Methane and Climate Change

Description:

Methane is one of the most powerful greenhouse gases, but it is often overlooked next to carbon dioxide. Students explore some of the largest sources of human-caused methane emissions and consider how they are measured and how decision-makers can reduce emissions.

Skills & Objectives

SWBAT

- Know what some of the major sources of methane emissions are
- Understand some of the challenges associated with measuring methane emissions
- Explain why methane is an important gas associated with climate change

Skills

- Reading and discussing technical and non-fiction writing
- Critical thinking
- Graph and map reading

Students Should Already Know That

- Certain gases, such as carbon dioxide and methane, act as parts of a heat-trapping blanket in Earth's atmosphere, heating Earth and changing the climate.

Standards Alignment:
HS-ESS3-4 Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.
HS-ETS1-1 Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.
RST.9-12.2 Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text.
WHST.9-12.7 Conduct short as well as more sustained research projects to answer a question or solve a problem.

Disciplinary Core Ideas:
ESS3.A Natural Resources
ESS3.C Human Impacts on Earth Systems
ESS3.D Global Climate Change

Methane and Climate Change

How To Use These Activities:

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

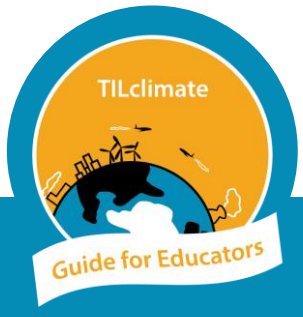
Each of the included activities is designed to be used as a standalone, in sequence, or integrated within other curriculum needs. A detailed table of contents, on the next page, explains what students will do in each activity.

A Note About Printing

All student pages are designed to be printable in grayscale.

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

Share with us! We would love to hear any podcasts or see any other projects you or your students create! Email us at tilclimate@mit.edu, tweet us @tilclimate, or tag us on Facebook @climateMIT.



Methane and Climate Change

Detailed Table of Contents

Methane and Climate Change

Methane Emissions

This Educator Guide includes a data investigation and readings. Educators may pick and choose among the pieces of the Guide, as suits their class needs.
Parts of this Guide may align with the following topics:

- Physical science: Methane vs other gases as heat-trapping agents in the atmosphere.
- Life/environmental science: Effects of methane, agricultural impacts.
- History/social science: Data needs for policy.
- ELA/nonfiction: Comparing and contrasting two pieces of nonfiction writing.

MIT Resources

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

- Climate Science, Risk & Solutions, an interactive introduction to the basics of climate change. https://climateprimer.mit.edu/
  Chapter 02 The greenhouse effect and us

- MIT Climate Portal Explainers are one-page articles describing a variety of climate topics. New Explainers are posted monthly. https://climate.mit.edu/explainers
  Greenhouse Gases
  Heating and Cooling

- MIT professors can answer your and your students' questions about climate change! Submit your questions or see other answers at https://climate.mit.edu/ask-mit-climate

Methane and Climate Change

Wrap-Up Discussion Questions

- Why is methane such a challenge to measure?
- Why is it important that we measure methane?
- Do scientists have all the tools we need to answer the questions we have?
- What other tools, data, or information do decision-makers need to dramatically reduce methane in the next few decades?

Climate Solutions

Climate solutions can be thought of as falling into four categories outlined below. Across all categories, solutions at the community, state or federal level are generally more impactful than individual actions. For example, policies that increase the nuclear, solar and wind mix in the electric grid are generally more effective at reducing climate pollution than asking homeowners to install solar panels. For more on talking about climate change in the classroom, see "How to Use This Guide".

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

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

Methane Sources & Solutions

"So typically methane emissions are categorized as anthropogenic and natural. And the anthropogenic means that it's human derived and natural is kind of this implication that it's from wetlands or lakes or those types of sources. But the reality is that humans are changing the earth system so much, even the natural sources have been augmented."

Prof. Desiree Plata, MIT Department of Civil and Environmental Engineering
TILclimate podcast: How tackling methane cools the planet fast

Sources of Methane

One of the biggest challenges for tracking and reducing methane emissions is that methane sources are all around us. Most carbon dioxide emissions come from relatively obvious places such as vehicles and electric power plants.[1] Methane, on the other hand, is emitted from a mixture of natural sources such as waterways and wetlands and human-generated sources such as livestock, fossil fuel processing, and landfills.[2]

These sources are so varied and spread out that they are difficult to track. The United Nations Environment Programme provides some estimates of the amount of methane emitted by various sources, based on combined data from multiple studies and models.

"Top-down" methods use satellites or other technologies to measure how much methane is in the atmosphere and estimate where that methane came from.

"Bottom-up" methods use data from specific parts of a sector (for example, all power plants in a certain region) and estimate global data from that number.

Consider

What are some pros and cons to "top-down" vs "bottom-up" measurements?

1 USEPA, Sources of Greenhouse Gas Emissions https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions
2 United Nations Environment Programme and Climate and Clean Air Coalition (2021). Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions. Nairobi: United Nations Environment Programme.
https://www.ccacoalition.org/sites/default/files/resources/2021_Global-Methane_Assessment_full_0.pdf
Images from The Noun Project by Adriansyah and Vector Portal

Methane Sources & Solutions

The Big Three

In pairs or small groups, you are going to read about sources and solutions for one of the top three anthropogenic (human-caused) sources of methane. As Prof. Plata says in the podcast episode, many of the "natural" sources of methane are also affected by human activity and human-caused climate change, but today we will focus on the sources that come directly from human actions.

Before You Begin

Take a moment to think about the questions you have about methane.

What do you already know, and what would you like to find out?

Incomplete Data

Because methane has historically been so hard to track, the numbers on the following pages are not necessarily complete or exactly accurate. They represent the best estimates from a wide range of studies and data sources.

Consider

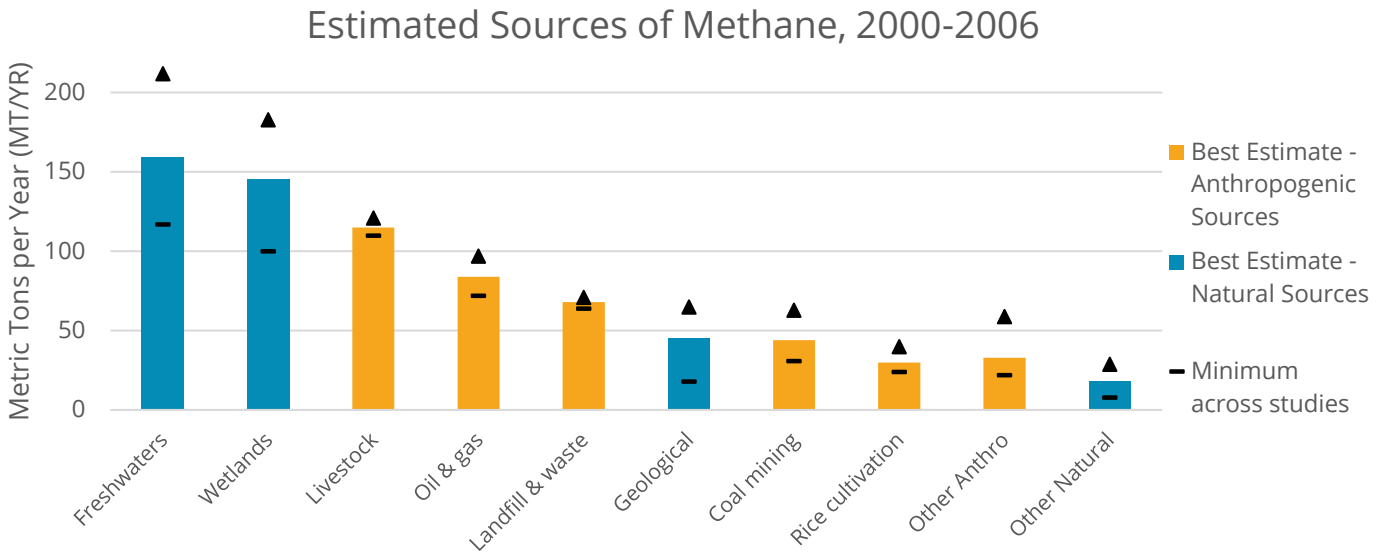
What tools would scientists need to get better measurements?

What information do decision-makers need to make better policies?

Methane Sources & Solutions

Sources of Methane

The United Nations Environment Programme provides some estimates of the amount of methane emitted by various sources, based on combined data from multiple studies and models. They report the best estimate, as well as the minimum and maximum found in any study. Everything is reported in MT/YR or Metric Tons of Methane per Year.



Observe

What do you notice about these sources? Which sources are a surprise?

Analyze

Look at the maximum and minimum for each source. Which sources have the largest ranges? Why do you think this might be?

Extend

What questions do you have? What tools or information would be needed to answer them?

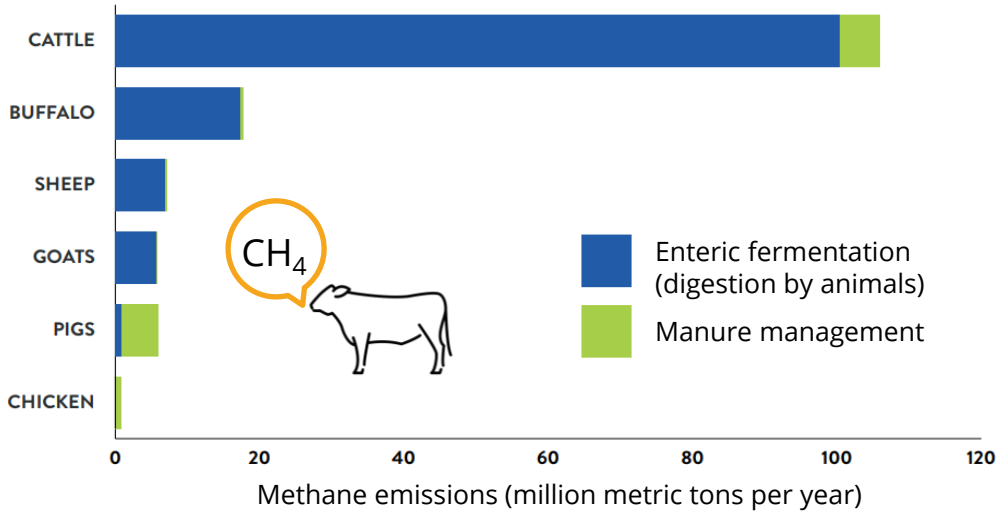
Read More

On the following pages, each group in your class will tackle one of the three largest sources of anthropogenic (human-caused) methane emissions: livestock & agriculture, fossil fuels, and landfills & waste.

United Nations Environment Programme and Climate and Clean Air Coalition (2021). Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions. Nairobi: United Nations Environment Programme. https://www.ccacoalition.org/sites/default/files/resources/2021_Global-Methane_Assessment_full_0.pdf

Methane Sources & Solutions: Agriculture

A Closer Look: Livestock



Animal	Population
Cattle (cows)	1.5 billion
Water buffaloes	204 million
Sheep	1.3 billion
Goats	1.1 billion
Pigs	975 million
Chickens	25.8 million

As animals, especially *ruminants* (cows, sheep, etc.) digest the plant matter that they eat, large amounts of methane are produced through *enteric fermentation*.

The management of animal waste (manure) also produces methane emissions, as the manure is broken down by bacteria.

Observe

What do you notice about the data? What surprises or interests you?

Analyze

Compare annual methane emissions to the world population for each group of animals. What do you notice?

Extend

What questions do you have? What tools or information would be needed to answer them?

Share

What is one takeaway you have from this information?

United Nations Environment Programme and Climate and Clean Air Coalition (2021). Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions. Nairobi: United Nations Environment Programme. https://www.ccacoalition.org/sites/default/files/resources/2021_Global-Methane_Assessment_full_0.pdf
Image from The Noun Project by Chatchai Pripimuk
Animal world populations as of 2021, from Food and Agriculture Organization of the United Nations https://www.fao.org/faostat/

Methane Sources & Solutions: Agriculture

Emissions Control Measures: Agriculture

The Global Methane Assessment lists the following measures that can be taken to reduce methane emissions from agriculture:

Ruminants

- Feed changes and supplements.
- Breeding animals to improve productivity.

Manure Management

- Treat manure in biogas digesters, capturing methane.
- Reduce storage time of manure, and increase covering of stored manure.

Rice Cultivation

- Improve water management.
- Change seeding and fertilizer processes.

Agricultural Burning

- Ban burning of agricultural waste.
- Enforce existing burn bans.

Observe

What do you notice about these actions? How would you characterize or describe them?

Analyze

Based on what you learned about how much methane each of these activities produce, which solutions do you think decision makers should focus on?

Extend

What questions do you have? What tools or information would be needed to answer them?

Share

What is one takeaway you have from this information?

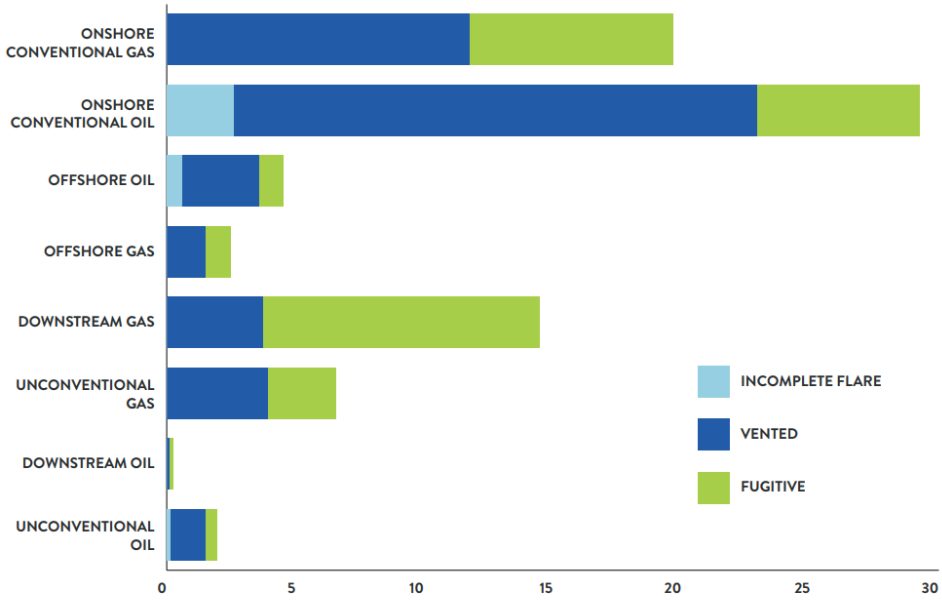
United Nations Environment Programme and Climate and Clean Air Coalition (2021). Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions. Nairobi: United Nations Environment Programme. https://www.ccacoalition.org/sites/default/files/resources/2021_Global-Methane_Assessment_full_0.pdf

Methane Sources & Solutions: Fossil Fuels

A Closer Look: Oil and Gas Sector

All parts of the oil and gas sector have the potential to release methane, either as part of natural gas extraction or as a byproduct of oil extraction. Each activity and process creates different opportunities for methane to be released to the atmosphere.

Definitions for all terms are on the next page.



Methane emissions (million metric tons per year)

Observe

What do you notice about the data? What surprises or interests you?

Analyze

Each of these categories of fuel are produced and used at different rates. How would you compare which ones release the most methane per unit used/produced?

Extend

What questions do you have? What tools or information would be needed to answer them?

Share

What is one takeaway you have from this information?

United Nations Environment Programme and Climate and Clean Air Coalition (2021). Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions. Nairobi: United Nations Environment Programme. https://www.ccacoalition.org/sites/default/files/resources/2021_Global-Methane_Assessment_full_0.pdf

Methane Sources & Solutions: Fossil Fuels

Oil and Gas Sector Definitions & Sources

Term	Definition
Onshore conventional gas	Natural gas that is drilled out of reservoirs underground on land, using wells or drills.
Onshore conventional oil	Crude oil that is pumped out of the ground on land, using standard equipment such as drills, pipes, etc.
Offshore oil	Crude oil that is pumped out of the ground under the ocean, using standard equipment such as drills, rigs, etc.
Offshore gas	Natural gas that is drilled out of reservoirs under the ocean, using wells or drills.
Downstream gas	Natural gas that is moved and used through above-ground pipelines, underground pipes, processing stations, and individual homes and businesses.
Unconventional gas	Natural gas that is drilled out of reservoirs using hydraulic fracturing ("fracking") and/or horizontal drilling.
Downstream oil	Crude and processed oil that is moved and used through above-ground pipelines, underground pipes, processing stations, and individual homes and businesses.
Unconventional oil	Crude oil that is brought out of the ground using non-standard equipment. This may include oil sands ("tar sands"), drilling horizontally, and hydraulic fracturing ("fracking").
Incomplete flare	Inefficient burning or "flare" of natural gas produced as a byproduct of oil extraction or processing.
Vented	Direct, intentional release of methane from the ground, a pipeline, a processing facility, etc.
Fugitive	Unintentional leaks of methane along all parts of natural gas infrastructure, from pipes, valves, equipment, etc.

Methane Sources & Solutions: Fossil Fuels

Emissions Control Measures: Fossil Fuels

The Global Methane Assessment lists the following measures that can be taken to reduce methane emissions from fossil fuel extraction, processing, and use:

Oil & Gas Extraction & Processing

- Leak detection and repair (LDAR).
- Recovery and use of vented gas.
- More efficient flares.
- Cap unused wells.

Oil & Gas Use

- Replace gas pumps and pneumatic devices with electric or air-powered systems.
- Replace gasoline and diesel engines with electric motors.
- Replace and repair compressor parts.

Coal Mining

- Pump gas out before coal mining.
- Improve ventilation in coal mining operations.
- Flood abandoned coal mines.

Observe

What do you notice about these actions? How would you characterize or describe them?

Analyze

Based on what you learned about how much methane each of these activities produce, which solutions do you think decision makers should focus on?

Extend

What questions do you have? What tools or information would be needed to answer them?

Share

What is one takeaway you have from this information?

United Nations Environment Programme and Climate and Clean Air Coalition (2021). Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions. Nairobi: United Nations Environment Programme. https://www.ccacoalition.org/sites/default/files/resources/2021_Global-Methane_Assessment_full_0.pdf
Images from The Noun Project by Chintuza and Nick Bluth

Methane Sources & Solutions: Waste

A Closer Look: Solid Waste & Landfills

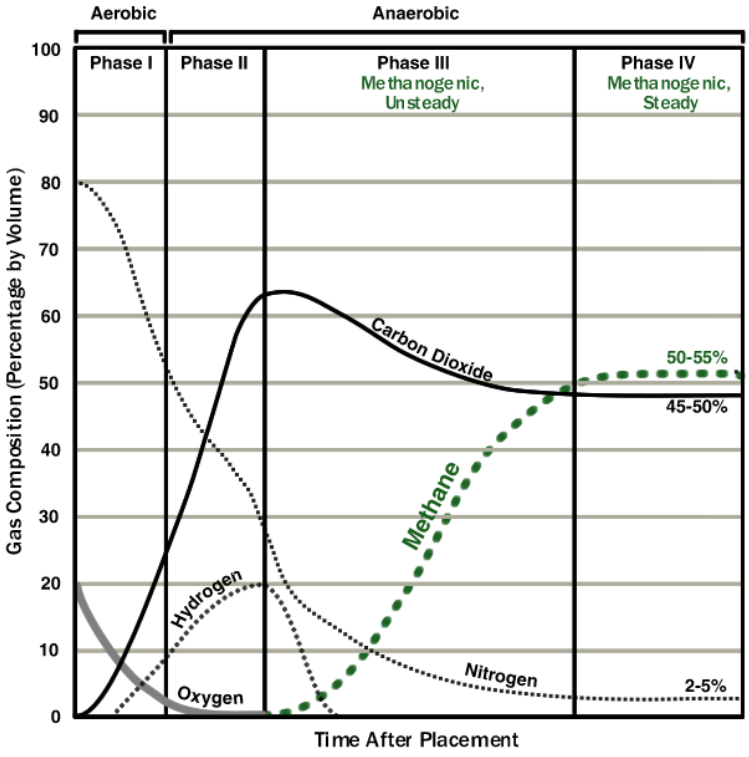
As solid waste (garbage) breaks down in a landfill, it goes through a series of phases, each of which release a different set of gases.

Phase I: *Aerobic* (oxygen-using) bacteria break down food and other organic wastes, using up oxygen and nitrogen and releasing carbon dioxide.

Phase II: *Anaerobic* (no oxygen used) bacteria break wastes down further, increasing acidity and releasing carbon dioxide and hydrogen.

Phase III: *Methanogenic* (methane-making) bacteria begin to consume the acids and some of the carbon dioxide, releasing methane.

Phase IV: Stable phase may last for 20-50 years, releasing about equal amounts carbon dioxide and methane.



Observe

What do you notice about this graph? What surprises or interests you?

Analyze

The time needed for each of these phases depends on many factors, including how tightly-packed the waste is, how much organic waste (food waste, plant matter, etc) is present, how much moisture is available, and many more. How and why might this information change how a landfill manages waste?

Extend

What questions do you have? What tools or information would be needed to answer them?

Share

What is one takeaway you have from this information?

Figure from US EPA, Basic Information about Landfill Gas. https://www.epa.gov/lmop/basic-information-about-landfill-gas

Methane Sources & Solutions: Waste

Emissions Control Measures: Waste

The Global Methane Assessment lists the following measures that can be taken to reduce methane emissions from waste management:

Solid Waste

- Separate and recycle/reuse usable materials.
- No landfilling of organic waste.
- Collect and use or flare landfill gas.

Wastewater & Sewers

- Upgrade systems to allow for biogas recovery and use
- Wastewater treatment plants instead of latrines

Observe

What do you notice about these actions? How would you characterize or describe them?

Analyze

Based on what you learned about how much methane each of these activities produce, which solutions do you think decision makers should focus on?

Extend

What questions do you have? What tools or information would be needed to answer them?

Share

What is one takeaway you have from this information?

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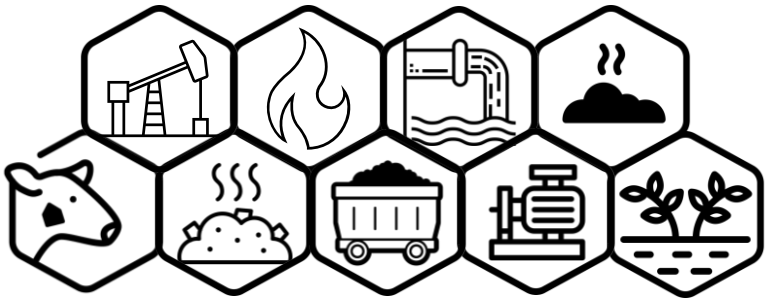
https://www.ccacoalition.org/sites/default/files/resources/2021_Global-Methane_Assessment_full_0.pdf
Images from The Noun Project by rendicon and Creative Mania

Methane & Solutions: Sources

Bring It All Together

Each group in your class has been reading about a different source of anthropogenic (human-caused) methane. Within your group, decide on the following takeaways to share:

1. What is the largest single source of methane in your category?
2. Which solutions do you think decision makers should focus on?
3. What questions still need to be answered? Do we need new and better tools or data to answer these questions?



Remix & Share

Remix groups such that each new group has at least one “expert” from the three major topic areas.

In these new groups, share takeaways. Then, discuss:

- Why is methane such a challenge to measure?
- Why is it important that we measure methane?
- Where should decision-makers focus to reduce the most methane? (Do you think the answer here is the same everywhere in the world?)
- Do scientists have all the tools we need to answer the questions we have?
- What other tools, data, or information do decision-makers need to dramatically reduce methane in the next few decades?
- What questions do you still have?

Methane: Fugitive Emissions

"Dealing with methane emissions is an enormous challenge. [skip] It's hard to find methane. It's hard to fix leaks. It's hard to abate methane from dilute sources like wetlands and dairy cows and things of that nature. But that doesn't mean it's not worthwhile. Methane is uniquely positioned to change the rate of climate forcing in our lifetimes."

Prof. Desiree Plata, MIT Department of Civil and Environmental Engineering
TILclimate podcast: How tackling methane cools the planet fast

Where is Methane Leaking?

"Fugitive emissions" are releases of methane before the fuel is even used. Fugitive emissions can occur at every point in the process of extracting methane from the ground or other source, processing it, moving it from place to place, and using it. This poses a huge challenge to scientists studying methane emissions. Large venting plumes from natural gas processing facilities can be measured from existing satellite data. However, smaller leaks from compressor facilities, long-distance pipelines, and the individual pipes bringing natural gas into homes and businesses are much harder to measure.

Fugitive emissions are adding to the amount of heat-trapping methane in the atmosphere. They can also have health impacts on the people and environments where they occur.

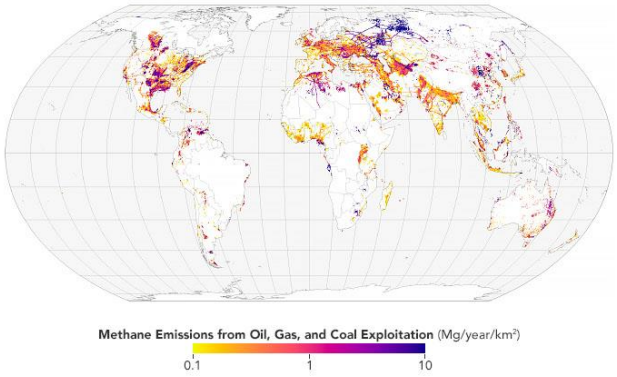
Groups of scientists and policy-makers are working together to answer two big questions:

- How can we ask the questions we need to ask with the tools we have?
- What tools do we need to develop?

Measurement: Big Picture and On-the-Ground

On the following pages are two different stories about two attempts to measure and map methane emissions. Both stories feature some of the same questions and challenges, as well as some major differences.

Methane: Fugitive Emissions



Methane From Fossil Fuel Extraction, Processing, and Movement

The process to get oil, natural gas, and coal out of the ground and into homes and businesses for use has many steps. Almost all these steps include opportunities for methane to escape. A group at NASA used data from the United Nations to attempt to map the places in the world with the largest amounts of fugitive methane emissions from fossil fuel extraction, processing, and movement.

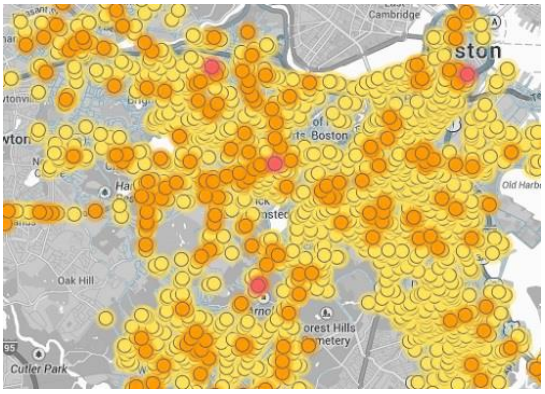
1. Read the article "Mapping Methane Emissions from Fossil Fuel Exploitation from the NASA Earth Observatory" at https://climate.mit.edu/ed/NASAmethane [1]

2. As you read, consider the following questions:
   - Where did the scientists get the data for this mapping project?
   - Do all countries report their methane emissions in the same way?
   - What kinds of structures or places are potential sources of fugitive methane emissions?
   - What are some of the challenges the scientists faced with finding and using the reported data?
   - How did the estimates based on reporting compare with the data from satellites?

3. Discuss the article with a partner or small group. Make sure everyone in the group understands the challenges and successes of this scientific effort. Then, discuss:
   - Is this kind of mapping project important to reducing methane emissions? Why or why not?
   - How could this mapping project be made more accurate?
   - What other questions do you have about fugitive methane emissions?

1 https://earthobservatory.nasa.gov/images/149374/mapping-methane-emissions-from-fossil-fuel-exploitation

Methane: Fugitive Emissions



Methane Leaks in Cities

Natural gas, which is mostly methane, is pumped through pipes under and around cities and towns all over the US. Many businesses and houses use natural gas for heat, hot water, and cooking. As it is moved around, unburned methane may escape from pipes, compressor stations, and appliances. Mapping these leaks is challenging, as the amounts from any one leak are small, but they can add up.

1. Read the article “Local leaks impact global climate” at https://www.edf.org/climate/methanemaps

2. As you read, consider the following questions:

   - Where did the scientists get the data for this mapping project?
   - What kinds of structures or places are potential sources of fugitive methane emissions?
   - What factors affect how many leaks a city is likely to have?
   - What are some solutions that EDF offers? (check the links under “Explore this project”)

3. Discuss the article with a partner or small group. Make sure everyone in the group understands the challenges and successes of this scientific effort. Then, discuss:

   - Is this kind of mapping project important to reducing methane emissions? Why or why not?
   - How could this mapping project be made more accurate?
   - What other questions do you have about fugitive methane emissions?