

Understanding Electricity Mix Tradeoffs

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Background

There are many different types of power plant technologies, each with positive and negative aspects. Here we explore ten primary power plant types: coal (where CO₂ is released), coal (where CO₂ is captured), coal-to-gas (where CO₂ is released), coal-to-gas (where CO₂ is captured), wind, natural gas, nuclear, solar cell, energy efficiency, and biomass-and-coal. Note that even though energy efficiency isn't a power plant, increasing personal energy efficiency decreases the number of power plants needed, and will thus be considered in this discussion.

In coal power plants where CO₂ is released, the coal is burned to create steam. The steam powers a turbine, which in turn runs a generator, producing electricity. As the coal is burned, it releases CO₂ into the air. While coal plants are steady and reliable, they release a lot of CO₂ into the atmosphere and produce a lot of solid waste in the form of ash. Coal mining also negatively impacts the environment by disturbing the land and potentially polluting streams. In addition, while coal plants are safe for operation, the coal mining is still dangerous today.

In coal power plants where CO₂ is captured, the plant produces electricity the same way as a coal power plant where CO₂ is released. However, there is additional equipment to convert the CO₂ into a liquid and transport it to rock formations, where the liquid CO₂ will be trapped. While this decreases the release of CO₂ into the atmosphere, there is a small chance that CO₂ can contaminate underground drinking water. In addition, there are also very small risks of CO₂ leaks and very small risks of earthquakes occurring as a result of the increase in pressure.

Coal-to-gas power plants (where CO₂ is released) use the heat from the burning of coal into gas to power a turbine. The turbine then runs a generator to produce electricity. The burning of coal to gas also provides heat to make steam, which is used to power a second turbine. Because coal-to-gas power plants have two turbines, they are more efficient than the previously mentioned coal power plants. While coal-to-gas power plants release less CO₂ than coal power plants, they release similar amounts of solid waste and also require coal mining.

Coal-to-gas power plants can also have capture equipment to reduce air pollution from the release of CO₂. This capture equipment is a little better than coal power plants with CO₂ capture, but work in the same way. CO₂ is converted to liquid and stored over 2500 feet underground. The risks are the same as those for coal-to-gas power plants where CO₂ is released, and for coal power plants where CO₂ is captured.

Wind machines are often 100 feet to 300 feet tall, and have large blades towards the top of the structure. The wind moves these blades, which powers a generator, creating electricity. Because wind varies in strength and frequency, the wind turbines are not always reliable, and may require a back-up power system. While the wind turbines don't create any air pollution or solid waste, they do require a lot of land, potentially disturbing plants and animals. In addition, wind turbines make low noise, which is noticeable because of their often isolated, countryside location.

Natural gas power plants work similarly to coal-to-gas power plants. The gas is burned, and the heat from the gas is used to power a turbine. The turbine runs a generator, producing electricity. The hot gas also makes steam, which is used to power a second turbine and a second generator. Natural gas can either be found in conventional sources or unconventional sources. Conventional natural gas is found in sandstone and other sponge-like layers of rock, while unconventional natural gas can be found trapped in shale deep underground. Unconventional natural gas can be extracted with methods such as horizontal drilling, where a vertical well is drilled, followed by a hole drilled sideways. A salty water solution is then pushed through the well, causing the rock to break up as the result of high pressure and releasing the gas to the surface. While natural gas still releases CO₂ into the atmosphere, it is about half that of a coal power plant, and doesn't release any solid waste. However, drilling for unconventional natural gas is controversial, and may disturb local plants, animals, and water supplies.

Nuclear power plants require enriched uranium atoms. These atoms are split to release heat, which powers a turbine that runs a generator, creating electricity. Many people worry about the safety of nuclear power plants. However, the chance of a nuclear accident is very small, and the plants release almost no radiation into the ground, air, and water. The waste from nuclear plants will emit radiation, but storage technology should keep the waste safe for up to thousands of years. Nuclear technology built in the future will be even safer than the already safe design as well.

There are two ways to produce electricity from the sun's rays. The first way is through solar cells, where the sunlight is directly converted into electricity. Many solar cells can be placed together to create a large scale power plant; however, they can also be used on a smaller scale in houses and businesses. The second way uses the sun's rays to heat water, creating steam. The steam then powers a turbine which runs a generator, creating electricity. Solar power is largely dependent on the amount of sunlight, making them an inconsistent source of electricity without some sort of back-up power generation. Otherwise, the solar cells release no pollutants into the air, and create no solid waste.

Energy efficiency is the idea that if people use more efficient products, less electricity will be used, and fewer power plants will be needed. This can be done through more efficient products like light bulbs and refrigerators, or through insulating buildings. Another core idea of energy efficiency is spending money now to save in the future. While an energy efficient light bulb will be more expensive than an incandescent light bulb, an energy efficiency light bulb will ultimately save the buyer money since it uses less electricity in the long run.

Biomass is made from plant and plant type materials, such as farm crops, wood chips, and residue from paper mills. In biomass-and-coal power plants, biomass is substituted for 10% of the coal, and then operates like a coal power plant. Because plants take in CO₂ when they're alive, most of the CO₂ burned into the air from biomass is not a new addition, which is different from the new CO₂ released from coal and natural gas. While it may reduce the CO₂ emissions, it costs money to grow new biomass, and chemicals used to grow biomass may pollute the soil and water ("TechnologySheets.")

Objectives

Students will be able to:

- Explain the challenges the U.S. faces in trying to achieve a low-carbon energy future.
- Explain the tradeoffs between the different electricity technologies.
- Explain that there is no one silver bullet technology.
- Use the computer tool to build their own low-carbon electricity portfolio.

Materials Needed

- Computers
 - Teacher's computer with Powerpoint and Computer Tool. The computer tool is available for download here: <http://cedmcenter.org/tools-for-cedm/informing-the-public-about-low-carbon-technologies/> Optionally, this computer also has the additional software to save 8 combinations.
 - One for each student or group of students with Computer Tool installed.
- Projector
- "Computer Tool Introduction.docx" (for teacher to read beforehand)
- "SUCCEED Computer tool presentation.pptx"
- Student handouts (one per student)
 - "Step-By-Step Computer Exercise handout.docx"
 - "Goal Center Graphs.pdf" (optional)
 - "Impact Comparison.pdf" (optional)
 - "Cost Comparison.pdf" (optional)
 - "TechnologySheets.pdf" (optional)

Safety Concerns

- None.

Vocabulary

- Coal plant: turbine is powered by steam from burning coal.
- CO₂ release: CO₂ is sent into the atmosphere.
- CO₂ capture: CO₂ is converted to liquid and stored underground.
- Coal-to-gas plant: coal is burned to form gas and heat, which powers the turbine.
- Wind plant: electricity is created by the movement of large blades powering a turbine.
- Natural gas plant: consists of methane and other hydrocarbons; can be burned to power a turbine.
- Nuclear plant: the splitting of uranium atoms to create heat, powering a turbine.
- Solar plant: using the sun's rays to create electricity.

- Energy efficiency: Employing more efficient technology that meets previous expectations/output and also reduces electricity demand.
- Biomass: plants and plant-derived material.

Procedure

Time	Activity	Discussion	Supplies
25	Prior to lesson plan	<ol style="list-style-type: none"> 1. Install computer tools 2. Familiarize yourself with the computer tool. See “Computer Tool Introduction.docx” for a detailed explanation. 	“Computer Tool Introduction.docx”, computers
25	1. Introduction to 10 electricity technologies	<ol style="list-style-type: none"> 1. Introduce the idea that there are pros and cons to all types of power plants 2. List the ten different types of plants to be focused on here. <ol style="list-style-type: none"> a. Coal (released), Coal (captured), Coal-to-Gas (released), Coal-to-Gas (captured), Wind, Natural Gas, Nuclear, Solar Cell, Energy Efficiency, Biomass-and-Coal 3. Show that each power plant releases different amounts of CO₂. <ol style="list-style-type: none"> a. Show the Carbon Dioxide Comparison graph from “Goal Center Graphs.pdf”. b. Note that because Coal (released) is the baseline, its bar is at 100%; anything that releases more CO₂ than Coal (released) has a higher bar. 4. Show that each power plant makes a different amount of electricity in a year. <ol style="list-style-type: none"> a. Show the electricity produced graph from “Goal Center Graphs.pdf”. b. Note that the larger the bar, the more electricity the plant makes, and that while plants can be different sizes, size is held constant here. 5. Show that each power plant has different health impacts because of air pollution. <ol style="list-style-type: none"> a. Show the Health Costs graphs from “Impact Comparison.pdf”. b. The larger the bar, the more health costs attributed to that power plant type. 6. Show that each power plant has different impacts on the water. <ol style="list-style-type: none"> a. Show the Water Impact graphs from “Impact Comparison.pdf”. b. The larger the bar, the more water that plant uses. 7. Show that each power plant has different impacts on 	<p>Computer, projector, “SUCCEED Computer tool presentation.pptx”</p> <p>Optional: Student handouts of “Goal Center Graphs.pdf”, “Impact Comparison.pdf”, “Cost Comparison.pdf”</p>

		<p>land.</p> <ol style="list-style-type: none"> Show the Land Impacts graph from “Impact Comparison.pdf”. The larger the bar, the more land that type of plant uses each year. <ol style="list-style-type: none"> Show that electricity from each power plant costs a different amount. <ol style="list-style-type: none"> Show the Cost Comparison graph from “Cost Comparison.pdf”. The graph shows how much the cost of electricity increases with the addition of each kilowatt-hour produced from each newly constructed plant. Overall, electricity is more expensive in plants with more bars to the right side of the graph, and cheaper in plants with more bars to the left side. Introduce the Problem Question via “SUCCEED Computer tool presentation.pptx”. 	
25	2. Computer Tool	<ol style="list-style-type: none"> Introduce the computer tool to the students using “SUCCEED Computer tool presentation.pptx” (Slides 10-23). Guide the students through the Group Exercise and discussion on “Step-By-Step Computer Exercise handout.docx” in order to answer the Problem Question (Slide 10, Slide 24) of “SUCCEED Computer tool presentation.pptx”. 	“SUCCEED Computer tool presentation.pptx”, “Step-By-Step Computer Exercise handout.docx”, Computers with computer tool installed
20	3. Power Plant Combination	<ol style="list-style-type: none"> Introduce New Problem Question using “SUCCEED Computer tool presentation.pptx” (Slide 25). Provide students with “TechnologySheets.pdf” (optional) Have the students complete “Step-By-Step Computer Exercise handout.docx”, in order to answer the New Problem Question. 	“SUCCEED Computer tool presentation.pptx”, “Step-By-Step Computer Exercise handout.docx”, “TechnologySheets.pdf” (optional), Computers with the computer tool installed,
15	4. Compare Portfolios	<ol style="list-style-type: none"> Ask each student what their favorite power plant combination was and why. Put a lot of emphasis on explaining the reason behind why it is the student’s favorite. As they’re describing their combination, ask students questions such as: <ol style="list-style-type: none"> Why did you choose this combination? Does anyone else have comments about this combination? What do you like about it? What don’t you like? If there is access to an additional computer with a tool that can save eight combinations, save and demonstrate a few of the students’ favorites. 	Computer with additional computer tool (optional)

5	5. Final Discussion	<ol style="list-style-type: none"> 1. If there is access to an additional computer with a tool that can save eight combinations, graph a comparison of the selected eight. Ask students questions such as: <ol style="list-style-type: none"> a. Whose combination has the most CO₂? b. Whose combination has the least CO₂? c. Whose combination has the most health costs? d. Whose combination has the least health costs? 2. Ask the students final questions such as: <ol style="list-style-type: none"> a. Overall, what do you think of the eight combinations? b. Do you still like yours the best? 	Computer with additional tool (optional)
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Additional Resources

Reputable

Emirates Nuclear Energy Corporation. “ENEC: How Does Nuclear Energy Work?” Emirates Nuclear Energy Corporation. Web. 19 Jul 2013. <<http://www.enec.gov.ae/learn-about-nuclear-energy/how-does-nuclear-energy-work/>>

The Emirates Nuclear Energy Corporation gives a succinct summary of how nuclear power works with an accompanying video to demonstrate the process. Teachers looking for a reputable source to explain the basics behind nuclear power could look here.

“Goal Center Graphs.” PDF file. 21 Jul 2013.

The Goal Center Graphs PDF file – titled Power Plant Comparison: Reach the Goals – shows two graphs comparing ten different types of power plants. The first compares the carbon dioxide released from the ten plants, and the second compares electricity produced.

“HW New COE comparison.” PDF file. 21 Jul 2013.

The HW New COE comparison PDF file – titled Cost Comparison – shows the increase in the cost of electricity with each new power plant of that type.

“Impact Comparison.” PDF file. 21 Jul 2013.

The Impact Comparison PDF file compares health impacts, water impacts, and land impacts from each of the ten power plant types. In addition to three separate graphs comparing factors such as the cost of health as the result of air pollution and annual water use, there are also checklist based charts to show which power plant type fits in a particular category. For example, in the Health Impacts page, the checklist chart is for different types of particulate matter.

Mass.Gov. "About Solar Energy." *Energy and Environmental Affairs*. Web. 5 Jul 2013. <<http://www.mass.gov/eea/energy-utilities-clean-tech/renewable-energy/solar/about-solar-energy.html>>.

Mass.Gov's page on solar power describes what solar power is, and the three primary technologies that use solar power. Teachers looking to give a complete overview on solar power technology and uses should look here.

National Renewable Energy Laboratory. "NREL: Learning - Biomass Energy Basics." *National Renewable Energy Laboratory*. National Renewable Energy Laboratory, 30 May 2013. Web. 11 Jul 2013. <http://www.nrel.gov/learning/re_biomass.html>.

The National Renewable Energy Laboratory page on biomass energy talks briefly of both the basics behind biomass energy and some of the benefits of using biomass energy. Teachers looking for a short, but positively skewed introduction to the topic could look here.

"Technology Sheets." PDF file. 21 Jul 2013.

The Technology Sheets PDF file talks about ten different types of power plants, and mentions some of the pros and cons of each. Teachers looking for a broad introduction to different power plant types could look here.

United States Department of Energy. "How Do Wind Turbines Work?" *United States Department of Energy: Energy Efficiency and Renewable Energy*. . 17 Jan 2013. Web. 11 Jul 2013. <https://www1.eere.energy.gov/wind/wind_how.html>

The DOE page on wind turbines gives a brief yet educational description of how wind turbines work, as well as offers a number of diagrams and animations to illustrate the process. Teachers looking to explain the technology behind wind energy could look here.

United States Environmental Protection Agency, "Natural Gas." *US Environmental Protection Agency*. 30 Apr 2013. Web. 13 Jun 2013. <<http://www.epa.gov/cleanenergy/energy-and-you/affect/natural-gas.html>>.

This EPA page gives a summary on what natural gas is, what natural gas is used for, and how it's used to generate power. If a teacher wanted to get a better background on natural gas, this would be a good place to start looking.

Opinion / Newspaper

Coal Can Do That. "Coal-To-Liquids & Coal-To-Gas." Coal Can Do That. Web. 21 Jul 2013. <<http://www.coalcandothat.com/coal-to-gas.php?view=section2>>

The Coal Can Do That page talks about the benefits and process of converting coal into either a liquid or a gas. Though it is clearly biased, teachers looking to introduce the process of gasification could look here.

International Risk Governance Council. “Power plant CO2 capture technologies.” International Risk Governance Council. 2009. Web. 21 Jul 2013. <<http://www.irgc.org/issues/carbon-capture-and-storage/power-plant-co2-capture-technologies/>>

The International Risk Governance Council primarily links to a research paper from Edward Rubin that discusses Carbon Capture and Sequestration technology. However, it also gives a brief summary of what it is, and how the IRGC approached the research. Teachers ultimately looking for an incredibly detailed summary of CCS – from the research paper – could look here.

Pittsburgh Tribune Review. “NRG Energy to burn natural gas at coal-fired generating plant.” Pittsburgh Tribune Review. 25 June 2013. Web. 21 Jul 2013. <<http://triblive.com/business/headlines/4249970-74/coal-gas-plant#axzz2Zi1t4eXg>>

Because of increasingly strict emissions standards, NRG Energy plans to convert their coal power plant to natural gas. The article gives some statistics on how many power plants NRG Energy has, what the estimated cost of the switch may be, and how power generation will differ. Teachers looking for a current event on why the topic is relevant could look here.

World Coal Association. “Coal electricity, coal power plants – World Coal Association.” World Coal Association. Web. 21 Jul 2013. <<http://www.worldcoal.org/coal/uses-of-coal/coal-electricity/>>

The World Coal Association page on coal power plants – while biased in favor of coal – provides statistics on coal usage globally, provides a helpful diagram of what a power plant consists of, and talks about recent improvements in efficiency. Teachers looking to highlight some of the positive aspects of coal power plants could look here.

Author(s):

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Next Generation Science Standards Alignment

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.

Crosscutting Concept: Influence of Science, Engineering, and Technology on Society and the Natural World

HS-ETS1-4: Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

Crosscutting Concept: System and System Models