Today I Learned About Fusion Energy

"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.

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"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
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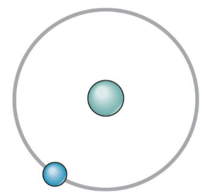
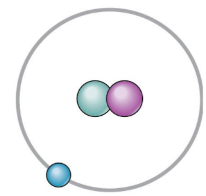
Inside a Fusion Chamber

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.

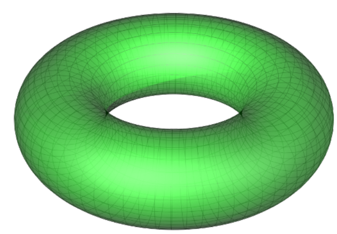


Protium (^{1}H)
1 proton
1 electron



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.

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/

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?

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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
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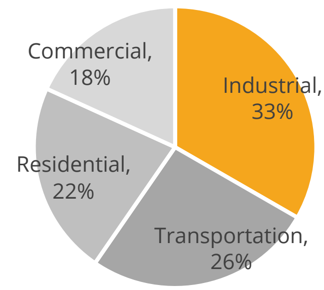
Industrial Energy Use

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.

Share of total US energy consumption by end-use sectors, 2020



https://www.eia.gov/energyexplained/use-of-energy/

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

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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/

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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://www.iaea.org/fusion-energy/fusion-ready-when-society-needs-it