Today I Learned About Fusion Energy

Description:

Fusion energy has great potential to be an almost-limitless low-carbon energy source. However, scientists haven't yet been able to harness its power. Through a model, a virtual tour, and a research project, students investigate the question – what is the potential of fusion energy, and what part could it play in our future?

Skills & Objectives

SWBAT

- Explain the basics of how fusion creates energy.
- Understand that industries use energy in different ways which have implications for converting to low-carbon energy sources.

Skills

- Research
- Modeling

Students Should Already Know That

- Atoms have a structure that includes subatomic particles such as neutrons, protons, and electrons.
- Most energy sources come from chemical reactions, not breaking subatomic bonds.

Standards Alignment:
HS-PS1-8 Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay.
HS-ETS1-3 Evaluate a solution to a complex real-world problem.

Disciplinary Core Ideas:
ESS2.D Weather and Climate
ESS3.C Human Impacts on Earth Systems
ESS3.D Global Climate Change

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How To Use These Activities:

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

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

A Note About Printing/Materials

All student pages are designed to be printable in grayscale.

The virtual visit to the Alcator facility could be done individually by students on computers or mobile devices or projected on the wall for students to experience as a group. The virtual tour is also available in a format compatible with Google Cardboard. Cardboard is a low-cost virtual reality system that pairs with a smartphone to create immersive experiences. Instructions to purchase ($10-40) or make a Cardboard viewer can be found at https://arvr.google.com/cardboard/get-cardboard/

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

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

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Detailed Table of Contents

Page	Title	Description	Time (min)
	Podcast Episode	Students listen to TILclimate: TIL about fusion energy, either as pre-class work at home or in the classroom. https://climate.mit.edu/podcasts/e8-til-about-fusion-energy	10-15
1	Fusion Reaction Model	Using ping-pong balls, students model a hydrogen fusion reaction and the heat generated.	5-10
2	Virtual Tour: Inside a Fusion Chamber (internet required)	Using a computer or mobile device, students virtually tour the Alcator C-Mod at MIT and consider what fusion science looks like.	10-15
3-5	Industrial Energy Use (internet required)	Students investigate the potential for fusion energy as a replacement for fossil-fuel-heavy industries.	20-45+

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Season 2 Collection

Season 2 of TILclimate from MIT covers a series of interrelated energy subjects. The associated teacher guides are structured for maximum flexibility. Each episode's activities could be done as a whole class or as small-group work while other teams work on other topics and share back in a jigsaw. Some activities also can be enrichment or homework, and many as asynchronous assignments for remote work. Activities of similar length could also be set up as rotating stations, with a group discussion at the end of class.

- Introductory activities are quick (15-25 minutes) and require no internet.
- Dive Deeper activities are longer (30-60 minutes) and require internet access.

The City of the Future overall project is flexible in terms of time, space, and materials. It will be engaging whether students have completed all activities in the collection, or just one. If teams of students have been working on one topic each, the City of the Future process will help them share their learning with the rest of the class.

Fusion & Industry

This Educator Guide includes a model, a virtual tour, and a research project. Educators may pick and choose among the pieces of the Guide, as suits their class needs.
Parts of this Guide may align with the following topics:

- Physical science: States of matter, stars, atomic interactions
- Life/environmental science: Impacts of energy use on the environment
- History/social science: Decisions about long-term scientific studies

MIT Resources

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

- Climate Science, Risk & Solutions, an interactive introduction to the basics of climate change. https://climateprimer.mit.edu/
  - Chapter 02 The greenhouse effect and us
  - Chapter 09 How long can we wait to act?
  - Chapter 10 What can we do?
- MIT Climate Portal Explainers are one-page articles describing a variety of climate topics. https://climate.mit.edu/explainers
  - Fusion Energy
  - Concrete
  - Mining and Minerals

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Wrap-Up Discussion Questions

- Why do you think fusion reactions can be sustained in stars but not in labs? What conditions might stars have that are difficult to replicate on Earth?
- In the episode, Professor Whyte talks about the advantage of fusion reactions creating high-quality heat. What are the advantages of an energy source that can provide raw heat, in addition to electricity?
- Not only would a fusion power plant provide high-quality heat, but it would provide it on a massive scale. Imagine a world where fusion is our main energy source. What might our energy, manufacturing, and transportation infrastructure look like? How might it be different from our infrastructure today?
- Fusion has the potential to generate much more energy than our current carbon-free energy technologies, but we don't know when it will work on a commercial scale. Do you think we should count on fusion shaping our energy markets, or invest now in other carbon-free energy infrastructure?

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.

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"At the center of a sun and a star, it becomes hot enough and there's enough pressure that the hydrogen ... is forced to get close enough to another hydrogen and they fuse, and they produce helium. And when that happens, it releases staggering amounts of energy. It's twenty to a hundred million times more energy release per particle than you can ever get out of a chemical reaction."

Prof. Dennis Whyte, MIT Plasma Science and Fusion Center

TILclimate podcast: Today I Learned About Fusion Energy

Fusion Reaction

Fusion reactions could create 20 to 100 million times more energy than the burning of fossil fuels. In fusion, the nuclei of two hydrogen atoms are forced together and form an entirely new atom, helium. When fossil fuels are burned, the atoms are rearranged, but the atoms themselves are not altered.

Fusion naturally occurs at the center of stars, at temperatures above 100,000,000ºF. The challenge of fusion is to recreate the conditions of the center of a star here on Earth.

Fusion Reaction Model

Materials: 4 ping-pong balls or similar – 2 labeled Proton, 2 labeled Neutron

1. Two students each hold 1 proton and 1 neutron to form a deuterium (^2H) atom. Deuterium is an *isotope* of hydrogen. The most common form of hydrogen simply has one proton and no neutrons.
2. The rest of the class represents the heat and pressure needed to start the reaction. Have the class gather around the students representing the deuterium atoms, then move closer together until these two "atoms" collide.
3. When the atoms collide, one student takes both protons and both neutrons to form a helium atom, which has two of each.
4. The students disperse as the reaction is completed, producing 1 helium atom and vast amounts of energy.

Today I Learned About Fusion Energy

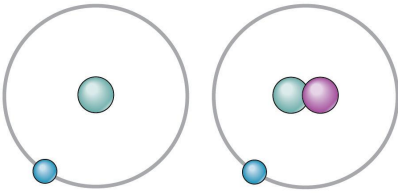
"The challenge of fusion is that fusion happens in one place, in the center of stars, because it's the one place that can get hot enough to make fusion happen. So at its heart it's about getting the fuel (the hydrogen) hot enough."

Prof. Dennis Whyte, MIT Plasma Science and Fusion Center
TILclimate podcast: Today I Learned About Fusion Energy

Inside a Fusion Chamber

How do fusion scientists recreate the center of a star on Earth?

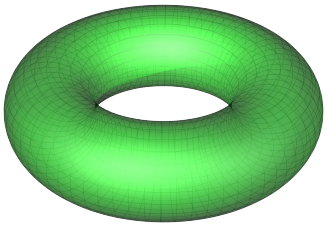
The nucleus of a 'heavy hydrogen' (deuterium, ^{2}H) atom has one proton and one neutron. A proton has a strong positive (+) charge, while a neutron has no charge. Two deuterium atoms naturally repel each other, like magnets with the same polarity. In order to cause fusion, these two repelled atoms must be forced together to form a helium atom, the same process that generates the heat of our sun and powers life on Earth.



Protium (^{1}H)
1 proton
1 electron

Deuterium (^{2}H)
1 proton
1 neutron
1 electron

If a gas is heated to 20 to 100 million degrees, it becomes a *plasma*, a superheated stage of matter where electrons are ripped away from their atoms. In this state, it is possible to force positively-charged hydrogen atoms to fuse together. Plasmas are very complex: controlling superheated plasma with magnetic fields is like trying to suspend gelatin between rubber bands. In some experimental fusion chambers, hydrogen plasma is confined in a donut shape, called a torus.



A torus

Visit http://research.psfc.mit.edu/alcator/intro/info.html to learn more.

Virtual Visit: Alcator C-Mod

1. What would you expect an experimental fusion chamber to look like? Make a quick sketch or describe what you would expect to see.
2. Visit http://research.psfc.mit.edu/alcator/cmod-tour.html on a computer or mobile device.
3. After exploring inside the Tokamak Vacuum Chamber, click **Torus Hall** to see the spaces outside the chamber, including the **Power Room** and **Control Room.**
4. Does anything surprise you? How does what you are seeing align with what you expected?
5. What do you think a day in the life of a fusion scientist looks like?

For an immersive experience, you can buy or make a Google Cardboard VR viewer and view Alcator on a smartphone. https://arvr.google.com/cardboard/get-cardboard/

Atomic images from OpenStax College via Wikimedia Commons

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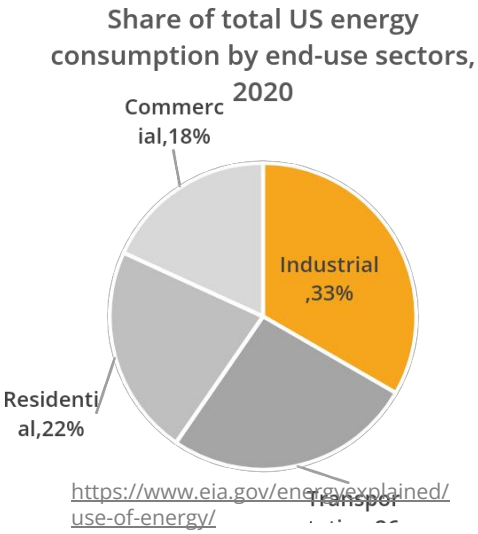
"We tend to keep thinking about de-carbonization and the climate crisis around making electricity. Electricity at most a quarter of the problem. Decarbonizing long range transportation, industrial heat processing, refining fuels, concrete, these things all have intense heat requirements. So what fusion has at its heart is that it doesn't just plug into the electrical infrastructure. It plugs into our energy infrastructure overall."

Prof. Dennis Whyte, MIT Plasma Science and Fusion Center

TILclimate podcast: Today I Learned About Fusion Energy

Industrial Energy Use

In 2020, the US used almost 93 quadrillion (92,940,000,000,000,000) Btu[1] of energy[2]. Of that, about 33%, or 31 quadrillion Btu were used in industry, such as manufacturing, mining, construction, and agriculture. While some of that energy is used similarly to other sectors (fuel for vehicles, electricity for lights, heat for buildings,) much of it is used directly to create heat for industrial processes.



As we burn fossil fuels like coal, oil, and natural gas, we release carbon dioxide (CO_2) into the atmosphere. This CO_2 acts like a blanket, trapping heat. Trapped heat is warming our Earth, ocean, and air. This warming is causing dramatic changes to climate and weather patterns worldwide.

In 2019, US industry released 1.4 billion metric tons of CO_2 from the burning of fossil fuels. This was 28% of total US CO_2 emissions for that year.[3]

Investigate

While other low-carbon energy sources (wind, solar, hydroelectric, and nuclear) create electricity, fusion has the capacity to create the direct heat needed for industry.

On the next page, find the six most energy-intensive industries in the US, along with the sources of energy used most by each industry.

Choose one industry and investigate how it uses energy. For this industry, how could a direct source of high-quality raw heat replace current carbon-producing energy sources?

1 British thermal units, a consistent unit of energy that allows comparison across energy sources and uses. https://www.eia.gov/energyexplained/units-and-calculators/british-thermal-units.php
2 US Energy Information Administration https://www.eia.gov/energyexplained/use-of-energy/industry.php
3 US Energy Information Administration https://www.eia.gov/environment/emissions/carbon/index.php

ENVIRONMENTAL SOLUTIONS INITIATIVE

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Energy Use in Industry

The US Energy Information Administration tracks energy use across sectors and sources via the Manufacturing Energy Consumption Survey. In 2018, six subsectors accounted for almost 90% of all industrial energy use. For each of these industries, energy sources are listed in trillion Btu used.

Industry	Includes	Electricity	Fuel Oils (oil, gasoline, diesel, etc.)	Natural gas	HGLs (hydrocarbon gas liquids)	Coal (including coke & breeze)	Other energy sources	Energy produced onsite
Chemicals	plastics, industrial chemicals, petrochemicals, pharmaceuticals, etc.	501	54	3,234	2,839	132	965	583
Petroleum and Coal Products	oil refineries, asphalt mixtures, coke plants, etc.	178	17	1,079	20	158	2,952	159
Paper	paperboad, paper, pulp, newsprint, etc.	174	13	575	3	54	1,223	0
Primary Metals	iron, steel, aluminum, etc.	385	6	683	3	528	30	125
Food	grain milling, animal processing, sugar, food preservation, dairy products, etc.	314	15	675	7	49	102	<0.5
Nonmetallic Mineral Products	cement, lime, glass, clay, etc.	129	21	350	2	195	149	0

Questions

1. How is electricity currently used in this industry? Most low-carbon sources of energy most easily produce electricity.
2. How is energy used in other ways in this industry? (Think about transportation, heat for melting or distilling materials, heating and cooling buildings, etc.)
3. Not only would a fusion power plant provide high-quality heat, but it would provide it on a massive scale. Imagine a world where fusion is our main energy source. What might our energy, manufacturing, and transportation infrastructure look like? How might it be different from our infrastructure today?

Consumption of Energy for All Purposes (First Use) https://www.eia.gov/consumption/manufacturing/data/2018/

MIT ENVIRONMENTAL SOLUTIONS INITIATIVE

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Research Resources: Energy Use in Industry

- Fusion Energy: https://climate.mit.edu/explainers/fusion-energy
- Use of Energy in Industry: https://www.eia.gov/energyexplained/use-of-energy/industry.php
- Steel Industry Analysis Brief: https://www.eia.gov/consumption/manufacturing/briefs/steel/index.php
- Chemical Industry Analysis Brief: https://www.eia.gov/consumption/manufacturing/briefs/chemical/index.php
- Concrete: https://climate.mit.edu/explainers/concrete
- Mining and Metals: https://climate.mit.edu/explainers/mining-and-metals
- Energy Use in the US Food System: https://www.ers.usda.gov/amber-waves/2010/september/fuel-for-food-energy-use-in-the-us-food-system/
- Energy Reduction in Pulp and Paper Industry https://www.pulpandpaper-technology.com/articles/Energyreduction
- International Atomic Energy Agency, Fusion: Ready When Society Needs It https://climate.mit.edu/ed/fusion

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