Global Energy Flows

Overview: Students analyze data detailing global energy sources and sinks (uses) and construct a diagram to show the relative scale and the connections between them. Discussions of scale, historical, socio-environmental and geographic variation in this data and implications for future energy use are included.

Levels
9-Undergraduate

Subjects
Science, Environmental Studies, Social Studies

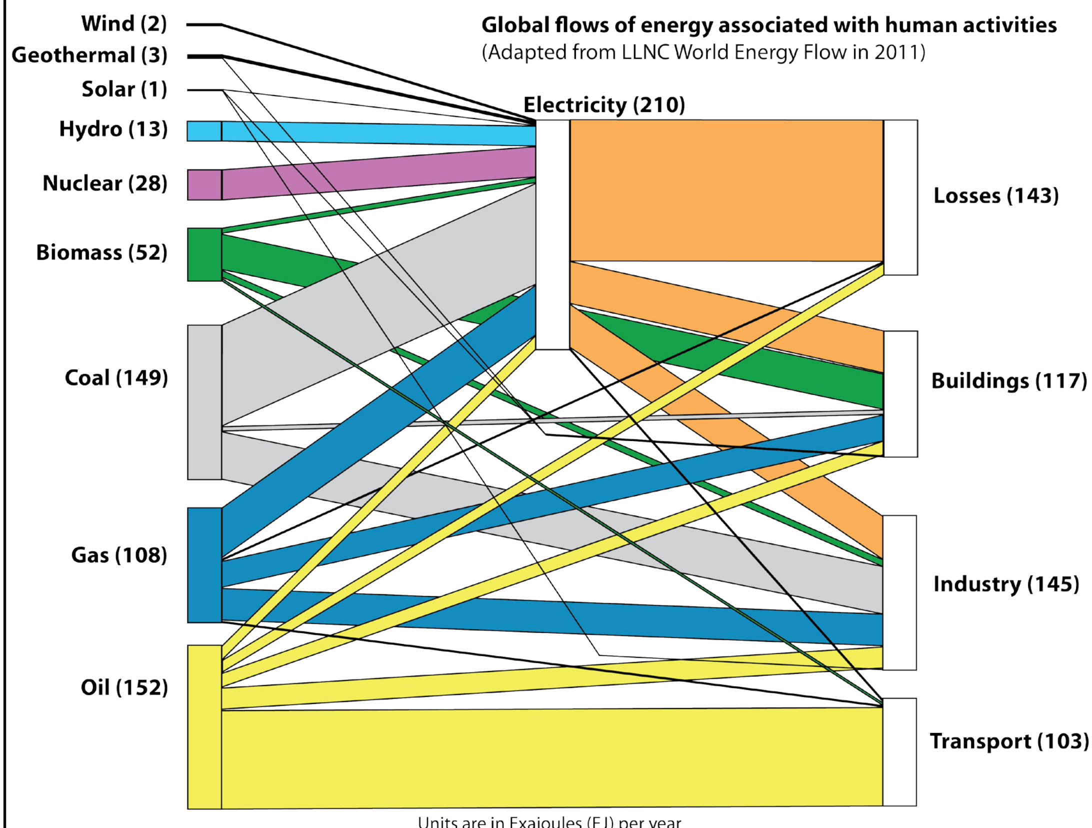
Objectives
- Identify major global energy sources and sinks.
- Construct a diagram showing the relative sizes of global energy sources and sinks and connections between them.
- Explain why energy transformations, especially electricity, result in significant loss of usable energy.
- Discuss the energy use differences between the global and national levels, especially in relation to bioenergy.
- Others described on pg 2T.

Materials
Global Energy Flows package

Activity Time
One-two 50-minute class periods

Standards
Next Generation Science Standards (2013)
- Scientific and Engineering Practices: analyzing and interpreting data; using mathematics and computational thinking
- Disciplinary Core Ideas: ecosystems; earth and human activity, engineering design
- Crosscutting Concepts: scale. proportion and quantity; systems and systems models, energy and matter
- Performance Expectations: See page 3 for details

NGSS Lead States. 2013. Next Generation Science Standards: For States by States. Washington DC: The National Academies Press



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Overview:

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Activity time is two 50-minute class periods, unless teachers use the flow model provided instead of having students construct their own.

Learning Outcomes: Students will...

- Identify major global energy sources and sinks.
- Construct a diagram showing the relative sizes of global energy sources and sinks and connections between them.
- Explain why energy transformations, especially electricity, result in significant loss of usable energy.
- Discuss the energy use differences between the global and national levels, especially in relation to bioenergy.
- Recognize that the nature of questions asked changes at increasing levels of data resolution (e.g. going from overall global energy to bioenergy)
- Compare differences in energy use from past to present, and even future projections.

This lesson assumes prior knowledge in the concepts of renewable and non-renewable sources of energy and their end-uses. Students should be familiar with the term joule.

Standards

Next Generation Science Standards (2013)

Performance Expectations

High School:

- **HS-LS2-7.** Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.
- **HS-ESS3-1.** Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.
- **HS-ESS3-6**. Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.
- **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.

Scientific and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Analyzing and interpreting data Using mathematics and computational thinking	**LS2**: Ecosystems: Interactions, energy, and dynamics **ESS3**: Earth and human activity **ETS1**: Engineering design	Scale, proportion and quantity Systems and systems models Energy and matter: Flows, cycles, and conservation

Sequence:

"Global Energy Flow Graph Slide Set"

Part 1. Overview of Global Energy Use (pages 1-2, slides 2-5) (10 minutes)
Pose the following questions to students: Where do we get our energy? How do we use it? How does the energy get from one place to another? Give them some time to journal about the answer or discuss ideas. Present them with the *Introduction* handout. In small groups, or as a class interpret the pie graphs. What stands out? Be sure students understand the differences between fossil vs non-fossil fuels as well as between renewable vs non-renewable energy sources. If students do not bring it up themselves, discuss the percent loss shown in figure 2. Introduce the idea of efficiency in energy transformations and heat losses during that process. (Note: If students have taken physics, connect this idea with the second law of thermodynamics and entropy.) Are there ways to reduce the percentage that goes to losses? What variations would you expect in these graphs if they only showed developed or developing countries?

Part 2. Building a Visual Model of Global Energy Use (pages 3-6, slides 10-12)

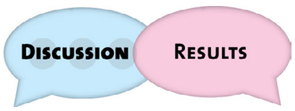
Option 1: Students use data to build their own visual model of global energy use.
Option 2: If operating under time constraints, the section can be shortened by not having students build their own model, but rather using those provided in the slide set (pages 4-6, slides 6-10).

Option 1: 60 minutes—can be spread over two class periods
Hand out the *Global Energy Source and Sink data page*. This set of data quantifies the connections between the sources and the sinks. Walk students through the data, asking them what stands out from this information. Discuss why the electricity category is shown in both sections. Electricity is an intermediate form of energy-neither source, nor sink-but rather helps transport energy from one place to another, and/or converts energy into a form usable for a specific function (for example as an intermediate between coal and a radio emitting sound).

Assign students to construct a diagram or map showing the flow of energy from sources to sinks. They may choose to make one complex diagram or one main diagram with supplements, such as graphs or charts, but all students should demonstrate:

- where the energy is coming from and where it is going and:

- the quantity of energy at each source and sink and the quantities moving between them. This could be done with written numbers and/or by varying the size of objects in the diagram according to your instruction.



Ask students to share diagrams with the class. As a group, discuss the pros and cons of the different representational choices. What do you learn from these diagrams that you could not see in the data table? When you finish this discussion, show the students the professional diagrams found in slides 10-12 and pages 4-5.

<u>Option 2: 30 minutes (use if operating under time constraints)</u>
If time is limited, shorten this section by using the step by step model provided in the slide set (pages 4-6, slides 6-10). Instead of students build their own visual model, lead students through the diagram step by step. Have students reflect and discuss questions along the way. Ask students to consider where energy is coming from and where it is going and the quantitiy of energy at each source and sink.

<u>Both options:</u>
Before moving on to part 3, consider some of the following discussion questions if they were not already raised:

- Why does the vast majority of energy for transportation come from oil, while the energy for industry and buildings comes from a number of different sources?
- Why is electricity used given that there is such a large quantity of lost energy associated with its production and consumption?
- Nuclear energy is largely used to generate electricity. Why?
- Which of the energy sources are strongly associated with the emission of greenhouse gases? Given your answer to this question, how would you rank the end-uses in terms of the difficulty to reduce these emissions? Explain your ranking.

Discussion Large Group

Part 3. Focus on biofuels (pages 7-8 optional, slides 6-10, 13-14) (15 min)
Return to slide 10 showing global energy flows and look at the bioenergy fluxes (Slides 6-10 step students through how to read this diagram). Then look at the zoomed image in slide 13 or hand out the graph of the same information (the data is available in raw form on page 15 as well). How is bioenergy used on a *global* scale? Is this surprising to you? Who is using biofuels and for what reason? It may take students a while to realize that this diagram largely represents individuals who burn wood and animal dung for home heating and cooking in developing countries (slide 14). This is very efficient, because the homes have little ventilation and people are very frugal because fuel is scarce. Also note that there are frequently significant environmental and health issues associated with this type of bioenergy use, mainly deforestation and poor indoor air quality.

Compare the global bioenergy slide to slide 15 showing energy flows in the United States. How are we using biofuel? *(industry—heating)* Research and development is currently underway to greatly expand the use of biomass for the production of ethanol and other fuels as an alternative to petroleum-based transportation fuels.

- How would you expect the proportions of sources to change if there was a significant increase in bioenergy used for transport?
- How would you expect the relative amount of losses to change in the global diagram if there was a significant increase in biofuels used for transport, and why?

Part 4. Changes in energy use over time. (slide 16-17) (10 min)
Look at slide 16, showing Supplies of Energy in the US from 1800 to the present. What caused these changes? How does this compare to our current energy source distribution? Have our energy sources been stable throughout our industrial history?

Post Assessment

What do you think will happen into the future? Have students create a "before and after" scenario either visually, or in writing, explaining how and why they think the major sources, sinks and flows will be different 20 years from now. Examine slide 17 to see the IPCC's prediction for 2030.

Discussion Questions for Figure 4

1. Why does the vast majority of energy for transportation come from oil, while the energy for industry and buildings comes from a number of different sources?

We are dependent on the combustion engine for transportation, which requires liquid fuels. Gasoline and diesel have high energy densities by volume making them efficient for transportation in a limited-sized fuel tank. Electricity and heat can be produced many ways at multiple scales.

2. Why is electricity used given that there is such a large quantity of lost energy associated with its production and consumption?

That is the form of energy necessary to run lighting, computers and other equipment. Electricity also provides a convinient method to distribute energy.

3. Nuclear energy is largely used to generate electricity. Why?

Uranium is extremely energy dense and generates heat efficiently to power electric generators. However, the technology is too dangerous to use in distributed systems and must be done at centralized locations.

4. Which of the energy sources are strongly associated with the emission of greenhouse gases? Given your answer to this question, how would you rank the end-uses on the right in terms of the difficulty to reduce these emissions? Explain your ranking.

Oil, coal and natural gas (fossil fuels) make up over 80% of global energy use, making replacement a huge challenge.

5. Biomass use currently accounts for about 10% of energy flow. On a global basis where (geographically, socio-politically, etc) do you think most of this use is located, and why?

Most the biomass is currently used in developing countries, especially in Africa, for home heating and cooking. People do not have access to other energy sources at this time.

6. Research and development is currently underway to greatly expand the use of biomass for the production of ethanol and other fuels as an alternative to petroleum-based transportation fuels. How would this change this diagram, and what would the potential opportunities and challenges be for this change?

We do not have enough biomass to replace all of our current petroleum use. In the United States, we estimate we can replace about 30% of petroleum use with biofuels. As developing countries begin to drive more, demand for transportation fuels will increase and we will need to find energy to meet those needs. Students may also consider opportunities for conservation and increase efficiency in our current uses.

7. What other questions do you have regarding the data in this graph?

Answers will vary.

Extensions:

1. Analyze and discuss downstream energy losses in buildings, industry, and transportation with the included "Energy Services and Energy Losses" supplement to this activity.
2. Create a similar diagram for your state or region. See the Lawrence Livermore National Laboratory's database of state data for comparison at https://flowcharts.llnl.gov/commodities/energy.
3. Consider greenhouse gas emissions and other environmental factors associated with each energy source. Look at more recent energy and carbon flow diagrams for the U.S. available from https://flowcharts.llnl.gov/commodities/carbon Discuss the links between energy and carbon.

Appendix

Cleveland, C. J. 2008. Fundamental principles of energy. Encyclopedia of Earth. This is a broad and wide-ranging article that covers topics including the physics of energy, climate and the earth's energy balance, energy use history and control of energy resources as a cause of violent conflict. There is an extensive list of "further reading". *http://www.eoearth.org/article/Ten_fundamental_principles_of_net_energy*

Cullen, J and J.M Allwood. 2010. "The efficient use of energy: Tracing the global flow of energy from fuel to service." Energy Policy. 38: 75-81. Demonstrates the ability to use the type of data in this activity to address issues of energy efficiency.

Metz et al. 2007. Climate Change 2007: Mitigation of Climate Change, UN IPCC 4th Report, Working Group III, Cambridge University Press. Rich in detail and data, the IPCC reports also contain excellent summaries, graphics and sidebars. *http://www.ipcc.ch/publications_and_data/publications_and_data_reports.htm*

Walter K. 2009. "Energy Goes with the Flow." Science and Technology Review. Short, simple article about the use of flow charts to document energy usage paths. PDF also in Supplemental Materials folder. *https://str.llnl.gov/Sep09/pdfs/09.09.3.pdf*

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