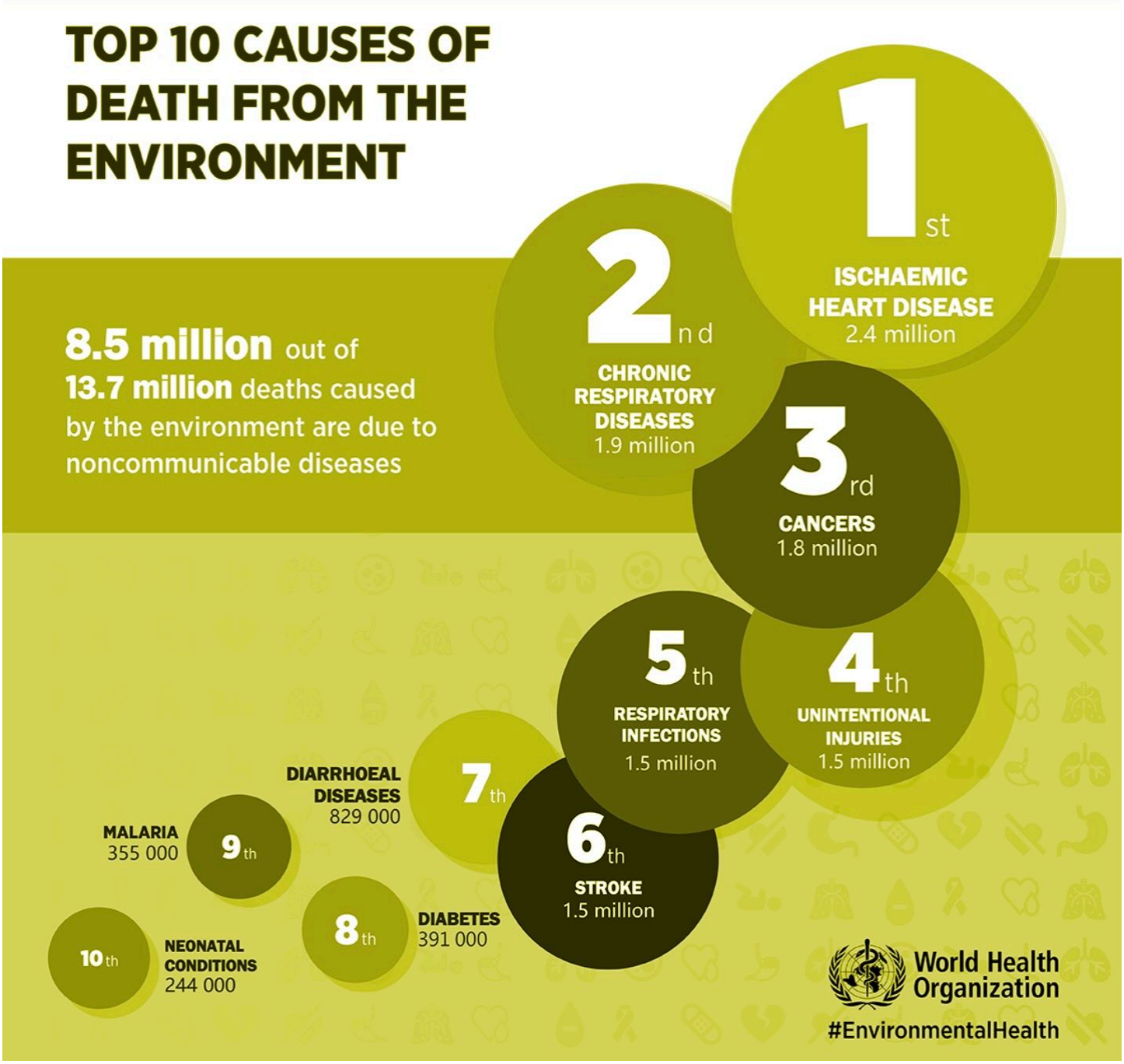
Important Details

1. _____

2. _____

3. _____

Text 3: Environmental Impacts on Human Health



Important Details

1. _____

2. _____

3. _____

Text 4: The Biodiversity Crisis Video

Important Details

1. _____

2. _____

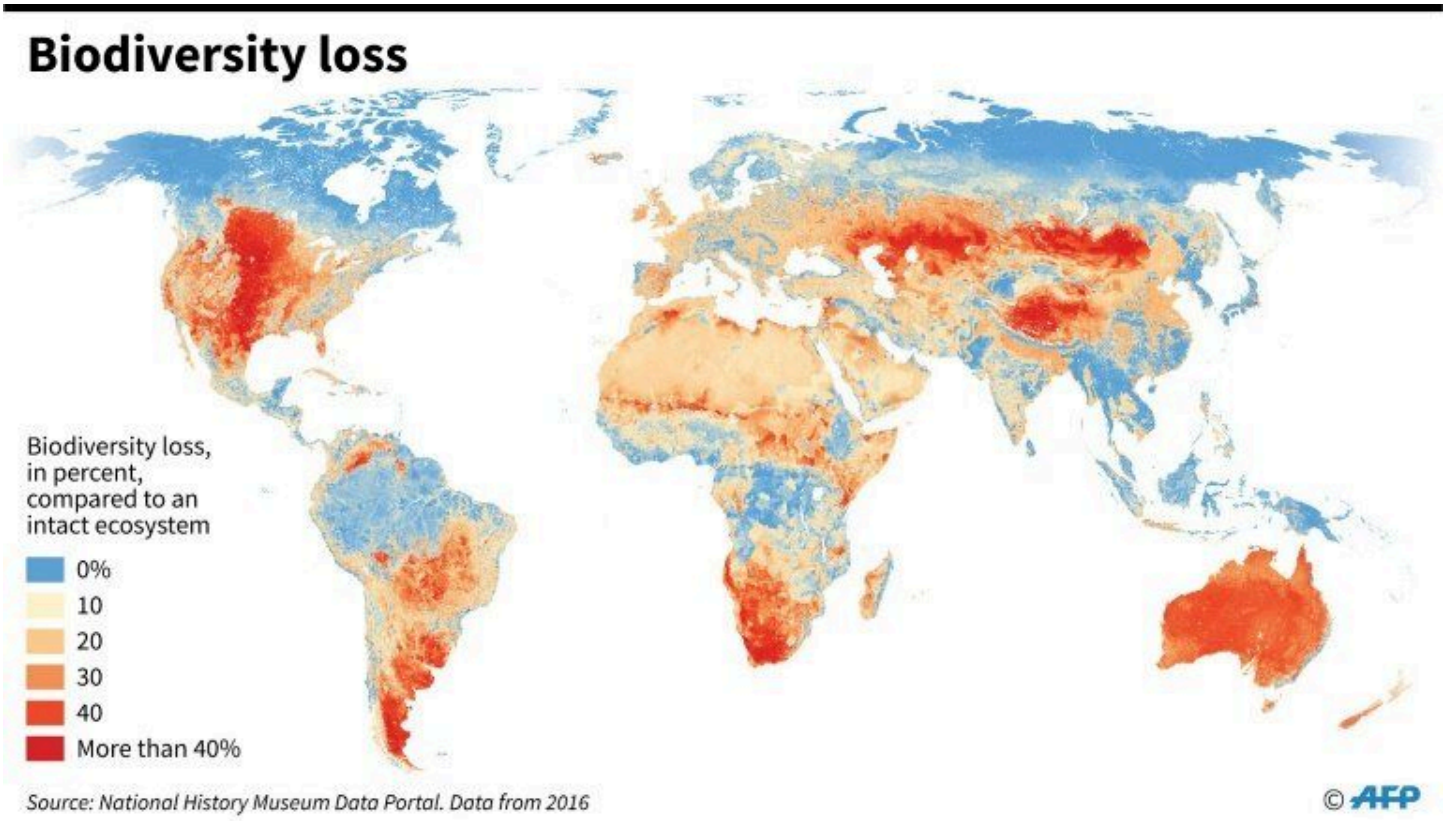
3. _____

Text 5: Percent of Biodiversity Loss Globally

Biodiversity refers to the variety of life, encompassing all living organisms from the smallest bacteria to the largest ecosystems; essentially, it's the different kinds of life found in a particular area or on the planet as a whole.

An intact ecosystem refers to an ecosystem that has not had its biodiversity impacted by human activity.

The map below shows the percent of biodiversity remaining in each region when compared to the biodiversity of the region if it were still fully intact (never touched by humans).



Important Details

1. _____

2. _____

3. _____

Important details our group surfaced from texts 1-5 (provide at least 5):

1. _____

2. _____

3. _____

4. _____

5. _____

Overall Story of the Phenomenon (based on group discussion):

Use details from above to tell the story of the phenomenon.

Introducing the Performance Task

Solutions for Environmental Sustainability

Environmental sustainability is the practice of managing natural resources in a way that meets the needs of the present without compromising the ability of future generations to meet theirs. It aims to balance ecological, economic, and social goals.

In this unit, you will explore the environmental issues caused by human activities and potential solutions to address them. You'll use what you learn to create and test models that help solve the negative effects these activities have on both human health and the environment. You'll also evaluate and improve these solutions to find the ones that best address the interconnected health of humans and nature, while considering practical limitations and trade-offs in the real world.

Developing Initial Solutions

Individually develop an initial model for how the solution idea your group decided to focus on will address one or more of the problems related to challenges associated with human health and biodiversity that surfaced during Tell the Story. Be sure to include annotations in your model that explain how the solution idea addresses one or more of the problems.

Description of your Model:

Return to the Performance Task: Burning Fossil Fuels

Reducing the Impacts of Burning Fossil Fuels

Restate how the emissions from burning fossil fuels are causing problems:

Explain how these problems relate to the overall problem of global death from environmental causes:

Analyze the Possible Solutions

Solutions the Class has Evaluated	What parts of the problem does it address?	What parts of the problem does it not address?	What are some constraints / tradeoffs?
Nuclear Energy			
Restoration of Coastal Ecosystems			

Zones of Limited Emissions			

Based on everything you have learned in this sequence, what solution (or solutions) would you recommend in order to both address the problems caused by burning fossil fuels and the larger problem of deaths from environmental causes? How would that solution or solutions work to reduce the impacts of human activities?

Return to the Performance Task: Land Use and Biodiversity 5E

Reducing the Impacts of our Land Use

Restate how changes to land due to human activity are causing problems:

Explain how these problems relate to the overall problem of global death from environmental causes:

Analyze the Possible Solutions

Solutions the Class has Evaluated	What parts of the problem does it address?	What parts of the problem does it not address?	What are some constraints / tradeoffs?
Green Corridors			
Reforesting or Stopping Deforestation			

Green Roofs			

Based on everything you have learned in this sequence, what solution (or solutions) would you recommend in order to both address the problems caused by human land use and the larger problem of deaths from environmental causes? How would that solution or solutions work to reduce the impacts of human activities?

Revisit the Performance Task: Mining

Reducing the Impacts of Mining

Restate how mining is causing problems:

Explain how these problems relate to the overall problem of global death from environmental causes:

Possible Solutions

Solutions the Class has Evaluated	What parts of the problem does it address?	What parts of the problem does it not address?	What are some constraints / tradeoffs?
Renewable Energy			
Mine Reclamation			

Regulation of Sustainable Practices			
Reusing Mining Waste			

Based on everything you have learned in this sequence, what solution (or solutions) would you recommend in order to both address the problems caused by mining and the larger problem of deaths from environmental causes? How would that solution or solutions work to reduce the impacts of human activities?

Unit Closing: Global Impacts of Solutions

Open this En-ROADS Simulation of contributions to global greenhouse gas emissions.

In the table below, list each solution we have considered in this unit. Using the simulation, find the variable(s) that would be impacted by the solution described, and state if the solution would increase or decrease that factor.

Solution	Variable(s) Impacted by the Solution	Increase or Decrease

Explore the model by moving the sliders to observe how each of these solutions could impact greenhouse gas emissions over the next 75 years.

1. How does breaking the total problem of deaths from environmental causes into smaller pieces help us consider solutions?

2. Which single solution has the greatest impact on reducing the total greenhouse gas emissions in this timeframe?

3. Find a combination of three factors that combine to reduce greenhouse gases the most. How much can three solutions combined potentially reduce greenhouse gas emissions? How much will it reduce the projected temperature change?

4. How do these solutions work together to jointly tackle greenhouse gas emissions?

5. If all of these solutions were employed, how much could greenhouse gas emissions be reduced? How much will it reduce the projected temperature change?

Decide what to do!
Based on the benefits, costs, trade offs, and constraints that you've considered over the course of this unit, what solutions or combinations of solutions would you prioritize?

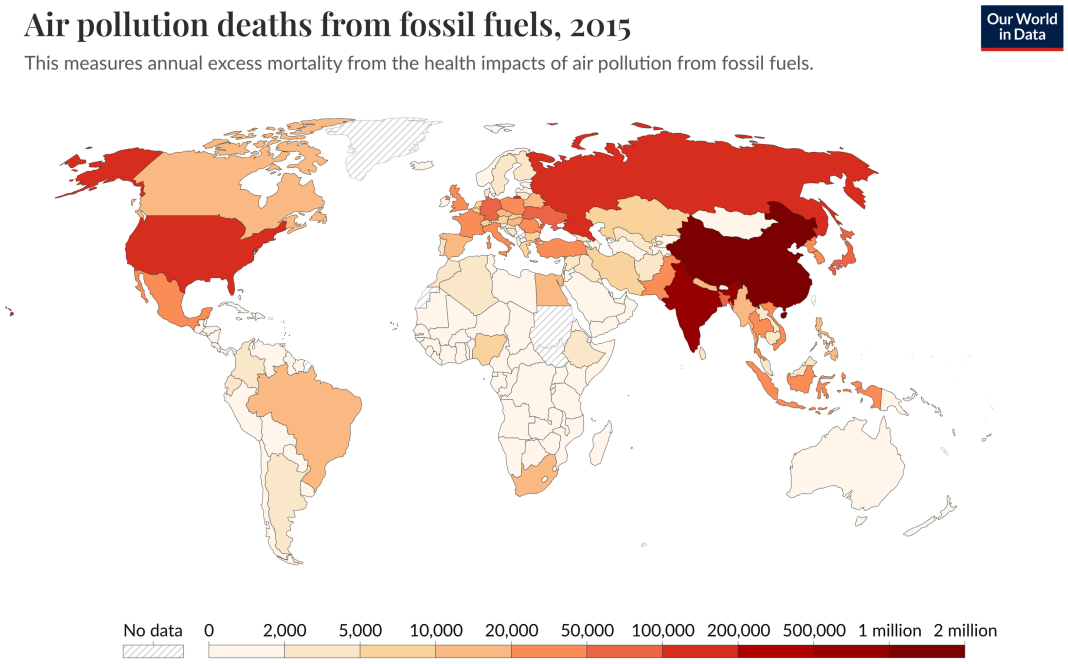
Burning Fossil Fuels 5E

Unit 6 Solutions for a Sustainable Future	Earth and Space Science
Student Name:	

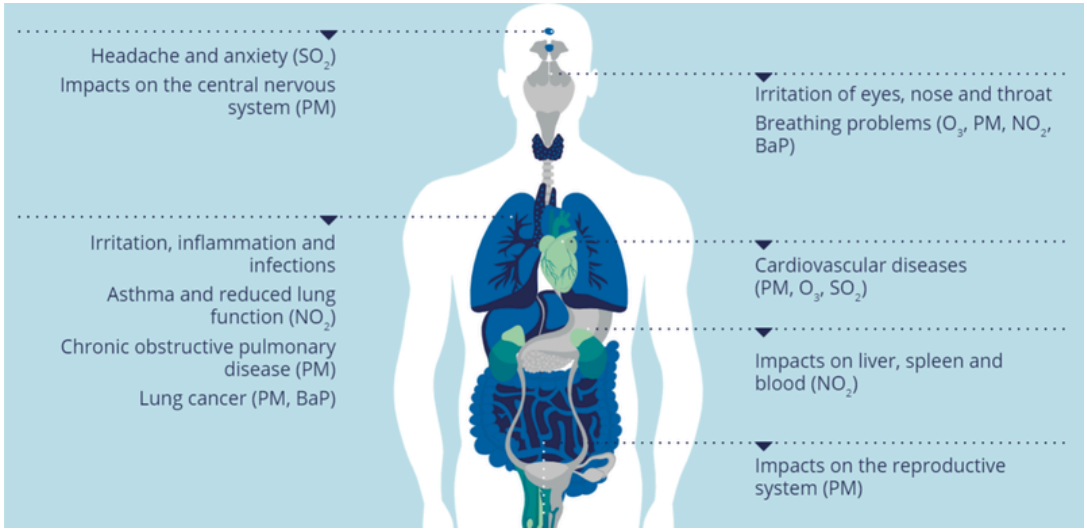
Death from Fossil Fuels

Introduction:
In the Unit Launch, we saw numbers of environmentally caused deaths globally. These deaths were not distributed evenly. In this sequence, we will examine one potential contributing factor to these types of deaths in order to refine solutions to minimize negative outcomes.

Examine the images below, then note your observations, thoughts, and questions in the See-Think-Wonder organizer that follows.



NO_2 = nitrous oxides PM = particulate matter, including Black Carbon
O_3 = ozone SO_2= sulfur dioxide CO = carbon monoxide



See-Think-Wonder

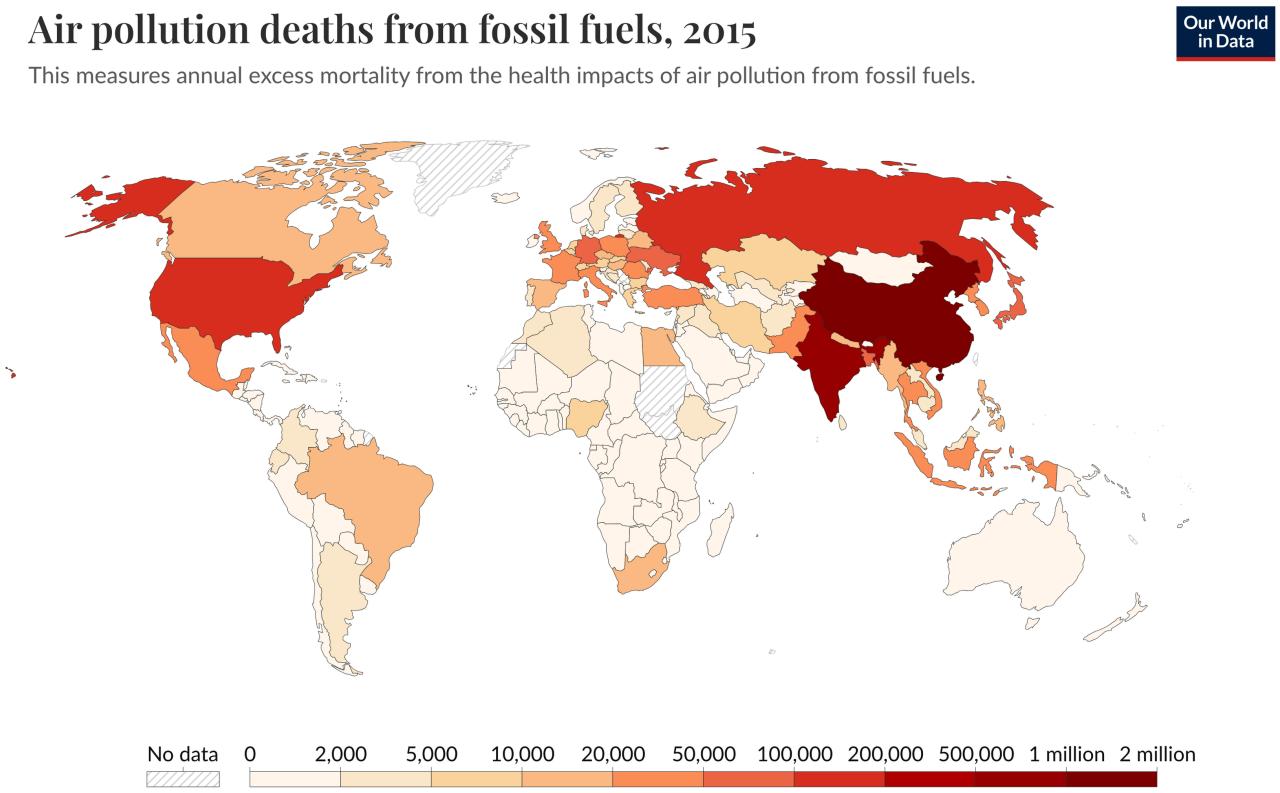
Use the graphic organizer below to record your ideas.

See What did you observe in the video and the graph?	**Think** What do those observations make you think about?	**Wonder** What questions do you have?
What do you notice about the distribution of deaths from fossil fuel air pollution?		
What do you notice about the pollutants emitted by cars and power plants?		
What do you notice about the relationship between pollution and health impacts?	Why do you think these deaths are related to fossil fuels?	

Fossil Fuel Air Pollution

Part 1: Why do different parts of the world have different rates of death from fossil fuel air pollution?

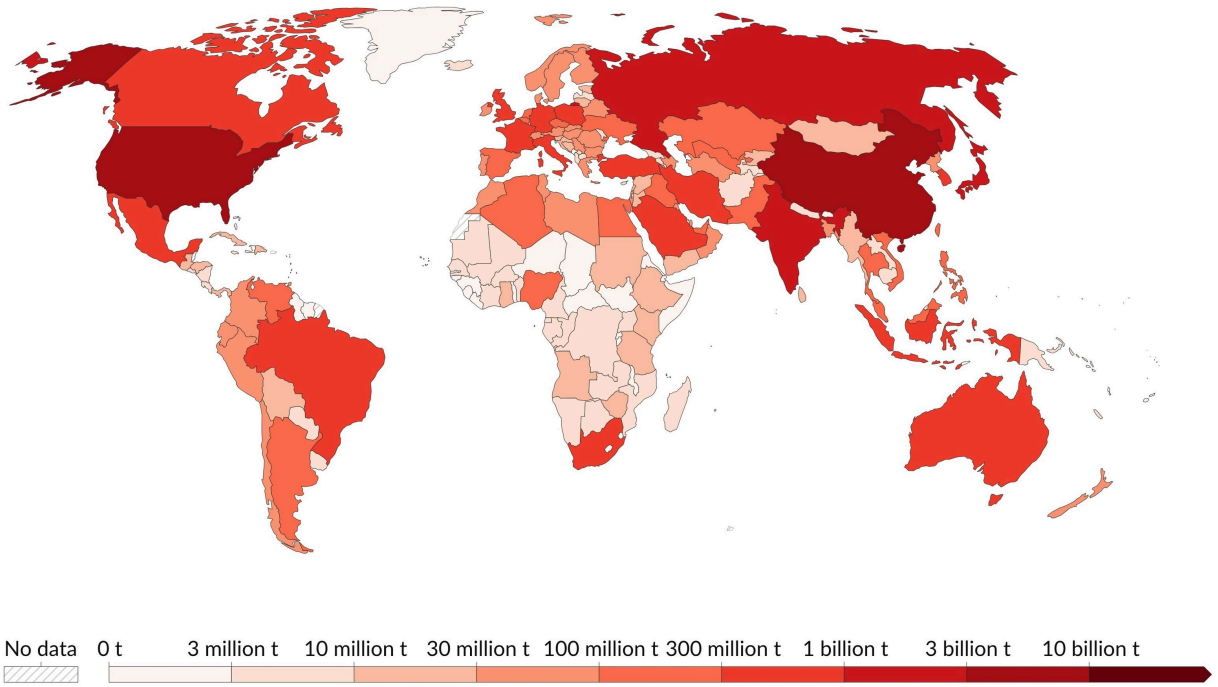
Directions: observe the two maps below. Compare and contrast them by answering the questions below.



Annual CO_2 emissions, 2015

Carbon dioxide (CO_2) emissions from fossil fuels and industry[1]. Land-use change is not included.

Our World in Data



Data source: Global Carbon Budget (2024)

OurWorldinData.org/co2-and-greenhouse-gas-emissions | CC BY

1. How do annual CO2 emissions compare air pollution deaths from fossil fuels?

2. While CO2 does not directly cause health issues, what connection does CO2 have to pollution that does cause health problems and death?

Calculate your carbon footprint using the ESS.U6.L1.Explore1.VID002 , and then answer the questions below.

3. Based on the questions the calculator asked you, what types of activities and actions impact your carbon footprint?

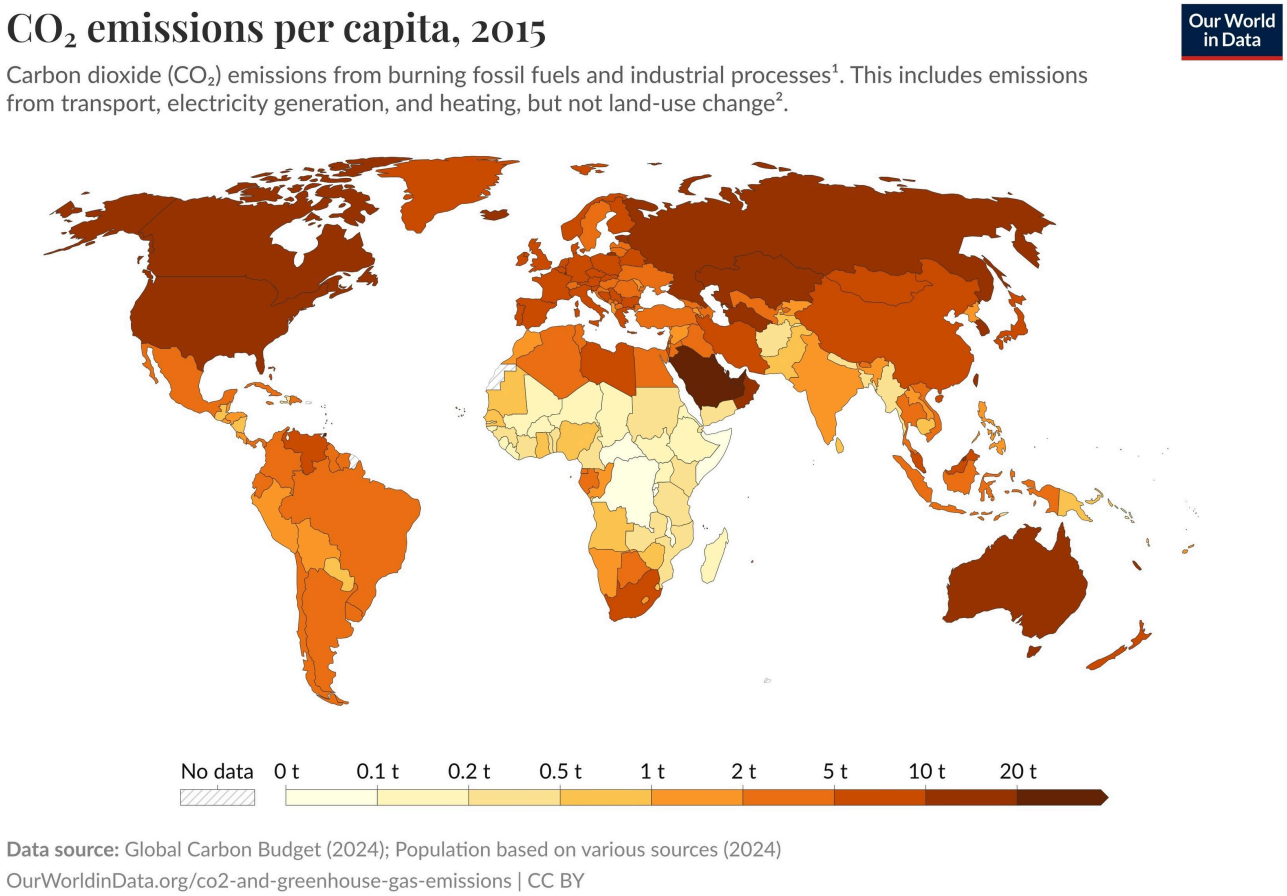
4. What do you think these activities share, and why are they causing carbon footprints?

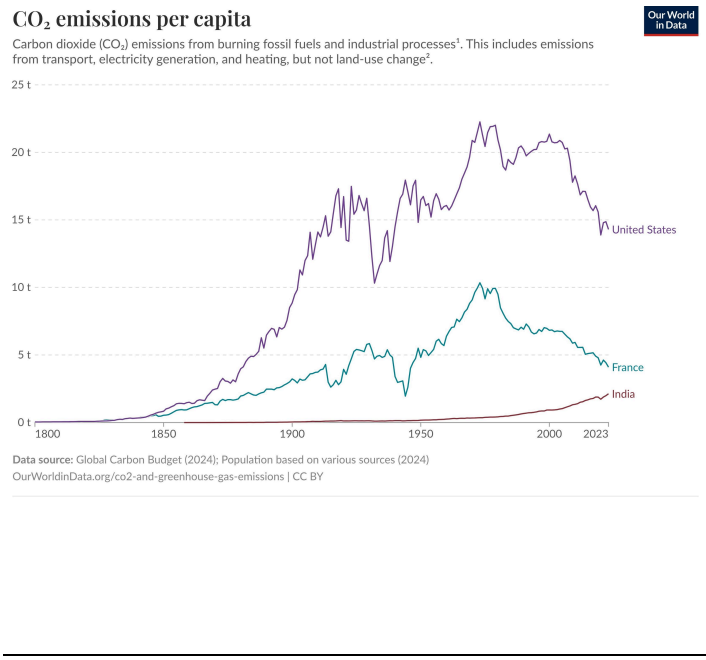
5. Based on what we've already learned, what other emissions do you think are released when carbon footprints are large?

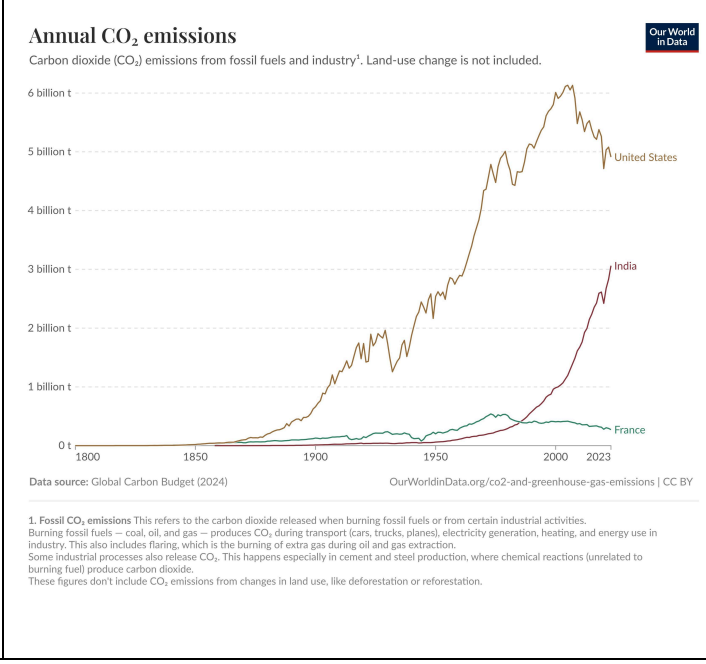
6. If carbon footprints were reduced, how do you think that would impact air pollution in those areas?

Examine three countries with very different numbers of deaths from air pollution resulting from air pollution: India, France, and the United States. Observe the data below and answer the questions below.

***Note: annual refers to the total emissions of the whole country, while per capita means the amount per person (on average).**







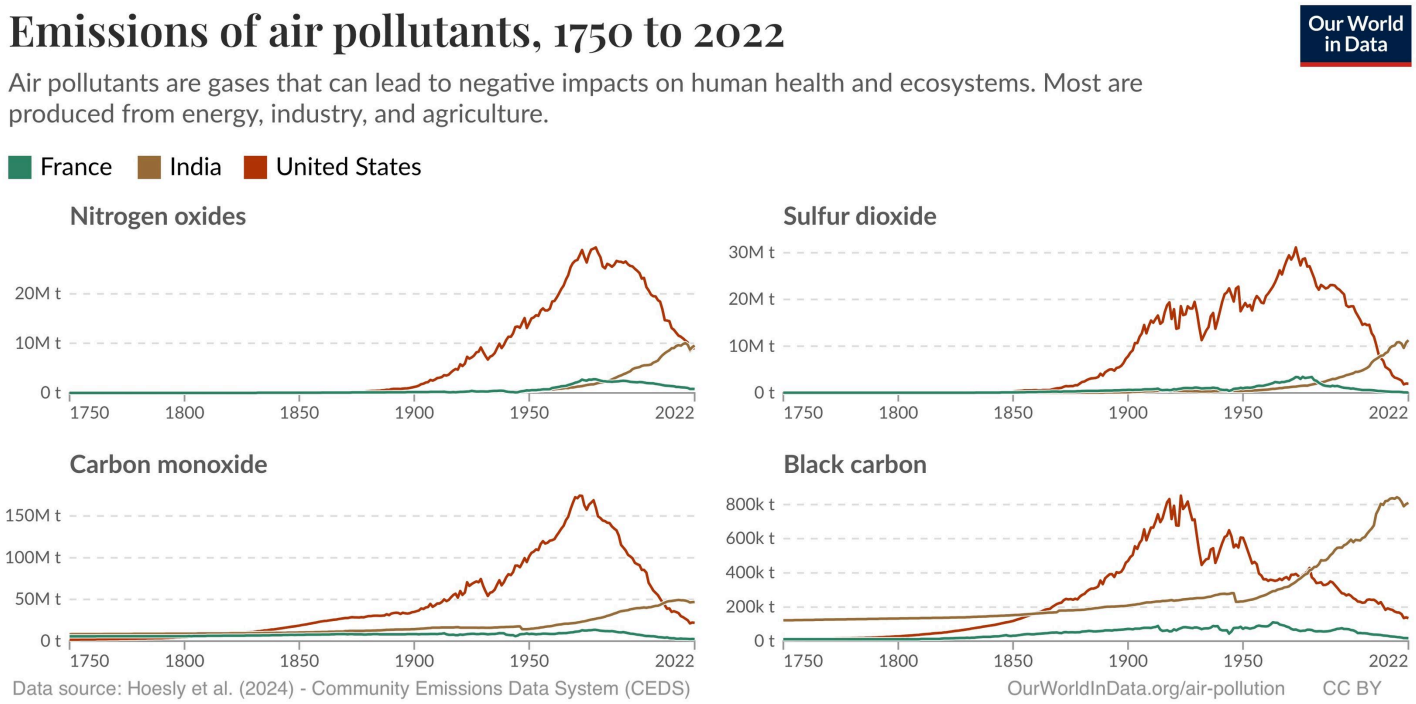
Predict:
Using what we learned about the connection between CO2 emissions, use of fossil fuels, and air pollution, answer the following questions:

1. Based on this information, how do you think air pollution differs between the United States, India, and France?

2. How do you think health outcomes differ between the United States, India, and France?

Part 2: How does fossil fuel pollution in the United States compare to other countries, and why?

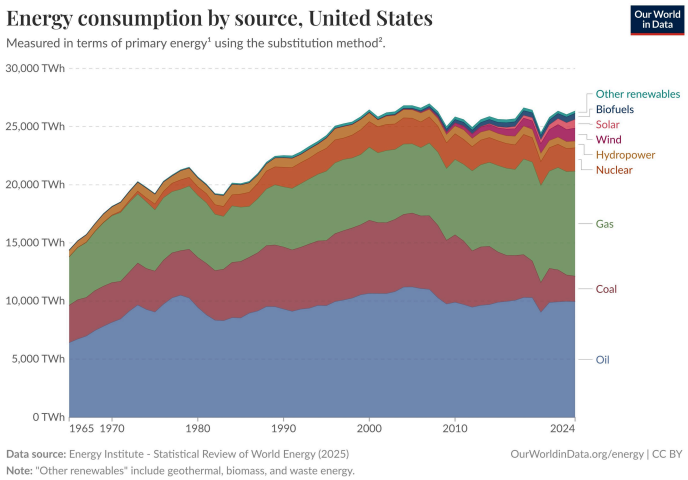
Observe the changes in pollution levels in India, France, and the United States from 1750 to 2022, then answer the questions below and fill in the see-think-wonder at the end of this section. Remember, some of these pollutants, like NOx, CO, and SO2, come almost entirely from burning fossil fuels; while others, like black carbon (a type of particulate matter), come largely from burning fossil fuels but can also come from other sources.

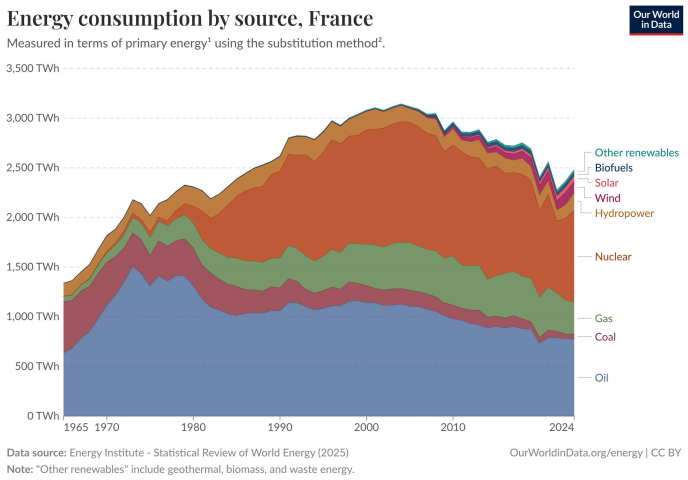


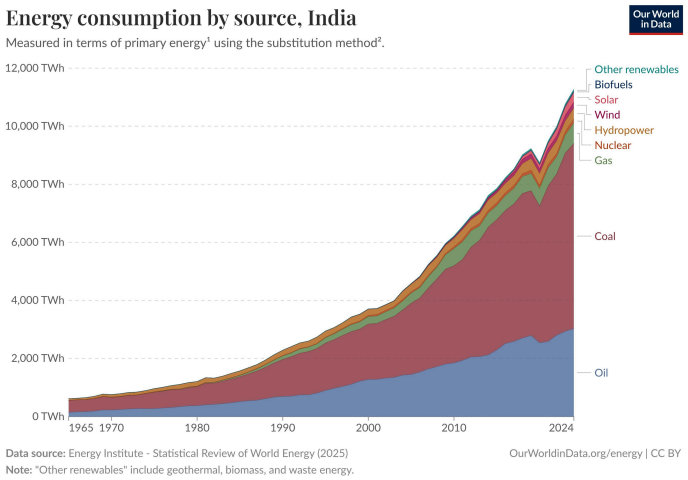
How have pollution levels changed from 1750 to 2022 in each country for each of the following pollution types?

	United States	France	India
NOx			
SO2			
CO			
Black Carbon (a type of particulate matter)			

Compare the types of energy used in the United States, India, and France, answer the questions below.







Note:

Oil, Gas, and Coal are all fossil fuels

Hydropower, wind, solar, and biofuels are renewable energy sources

Nuclear energy is not considered a renewable energy source, but also does not involve fossil fuels

1. What are the top two energy sources used by each country?

United States:

France:

India:

---

2. How would you describe each country's reliance on fossil fuels compared to other energy sources?

---

3. How do you think these differences in energy sources contribute to pollution levels in each country?

Making Sense of the Fossil Fuel Air Pollution Investigation

See-Think-Wonder

Directions: Refer to the data from the Fossil Fuel Air Pollution investigation to fill in the table

See **What pattern did you observe in the data?**	**Think** **What could this pattern mean?**	**Wonder** **What questions do you have about this pattern?**
What do you notice about the changes in pollution levels in the United States, India, and France?		
How have the changes in emissions been different between the United States, India, and France?		
What do you notice about the differences in energy sources in the United States, India, and France?	How do you think those differences might affect pollution?	

Refining Solutions for Fossil Fuel Air Pollution

What solutions best address this inequity in air pollution deaths?

Deaths from air pollution resulting from burning fossil fuels depend on several factors: the amount and types of fossil fuels used, the health of the population (including things like smoking and dietary habits), access to healthcare, and exacerbating environmental factors like heat. No single solution can solve each of those factors, but different solutions can be combined to reduce the problems overall.

In this part, you will explore a solution being used in France and refine it to work in the United States. To do so, follow the Read-Generate-Sort-Solve steps below. First, you will summarize the problem and differences between France and the United States. Then, you will read texts and answer questions. Then, in groups, you will generate ideas to refine a solution of nuclear energy to apply to the United States, and sort your ideas for the best ones. Finally, you will generate a refined solution and analyze its impact on the problem at hand.

Initial solution thoughts:
Based on what you saw about air pollution deaths, distribution of those deaths, and distribution of resource use globally:

1. Describe the problem in need of solving that you explored.

2. In this context, how are France and the United States different?

3. Earth's systems include the hydrosphere (water), atmosphere (air), biosphere (living things), geosphere (rocks and minerals), and cryosphere (frozen places). Which systems do you think are affected by this problem? Support your answer.

Read-Generate-Sort Solve Organizer

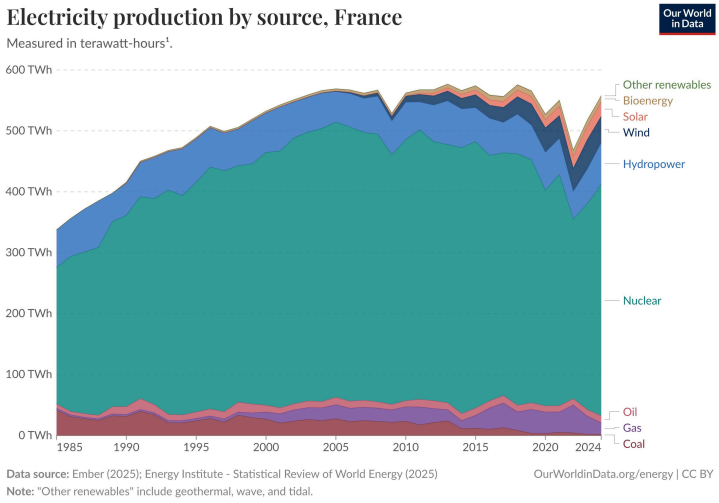
Read:
Air pollution and climate change are two pieces of the same problem, but they are typically addressed separately. They should be tackled jointly, with a focus on protecting peoples' health – particularly in low- and middle-income countries – to strengthen human capital and reduce poverty.

Air pollutants and greenhouse gases often come from the same sources, such as coal-fired power plants and fossil fuel burning vehicles. A World Bank study found that pollution from the burning of certain fossil fuels, such as coal combustion, is among the most toxic because it includes black carbon. Particles from these sources are more damaging to health than particles from most other air pollution sources. Given that these sources are also key contributors to climate warming, tackling air pollution from these sources also mitigates climate change.

Since the 1970s, France, which has almost no local natural gas, oil, or coal to burn, has relied heavily on nuclear energy to meet its electricity needs. In fact, approximately 70% of France's electricity comes from nuclear power, which harnesses the heat released during the process of nuclear fission to generate electricity. This energy source is popular in France: electricity is relatively inexpensive to generate with nuclear power plants, so France is able to export electricity to other countries; the industry employs more than 200,000 people, and because nothing is being burned, there is no release of greenhouse gas or other air pollutants. As a result, pollution is lower from nuclear energy than some other types of energy generation.

However, nuclear power plants do produce radioactive waste, which must be carefully stored to prevent dangerous leakage into the environment. Additionally, building new nuclear reactors is expensive, and locations must be considered carefully to minimize the risk of accidents.

Source, Source 2, Source 3, Source 4



1. How does nuclear energy help solve the problem you identified above?

2. How does it stabilize (help) or destabilize (hurt) the systems you identified above?

3. What constraints is the solution trying to work within?

4. What are the costs and benefits of the solution? Trade Offs?

The United States has a very different perception of nuclear energy. In the 1960s, the United States began operating nuclear power plants, and since 1990, nuclear power has generated about 20% of the country's electricity. However, the number of nuclear reactors operating in the United States has decreased since 1990, and new ones are not being built quickly enough to replace them. A little over half of Americans support increasing our nuclear energy capacity, but actions have not followed.

The resistance to nuclear energy comes from several different areas. First, building new nuclear power plants is very expensive.Two new power plants, one of which opened in Georgia in April 2024, and the other of which is still under construction, cost approximately $35 billion to construct. Second, there have been three large accidents at nuclear power plants: The Fukushima nuclear disaster in 2011, the Chernobyl disaster in 1986, and the Three Mile Island accident in 1979. While all three were contained, concerns about nuclear power safety still weigh on public perception. Third, nuclear energy generation produces radioactive waste, which can cause health problems and harm to ecosystems if left uncontained. Finally, the United States has other energy resources, including reserves of coal and natural gas, which have disincentivized transitioning to other energy sources like nuclear.

These problems are not impossible to solve.

- Coal plants can be converted to nuclear generators, reducing construction costs
- Accidents are rare, and all resulted from mismanagement of nuclear energy plants; and the number of resulting deaths has been small in comparison to those from fossil fuel energy plants
- Storage of nuclear waste is already happening in the United States: waste is contained safely in cooling pools and concrete-and-steel containers.

1. What are the constraints in the United States that don't exist in France?

2. What criteria would a solution have to fulfil in order to be useful in this context?

3. If a solution could not meet all the criteria for it, which would be most important? Prioritize your criteria from most to least important.

Generate: Brainstorm how nuclear energy generation could be increased in the United States. Consider how the technology or approach would have to be modified in order to address cultural attitudes towards nuclear energy and concerns of cost, safety, and aesthetics.

Name: _____	**Name: _____**	**Name: _____**

Sort: Discuss each solution or idea and ☆star☆ the ideas that seem the most useful

Solve: Write your group's response to the prompt "How could nuclear energy be refined or modified in order to fit the needs of the United States?" Be sure to include how these refinements would address cultural attitudes towards nuclear energy and concerns of cost, safety, and aesthetics.

Evaluate your refinements to nuclear energy implementation by responding to the prompts below:

4. What barriers might nuclear energy face in the United States? Do your refinements help overcome these barriers?

5. Would applying nuclear energy to this new location and context stabilize or destabilize the natural systems you selected? Support your answer with evidence from this 5E.

6. Weigh the costs and benefits of this technology. Does applying this solution to the United States make sense?

7. Would using nuclear energy solve all of the problems with air pollution and health outcomes in the United States? If not, what issues would still remain?

8. Consider applying this solution to India. Do you think your refinements would work in this context? How do you think the cost/benefit ratio would be different in India compared to the United States?

Summary Task

Today we completed the first class consensus discussion of the unit! How did it go?

1. One thing that went well in the discussion:

2. One thing we can improve the next time we have a discussion:

3. One person who helped me learn today:

What did you learn from this person?

4. One idea that I contributed to my group or my class:

Explain what you know about the following questions, based on what we discussed today:

5. Explain how considering criteria, constraints, and tradeoffs helped you think about ways to refine this solution to maximize benefits and minimize costs.

6. What role do solutions play in stabilizing or destabilizing natural systems, and how does that contribute to maintaining biodiversity and human health?

Fossil Fuel Emissions in Global Systems

Part 1: How does carbon move between reservoirs?

In the first part of this 5E, we looked at the impacts of polluting emissions from burning fossil fuels, which have direct effects on human health. In this part, we will look at the impacts of carbon dioxide itself on global systems, biodiversity, and human health.

Carbon dioxide doesn't directly impact human health, however, it does cause large-scale changes to global systems that impact environmental and human health as a result.

In this activity, you will explore how carbon moves between systems and analyze the impact that burning fossil fuels has had on the storage of carbon dioxide.

Open the interactive Carbon Dioxide and the Carbon Cycle and complete the table below based on the *Carbon Cycle Reservoirs* tab.

Carbon Reservoir	Brief Description	Amount of Carbon Held measured in Gigatons (Gt)

Toggle between the *Carbon Cycles Reservoirs* to the *CO2 and the Atmosphere* (both 300 years ago and present day) tab and look at carbon reservoirs and its flow 300 years ago.

Analyze the model by determining the different components of the system it shows.
Note: Models represent systems and all the components of them. In this model, the "system" represented contains all the parts of the carbon cycle, which includes several smaller "systems" including the geosphere (Fossil Fuels and Rocks), hydrosphere (Ocean), biosphere (Living Things), and atmosphere. In this case, the larger system includes carbon moving between the systems within it.

1. The system model boundaries: what carbon reservoirs are included in this model?

2. The initial conditions: How much carbon is in each part of the system before humans interfere?

3. The inputs and outputs 300 years ago: How much CO2 is being added to each system and how much is being removed?

Atmosphere:	In:	Out:	Net Change:
Biosphere:	In:	Out:	Net Change:
Hydrosphere:	In:	Out:	Net Change:

4. The inputs and outputs in our present day: How much CO2 is being added to each system and how much is being removed?

Atmosphere:	In:	Out:	Net Change:
Biosphere:	In:	Out:	Net Change:
Hydrosphere:	In:	Out:	Net Change:

5. Relationships that determine the interaction: which parts of the system interact to exchange or move carbon dioxide?

Using the illustration and chart in the tab *CO2 and the Atmosphere,* in the space below, illustrate how carbon moved between reservoirs 300 years ago. In your illustration, include:

- The systems the carbon is moving between
- The amount of carbon moving
- The proportion of carbon moving in each direction
- If the system is stable or unstable and why

Switch the view to look at carbon flow in the present day. Using the illustration and chart, in the space below, illustrate how carbon moves now. In your illustration, include:

- The systems the carbon is moving between
- The amount of carbon moving
- The proportion of carbon moving in each direction
- If the system is stable or unstable and why

Analyze:

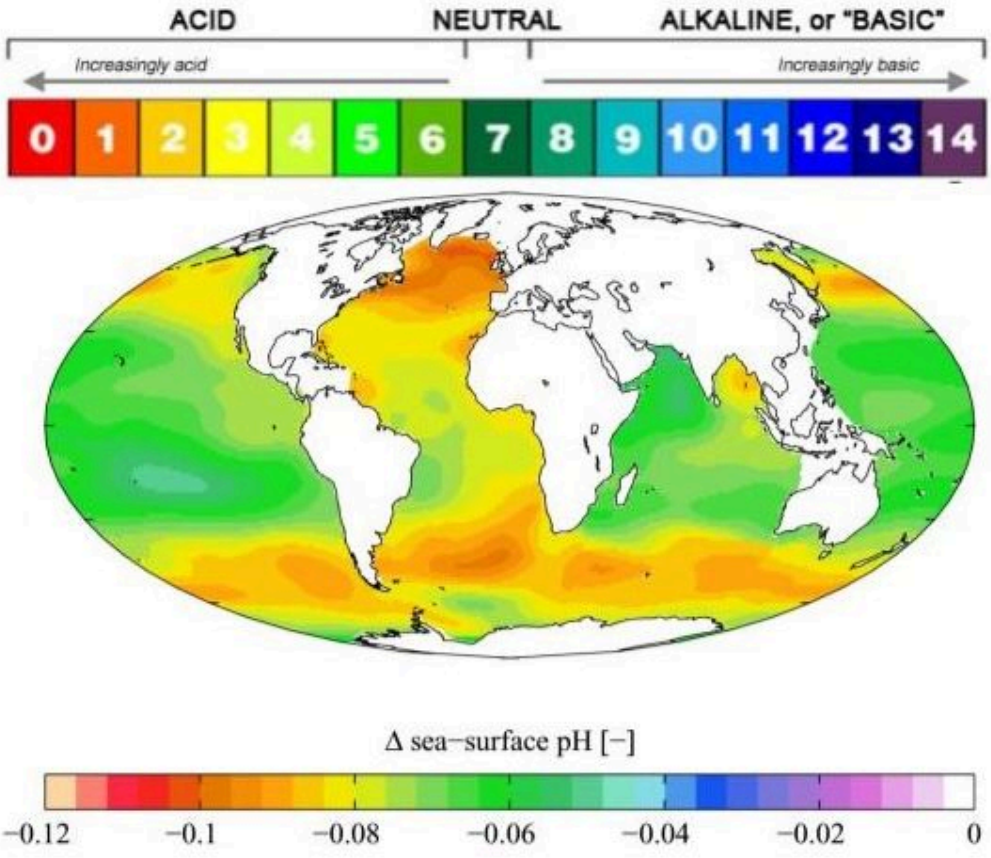
1. Which reservoirs are holding more carbon now than they were 300 years ago?

2. How did human activity change the relationships between the geosphere, atmosphere, the biosphere, and the hydrosphere?

Part 2: How does excess carbon impact natural systems?

Introduction

Before the industrial revolution in the early 1800s, the ocean had been slightly basic for the previous 600,000 years, with a pH of about 8.2. But, since the industrial revolution, the pH has changed to 8.1. That may not seem like a big change, but it is a 30% increase in acidity.



In this activity, you will model the impact of increasing carbon dioxide in oceans by adding carbon dioxide from your breathing to a cup of water.

Materials

- 2 beakers or cups to hold 100 ml of seawater
- Straw
- Blue or red sticky dots (or colored pencils)
- Timer
- pH meters or pH paper
- If using pH meters, distilled or tap water for rinsing off pH meters

Procedure

1. Measure the initial pH of the seawater in each beaker.
2. Place a blue dot on one beaker. This beaker will be blown into for 10 seconds.
3. Place a red dot on the other beaker. This beaker will be blown into for 20 seconds.
4. One member of the team will serve as the timer; the second member will use the straw to blow gently, but consistently, into the beaker for the correct amount of time.
5. Start by blowing into the first cup for 10 seconds. At the end of the time period, record the final pH of the seawater in the beaker.
6. Rinse your pH probe, or put your pH strip to the side.

7. Next, blow into the second cup for 20 seconds. At the end of the time period, record the final pH of the seawater in the beaker.
8. Rinse your pH probe, or throw away your pH strips, and clean up as directed by your instructor.
9. **Determine the CO_2 concentration:** Using dots of the appropriate color (blue for 10 seconds, red for 20 seconds), place one dot on Graph A: pH of Seawater Versus Atmospheric CO_2 Concentration.
10. **Determine date of CO_2 concentration:** Using the atmospheric CO_2 concentration determined in Graph A, place a second dot (of the same color) on Graph B: Projected Dates of Atmospheric CO_2.

Ocean Acidification Data Table

Time	pH	Atmospheric CO_2 concentration at that pH	Year in which experimental atmospheric CO2 concentration will be reached
0 seconds			
10 seconds			
20 seconds			

Analysis

1. How are atmospheric carbon dioxide and pH levels in the ocean related?

2. The beakers were blown in for 10 and 20 seconds. Describe the patterns or trends you observed as you compare the data from the different lengths of time.

See-Think-Wonder
Directions: Refer to the Fossil Fuels Emissions in Global Systems Investigation to complete this table.

See **What pattern did you observe in the data?**	**Think** **What could this pattern mean?**	**Wonder** **What questions do you have about this pattern?**

What do you notice about where carbon is stored?		
What do you notice about how carbon moved between reservoirs 300 years ago?		
What do you notice about how carbon moves between reservoirs now?	What do you think causes the change from 300 years ago to now?	
What did you notice about the relationship between carbon dioxide and pH of the water?	How do you think that impacts ocean life?	
How does pH continue to change over time as CO2 is added?	How do you think this trend relates to the real world scenario?	

Diagramming the Impacts of CO2

Introduction: As you saw in the explore phase, there are increasing amounts of carbon in the atmosphere, biosphere, and hydrosphere as a result of human activities. In this part, we will see the impacts that change has had on the ocean, and then diagram how the different systems and effects we've observed so far connect with each other.

Ocean Acidification and Human Health

Many people know that atmospheric carbon dioxide is a greenhouse gas, which contributes to warming temperatures around the world. Warming the air also warms the oceans, which can cause organisms to die off. Beyond the temperature effects, carbon dioxide interacts with sea water directly. Atmospheric carbon dioxide (CO_2) is in equilibrium with dissolved carbon dioxide in seawater. When the atmospheric CO_2 level increases, more CO_2 is absorbed by the oceans. Scientists estimate that something like a quarter to a third of all human-created CO_2 emissions is absorbed by the ocean. When carbon dioxide dissolves in the water at the ocean's surface, it reacts with water to form carbonic acid. Carbonic acid is the same chemical that gives carbonated beverages their fizz.

Acidity is measured in pH; as the acidity increases, the pH decreases. Changing the pH of the environment has a large impact on chemical reactions and life processes, which in turn affect human health.

One thing that happens when the ocean becomes more acidic is that the free hydrogen ions that make the ocean acidic combine with dissolved carbonate ions. Without the extra hydrogen ions, the carbonate ions would combine with calcium ions, which would make a substance called calcium carbonate. Calcium carbonate is the shells and exoskeletons are made of for corals, clams, oysters, plankton, sea urchins, barnacles, crabs, and lobsters. With the acid stealing carbonate away, less calcium carbonate can form and the animals that use it to build their shells are not able to grow as quickly and are more at risk of dying.

Several populations of oysters around the world have collapsed as ocean acidification kills larvae. Coral reefs have also died as a result. These species are foundational in many ecosystems; when these species experience negative impacts, it affects the entire food web that relies on them, resulting in decreases of several fish species. Humans rely on many of those species for food. Over 7.8 million people get 15% of their animal protein from seafood; and some people in West Africa, Asian coastal countries, and many island countries get more than 50% of their animal protein from fish. As ocean acidification increases, these food sources put human populations at risk of malnutrition.

Besides causing species numbers to decline, ocean acidification also changes the nutritional composition of seafood. It has been shown to cause a decrease in fats and proteins in phytoplankton and shellfish, specifically omega-3 fatty acids. Omega-3 fatty acids accumulate up the food chain, eventually ending up in food species for humans. Omega-3 fatty acids are known to reduce the risk of heart disease and reduce inflammation, both of which contribute to causes of death like stroke, cardiovascular disease, and cancers. If ocean acidification decreases the nutritional value of these food species, humans are at increased risk of dying from these other diseases.

Additionally, acidified water can increase the growth of toxic algae that cause blooms called "red tides." During red tides, fish in the area can die and food species become unsafe to eat. The toxins present in these algal blooms can become aerosolized, and people breathe those toxins in, causing respiratory irritation. While the symptoms get better on their own, it can exacerbate asthma and decrease pulmonary function for several days.

Sources: https://pmc.ncbi.nlm.nih.gov/articles/PMC7344635/, https://www.agriculturedive.com/news/oyster-die-offs-future-shellfish-climate-change/706547/

Think-Talk-Open Exchange

1. **Think -** Respond to the prompt individually, in the space below.

How does ocean acidification affect biodiversity and human health?

Discuss your ideas with your group, using Think-Talk-Open Exchange, and then write down any new ideas you have about how ocean acidification impacts biodiversity and human health.

Summary Task

Today we completed the first class consensus discussion of the unit! How did it go?

1. One thing that went well in the discussion:

2. One thing we can improve the next time we have a discussion:

3. One person who helped me learn today:

What did you learn from this person?

4. One idea that I contributed to my group or my class:

Explain what you know about the following questions, based on what we discussed today:

5. Describe how comparing the inputs and outputs of the model in the past and present helped you describe how human-generated greenhouse gases are changing the way carbon is stored in the ocean and biosphere.

6. Explain how using the computational model supported your claims about how human activities have impacted carbon movement between systems.

Using Oceans to Capture Carbon

Now that you have explained how burning fossil fuels impacts multiple systems in different ways, you will read about one potential solution to mitigate some of its negative effects.

Based on the diagram you constructed in Explain 2, where might humans be able to act in these systems to minimize the impacts of burning fossil fuels? Hint: look for one impact arrow in the diagram that you think could be changed with an engineering solution.

Directions:
Read the text below. As you read,

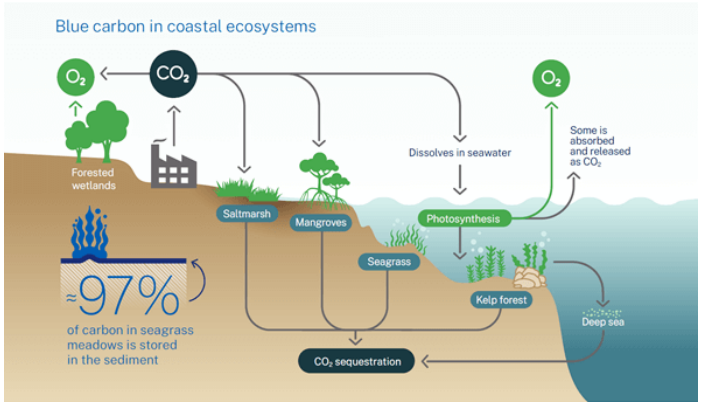
- Underline how coastal restoration impacts systems
- Put a + next to ways it would help solve the problem
- Put a - next to challenges or costs
- Put a ? next to anything you don't understand

Scientists and engineers are working on minimizing the impacts of burning fossil fuels, both by attempting to reduce our reliance on fossil fuels, as we saw in the first explore/explain, and by mitigating the effects of fossil fuel emissions. One potential solution is to restore coastal ecosystems like mangrove forests and seagrass beds, which play a crucial role in removing carbon from the atmosphere.

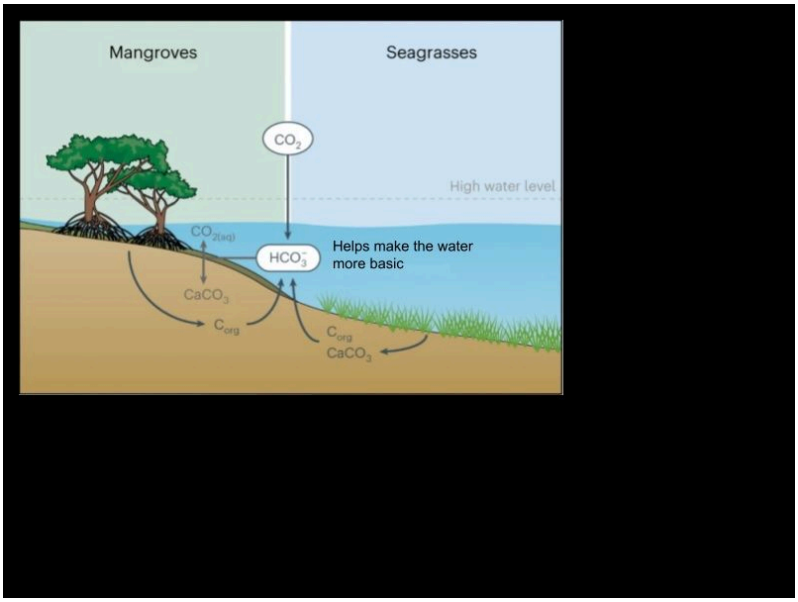
A recent study published in *Nature Sustainability* explores the effects of coastal restoration on the environment. Researchers investigated how helping to restore coastal ecosystems can make use of natural processes that reduce atmospheric carbon.

A mangrove forest

A seagrass bed



Reducing atmospheric carbon dioxide is essential for a stable environment. Artificial carbon removal technologies, like capturing carbon dioxide and pumping it underground, can be expensive and have not demonstrated large-scale effectiveness. Healthy ecosystems capture carbon dioxide through photosynthesis, where it can be stored in plants. However, coastal ecosystems are special because they add more carbon dioxide to the sediment, where it becomes trapped. When organisms in coastal ecosystems die, they decay very slowly and get buried in the sediment, storing that carbon long-term, instead of releasing it back into the atmosphere. As a result, coastal ecosystems are a strong tool for reducing atmospheric carbon dioxide, and in turn reducing the carbon dioxide absorbed by oceans.



Additionally, this slow decay of dead organisms increases the water's pH (making it more basic) which affects dissolved carbon levels. When basic water enters the ocean, it allows the ocean to better offset the acidic effects of the carbon dioxide that it is absorbing. Measurements show that coastal ecosystems generate and send basic water to the ocean. The scientists created models to simulate how restoring mangrove and seagrass ecosystems impacts carbon dioxide absorption. Their findings indicate that both types of ecosystems increase coastal water pH, aiding carbon dioxide mitigation. Unlike carbon stored in plants, carbon captured through changes in ocean chemistry remains for longer periods—over 1,000 years, making it effectively permanent.

Restoring coastal ecosystems offers benefits beyond carbon capture and reduction of ocean acidification, such as enhancing fish habitats and protecting infrastructure by stabilizing coastlines to reduce flooding and erosion. In doing so, it helps maintain biodiversity and also supports human health by stabilizing food populations, nutritional content of seafood, and helping to prevent dangerous red tides.

There is still much to learn about pH's role in carbon storage. Real-world sites have more variables than models can take into account, so future steps include testing model predictions against actual restoration projects. Coastal restoration is also very expensive: some studies put its cost at $80,000-160,000 per hectare (an area of about 2.5 acres). While this is a relatively low cost compared to other technological solutions, funding for these projects is challenging to obtain. Success rates of restoration vary between 38% and 64.5%, measured by the survival of organisms one or two years after restoration, and few restoration sites have ongoing monitoring to measure their continuing success. Nonetheless, restoration work shows promise in capturing and mitigating the negative effects of carbon dioxide on oceans by reducing acidification and protecting the species that humans rely on.

Adapted from source and source

Directions: work in your groups to respond to each prompt below. When you are finished, represent your ideas on the chart paper provided.

Step 1. Use a Model to Analyze the Solution
Use your group's concept map from Explain 2 to analyze the impacts of coastal restoration on the atmosphere, biosphere, hydrosphere, and on human health. How would each system be affected by restoring ocean coasts? You can represent your thoughts using words, models, and/or a diagram.

Step 2. Defining the Problem and Describing the Solution
Use your model analysis and the text to describe the problem that coastal restoration is trying to solve. In your explanation, be sure to include

- What system(s) are impacted by this problem
- How humans have altered the systems
- How coastal restorations work to solve the problem and if they stabilize or destabilize the system(s)

Step 3. Refining the Solution
Describe a way to refine coastal restoration projects. In your refinement, include

- criteria for a successful solution
- constraints on the solution
- any tradeoffs that are inherent to the solution
- How you would alter the solution to better fit the criteria, keeping in mind the constraints and tradeoffs you've described

Step 4. Evaluating the Refinement

Evaluate the efficacy of your refinements by describing

- How the proposed solution would solve the problem
- How the solution would impact the system(s) involved
- The costs, safety, and environmental impacts of your solution

Reflect:
How does this solution impact communities locally?

How does this solution impact communities globally?

Limited Emissions Zones

In 2015, France ranked third in Europe for the most deaths from emissions from cars and trucks. As a result, in 2016, it began an initiative to ban the worst polluting vehicles from the City of Paris by creating Zones of Limited Emissions where only certain cars are allowed from the hours of 8am - 8pm. In later years, it expanded the program to include 15 cities as of 2024.

In order to implement this plan, France created categories to group cars by their emissions levels, and assigned each category a number and color. Cars entering the limited emissions zones must have a sticker stating its category posted on the front windshield.

- **Badge E (Green)**: electric or hydrogen-powered (environmentally-friendly) vehicles
- **Badge 1 (Purple)**: plug-in hybrid or gasoline vehicles registered after December 2010*
- **Badge 2 (Yellow):** gasoline vehicles registered between January 2006-December 2010*, or diesel from January 2011*
- **Badge 3 (Orange)**: gasoline vehicles registered between 1997-2005*, or diesel between January 2006-2010*
- **Badge 4 (Brown)**: diesel vehicles registered between January 2001-December 2005*
- **Badge 5 (Grey):** diesel vehicles registered between January 1997-2000*
- Any vehicles made **before 1997*** are considered "unclassified" and are ineligible to get the sticker.

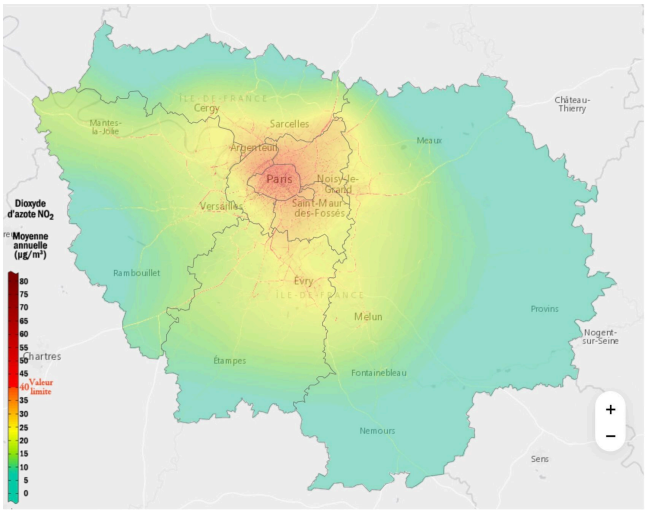
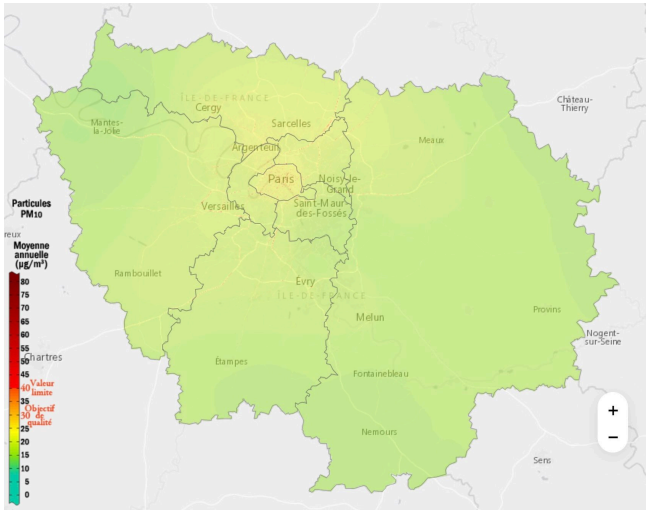
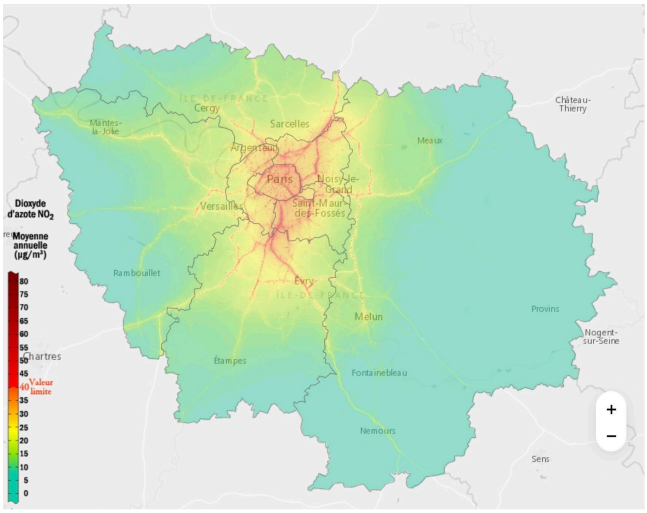
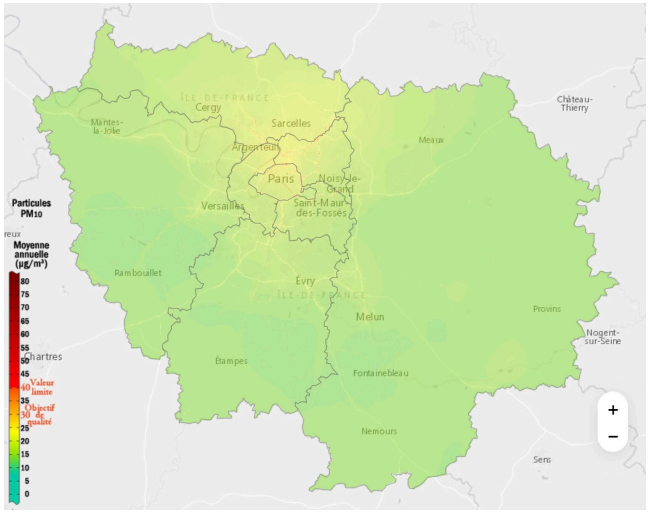
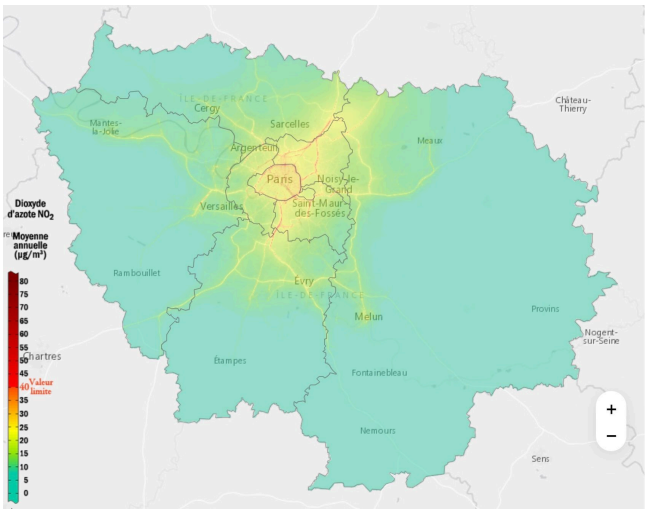
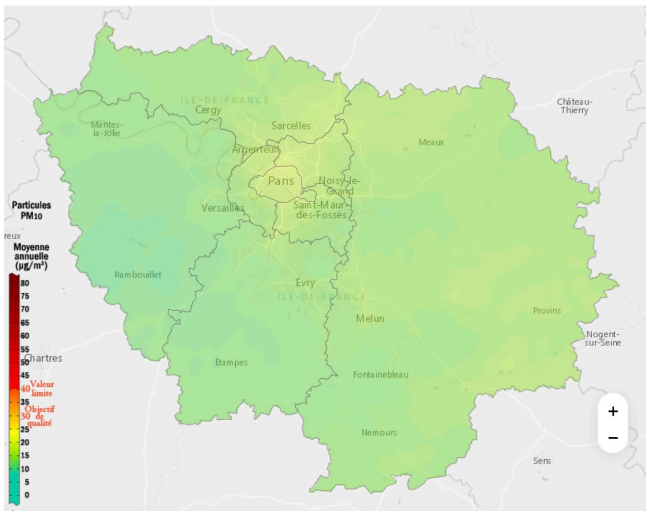
*Note: vehicles are separated by years because registration requirements for vehicle emissions have changed. Over time, regulations required cars to be cleaner, so more recently registered cars are required to produce less emissions than cars registered longer ago.

When the zones of limited emissions began in 2016, only the worst polluting vehicles were banned from entering the center of Paris. Over time, the restrictions tightened; and by 2030, only cars with green badges (fully electric or hydrogen-powered, meaning emission-free) will be allowed in Paris.

	Phase 1 All vehicles need at least CRIT'Air 5 certificate	Phase 2 All vehicles need at least CRIT'Air 4 certificate	Phase 3 All vehicles need at least CRIT'Air 3 certificate	Phase 4 All vehicles need at least CRIT'Air 2 certificate	Phase 5 All vehicles need at least CRIT'Air 1 certificate	Phase 6 All vehicles need a green CRIT'Air certificate
City of Paris	July 1, 2016	July 1, 2017	July 1, 2019	2022[a]	2024[a]	2030[a]
Greater Paris	-	July 1, 2019	January 1, 2021	July 2022	January 2024	2030[a]

Air pollution has improved in Paris since this plan was implemented.

	NO2	PM 2.5 (including black carbon)

2015		
2019		
2023		

In New York City, transportation accounts for approximately 11% of fine particulate matter, and 28% of nitrous oxide emissions. One study found that vehicle pollution in New York City contributed to approximately 1400 deaths in 2016.

In January 2025, New York City implemented a system of congestion pricing, which charges a toll for vehicles entering the busiest part of Manhattan, partially with the aim of reducing air pollution in that area. This plan does not distinguish between emission levels of the vehicles, however, and applies only to a portion of the city. Generally, in the United States, plans to limit or restrict vehicles are not popular, and no low emission zones similar to ones being used in France have been implemented in the US.

Evaluating and Refining Limited Emissions Zones for a New Context
For this task, you will evaluate and refine France's solution of low emissions zones to work for New York City.

Step 1. Use a Model to Analyze the Solution
Use your group's concept map from Explain 2 to analyze the impacts of reducing car emissions on the atmosphere, biosphere, hydrosphere, and on human health. How would each system be affected by implementing zones of limited emissions? You can represent your thoughts using words, models, and/or a diagram.

Step 2. Defining the Problem and Describing the Solution
Use your model analysis and the text to describe the problem that low emissions zones are trying to solve. In your explanation, be sure to include

- What system(s) are impacted by this problem
- How humans have altered the systems
- How the low emissions zones work and if they stabilize or destabilize the system(s)

Step 3. Refining the Solution
Describe a way to refine France's low emission zones to apply to New York City. In your refinement, include

- criteria for a successful solution
- constraints on the solution
- any tradeoffs that are inherent to the solution
- How you would alter the solution to better fit the criteria, keeping in mind the constraints and tradeoffs you've described

Step 4. Evaluating the Refinement
Evaluate the efficacy of your refinements by describing

- How the proposed solution would solve the problem
- How the solution would impact the system(s) involved
- The costs, safety, and environmental impacts of your solution

Reflect:
How does this solution affect systems locally?

How does this solution affect systems globally?

Fossil Fuels Performance Task Rubric

Burning Fossil Fuels	Proficient	Developing
Argument Rubric	Effectively and clearly provides an evaluation of the presented competing solutions that includes **all** of the elements below: • A description of the real world problem • An explanation of how the solution helps with the real world problem, using empirical evidence and scientific ideas • An identification of the ways solution does not fully solve the real world problem • An analysis of the tradeoffs of the solution, including economic, societal, and/or ethical considerations • An argument for the use of one or more competing solutions using the relevant evidence and scientific ideas supporting each solution and its drawbacks	Provides an evaluation of the presented competing solutions that includes **some** of the elements below: • A description of the real world problem • An explanation of how the solution helps with the real world problem, using empirical evidence and scientific ideas • An identification of the ways solution does not fully solve the real world problem • An analysis of the tradeoffs of the solution, including economic, societal, and/or ethical considerations • An argument for the use of one or more competing solutions using the relevant evidence and scientific ideas supporting each solution and its drawbacks
Connections to Engineering, Technology, and Applications of Science	Argument includes a discussion of how the solution has been or could be modified in order to maximize benefits while minimizing costs and risks.	Argument does not include a discussion of how the solution has been or could be modified in order to maximize benefits while minimizing costs and risks.
Student Self- Score	**Circle One** **Proficient** **Developing**	**Glow**: **Grow**:
Teacher Score	**Circle One** **Proficient** **Developing**	**Glow**: **Grow**:

Relevance to your life: Think about everything that you have learned throughout this unit so far.

1. What is one idea and/or skill you learned that you think is important to teach someone in your family or community?

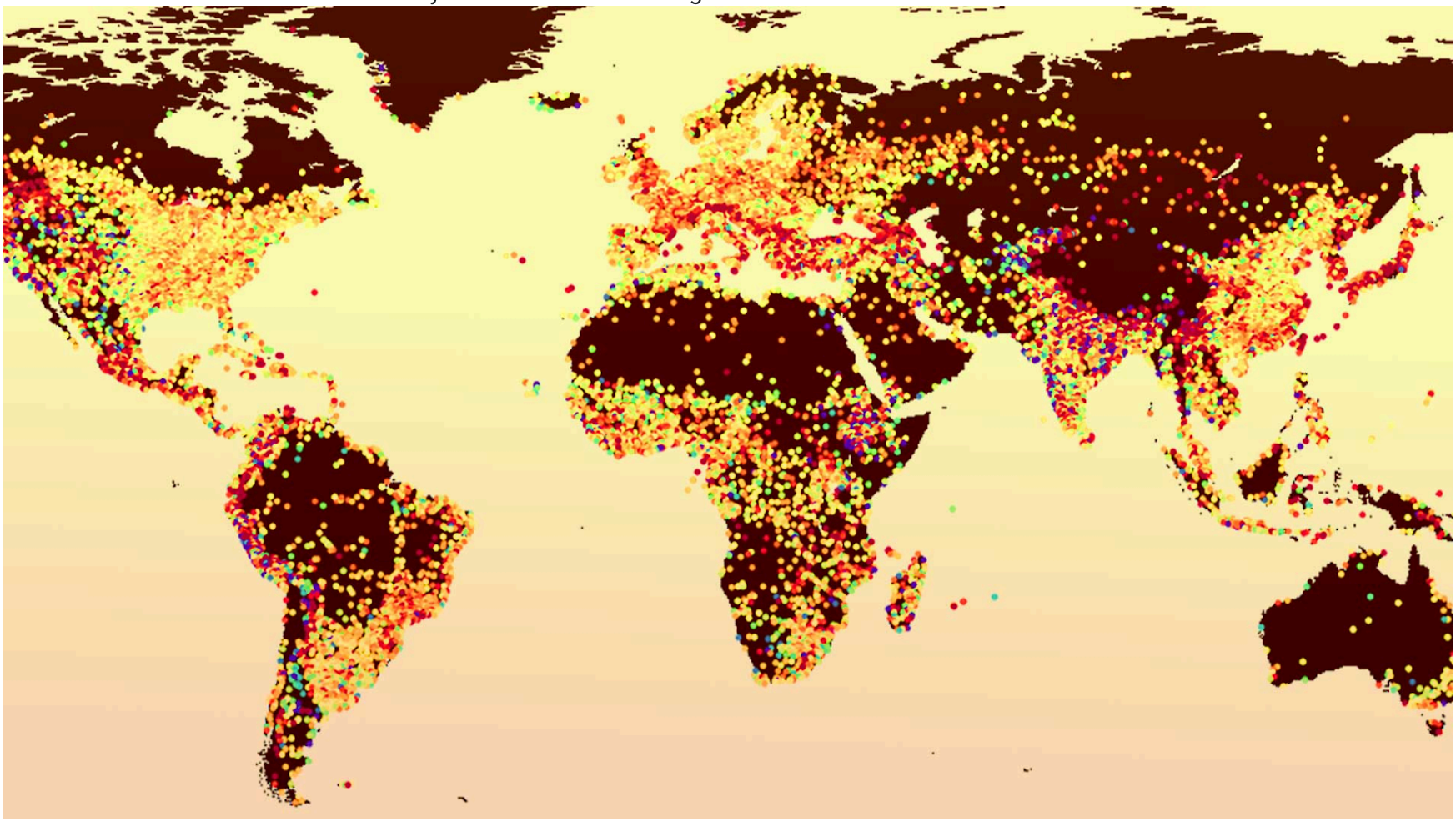
2. To whom do you intend to teach this idea and/or skill? Why do you think it is important for this person to learn this idea and/or skill?

Land Use and Biodiversity 5E

Unit 6 Solutions for a Sustainable Future	Earth and Space Science
Student Name:	

Land Use and Biodiversity Map of Urban Heat Maps Around the World

In summer heat, cities may swelter more than nearby suburbs and rural areas.
On the map shown here, cities are marked by colored dots that correspond to the intensity of their urban heat island effect — red and orange dots indicate cities that are considerably hotter than surrounding areas.



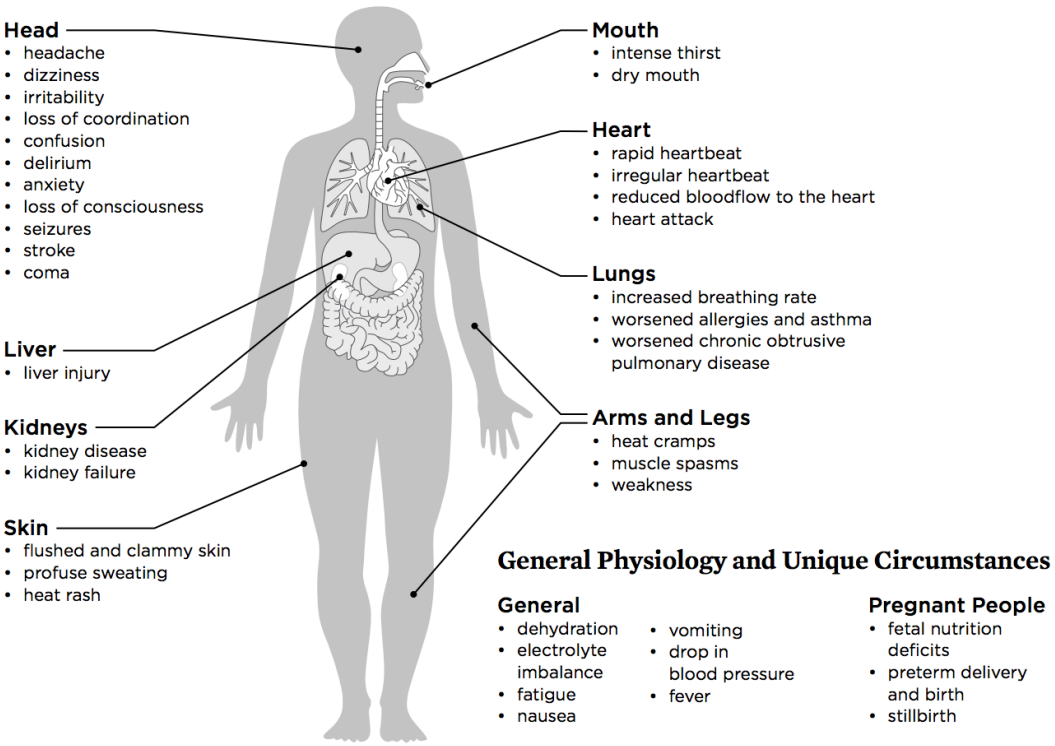
Heat in NYC

Instructions: Analyze the data and maps below. Write your observations, thoughts, and questions in the See-Think-Wonder chart at the end.

As you watch the video, record the key points that describe what is happening in New York City:

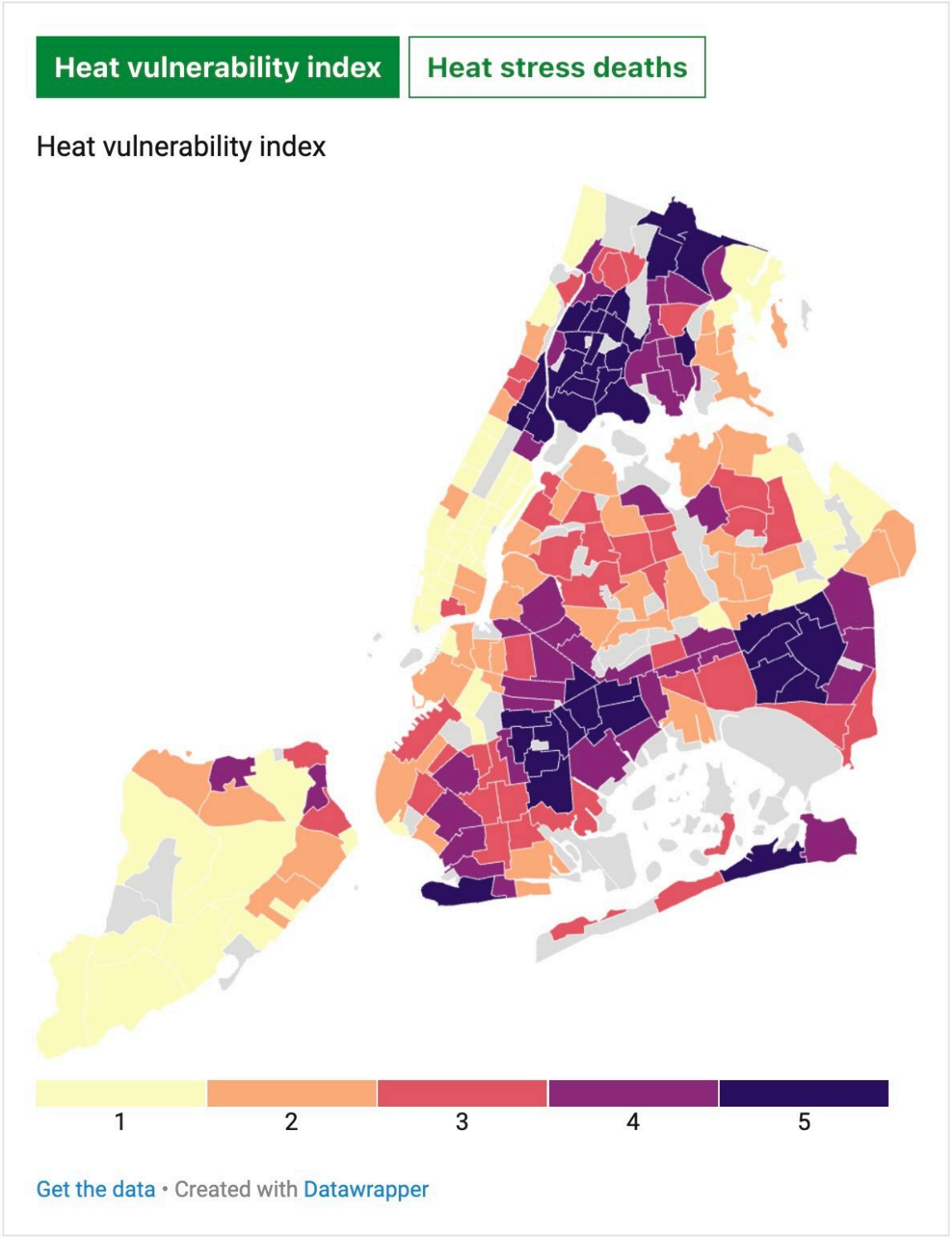
Global Urban Heat Islands

Each summer, on average, an estimated 350 New Yorkers die prematurely because of hot weather in New York City (NYC).



How Heat Affects Our Bodies

These heat-related health impacts are not equally distributed around the city. This map shows the way the city has categorized the heat-related health risks to people living in different neighborhoods.


Heat vulnerability index
Heat stress deaths
Heat vulnerability index
1
2
3
4
5
Get the data • Created with Datawrapper

See-Think-Wonder

Use the graphic organizer below to record your ideas.

See What did you observe in the video and the graph?	**Think** What do those observations make you think about?	**Wonder** What questions do you have?
What do you notice about the distribution of vulnerable areas across New York City?		

Land Use in New York City

In this activity, you will investigate the heat island effect to begin to understand how our use of land is contributing to negative impacts on humans and other organisms.

Directions: Follow the steps below to view and analyze maps and interactive data sources about New York City.

View *Map 1: Increased Heat in New York City.*

1. What do you notice about heat in New York City compared to what it would be if it were the natural landscape?

2. What do you notice about the distribution of heat within New York City?

Open The Welikia Project and click “launch the map explorer” to open an interactive map of Manhattan. Use the slider to see how the land has changed over the past 400 years. You can choose to click on the “Streets” button to add an overlay of Manhattan’s streets to the map. Record your observations and wonderings in the See-Think-Wonder chart at the end of this phase.

3. Describe what you observe below.

4. How do you think this change impacted biodiversity in New York City? What types of organisms might have been impacted, and in what ways?

5. Do you think this change is reversible? Why or why not? How long do you think it would take if yes?

View *Map 2: Zoning Areas in New York City*

6. What do you notice about how land is used compared to 400 years ago?

7. Are there places where you see a strong correlation between heat and the type of zone? Use New York City Neighborhoods of neighborhood names or *Map 5, New York City Neighborhoods,* to find the names of the areas you are looking at.

8. How do you think differences between Manhattan 400 years ago and the current use of land contribute to the heat island effect?

Even within areas that have the same zoning type, tree cover can vary dramatically, so understanding how the land has changed requires analyzing the number of trees in addition to the zoning category. View *Map 3. Tree Cover in New York City.*

9. How do you think the percentage of tree cover in each neighborhood impacts the biodiversity of the area? In other words, how do you think it impacts the other organisms living in there?

10. Compare the levels of tree cover with the temperatures found in the city. How do they compare? Do you think there is a connection between those variables?

11. Compare the levels of tree cover with the zone types found in the city. How do they compare? Do you think there is a connection between those variables?

View *Map 4: Energy Use in New York City*.

12. What do you notice about the distribution of energy use in the city?

13. What correlations do you notice between the energy use map and the other maps we've viewed?

See-Think-Wonder

See What pattern did you observe in the data?	Think What could this pattern mean?	Wonder What questions do you have about this pattern?
What do you notice about the amount and distribution of heat in New York City?		
What do you notice about how land use has changed over the past 400 years?		
What do you notice about the relationships between tree cover and other variables?		
What do you notice about the relationships between energy use and the other variables?		

Making Sense of the Land Use in New York City Investigation

Summary

1. What was the natural resource we observed in this investigation?

2. How have human population and urbanization altered that resource?

3. Are these impacts reversible? Why or why not?

4. How has this alteration impacted human health?

5. Based on what you learned here and on what you already know, would you consider New York City to be a sustainable habitat for humans and other organisms? What do you think goes into how sustainable a habitat is?

Modeling Sustainability

Part 1. Creating a Computational Model of the Urban Heat Island Effect

In trying to figure out why different neighborhoods are experiencing different heat vulnerability, one thing to explain is why the heat levels across different neighborhoods are so varied. Understanding how these different components of the system work together can be very complicated.

When things are complicated, scientists use a mathematical model to put pieces together to understand how they work together and impact each other. In order to explain why some neighborhoods may have a higher rate of negative health outcomes during heat waves, you will construct a computational model of relative heat in four neighborhoods of New York City:

1. Mott Haven - Port Morris in the Bronx
2. Midtown - Midtown South in Manhattan
3. Prospect Lefferts Garden - Wingate in Brooklyn
4. Glen Oaks - Floral Park - New Hyde Park in Queens

Use *Map 5. New York City Neighborhoods* to view these areas.

1. Based on the class discussion and what you saw in the Explore phase, what variables should be included in this computational model?

2. For each variable you plan to include in your model, consider how to assign values based on the information you've been given. How could you quantify the impact of each?

3. For each variable you plan to include in your model, state whether it would increase or decrease the relative heat of the neighborhood.

Increase	Decrease

4. In order to represent the relationships between different variables and the phenomenon that scientists are trying to model, they either multiply or divide the variables by each other, or add or subtract them, depending on how they affect the phenomenon.

For example, if you are modeling the effects of hours worked (H) and wages (W) on your income (I),

Your model could be I = H x W. In this equation hours worked (H) and wages (W) both increase income (I), so we multiply them.

Or if you are modeling the effects of sleep (S), food (F), and physical activity (P) on Energy (E) you have at the end of the day, your model could be

.

$$E = \frac{S \times F}{P}$$

In this equation sleep (S) and food (F) both increase Energy (E), so we multiply them. While physical activity (P) decreases energy so we divide by it.

State which operation you plan to use for each variable in your model.

5. Write an equation to represent how these variables interact.

6. Use your equation, a calculator, and the information from the map to calculate relative heat scores for each neighborhood

Mott Haven - Port Morris in the Bronx	
Midtown - Midtown South in Manhattan	
Prospect Lefferts Garden - Wingate in Brooklyn	
Glen Oaks - Floral Park - New Hyde Park in Queens	

7. Analyze: do these heat scores feel realistic to you? Do you think they represent an aspect of the urban heat island effect? Support your answer.

Part 2. Utilizing a Computational Model of the Urban Heat Island Effect

One way to structure a computational model of relative heat has been constructed in Land Use Computational Model .

In this model, the variables included are:

- Zone score:
    - Manufacturing: 100
    - Commercial: 50
    - Residential: 25
    - Parks: 1

**for neighborhoods that include two zone types, take an average of the zone scores. For example, if a neighborhood is half commercial and half residential, take the average of those scores:*

- Tree cover: the median percentage tree cover in the area
- Energy Use: the heat score based on the amount of energy used by the buildings in that neighborhood

Use the data in the maps to find the values to put into the spreadsheet according to those categories.

1. After you are done, record the relative heat scores below:

Mott Haven - Port Morris:

Midtown - Midtown South:

Prospect Lefferts Garden - Wingate:

Glen Oaks - Floral Park - New Hyde Park:

---

2. Compare the results here to the computational model you created. How do the heat scores compare? What differences in the equations could explain those differences?

---

3. Compare your results to *Map 1: Increased Heat in New York City.* How do the relative heat scores of the four neighborhoods you examined compare to the relative heat increases in these neighborhoods according to the map?

---

4. Based on these scores, where would you expect the most people to have negative health outcomes from heat?

5. Based on these scores, where would you expect the fewest people to have negative health outcomes from heat?

Part 3. Creating a Computational Model of the Sustainability of Neighborhoods

Sustainability is about being able to meet the needs of a society today without compromising the ability of future generations to meet their needs. In the case of New York City, we have seen how the use of land affects people through creating life threatening heat islands, impacting individuals' ability to meet their health needs. The use of land in the city also affects all of the other organisms living within it. In this activity, we will quantify the sustainability of the city as a habitat for humans and other organisms.

The model in the first part of this activity took into account the percent of tree cover in each area, but neighborhoods are different sizes and have different numbers and species of trees. These different numbers and species impact the types of other organisms that can be supported in that neighborhood, such as birds and rodents that live in or feed off the trees, insects that pollinate them, and microbes in the soil.

1. How do you think having different species of trees (tree biodiversity) impacts the sustainability of different neighborhoods as habitats?

2. Open New York City Tree Map to view the numbers and types of trees found in each neighborhood in New York City. Zoom out to see each neighborhood outlined. Click on each neighborhood to view the numbers of tree types in each and record them below.

	Mott Haven - Port Morris:	Midtown - Midtown South:	Prospect Lefferts Garden - Wingate	Glen Oaks - Floral Park - New Hyde Park
Number of tree types:				

3. Reopen your computational models, and go to the second tab called "Sustainability Score." Use the values you had from the Relative Heat Score model to fill in values for Energy Use, Land Use, And Tree Cover. Use the map of tree types to fill in the column Biodiversity by entering the number of tree types in each neighborhood as found in the interactive map. Fill in the results below:

Mott Haven - Port Morris:

Midtown - Midtown South:

Prospect Lefferts Garden - Wingate:

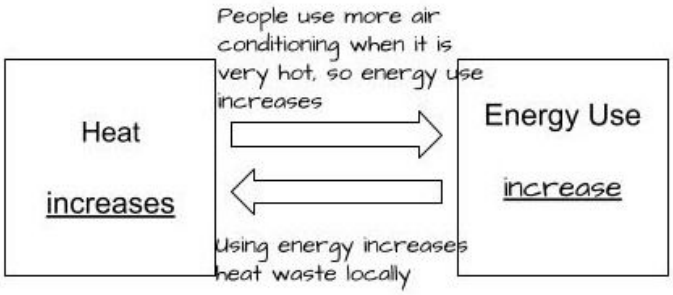
Glen Oaks - Floral Park - New Hyde Park:

Part 4. Analyzing Feedbacks between Parts of the System

Using the computational model, we saw how tree cover impacts the sustainability of the neighborhood overall. However, there can be additional impacts through feedbacks within the ecosystem. In this part of the activity, you will diagram how different parts of the system you explored are related by explaining how they would react when one part of the system is altered.

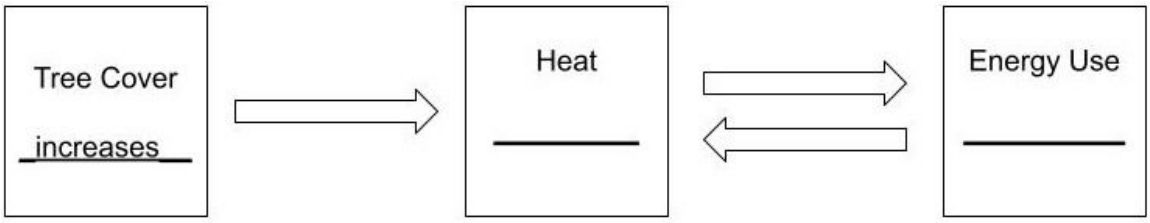
Scenario 1. Temperature increases (this one is completed as an example)
Air conditioners create heat waste, and high levels of air conditioner use can increase local temperatures by more than 1 degree C (1.8 F) (source), further compounding the need for air conditioning.

1. Analyze how a change in heat impacts energy use, and how energy use might impact heat



Scenario 2. Tree cover increases
Tree cover cools areas in several ways. Globally, they absorb carbon dioxide, reducing the greenhouse effect. Locally, they provide shade that cools sidewalk surface, and in ecosystems, they cool the air by releasing water vapor through transpiration.

a. For each arrow, add a description of how the changing variable effects the others



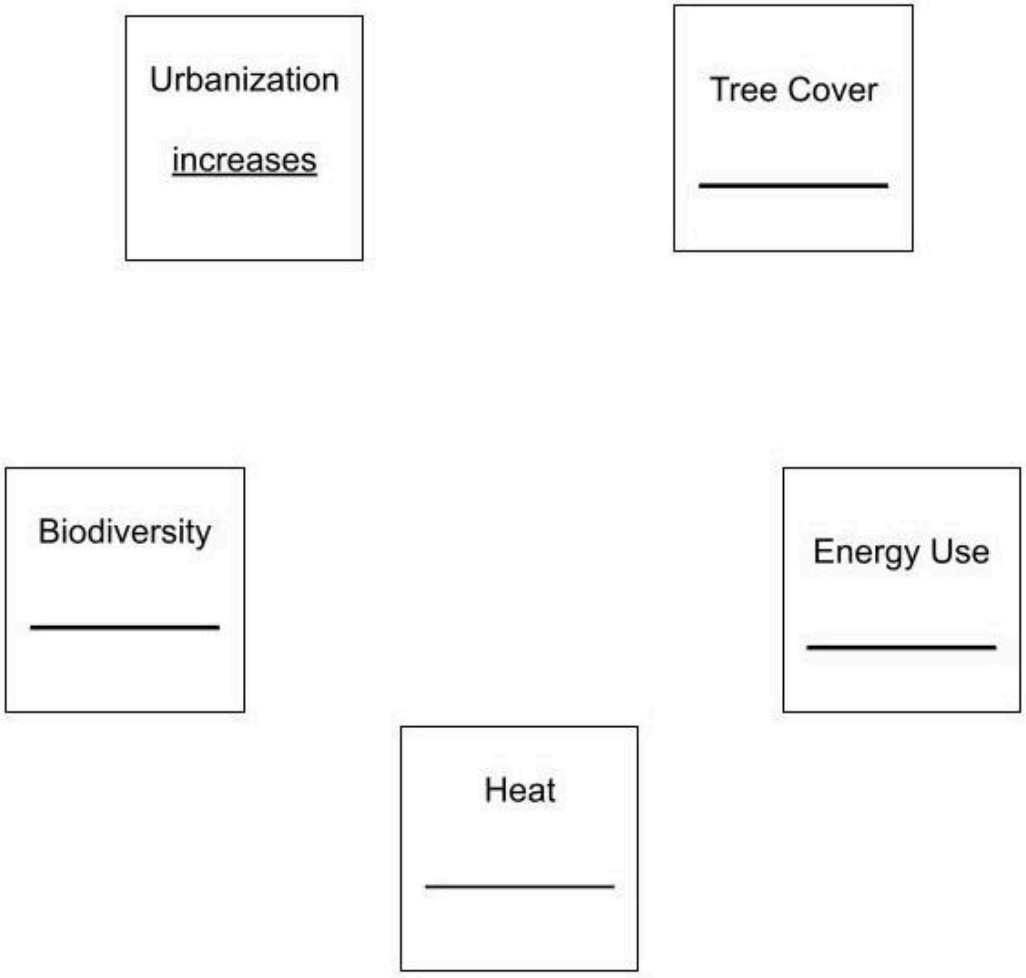
Scenario 3. Biodiversity increases
Additionally, as increased tree cover increases biodiversity (both if the trees include more species, and because the trees provide homes for other organisms), increased ecosystem biodiversity also promotes more tree cover by creating healthier soil, distributing more seeds, and increasing pollination of trees and other plants.

a. Use the the paragraph above to figure out how the other variables would change as a result of increased biodiversity
b. Decide where feedback loops exist in order to determine if there should be one or two arrows between the variables
c. Draw the arrows to show the relationships between those variables
d. Add captions to describe why those variables would change in those ways


Biodiversity
increases
Tree Cover
_____
Heat
_____
Energy Use
_____

Scenario 4. Urbanization/paving increases

a. Decide which variables have an impact on each other, and how they impact each other
b. Decide where feedback loops exist in order to determine if there should be one or two arrows between the variables
c. Draw the arrows to show the relationships between those variables
d. Add captions to describe why those variables would change in those ways



Part 5. Evaluating the Model
Based on the investigation and the diagrams above, answer the following questions:

1. How do trees create or interrupt feedback loops that either stabilize or destabilize the sustainability of the city as a habitat for humans and other organisms?

2. Compare your results to the Vulnerability Index in the Engage text. How do your relative heat scores compare with the areas of highest vulnerability? Are there any areas where your model predicts large heat impacts but that the vulnerability index marks as low risk, or vice versa?

3. What are the limitations of using this mathematical model to predict health outcomes in New York City? In other words, what factors might play a role that this model is not taking into account?

4. Based on the model you created, where are there opportunities to change this equation to reduce heat stress in cities? In other words, how do you think we could reduce heat islands in cities and improve health outcomes?

Summary Task

Today we completed the first class consensus discussion of the unit! How did it go?

1. One thing that went well in the discussion:

2. One thing we can improve the next time we have a discussion:

3. One person who helped me learn today:

What did you learn from this person?

4. One idea that I contributed to my group or my class:

Explain what you know about the following questions, based on what we discussed today:

5. Using a computational model, an annotated diagram, or a written description, represent the relationships between responsible use of natural resources (like land) and the sustainability of human societies.

6. Describe how technologies used by humans can stabilize or destabilize the systems they impact, and how they can have impacts on society and the environment that were not anticipated.

Intervening in Systems to Increase Sustainability

Introduction. In this activity, you will read about a way other cities have tried to intervene in urban systems to reduce heat stress and increase the human sustainability in an area.

We often hear the word sustainability, but what does it mean? In 1969, the National Environmental Policy Act (NEPA) described sustainability as being able to "create and maintain conditions under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic and other requirements of present and future generations."

Every society has needs such as food, space to live, energy sources, water, and materials to create or build everything we use. All of our needs originate in the environment in which we live. For example, drinking water comes from underground sources, rivers, and lakes. We grow our food using the soil and land. Land, forests, water, energy resources are all examples of natural resources. Biodiverse spaces help maintain those natural resources using feedback loops to support the organisms that support strong ecosystems.

Now, watch the Medellin's Green Corridors describing a solution used in the city of Medellin, Colombia. As you watch, record any notes in the table below.

Action(s) Medellin has taken	Impact(s) of the action(s)	How could the action be helpful to New York City?

Think-Talk-Open Exchange

Think - Respond to the prompt individually, in the space below.

Altering components of systems can result in changes in other components. Discuss how increasing green space in cities impacts other components of the city, and how it creates feedback loops that either stabilize or destabilise the sustainability of the system.

Buzzwords: feedback, stabilize / destabilize, sustainability

Talk: Share with your group one at a time. Write a tally mark (✔✔✔✔) each time you hear a specific buzzword during the share.

	Feedback	Stabilize/Destabilize	Sustainability
Person 1			
Person 2			
Person 3			

Open Exchange: As a group, discuss the following questions- be sure to use the buzzwords!

- Describe patterns or commonalities between what each group member shared.
- Which buzzwords did you hear the most? Least?
- Are there buzzwords that your group doesn't understand?
- Are there other words you heard a lot? If so, which words?

Application

1. Go back to your Sustainability Score Computational Model. Try increasing the green cover in each neighborhood; how does it impact the heat of the neighborhood?

2. Does this change in tree cover increase or decrease sustainability of New York City? Support your answer.

3. Are there other components of the model that might change as a result of increasing green space, which would further impact sustainability beyond what your model shows?

4. What costs or negative impacts might increasing tree cover have for the city? What might be stopping the city from achieving an increase in tree cover?

5. Based on this information and the feedback loops you described in Explain 1, how might engineering green spaces to have high levels of biodiversity help reduce the costs of maintaining green corridors in New York City?

Deforestation of the Amazon

Around the world, experts agree that we need more natural spaces with high levels of biodiversity, and that these areas can protect us from rising temperatures and pollution.

Amazon Basin

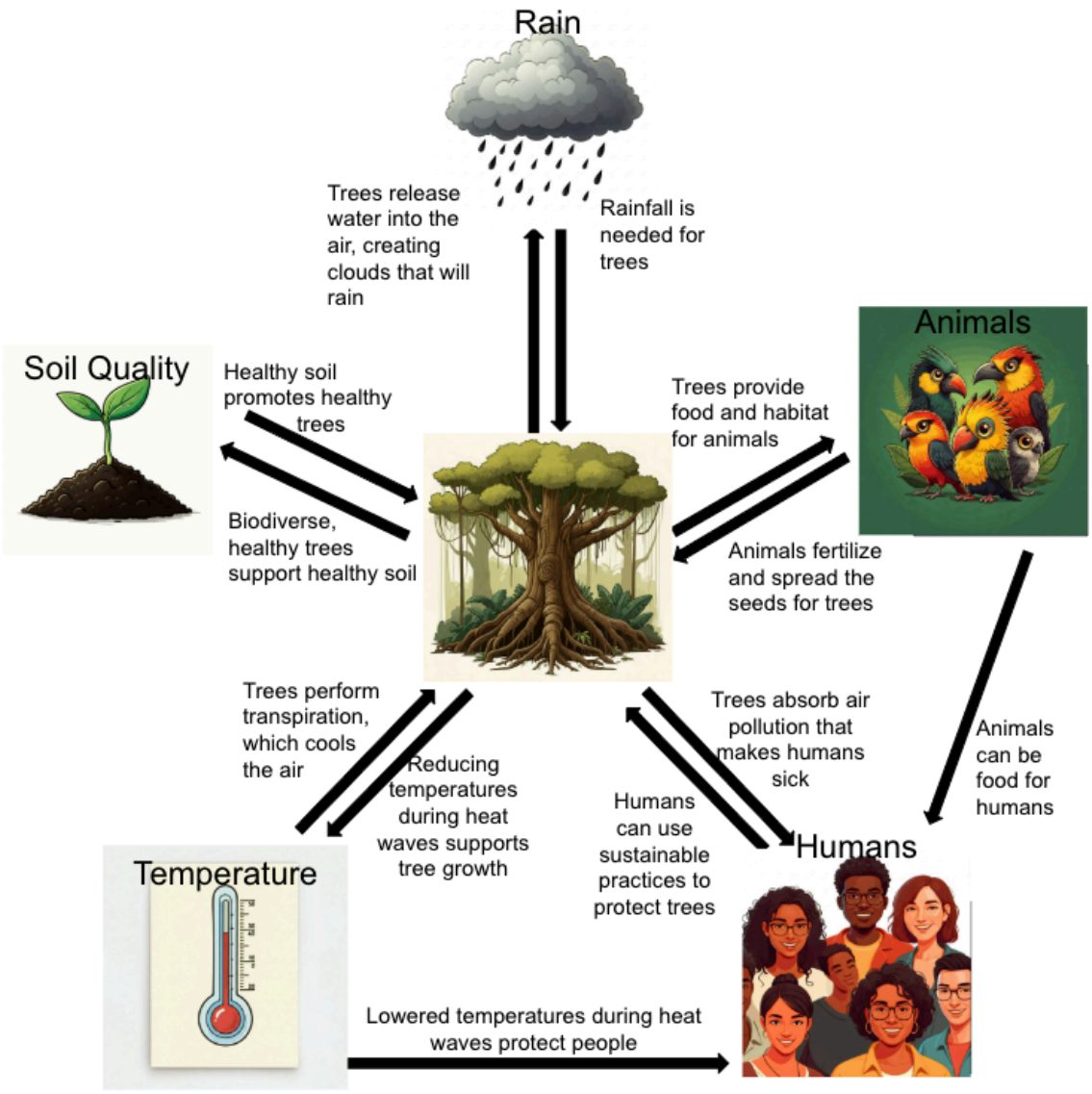
The Amazon rainforest has tremendous benefits for the planet. Globally, it absorbs about a quarter of the carbon dioxide absorbed by all land on Earth (National Geographic). Its trees are not alone in absorbing CO2; about half the CO2 held in the Amazon rainforest is stored in the soil, which is only possible in a healthy ecosystem with high levels of biodiversity (Scientific American).

Beyond the global effects of absorbing carbon dioxide, trees cool the air by circulating water, acting like a sweat system for the planet (Huang et al., 2022). This process both cools the local surroundings, helping to combat heating resulting from climate change, and increases moisture in the atmosphere which contributes to the rain that keeps organisms healthy.

Trees also help maintain human health in many ways. Trees can absorb pollution, including particulate pollution from burning fossil fuels and from forest fires. Well maintained parts of the Amazon are especially good at reducing pollution; areas of the forest that are sustainably maintained by indigenous populations absorb disproportionately high levels of pollution and reduce rates of respiratory diseases in those areas (Prist, et al. 2023)

These trees support a stable and sustainable ecosystem that is operating at maximum capacity. The diagram below shows positive feedback loops that increase the stability of the ecosystem by increasing plants, animals, and soil quality; maintaining proper amounts of rain and temperature; and support human interactions. This set of positive feedback loops is at its upper limit: tree number cannot increase past this point due to the physical constraints of the habitat, but these interactions are keeping the numbers as high as possible.

Positive Feedback Loops Related to Trees



1. Choose two of the interactions on the diagram and describe how these stabilizing feedback loops create an ecosystem that sustains itself.

However, humans are destroying forests and other natural habitats.

1. Based on what you've learned in this investigation so far, how do you think that deforestation impacts the sustainability of human societies around the world?

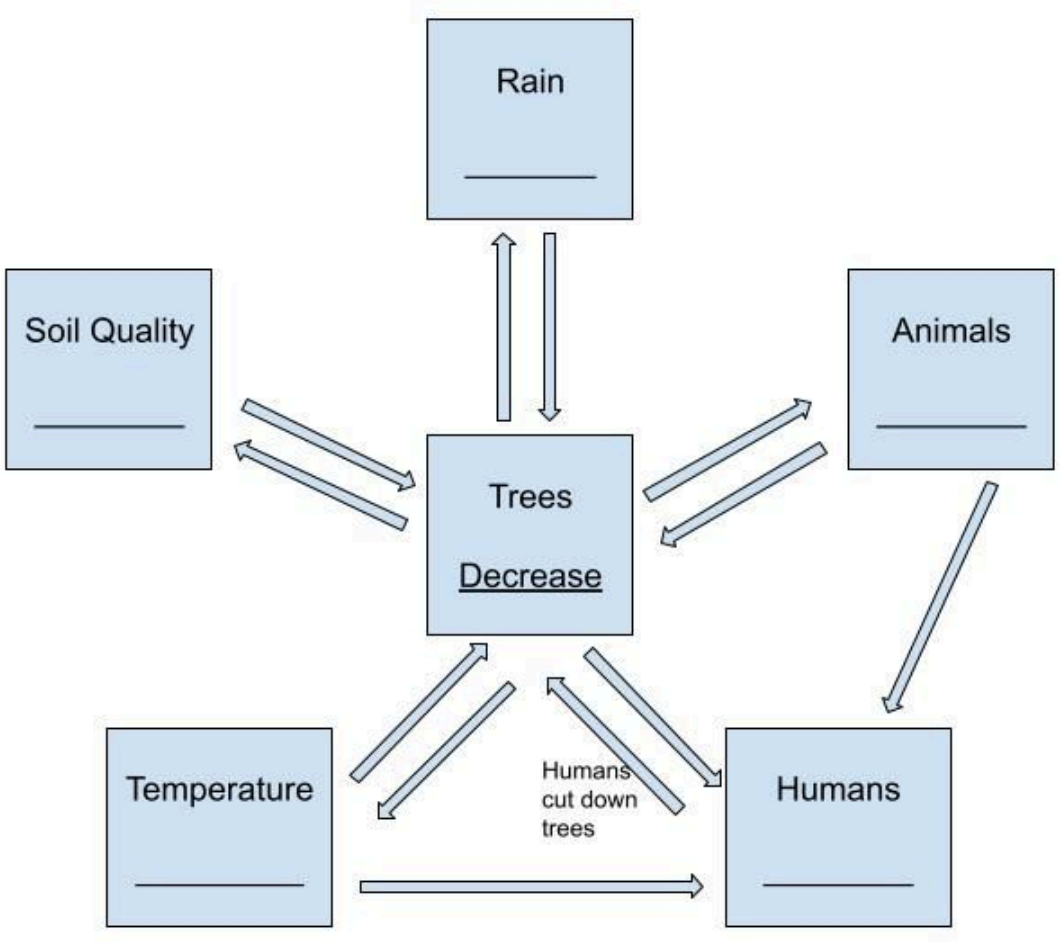
2. One area that has been greatly impacted over the past 30 years is the Amazon rainforest. View the time lapsed aerial images available Amazon Deforestation , from July 2000 to July 2012. Describe what you observe below.

3. Quantify the rate of change in the Brazilian Amazon from pre-1970 to 2019, using this Amazon Deforestation Data . What do you notice?

Calculations:

$$\frac{\text{Estimated Natural Forest Cover in 1970 - Estimated Natural Forest Cover in 2018}}{\text{Number of Years}} = \text{Rate of Change } (km^2/yr)$$

4. Annotate the diagram below to describe how each part of the system will be affected by deforestation. Refer to the *Positive Feedback Loops Related to Trees* diagram to inform your thinking.



Analyze

1. How does deforestation impact the health of humans? In your response, include both direct impacts and impacts resulting from changes to other parts of the system.

2. How does deforestation of the Amazon destabilize the system? In your response, consider how deforestation impacts the other components of the system negatively or positively.

3. Scientists estimate that if approximately 25% of the Amazon is deforested, the entire ecosystem could collapse (Lovejoy and Nobre, 2018). Based on the relationships you've identified above, explain why that could be true.

4. Based on the rate of change you calculated, calculate how long it will take to reach 25% deforestation of the Amazon.

Calculations:

Step 1. Calculate how much of the original Amazon rainforest would remain is 25% were gone (in square kilometers)

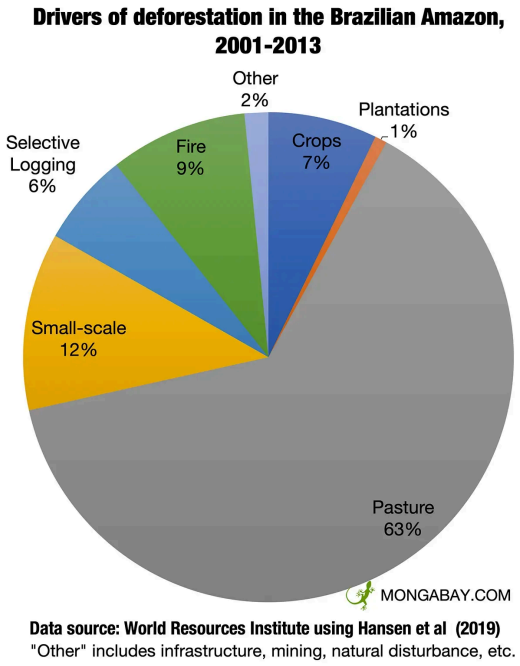
Estimated Natural Forest Cover in 1970 x .75 = Amount of Forest Cover Left after 25% deforestation

Step 2. Use the rate of change calculated above to figure out how many years it will take to reach 75% remaining compared to the amount present now

$$\frac{\text{Estimated Natural Forest Cover in 2018 - Amount of Forest Cover Left after 25\% deforestation}}{\text{Rate of Change } (km^2/yr)} = \text{Number of Years}$$

While it may seem straightforward to say that deforestation of the Amazon needs to stop, the reality is more complicated. Read and reflect on the text below, and then respond to the prompts below to compare costs and benefits of deforestation.

The Amazon rainforest spreads across Brazil, Bolivia, Colombia, Ecuador, French Guiana, Guyana, Peru, and Venezuela. In each country, the reasons for deforestation vary, but looking at Brazil as an example, deforestation is a result of clearing land for cattle pasture, crops, small-scale agriculture, logging, fire, mining, and other infrastructure.



Benefits

The major cause of deforestation in the Amazon is cattle ranching. The rainforest is cut down to create pasture land for cows. The beef produced is mainly exported to countries like the United States, and is an important economic factor for people in Brazil. Many people see the rainforest as empty land that should be developed and used to fulfill human needs. It is very cheap to clear the forest and create space for cows, as much of the land is not owned by anyone or is owned by the government.

1. What are the benefits of Amazon deforestation for the people living in those areas?

Costs

However, though these practices may be lucrative for certain people living in the Amazon, it is important to note that reducing cattle ranching would not create a food shortage for any population. Additionally, though some individuals and companies are gaining benefits through these deforesting behaviors, other individuals are suffering costs.

For example, studies have shown that in areas where tropical rainforests have been cut down, temperatures have warmed more than the average increase globally. Deforested areas can be as much as about 8°F warmer than they otherwise would be, creating effects similar to heat islands in cities. Additionally, when the Amazon is deforested, it is often accomplished by burning the trees. These fires cause increased pollution while removing the very trees that can absorb that type of pollution, causing respiratory health issues.

2. What are the costs of Amazon deforestation for the people living in those areas?

Based on everything you have learned so far, what solution might be effective to maximize the benefits and minimize costs associated with deforestation? In your response, consider the

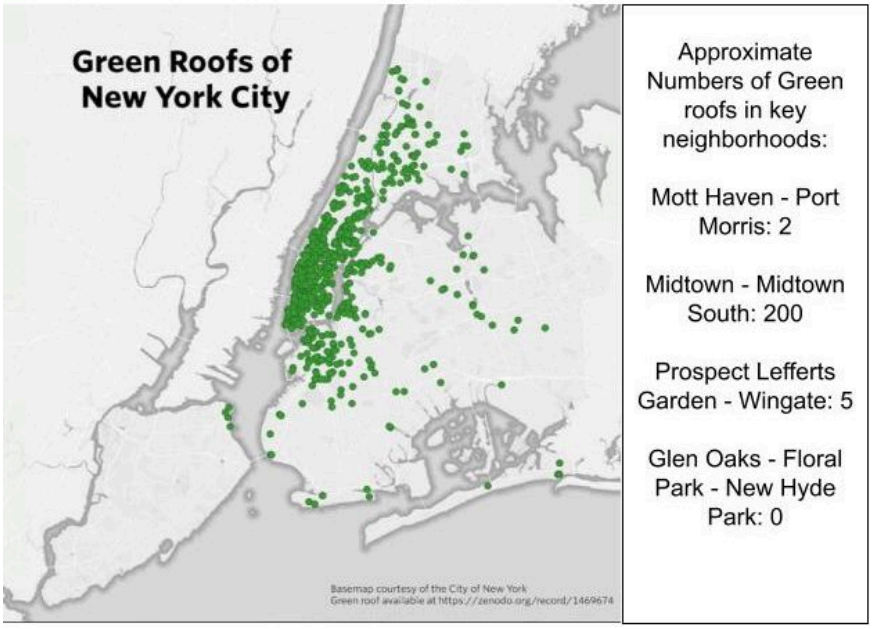
- The priorities of the solution - which stakeholders' needs are you prioritizing?
- Benefits of the solution
- Costs of the solution
- Tradeoffs

Green Roofs

Crowded cities have some environmental benefits: robust public transportation systems and closely packed resources like access to walkable grocery stores can reduce vehicle use by individuals; apartment buildings have less energy waste per unit than the same number of standalone houses would have, etc. But, due to the density of buildings, it can be challenging to incorporate new green spaces because buildings cannot be moved to create public parks. Taking advantage of sidewalks and street space, as was done in Medellin, is one approach for increasing green cover. However, in other places, this space is more limited.

Rotterdam, a city in the Netherlands, has taken a different approach. It has been converting roof space into green roofs, building 100 acres of green space on otherwise unused rooftops, with plans to increase that to 230 acres in the coming years (climate central). According to the EPA, green roofs can lower city temperatures by 5°F and reduce energy demand by up to 0.7% (World Economic Forum).

In New York, there are already 60 acres of green roofs, but that represents only about 0.15% of the total available rooftop space across the city (The Nature Conservancy). The existing green roofs in New York City tend to be in higher income areas, further amplifying the inequalities in cooling infrastructure.



Based on this information, your task is to incorporate green roofs into our previous computational model of neighborhood sustainability. Remember, the previous computational model of sustainability used this equation:

$$\text{Sustainability} = \frac{\text{Biodiversity x Tree Cover}}{\text{Land Use x Energy Use}}$$

Respond to the questions below in order to help you think about how to incorporate the variable of green roofs into the model.

1. Why do you think Biodiversity and Tree Cover are in the numerator of the computational model?

2. Why do you think Land Use and Energy Use are in the denominator of the computational model?

3. Based on the texts about green roofs and what you have learned so far in this unit, will green roofs increase or decrease sustainability? Explain your reasoning.

4. Considering your responses above, where would the variable green roofs be incorporated into the computational model? Explain your reasoning.

5. Rewrite the sustainability computational model equation to include green roofs.

6. Use your equation, a calculator, and the information from the map to calculate relative heat scores for each neighborhood

Mott Haven - Port Morris in the Bronx	
Midtown - Midtown South in Manhattan	
Prospect Lefferts Garden - Wingate in Brooklyn	
Glen Oaks - Floral Park - New Hyde Park in Queens	

7. What other factors could be impacted by creating more green roofs?

8. How would increasing green roofs impact the sustainability of each neighborhood?

9. Based on your model, would adding green roofs stabilize or destabilize New York City as a habitat for humans and other organisms?

Land Use and Biodiversity Performance Task Rubric

Land Use and Biodiversity	Proficient	Developing
Argument Rubric	Effectively and clearly provides an evaluation of the presented competing solutions that includes **all** of the elements below: • A description of the real world problem, including quantified data that shows the impact or extent of the problem • An explanation of how the solution changes the impacts of the real world problem, using empirical evidence and scientific ideas • An identification of the ways solution does not fully solve the real world problem • An analysis of the tradeoffs of the solution, including economic, societal, and/or ethical considerations • An argument for the use of one or more competing solutions using the relevant evidence and scientific ideas supporting each solution and its drawbacks	Provides an evaluation of the presented competing solutions that includes **some** of the elements below: • A description of the real world problem, including quantified data that shows the impact or extent of the problem • An explanation of how the solution helps with the real world problem, using empirical evidence and scientific ideas • An identification of the ways solution does not fully solve the real world problem • An analysis of the tradeoffs of the solution, including economic, societal, and/or ethical considerations • An argument for the use of one or more competing solutions using the relevant evidence and scientific ideas supporting each solution and its drawbacks
Stability and Change	Argument includes quantified data that shows to what extent the solution can reduce or reverse the negative changes caused by land use	Argument does not include quantified data that shows to what extent the solution can reduce or reverse the negative changes caused by land use
Student Self- Score	**Circle One** **Proficient** **Developing**	**Glow**: **Grow**:
Teacher Score	**Circle One** **Proficient** **Developing**	**Glow**: **Grow**:

Relevance to your life: Think about everything that you have learned throughout this unit so far.

1. What is one idea and/or skill you learned that you think is important to teach someone in your family or community?

2. To whom do you intend to teach this idea and/or skill? Why do you think it is important for this person to learn this idea and/or skill?

Mining 5E

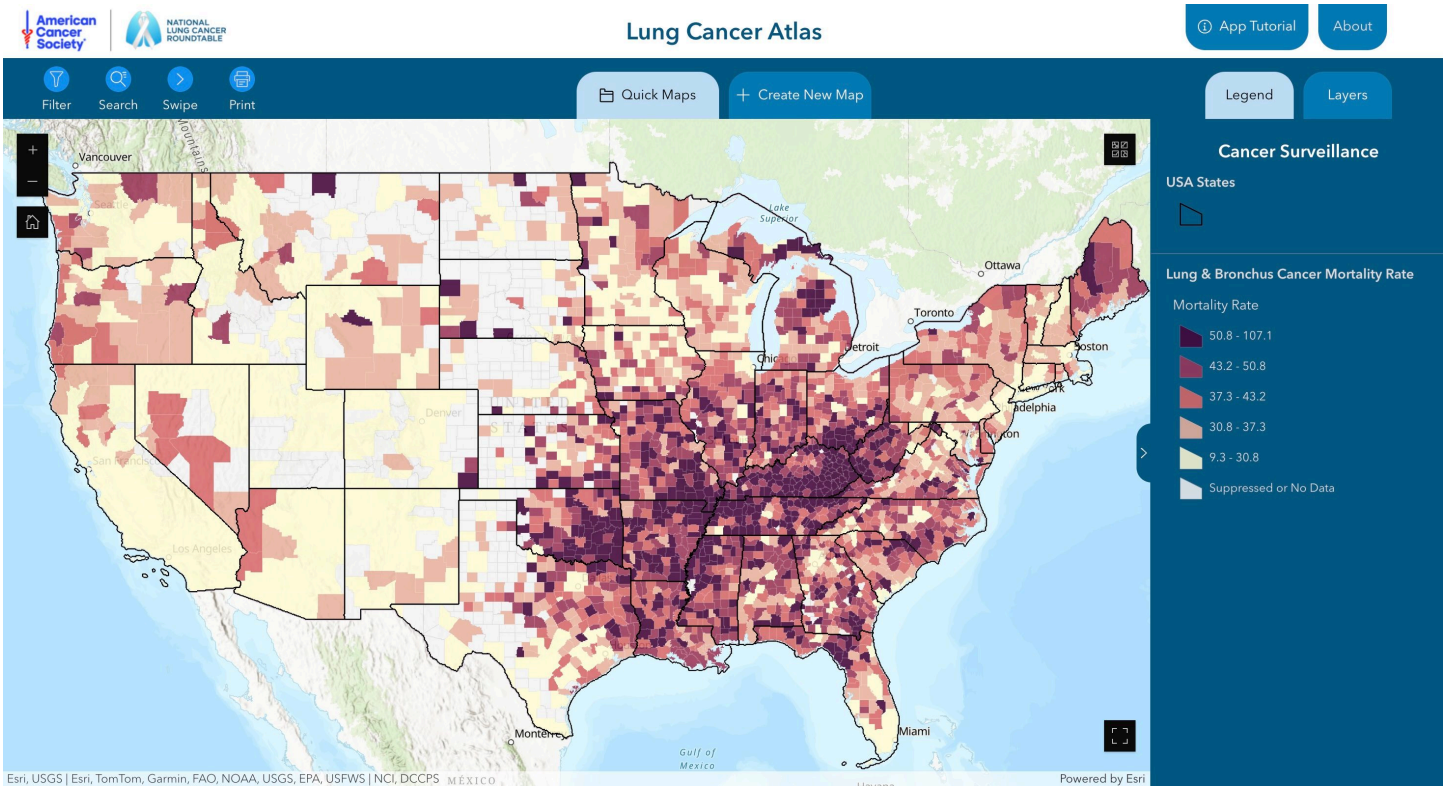
Unit 6 Solutions for a Sustainable Future	Earth and Space Science
Student Name:	

Cancer and Biodiversity Loss in the United States

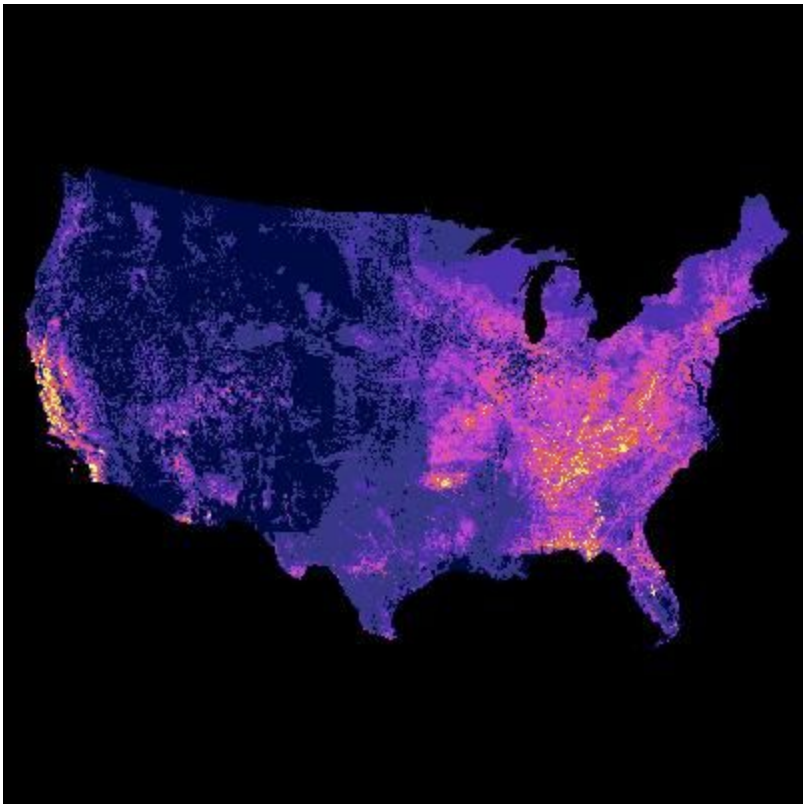
One of the diseases that can be caused by environmental causes and kills many people worldwide is cancer. In the United States, cancer diagnoses are not evenly distributed, which may be related to varied environmental conditions.

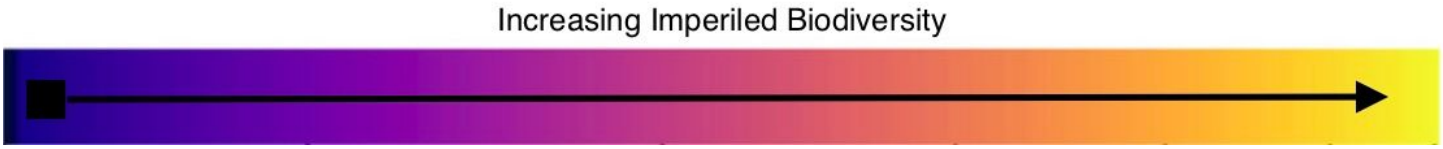
Directions: Analyze the maps below and write down your observations, what they make you think about, and any questions you have in the See-Think-Wonder chart below.

American Cancer Society Lung Cancer Atlas



Map of Imperiled Biodiversity in the United States




Increasing Imperiled Biodiversity

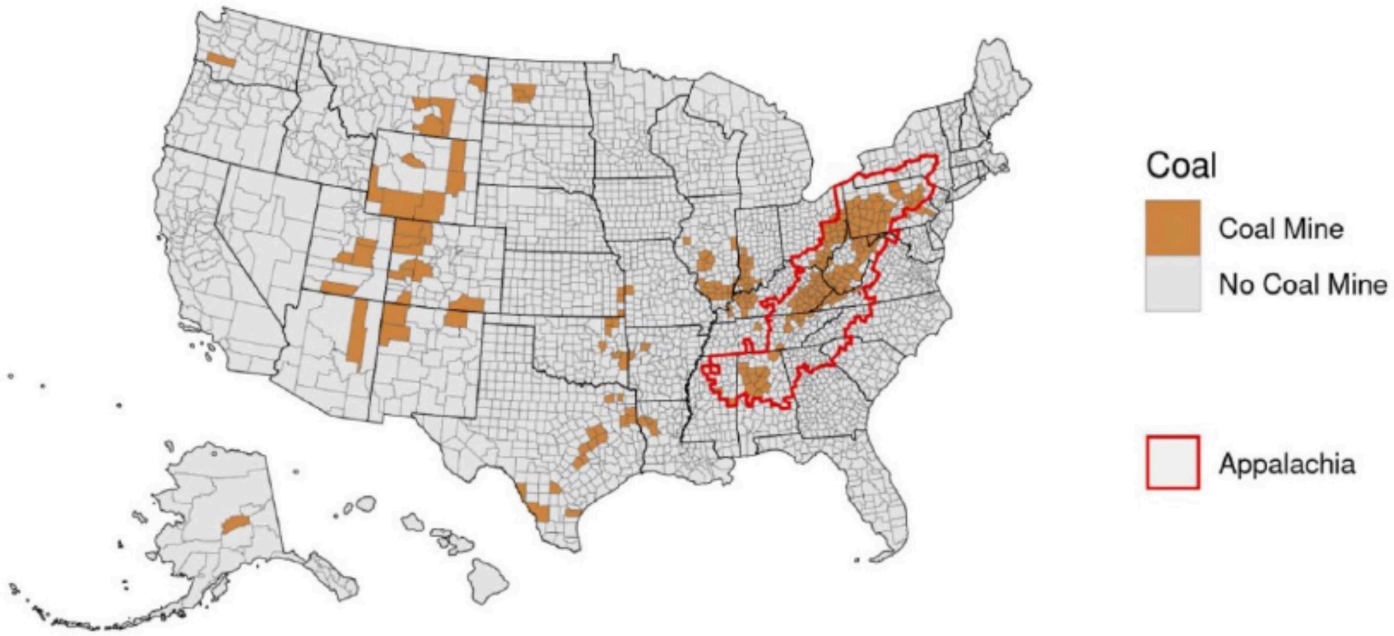
See-Think-Wonder

Use the graphic organizer below to record your ideas.

See What did you observe in the video and the graph?	**Think** What do those observations make you think about?	**Wonder** What questions do you have?
What patterns do you notice about the distribution of lung disease?		
What patterns do you notice about the distribution of at-risk biodiversity?		

Extracting Materials from the Earth

Introduction: Coal is a fossil fuel burned to generate electricity and used in industrial processes. It is found underground and must be extracted from the earth through mining. Mining is concentrated in two areas in the United States as shown below.



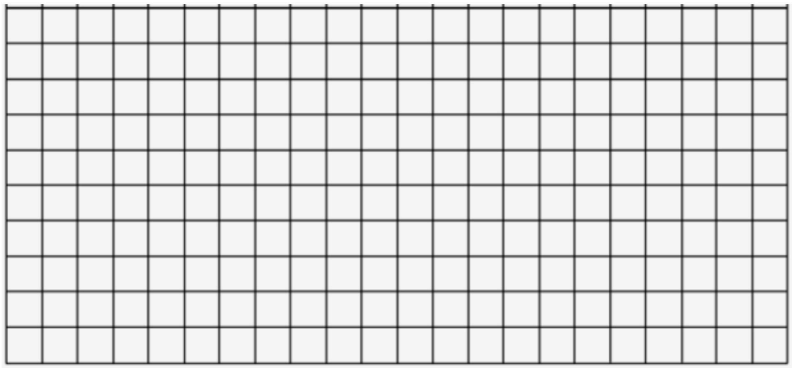
Predict: How do you think mining for resources impacts the environment around mines?

Procedure

Part 1: Extraction of ores from the Earth

Mine owners and investors face many challenges in the successful operation of any mine, where it may be extremely difficult to turn a profit. Obtaining the land, labor, equipment, safety, and reclamation are the chief concerns of the owner. To understand some of these challenges, you will attempt to conduct a rare Earth element mining business in an experiment that requires you to mine the ore (chocolate chips) from a plot of land (cookies). The equipment for your mining will be a paperclip that you may modify in any fashion.

1. Measure the mass of the cookie holder and the processing plant, and record it above Table 1.
2. Measure the mass of the complete cookie and record it in Table 1 in the first row.
3. Looking from the side of the cookie, sketch the shape of the "landscape" (the shape of the side view)



4. Place your cookie in the mining container provided by your teacher.

5. Choose a spot to put your cookie in its container on the Mining Area Grid and trace around the edge of the container.

6. Next to your cookie, place the “processing plant” provided by your teacher. Trace the outline of this processing plant.

7. **Extracting the Ore:** Set a 5 minute timer for the ore extraction. Extract the ore from the cookie by removing as many chocolate chips as possible from the cookie and relocating them to the processing plant using only your toothpicks or paper clips.

Rules for extraction of ore
The cookie must stay flat on the grid at all times. You may use your fingers to hold it stably in place.
Only mining tools (paperclips or toothpicks) may be used to extract chocolate chips from the cookie.
Calculating Contamination: Determine the masses of the cookie, the chocolate chips in the processing plant (including any pieces of cookie that are stuck), and any stray crumbs and record them in the second row of Table 1. Follow the steps below:

- Measure the mass of chocolate chips and any crumbs that are in your processing plant by lifting the processing plant container off the paper and onto the scale.
- Measure the mass of the remaining cookie by lifting the cookie container off the paper and moving it onto the scale.
- Subtract the remaining cookie’s mass and the mass of chocolate chips and crumbs in the processing plant from the original cookie’s mass to calculate the mass of any stray crumbs that may have gotten lost or landed on another part of the grid.
- Replace the cookie in its container and the processing plant to their original locations marked on your paper.

8. **Reclamation of the Land:** Set a 5 minute timer, then process the ore and attempt to reclaim your land by using your mining tools to clean the chocolate chips by removing any remaining cookie and return all crumbs from the processing plant back within the original circle of your mining operation.

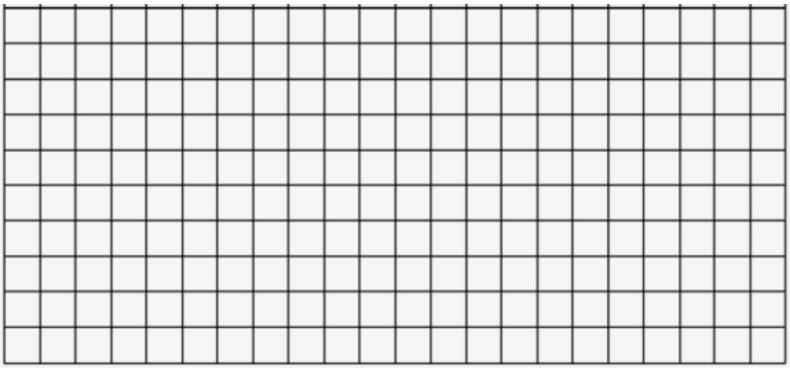
Rules for reclamation (taking back the land) and ore processing
All mined ore (chocolate chips) must be cleaned and transported to the processing plant on your paper.

9. **Calculating Land not Reclaimed:** After the reclamation time is up, determine the final masses of each item in Table 1 and record the measurements in the third row of that data table.
    - Measure the mass of the processed (clean) chocolate chips by using the mining tools to remove the clean chips from the processing plant and move them into a new container on the scale.
    - Measure the mass of any remaining crumbs and uncleaned chocolate chips in the processing plant by lifting the processing plant off the paper and moving it onto the scale (ideally, this is 0)

- Measure the mass of the cookie remaining in the original mining area by lifting the cookie container off the paper and moving it onto the scale.
- Use those three numbers to calculate the stray crumbs that did not get reclaimed.

Part 2: Evaluating impacts from extraction of ores from the Earth
When mining is complete, the mining companies have the benefit of the economic impact (money) from whatever they mined. However, there are also impacts to the environment that have to be considered. In this part, we will try to quantify the environmental effects from mining.

1. Looking from the side, sketch the topography (the natural physical features of the land) on the "Post-Mining Topography (*side view*)" graph below to show the ridges and valleys of the land.



Now, we will count how much of each natural feature was impacted directly by the mine or processing plant, indirectly, or remained healthy at the end. Work with your partner to determine the numbers of affected and healthy squares of each resource by following the steps below.

2. Lightly shade in all the boxes containing the mine or processing plant.

3. Count how many grid squares contain cookie/crumbs/smudges the mining operation left behind. Even the *tiniest* speck counts! Draw an X through each of those boxes.

4. The water flows from the top left of the grid to the bottom right, following the branches as it goes down. Find all the water downstream from any shaded box or box with an X, and draw Xs through those boxes. This water is all contaminated by acid runoff from the mining process.

5. Each topsoil square not shaded brown or within the mining or processing areas may still be healthy, but each square needs two clean water squares to keep its moisture. Divide your clean water by two to determine how many rich topsoil squares have remained clean, and draw an X through all the remaining topsoil boxes.

Clean water squares _____ = number of remaining topsoil squares 2

6. One clean rich topsoil will support three trees. Take the number of rich topsoil boxes remaining and multiply it by three to determine how many trees can be supported. Draw an X through the other tree boxes.

Clean topsoil squares x 3 = number of remaining tree squares

7. Each deer requires three trees and three water. Using the number of healthy remaining water and trees, determine how many deer remain. Draw an X through the other deer boxes.

Clean tree squares _____ = possible number of remaining deer squares 3 Clean water squares _____ = possible number of remaining deer squares 3 Select whichever number is smaller

8. Scenic vistas cannot have any damaged (shaded or crossed off) boxes touching them on any side or corner. Draw an X through any shaded vistas in contact with an impacted box.

9. Count the number of boxes containing each resource in the mining or processing areas (shaded squares). These are the resources directly impacted by mining and processing. Record these numbers in the first column of Table 2.

10. Count the number of boxes containing each resource that were indirectly affected by mining (squares with Xs). Record these numbers in the second column of Table 2.

11. Count the number of boxes of each resource remaining healthy (no shading or Xs). Record these numbers in the third column of Table 2.

12. Once your land and ore have been assessed you may eat your cookie.

Data Tables

Mass of empty cookie holder:

Mass of empty processing plant:

Table 1: Ore at Mining Location				
	Cookie	**Chocolate Chips**	**Crumbs in Processing Plant**	**Stray Crumbs**
Before Mining		**0**	**0**	**0**
After Mining, Before Reclamation		*These numbers are combined at this point:*		
After Mining and Reclamation				

Table 2: Environmental Impacts			
Natural Attribute	**Quantity Directly Impacted by Mine or Processing Plant Location**	**Quantity Indirectly Impacted by Mining & Processing**	**Remaining Healthy Attributes After Mining and Reclamation**
Tree (33)			
Deer Habitat (10)			
Rich Topsoil (12)			
Water (41)			
Beautiful Vista (9)			

Analysis of the mining impact

1. Using *Table 1. Ore at Mining Location*, calculate the benefit of mining ore.
    - Each gram of chocolate is 100 tons of coal
    - Each ton of coal generates $50
    - Each ton of coal provides 2000 kilowatt hours of electricity, costing about $350 - about 1 month of electricity for one household
    - Each ton of coal employs 1 person for 15 minutes, earning them about $5

1. Calculate the number of tons of coal: weighed mass x 100 = number of tons of coal
   Your work here:

2. Calculate the financial benefit:
   Financial Benefit = (money earned) + (months of electricity gained) + (salary paid)

   Financial Benefit = (number of tons x $50) + (number of tons x $350) + (number of tons x $5)

   Your work here:

2. Using *Table 2. Environmental Impacts*, determine a way to calculate the impact mining had on the environment.

1. Calculate the percent of each resource lost to mining

Percent lost = (number of lost squares/number of original squares) x 100
Your work here:

Tree:

Deer Habitat:

Rich Topsoil:

Water:

Beautiful vista:

2. Calculate the amount of unrecovered land (lost cookie crumbs)

Percent lost = (stray crumbs/original cookie mass) x 100
Your work here:

3. Calculate the environmental impact on the area

Environmental Impact = Lost Trees + Lost Deer + Lost topsoil + Lost water + lost vistas + unrecovered land
Your work here:

3. Compare your environmental impact scores with those of your tablemates. How did their different approaches (placement of the mine and method of removal) affect their scores compared to yours?

Analysis questions - answer the following in complete sentences.

1. Were you able to restore the mined cookie to exactly its original size and topography? Explain why or why not.

2. How easy was it to refine your ore so you had clean chocolate chips? Were you successful at refining the chocolate without impacting other areas of the grid?

3. Based on what you experienced in this activity, how do you think mining and refining processes impact ecosystems?

4. The benefits of mining were calculated as financial benefit (in dollars), which is earned by mining companies, electricity companies, and wage earning mining staff. The costs of mining were measured as natural features that were lost (not in dollars).

Why do you think we did not measure the loss of natural resources in dollars?

5. If mining companies were responsible for paying for the environmental costs of their work, energy from coal would likely become more expensive.

    a. Would this be a good or bad thing? Explain.

b. How do you think an increase in the price of coal-generated energy would affect the demand for coal?

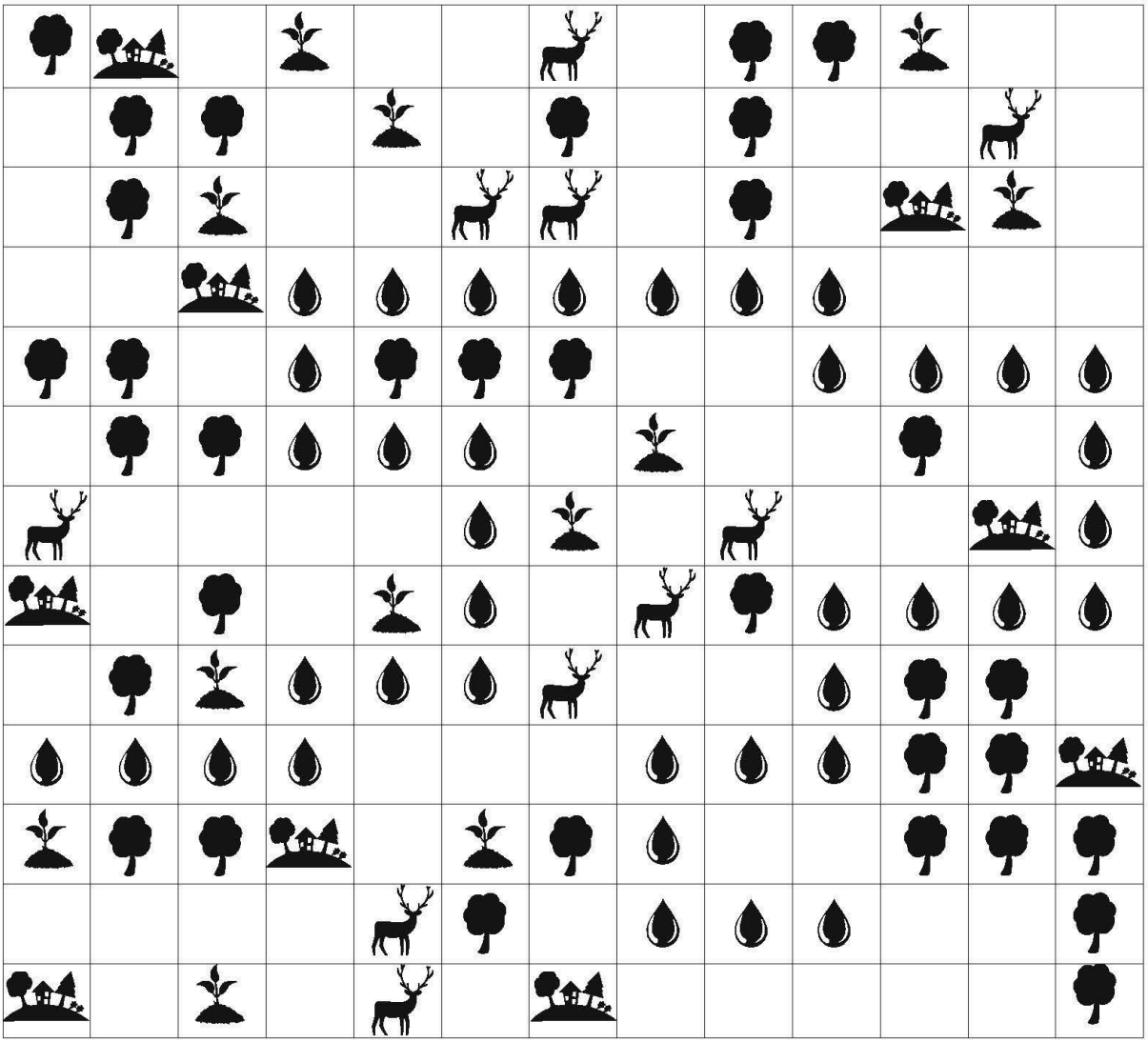
c. How do you think an increase in the price of coal-generated energy would impact the demand for other energy sources?

See-Think-Wonder

Directions: Refer to the mining investigation to complete this chart.

See What pattern did you observe in the data?	Think What could this pattern mean?	Wonder What questions do you have about this pattern?
What did you notice about the ease or difficulty of getting the ore?		
What did you notice about the ways coal benefits the economy?		
What did you notice about the impacts mining had on the land and natural resources?	How do you think the use of coal would be changed if companies had to consider the environmental costs?	

MINING AREA GRID



Natural Attributes:

Tree

Deer habitat

Rich top soil

Water

Beautiful vista

Costs and Benefits of Mountaintop Removal Coal Mining

In this activity, you will apply what you learned in the explore phase to human health. First you will brainstorm how the environmental impacts of mining might cause human death. Then you will read about the known impacts of coal mining on environmental and human health to fully define the problem in need of solving.

Based on what you observed in the explore phase, describe the costs and benefits of mining. How do you think our ability to use technology like mountaintop removal mining to extract useful resources impacts human health?

Benefits	Costs

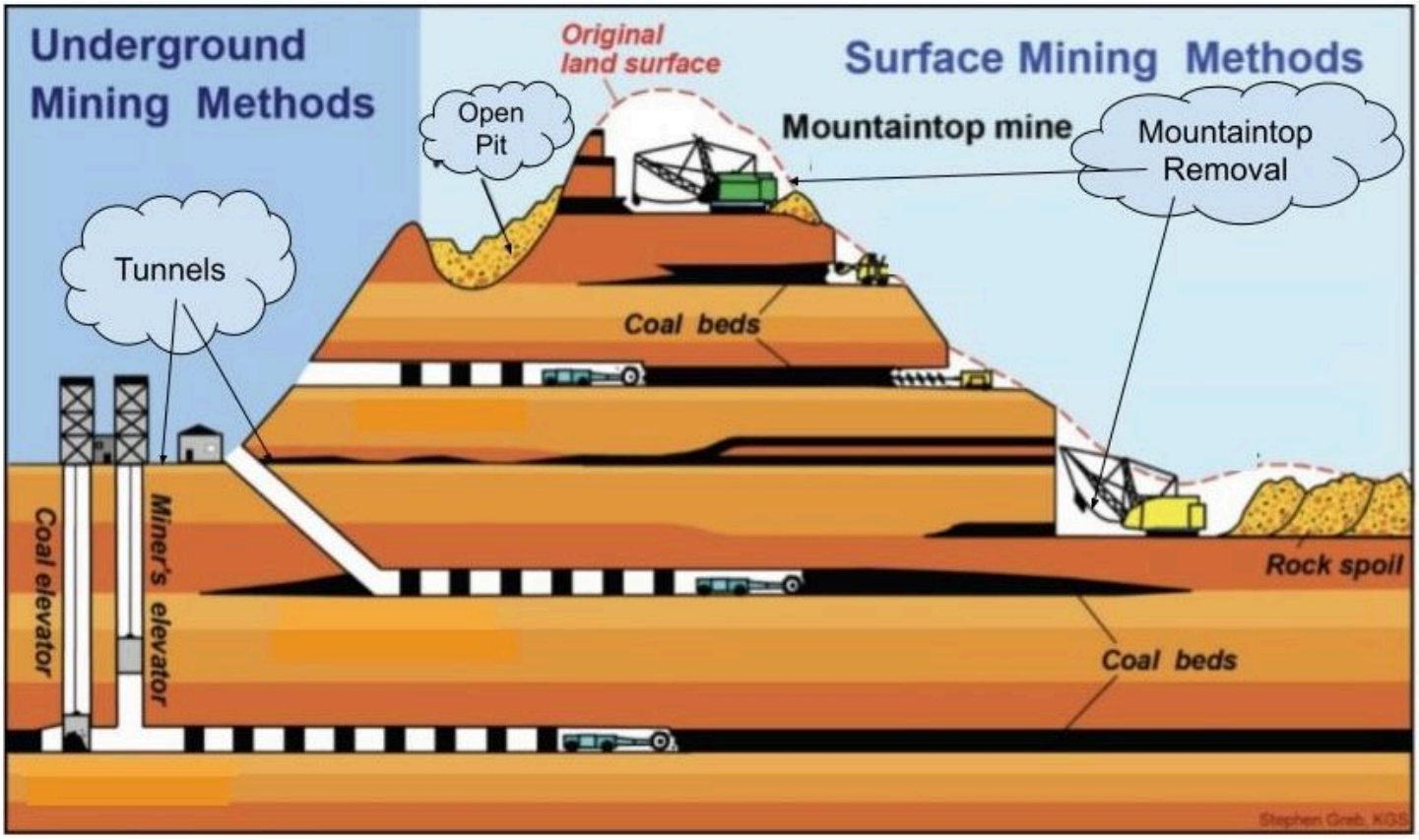
Introduction: Read and annotate the text
While you read the text, annotate it by:

- Putting (+) next to benefits of coal mining
- Putting (-) next to costs of coal mining

Coal is a fossil fuel used to generate electricity in power plants and in industrial processes like making steel and cement. Some historians have argued that the industrial revolution couldn't have happened without coal to power steam engines and refine the steel used for building bridges and railroads. However, obtaining coal is costly. Mining it requires digging into rocks to extract coal from the ground, separating out the valuable coal from the waste rock. In some places, like Wyoming, the coal is near the surface and can be mined by removing all the plants and soil from the area, extracting the coal, and filling the pit back in with soil and replanting.

In other places, like the Appalachian mountains across Kentucky and West Virginia, the coal is buried deep underground and within mountains, which makes it very hard to access. Historically, tunnels were carved into the mountains to access the deep coal inside, creating very dangerous working conditions for the miners inside.

In present times, coal is extracted from the Appalachian mountains using a technology called mountaintop removal coal mining. In this process, the tops of mountains are blasted off with explosives, revealing the coal underneath. Because this method is so disruptive to the natural environment, it is very difficult, if not impossible, to return these mining sites to the way they were before. While this process is safer for miners, less expensive for mining companies, and more efficient for extracting coal, it comes with costs to ecosystems and people in the surrounding communities.



Read your assigned text and take notes about your ideas and questions in the space below.

Text 1: Mountaintop Removal Coal Mining and the Ecosystem
Text 2: Mountaintop Removal Coal Mining and Human Health

I am reading text #

Notetaker:
How does mountaintop removal coal mining stabilize or destabilize the environment and human health?

Think-Talk-Open Exchange

1. **Think -** Respond to the prompt individually, in the space below.

Developing new technologies, like mountaintop removal mining, creates both benefits and costs to natural and man-made systems. Write a paragraph about the benefits and costs of using mountaintop removal coal mining (societal, economic, environmental, and health), and how it stabilizes and/or destabilizes man-made or natural systems.

Buzzwords: benefit, cost, stabilize / destabilize, resource

2. **Talk**: Share with your group one at a time. Write a tally mark (✔✔✔✔) each time you hear a specific buzzword during the share.

	benefit	cost	stabilize / destabilize	resource
Person 1				
Person 2				
Person 3				

3. **Open Exchange:** As a group, discuss the following questions- be sure to use the buzzwords!

- Describe patterns or commonalities between what each group member shared.
- Which buzzwords did you hear the most? Least?
- Are there buzzwords that your group doesn't understand?
- Are there other words you heard a lot? If so, which words?

4. **Reflection -** Individually respond to the prompt below.

What are some new ideas you heard during your discussion with your group?

Summary Task

Today we completed a class consensus discussion! How did it go?

1. One thing that went well in the discussion:

2. One thing we can improve the next time we have a discussion:

3. One person who helped me learn today:

What did you learn from this person?

4. One idea that I contributed to my group or my class:

Explain what you know about the following questions, based on what we discussed today:

1. Describe how human actions may both stabilize and destabilize a natural system.

2. Evaluate the use of mountaintop removal to mine coal for energy and industry. Be sure to include a discussion on the use of this technology based on associated economic, environmental, and geopolitical costs, risks, and benefits.

Mining and Mineral Identification in New York State

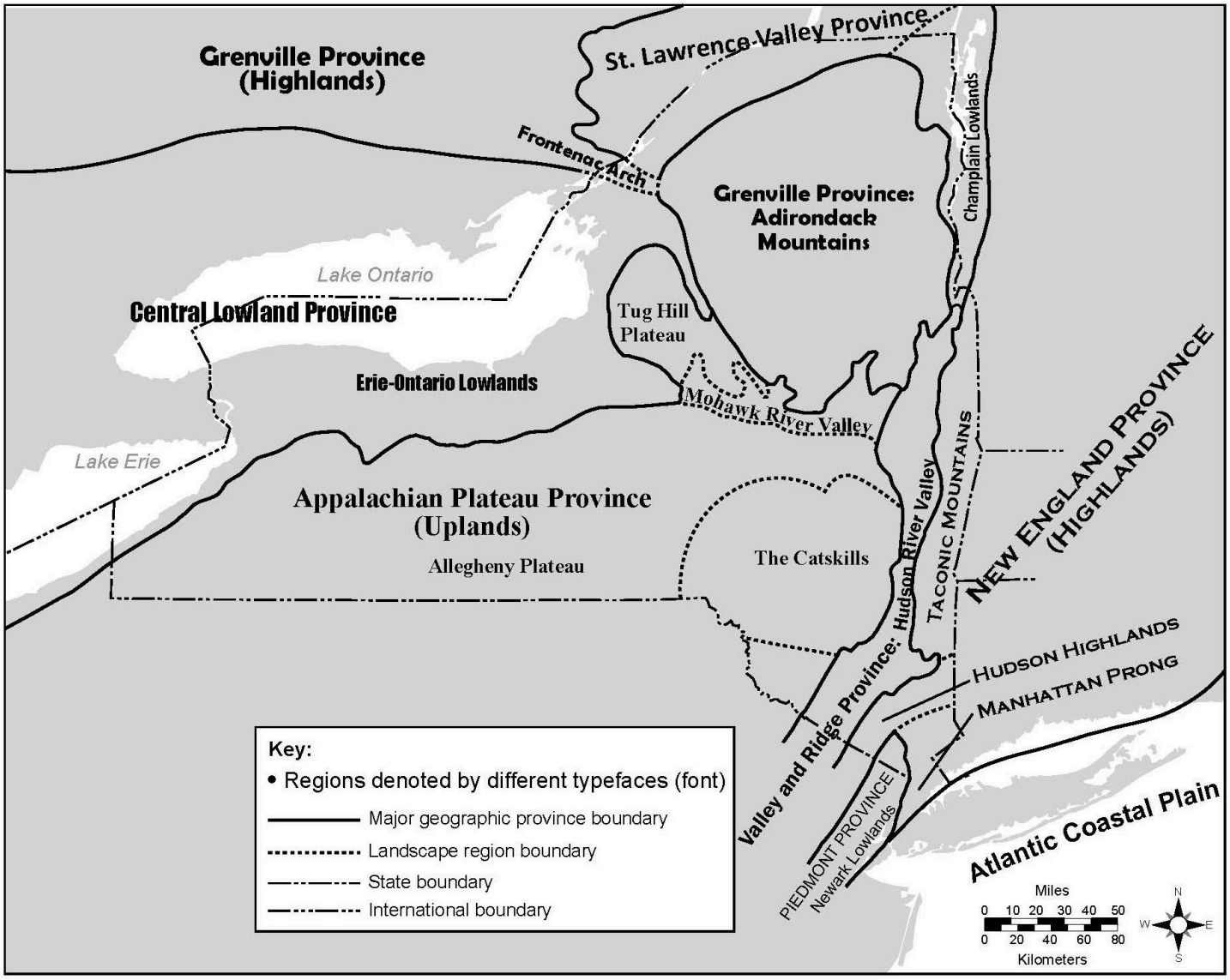
Part 1. What mineral resources are available in New York?

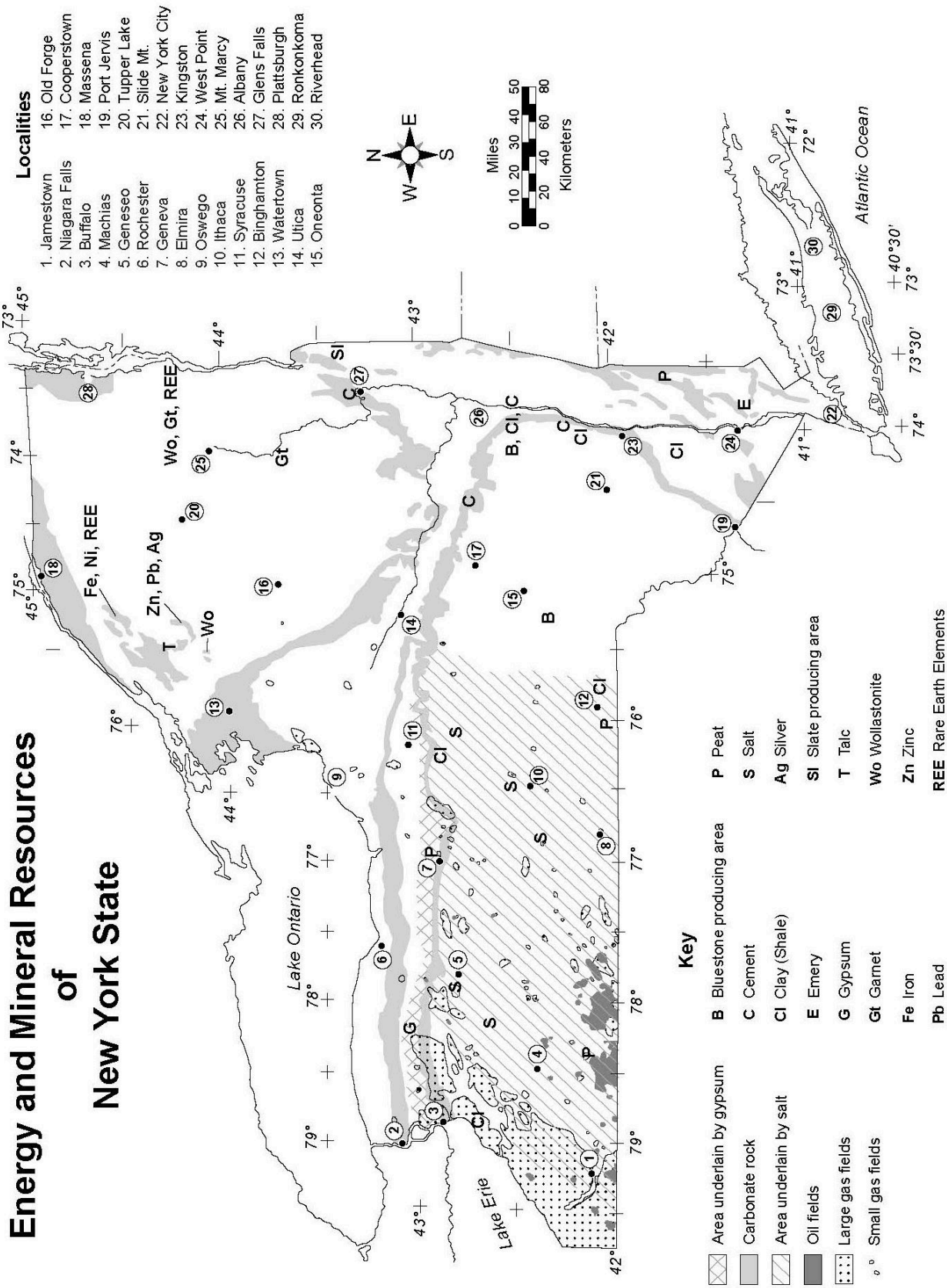
Just north of the Appalachian coal mining region is New York State, which includes the top part of the Appalachian Plateau Province, as seen below. Unlike the rest of Appalachia, however, New York does not have any coal reserves.

Instead, New York has a different set of energy and mineral resources which vary depending on the region within the state.

Use the maps on this page and the next to determine what resources are available in New York and predict how their mining approaches may vary based on where they are located.

GEOGRAPHIC PROVINCE AND LANDSCAPE REGIONS OF NEW YORK STATE





1. What types of energy resources does New York have?

2. What other types of resources does New York have?

3. Based on these maps, which types of resources tend to cluster around water sources or rivers?

4. Based on both maps, which resources tend to cluster in mountains?

5. Using what you learned about the challenges of coal mining in Appalachia versus Wyoming, which resources do you think would be most environmentally damaging to extract?

Part 2. How do we know when we find a valuable mineral?

Scientists use various tests to determine what type of mineral they are looking at. In this investigation, you will analyze samples using different tests and then sort them using the mineral identification chart to determine what minerals you are looking at.

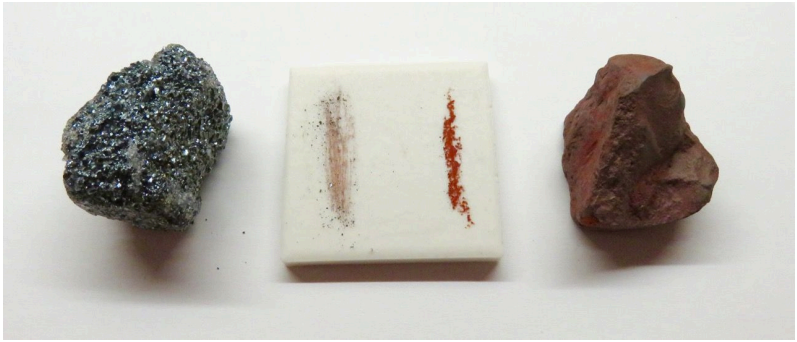
Materials:

- Mineral samples
- Copper penny
- Steel nail
- Glass plate
- Streak plate
- Dilute HCl
- Dropper

Test 1. Metallic or Nonmetallic luster.
Look at the surface of the mineral. If it is opaque (you can't see light through it) and shiny, the mineral is "metallic." If you can see light through it or if it isn't shiny, it is "nonmetallic." Examine each sample and record your observation in Table 1.

Test 2. Hardness: determine the nonmetallic minerals' hardness by following the steps below and recording the results in Table 1.

1. Scratch the mineral with your fingernail. If your fingernail leaves a mark, the mineral has a hardness of less than 2.5.
2. If your fingernail doesn't leave a mark, scratch the mineral with a copper penny. If the copper penny leaves a mark but the fingernail did not, the mineral has a hardness of approximately 3.
3. If the penny doesn't leave a mark, scratch the mineral with a steel nail. If the nail leaves a mark but the penny did not, the mineral has a hardness of approximately 4.
4. If the nail doesn't leave a mark, scratch the mineral with the glass plate. If the glass leaves a mark but the penny did not, the mineral has a hardness of higher than 5.5.

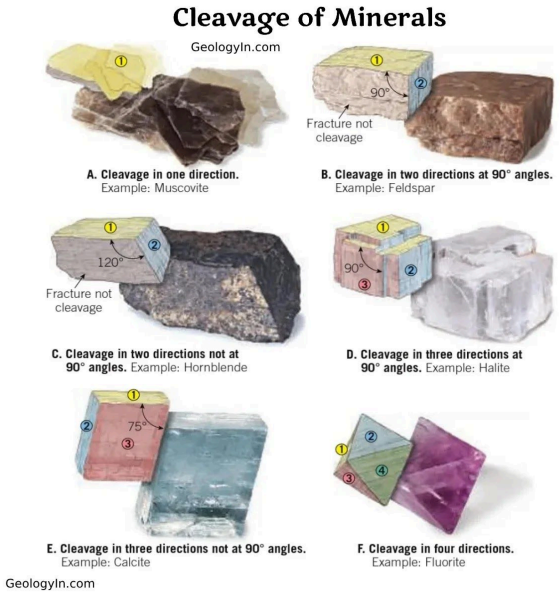


Test 3. Streak Test
Drag each mineral across the streak test plates. Record the color (or lack of color) left behind in Table 1.

Test 4. Rock Cleavage
Cleavage means how a mineral breaks. Minerals with cleavage mean the mineral breaks along flat planes, creating smooth sides in at least one direction. Minerals with no cleavage are rough or irregular shapes.

Minerals with cleavage in one direction have smooth flat surfaces in one direction (two opposite sides parallel to each other); minerals with cleavage in two directions have smooth flat surfaces in two perpendicular directions (four sides of a cube), with rough sides on the remaining direction; minerals with three directions of cleavage are smooth all around. Cleavage in 4 directions will produce a shape that looks like two pyramids put together. These directions of cleavage can be at perfect 90 degree angles or slanted.

Observe the shapes of each mineral sample and record your observations in Table 1. You can use the image to the left or the video link to help you determine if the mineral has cleavage, and if so, in how many directions.



When all four tests are complete, use the Mineral Identification Flowchart below to determine which mineral(s) your sample could be. It is likely that you will not have a final determination for them yet.

Table 1. Mineral Test Results

Sample	Metallic or Nonmetallic	Streak Test	Hardness	Cleavage	Based on the first four tests, what minerals could the sample be?
A					
B					
C					
D					
E					

For each of your samples, complete Table 2 by following these directions:

1. State the information you need in order to determine which of the possible minerals the sample is.
2. Conduct the necessary tests or observations, and record your observations.
3. Determine what mineral each sample is, and support your answer with evidence from your tests and observations.

Additional information that may help you with these tests and observations is listed here:

- For any sample that requires an acid test, place one drop of dilute hydrochloric acid (HCl) on the sample and watch for bubbles to appear. If there are bubbles, it has a positive acid test.

- Types of nonmetallic luster:
    - Vitreous = glassy
    - Earthy/dull = not shiny
    - Resinous = like tree sap
    - Pearly = shiny like pearls
    - Waxy = like a candle

Table 2. Determining mineral identification

Sample	What additional information would help you determine which mineral you have?	Conduct the test(s) or observation(s). Record your observations in the space below.	What mineral is it? Support your answer with evidence from your tests and observations.
A			
B			
C			
D			
E			

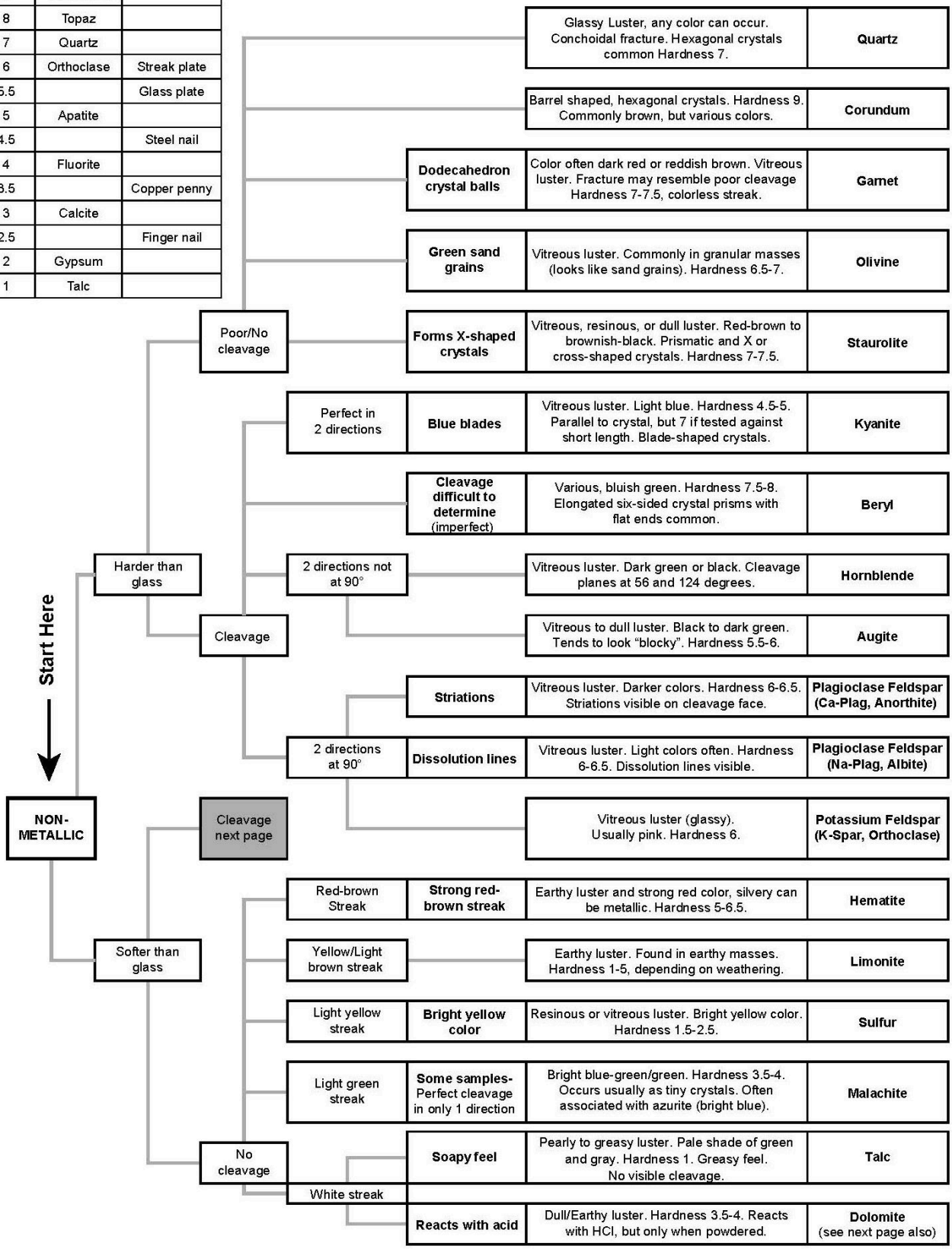
See-Think-Wonder
Directions: Refer to the mineral investigation to complete the table below.

See What pattern did you observe in the data?	Think What could this pattern mean?	Wonder What questions do you have about this pattern?
What do you notice about the distribution of energy resources in New York?		
What do you notice about the distribution of mineral energy resources in New York?		
What do you notice about the types of land the minerals are found in?	How do you think geological features might impact the difficulty of extracting the resource? How do you think the difficulty of extracting the resource relates to the damage done to extract the resource?	

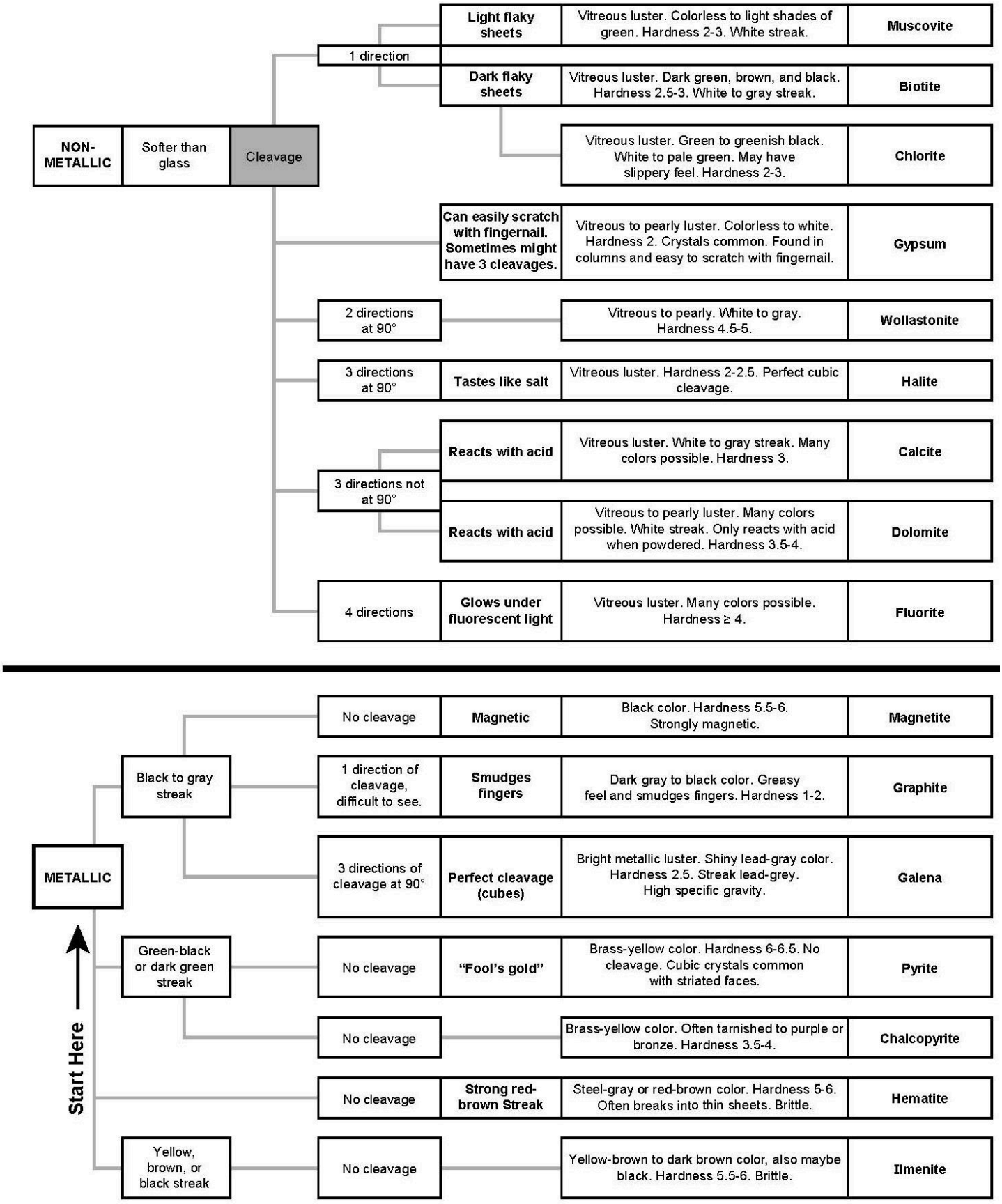
Mohs Hardness Scale

Hard-ness	Mineral Name	Tools
10	Diamond	
9	Corundum	
8	Topaz	
7	Quartz	
6	Orthoclase	Streak plate
5.5		Glass plate
5	Apatite	
4.5		Steel nail
4	Fluorite	
3.5		Copper penny
3	Calcite	
2.5		Finger nail
2	Gypsum	
1	Talc	

Mineral Identification Flowchart



Mineral Identification Flowchart (Continued)



Summary Task

Today we completed a class consensus discussion! How did it go?

1. One thing that went well in the discussion:

2. One thing we can improve the next time we have a discussion:

3. One person who helped me learn today:

What did you learn from this person?

4. One idea that I contributed to my group or my class:

Explain what you know about the following questions, based on what we discussed today:

1. How do social and cultural contexts impact the ways solutions are evaluated to inform decisions about mining regulations?

2. In what ways does New York balance competing economic, societal, environmental, and ethical considerations to increase benefits and decrease costs?

Costs and Benefits of Mining in New York

In this activity, you will read about the types of mining conducted in New York and the ways that it is regulated. Then, you will compare New York's mining with the coal mining happening in Appalachia and construct an argument about why New York has fewer environmental and health impacts from mining than Appalachia.

Step 1. Read and annotate the text
While you read the text, annotate it by:

- Putting (+) next to benefits of New York's mining regulations
- Putting (-) next to costs of New York's mining regulations

Mining in New York State

In New York, mineral mining is worth about $1.87 billion as of 2020; it ranks first in the nation for garnet (a semi-precious stone) production and third for salt. There is also oil and gas pumping, for a combined value of $28.4 million.

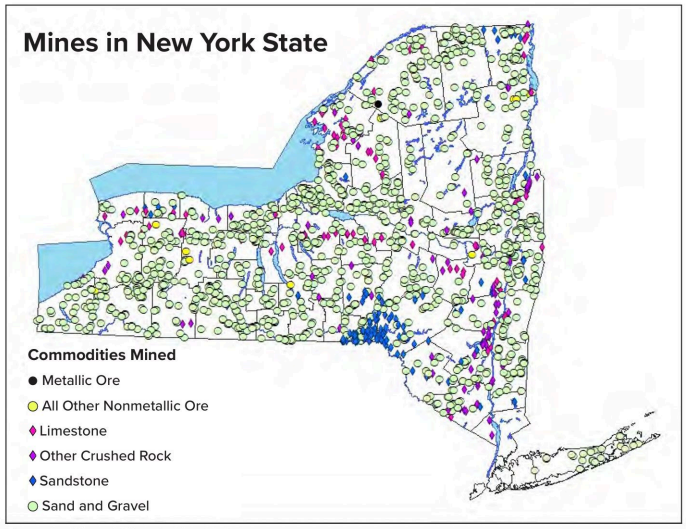


Figure 8 – Map of Mines in New York State

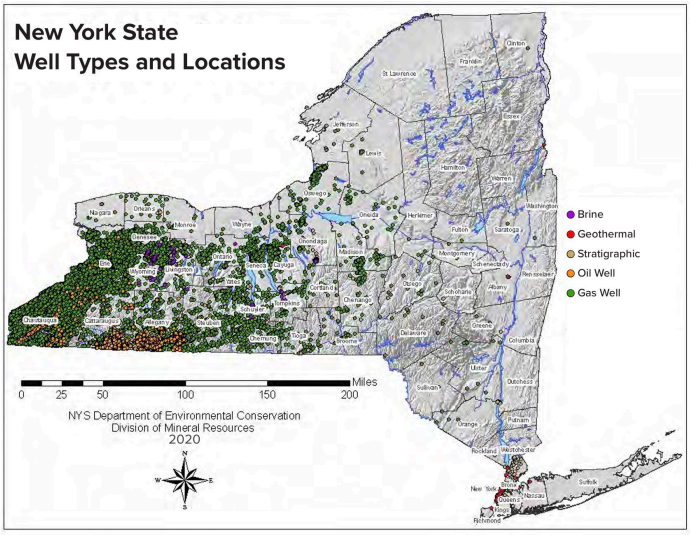


Figure 4 – Map of Well Types and Locations

One way that New York reduces the impact of mining and drilling on the environment is to require that all mines have an approved use and reclamation plan before they are granted a permit. The state requires rigorous planning when a company applies for a mining permit, turning down applications that don't sufficiently protect the environment. For example, in 2023, New York told a garnet mine looking to expand that its plans were deemed incomplete because they did not sufficiently address concerns surrounding visual impact to the area, protection of wetlands, and environmental impacts of forest removal, among other issues. When a permit is approved, the state holds a security deposit from each mine which is only returned when reclamation is completed; the state seizes the funds from any mining operation that abandons its reclamation responsibilities and uses that money to do the restoration itself. Because mine operators know that they will have to fully reclaim the land once mining is complete, they design mines to minimize disruptions as much as possible; in some cases reclaiming land from one part of a mine while it is ongoing in another area.

Despite these protections, mining still has negative impacts on the environment and on human health in New York. Open pit mines, like those for gravel, garnets, and sand, disrupt ecosystems and vistas while they are operating. Mines produce noise pollution from heavy machinery, and explosives used to break up rocks create

dust plumes in the air. In Long Island, waste storage during sand mining has been reported to be polluting the groundwater underneath.

Photo 12 – Rolling Hills Pond Mine – Concurrent reclamation of side slopes around the pond, with active mining occurring in background.

At the same time, some mining operations have shut down as a result of stringent regulations, costing the state money and jobs. The number of permitted mines has declined for 21 years in a row. Though New York has large reserves of oil and gas, drilling has decreased dramatically. This decrease is largely because drilling became more expensive due to bans on fracking, a technology that uses water or liquid CO2 to force gas and oil up out of the ground, but which can cause earthquakes and water pollution. New York, however, has decided that the risks to public health outweigh the economic benefits of these mines.

Step 2. Working in pairs, use the information from this text and the first Explore/Explain phases to compare and contrast mining in New York and Appalachia

	New York	**Appalachia**
Differences		
Similarities		

Step 3.
Construct an argument in response to the prompt: how is the New York mining industry able to reduce its health and ecological impacts compared to the Appalachian mining industry?

In your argument, include:

- The steps New York has taken to minimize the impacts of mining
- How those steps are different than ones taken in Appalachian coal mines
- The extent to which those steps have been effective in mitigating the problems of mining
- Any costs (social, economic, or otherwise) that have been associated with those steps
- The constraints these solutions are working within

Solution A: Switching to Renewable Energy
Source information: Harvard International Review

One way to reduce the health impacts of mining coal and other energy is to stop using these types of fossil fuels to generate electricity by increasing our use of renewable energy sources like solar and wind. Making this change would also reduce the amount of emissions from fossil fuels released into the air, like carbon dioxide and air pollution, helping prevent (or reverse) climate change and improve air quality for millions of people.

However, renewable energy sources require machinery to harness and store the energy, including wind turbines, solar panels, and batteries. All of these items require a different set of mineral resources, called Rare Earth Elements (REEs). Surprisingly, REEs are found all over the world, but they exist in low concentrations in minerals and are very hard to separate from other elements. Extracting and refining them has huge environmental costs to communities and ecosystems around them.

There are two main ways to mine REEs, both of which release toxic chemicals into the environment. The first involves removing topsoil and creating a pond where chemicals are added to dissolve rare earth elements out of the ground, so they can be collected, concentrated, and refined. The other method involves digging holes in the ground to pour those chemicals into instead of removing the topsoil. In both cases, the ponds of chemicals created can leak into groundwater and contaminate waterways. When rare earth element ores mix with the chemicals, they can react to create toxic air, water, and soil pollution. Perhaps most worrying is that rare earth element ores often include radioactive thorium and uranium, which can be released into the environment.

Supply chains for REEs are politically challenging as well. China produces 70% of REEs globally; the United States produces 14%, and other countries produce 6% or less (source). China has used that dominance to try to control other nations: in 2010, it blocked REE exports to Japan as punishment for Japan's detention of a Chinese captain. In 2019, China considered limiting REE exports to the United States in response to tariffs, presenting a tremendous threat since the US defense industry relies heavily on these minerals.

China has been able to get ahead in this industry because it has relaxed environmental regulations that allow polluting mining operations to grow quickly. Those mines have caused significant damage: one mine has resulted in 70,000 tons of radioactive waste that are seeping into the groundwater and towards the Yellow River, which is a key source of drinking water; other mines have caused "cancer villages" to pop up, areas where a disproportionately large number of people have gotten cancer from mining pollution; and workers have developed heart, lung, and skin diseases from working in the mines. Furthermore, China has made agreements with many African countries, including the Democratic Republic of Congo and Kenya, to build mines in those places. Many people are worried that the industrialized world is offloading its dangerous mining to developing countries that will not benefit from them.

Hopefully, these problems won't exist forever as technology improves. The United States is working to create its own REE supply chain and find cleaner ways to extract the elements. Some companies are working to recycle REEs rather than mine new ones, and others are working on renewable energy technology that doesn't require REEs at all. However, at the moment, there are real costs associated with the benefits of renewable energy. The question is: how do those costs compare to the benefits gained by avoiding fossil fuel mining and burning?

Solution B: Reclaiming Mined Habitats

One way to reduce the impacts of mining coal and other energy and mineral resources is to restore lands once mining is completed. In 1977, the Surface Mining Control and Reclamation Act introduced regulations for active mines and required that abandoned or completed mining sites be cleaned, returned to natural habitat, or used for construction of homes or commercial buildings. This process is called mine reclamation: mines are *reclaimed* for other uses (source). In some cases, mines can even be reclaimed while they are still in use: only certain parts of the mine are used for mining at a time, while the rest is preserved and reclaimed. In reality, reclaiming mines is very complicated and expensive, with a wide range of success.

The active Suffern quarry before reclamation.


View of the erosion control matting installed on a 2:1 slope after cutting and regrading.


View showing the slope with grasses established.

In best-case scenarios, surface mines have been carefully cleaned, rocks and soil have been returned to recontour the landscape to its original shape, and native plant species have been replanted to reduce biodiversity loss (source). In one particularly successful example in Pennsylvania, a species of Elk, which had been wiped out in the area, returned to reclaimed land (source). In other areas, old coal mines from the 1970s and 1980s had been reforested, but with non-native plants that did not restore original biodiversity; efforts are underway now to replant those areas with more productive species (source).

By law, reclamation efforts can also turn old mines into useful areas for humans. By law, mines are supposed to be returned to their original shape, Image source but exceptions are made for reclaimed mines that will have economic use when reclaimed. Mines have been turned into parks, golf courses, and agricultural fields. These uses are better than open mines left behind, but do not restore the natural environment that used to exist.

Reclaiming lands used for mountaintop removal coal mining is particularly challenging. In Appalachia, 500 of the oldest and most biodiverse mountains in the United States have already been destroyed, leaving environmental destruction and toxic chemicals behind. These mines do not simply dig into the surface, but use explosives to remove the entire tops of mountains, so restoring the mountains is particularly challenging. The companies responsible for this destruction have claimed that the land will be converted for economic use, thereby avoiding the need to restore mountains to their original shapes. However, 90% of mined sites have not been reclaimed for economic purposes; instead, they have simply been abandoned (source).

Efforts to reclaim land in Appalachia are underway, however. Projects begun in 2017 have introduced solar farms and water treatment plants to locations across the region (source). In 2021, the Bipartisan Infrastructure Law allotted $11.2 billion to reclaiming abandoned mines, with hundreds of millions of dollars going to the Appalachian region. With that money, states are initiating work to remove mining waste piles, stabilize hills against landslides, clean water sources, and restore watersheds (source). These projects can go a long way in improving the health of communities impacted by nearby mining operations, but they are undermined by private companies continuing to destroy the environment even while public money tries to clean it up. Mine reclamation has clear benefits, but how do those benefits compare to the cost of implementing them and of ongoing environmental damage from mining?

Reducing the Impacts of Mining

Now that we have fully analyzed the challenges of mining without damaging human health and ecosystems, we will consider two solutions to reduce its impacts. Follow the steps below to evaluate each solution and select one that has better cost-benefit ratios.

First, describe the overall phenomenon.

1. What is the human activity that is causing a problem?

2. Why is it happening? What needs are being met?

3. How is that causing problems? What are the costs to human and ecosystem health?

4. Now, based on what you have read so far, brainstorm some ways to reduce the impacts of human activities.

5. Think about what you'd want a good solution to accomplish. What does a successful solution look like to you? What criteria would be most important to you when comparing solutions?

Read-Generate-Sort Solve Organizer

Guiding prompt: How can we evaluate solutions to real-world problems? The need for energy and mineral resources has continued to increase, but scientists, engineers, and policymakers are constantly trying to reduce human and environmental costs while maintaining benefits. There are many different ways to reduce the impact of mining on human and ecosystem health. Follow the steps of the Read-Generate-Sort-Solve routine below to evaluate two solutions and identify which one has the most preferred cost-benefit ratios.

1. **Read** about each solution and capture your ideas in the note taker below

Solutions:

A. Switching to Renewable Energy
B. Mined Land Reclamation

As you read, capture ideas to fill in the note catcher below

	Solution A	**Solution B**
What are the costs of the solution?		
What are the benefits of the solution?		
What are the strengths of each solution in terms of its costs and benefits? • economic • environmental • Geopolitical		

What constraints exist that the solutions must work within, including cost, safety, reliability, aesthetics, cultural effects, environmental effects?		

2. **Generate** ideas on the prompt: Which solution maximizes benefits while reducing costs the most?

Name: _____	**Name: _____**	**Name: _____**

3. **Sort -** Discuss each solution or idea and ☆star☆ the ideas that seem the most useful

4. **Solve -** Write your group's response to the prompt "Which solution maximizes benefits while reducing costs the most?" incorporating the most useful ideas from the sorting process! To do so, write a logical argument in factor of one of the solutions based on all the factors above.

Use evidence from the investigation and texts in this 5E to support your evaluation.

Reflect:

1. Does this solution affect people equitably? Do some people gain more benefits than others?

2. What changes to the technology or environment would change your opinion on the solutions? What would have to change for you to believe that the other solution is better, or that your choice is no longer best? What improvements could be made to either solution which might change the cost-benefit analysis?

Arguing for Solutions

Read about each one and capture your ideas in the note taker below

Solutions
A. Increased Regulation of Sustainable Practices
B. Reuse Mining Waste

As you read, capture ideas to fill in the note catcher below

	Solution A	Solution B
What are the costs of the solution?		
What are the benefits of the solution?		
What are the strengths of each solution in terms of its costs and benefits? • Economic • Environmental • geopolitical		
What constraints exist that the solutions must work within, including cost, safety, reliability, aesthetics, cultural effects, environmental effects?		

Brainstorm ideas on the prompt: Which solution maximizes benefits while reducing costs the most?

Write a logical argument in factor of one of the solutions based on all the factors above.
Use evidence from the investigation and texts in this sequence to support your evaluation.

What changes to the technology or environment would change your opinion on the solutions? What would have to change for you to believe that the other solution is better, or that your choice is no longer best? What improvements could be made to either solution which might change the cost-benefit analysis?

Evaluate Mining Student Texts

Solution A: Increased Regulation of Sustainable Practices

Because coal is a valuable resource that is known to cause many health and environmental problems, many organizations try to find a middle ground by advocating for maintaining the coal industry but increasing regulations that promote sustainability. In some ways, the United States has begun that process: In 1977, a law passed called the Surface Mining Control and Reclamation Act, which required reclamation of abandoned mines and set requirements that new mining operations be set up "in an environmentally friendly manner." However, many people argue that its requirements are not strict enough, and enforcement of the law has been largely left to states, not all of which uphold it strictly. Different regulatory bodies within the United States have continuously added or removed environmental protections over the past 50 years, resulting in a patchwork of active and inactive regulations and uneven regulation over time.

Globally, the mining industry reports that it has become more sustainable overall. Technology has become more efficient, and some areas are switching over to energy-efficient machinery and vehicles to reduce the overall carbon footprint of mining operations. Some mines use water recycling technology to reduce the water burden on local areas, and others capture methane gas that would otherwise pollute the air and use it for energy. However, none of these strategies fundamentally change how mines interact with ecosystems.

Within the United States, many advocacy groups are arguing for more stringent regulations on coal mining. Some groups are campaigning to end mountaintop removal coal mining entirely, while others are lobbying to restrict its use to areas where it would not interfere with natural features like streams. Opponents of regulations say that these limitations would result in the end of coal mining in appalachia completely; though traditional underground mining using tunnels has become safer and produces a much smaller footprint than mountaintop removal, so much coal has already been extracted from appalachia that the remaining coal is too sparse to be mined using tunnels. As a result, there is disagreement about whether mining can be made healthy and environmentally friendly at all.

Solution B: Reusing Mining Waste
Modified from the Washington Post and The Journal of Minerals Engineering

Though it is well-established that coal mining, especially across Appalachia, has caused huge amounts of damage, cleaning up dangerous mining pollution has been challenging and very expensive. For example, in West Virginia alone, there are 184 water treatment plants costing $4 million per year, working to clean up acid mine drainage, a type of pollution from coal mines that contaminates drinking water and kills organisms. One report has estimated that cleaning up all of the abandoned coal mines around the country would cost $20 billion. However, new initiatives are working to reuse waste from coal mining, helping reduce the pollution footprint of those mines and create commercially useful other products.

One such reuse project is to extract value from acid mine drainage itself. This corrosive pollutant happens to be high in minerals, including cobalt, nickel, and rare earth elements. A new recycling plant near the Potomac River in West Virginia plans to clean acid mine drainage pollution and recapture those pressures metals and other minerals. Researchers hope that, over time, the financial gain of recovering these minerals, which are needed for building cell phones and other electronics, will cover the cost of cleaning up the pollution itself. Other projects are trying to mine rare earth elements from solid coal mining waste. Research indicates that land displaced from coal mines could contain 300 to 400 tons of rare earth elements. Using these wastes to gather rare earth elements would help the United States gain an important supply of these elements, which currently come mostly from China, and reduce the need to open new mines for these valuable supplies.

Coal mining produces large amounts of waste rock and dirt, which are often displaced and left disrupting natural landscapes. Around the world, these waste rocks are recycled and used to create bricks and other construction materials. Recently, scientists have improved that process to extract residual coal from these waste rocks and construct new bricks with the remaining waste, which both maximizes the coal resources gained from mining and creates strong building materials.

Neither of these solutions solve all of the problems associated with coal mining and its resultant pollution, but if mines operated with plans for safely disposing of their waste before it becomes environmentally-damaging, their overall footprints would be decreased

Mining Performance Task Rubric

Mining	Proficient	Developing
Argument Rubric	Effectively and clearly provides an evaluation of the presented competing solutions that includes **all** of the elements below: • A description of the real world problem • An explanation of how the solution helps with the real world problem, using empirical evidence and scientific ideas • An identification of the ways solution does not fully solve the real world problem • An analysis of the tradeoffs of the solution, including economic, societal, and/or ethical considerations • An argument for the use of one or more competing solutions using the relevant evidence and scientific ideas supporting each solution and its drawbacks	Provides an evaluation of the presented competing solutions that includes **some** of the elements below: • A description of the real world problem • An explanation of how the solution helps with the real world problem, using empirical evidence and scientific ideas • An identification of the ways solution does not fully solve the real world problem • An analysis of the tradeoffs of the solution, including economic, societal, and/or ethical considerations • An argument for the use of one or more competing solutions using the relevant evidence and scientific ideas supporting each solution and its drawbacks
Connections to Engineering, Technology, and Applications of Science	Argument includes data that shows to what extent the solution can reduce or reverse the negative changes caused by land use	Argument does not include data that shows to what extent the solution can reduce or reverse the negative changes caused by land use
Student Self-Score	**Circle One** **Proficient** **Developing**	**Glow**: **Grow**:
Teacher Score	**Circle One** **Proficient** **Developing**	**Glow**: **Grow**:

Relevance to your life: Think about everything that you have learned throughout this unit so far.

1. What is one idea and/or skill you learned that you think is important to teach someone in your family or community?

2. To whom do you intend to teach this idea and/or skill? Why do you think it is important for this person to learn this idea and/or skill?