Alternative Fuels Used in Transportation

Grades: 5-8

Topic: Hydrogen and Fuel Cells, Vehicles, Biomass

Owner: National Renewable Energy Laboratory

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For the Teacher:

The use of energy is a factor in all our lives, and that is why it is important for us teachers to have our students learn about the energy we use now and the new forms of energy that are becoming available. Non-renewable energy sources are diminishing everyday, and it is vital that students learn about renewable energy sources to help them as they grow to become better informed and more responsible about the energy resources they use.

The use of gasoline for transportation is the most commonly used fuel. However, there are multiple alternative fuels that are making their ways to the market. These alternative fuels include such things as propane, natural gas, electric hybrids, hydrogen fuel cells, and biodiesel. Students will probably have heard of some of these alternative fuels, but they may not understand how and why they are better then ordinary gasoline. The projects included in this section are designed to give students the opportunity to create their own investigation and test alternative fuels and their relation to transportation.

The projects included will fit easily with regular classroom lessons surrounding scientific inquiry and the scientific method. The projects have of the capability to cross multiple education disciplines such as chemistry, physics, economics, and marketing and they involve social interaction as well as group learning.

Alternative fuels are being researched by top scientists every day at NREL to discover which fuel methods work best, how well they work and how easily they can be distributed to the public. The authors of this section are studying the emissions released from large trucks running on different biodiesel fuels to compare which blends create lower emissions.

National Science Education Standards by the National Academy of Sciences:

Science Content Standards: 5-8
Science as Inquiry
- **Content Standard A:**
  "Abilities necessary to do scientific inquiry"
  "Understandings about scientific inquiry"

Physical Science
- Content Standard B:
  "Properties and changes of properties in matter"
  "Transfer of energy"

Earth and Space Science
- Content Standard D:
  "Structure of the earth system"

Science and Technology
- Content Standard E:
  "Abilities of technological design"
  "Understandings about science and technology"

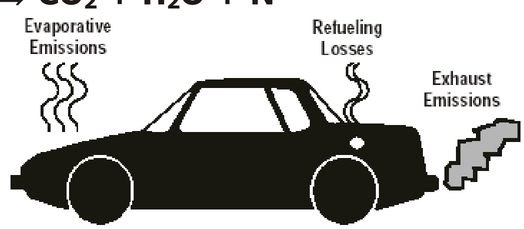
Science in Personal and Social Perspectives
- Content Standard F:
  "Populations, resources, and environments"
  "Science and technology in society"

Technology Description:

Transportation by cars and trucks radically changed the face of our country over the last hundred years, with petroleum providing the fuel for our vehicles. We use about 13 million barrels of oil each day to keep us on the move. Americans drive their personal vehicles about 2.3 trillion miles a year with 98 percent of our vehicles running on petroleum or diesel fuels. United States imports two-thirds of all the petroleum we use; therefore, cheaper and renewable alternative fuels would be desirable to reduce our dependence. In addition to the dependence factor, one also needs to consider that the emissions from gasoline-powered vehicles are fairly extensive and include CO, CO_2, NOx, SOx, VOCs, OH^-, and PM. Some of these emissions are known or probable human carcinogens, including benzene (known), formaldehyde, acetaldehyde, and 1,3-butadiene (probable). Gasoline can also impact the environment if spilled, since it spreads on water surfaces and quickly penetrates porous soils and groundwater.

The idea of alternative fuels has been around about as long as there been vehicles. In the 1880s, Henry Ford built one of his first automobiles to run on ethanol. The alternative fuels that are being actively explored by the Department of Energy include: methanol; propane; ethanol; compressed and liquefied natural gas; electricity; hybrid electricity; biodiesel; and hydrogen fuel cells. Factors such as cost, fuel distribution, emissions, vehicle systems analysis, energy storage, power and propulsion systems, and advanced power electronics are just some of the considerations in phasing in alternative fuels and advanced vehicle design.

Complete Combustion
Fuel (hydrocarbons) + Air (O_2& N) $\Rightarrow$ CO_2 + H_2O + N



<u>Typical Engine Combustion</u>
Fuel + Air Unburned Hydrocarbons + NO_x + CO + CO_2 + H_2O

Improving fuel economy, cost, availability, and emissions are the primary goals of research into alternative fuels and transportation.

Alternative Fuels-
Methanol

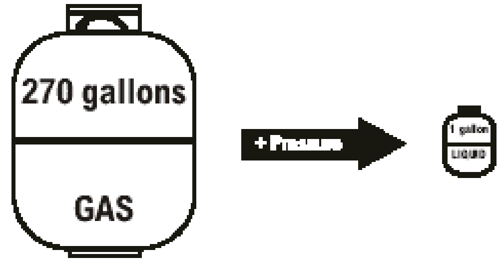
Methanol, or wood alcohol, is a colorless, odorless, toxic liquid. Methanol is the simplest alcohol (CH_3OH), produced by replacing one hydrogen atom of methane with a hydroxyl radical (OH). Methanol can be produced from natural gas, coal, residual oil, or biomass.

Although vehicles can operate on pure methanol fuel (M100), methanol blended with 15 percent unleaded gasoline–M85- is more practical for real world applications. Because methanol is a liquid fuel, it does not require major changes in the distribution system or in car engines, but no major auto manufacturers offer M85 compatible vehicles at this time. The cost of M85 is equal to or slightly higher than premium blends. M85 has a lower energy content per gallon, so mileage is lower; but power, acceleration and payload capacity are comparable to gasoline. Vehicles using methanol, however, must use a special, expensive lubricant.

Propane

Propane is an energy-rich fossil fuel often called liquefied petroleum gas (LPG). It is colorless and odorless; an odorant called mercaptan is added to serve as a warning agent. Propane is a by-product of petroleum refining and natural gas processing. And, like all fossil fuels, it is nonrenewable. The chemical formula for propane is C_3H_8.

Under normal atmospheric pressure and temperature, propane is a gas. Under moderate pressure and/or lower temperature, however, propane can easily be changed into a liquid and stored in pressurized tanks. Propane is 270 times more compact in its liquid state than it is as a gas, making it a portable fuel.



Propane has been used as a transportation fuel for more than half a century and is the most widely used and most accessible alternative fuel. Today about three percent of total propane consumption is used to fuel 270,000 vehicles, mostly in fleets. For fleet vehicles, the cost of using propane is 5 to 30 percent less than for gasoline.

Ethanol

Ethanol is a clear, colorless alcohol fuel made by fermenting the sugars found in grains—such as corn and wheat—as well as potato wastes, cheese whey, corn fiber, rice straw, urban wastes, and yard clippings. There are several processes that can produce alcohol (ethanol) from biomass. The most commonly used processes today use yeast to ferment the sugars and starch in the feedstock to produce ethanol. A new process uses enzymes to break down the cellulose in woody fibers, making it possible to produce ethanol from trees, grasses, and crop residues.

In the 1970s, the oil embargoes revived interest in ethanol as an alternative fuel. Today, more than fifty ethanol plants, mostly in the Midwest, produce over a billion gallons of ethanol. Gasoline containing ten percent ethanol—E10—is widely used in urban areas that fail to meet standards for carbon monoxide and ozone. Since ethanol contains oxygen, using it as a fuel additive results in up to 25 percent fewer carbon monoxide emissions than conventional gasoline. E10 is not considered an alternative fuel under EPACT, but a replacement fuel.

E85 pump in Lexington, KY 3/6/2002

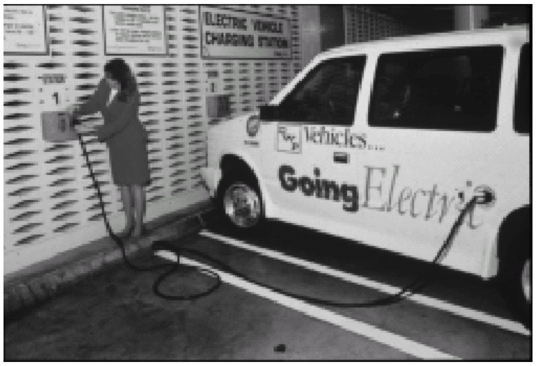
Methane

Methane, the natural gas we use for heating, cooking, clothes drying, and water heating, can also be a clean burning transportation fuel when compressed (CNG) or liquefied (LNG). Compressed natural gas (CNG) vehicles emit 85-90 percent less carbon monoxide, 10-20 percent less carbon dioxide, and 90 percent fewer reactive non-methane hydrocarbons than gasoline-powered vehicles. (Reactive hydrocarbon emissions produce ozone, one of the components of smog that causes respiratory problems.) These favorable emission characteristics result because natural gas is 25 percent hydrogen by weight; the only combustion product of hydrogen is water vapor. Natural gas is usually placed in pressurized tanks when used as a transportation fuel. Even compressed to 2,400-3,600 pounds per square inch (psi), it still has only about one-third as much energy per gallon as gasoline. As a result, natural gas vehicles typically have a shorter range, unless additional fuel tanks are added, which can reduce payload capacity. With an octane rating of 120+, power, acceleration and cruise speed are comparable.

Louisville Metropolitan Sewer District Fleet CNG Vehicle

Electricity

In 1891, William Morrison of Des Moines, Iowa, developed the first electric car. By the turn of the century, dedicated electric vehicles (EVs) outnumbered their gasoline-powered counterparts by two-to-one. Today there are about 10,500 dedicated EVs in use in the United States, mostly in the West and South. Researchers are still working on the same problem that plagued those early dedicated EVs: the need for an efficient battery. The batteries limit the range of a dedicated EV, which is determined by the amount of energy stored in its battery pack. The more batteries a dedicated EV can carry, the more range it can attain, to a point. Too many batteries can weigh down a vehicle, reducing its load-carrying capacity and range, and causing it to use more energy. The typical dedicated EV can only travel 50 to 130 miles between charges. This driving range assumes perfect driving conditions and vehicle maintenance. Weather conditions, terrain, and some accessories use can significantly reduce the range.



Hybrid Electricity
Hybrid Electric Vehicles (HEVs) may be the best alternative vehicle for the near future, especially for the individual consumer. HEVs offer many of the energy and environmental advantages of the dedicated electric vehicle without the drawbacks. Hybrids are powered by two energy sources: an energy conversion unit (such as a combustion engine or fuel cell) and an energy storage device (such as battery, flywheel, or ultracapacitor). The energy conversion unit can be powered by gasoline, methanol, compressed natural gas, hydrogen, or other alternative fuels. HEVs have the potential to be two to three times more fuel-efficient than conventional vehicles. An HEV battery doesn't have to be recharged. It has a generator powered by the internal combustion engine to recharge the batteries whenever they are low. A regenerative braking system captures excess energy when the brakes are engaged. The recovered energy is also used to recharge the batteries.

Gas-Electric Hybrids

Biodiesel
Biodiesel is a fuel made by chemically reacting alcohol with vegetable oils, fats, or greases, such as recycled restaurant greases. It is most often used in blends of two percent or 20 percent (B20) biodiesel. It can also be used as neat biodiesel (B100). Biodiesel fuels are compatible with and can be used in unmodified diesel engines with the existing fueling infrastructure. It is the fastest growing alternative transportation fuel in the U.S. Biodiesel contains virtually no sulfur, so it can reduce sulfur levels in the nation's diesel fuel supply. Removing sulfur from petroleum-based diesel results in poor lubrication. Biodiesel is a superior lubricant and can restore the lubricity of diesel fuel in blends of only one or two percent. Biodiesel can also improve the smell or diesel fuel, sometimes smelling like french fries.

Berkeley Curbside Recycling Trucks Now Fueled by Recycled Vegetable Oil

Hydrogen Fuel Cell
In the future, hydrogen may provide a significant contribution to the alternative fuel mix. The space shuttles use hydrogen for fuel. Fuel cells use hydrogen and oxygen to produce electricity without harmful emissions; water is the main by-product. Hydrogen is a gas at normal temperatures and pressures, which presents greater transportation and storage hurdles than liquid fuels. No distribution system currently exists. Today, the predominant method of producing hydrogen is steam reforming of natural

gas, although biomass and coal can also be used as feedstocks.

SunLine Transit Agency
Hydrogen Fuel Cell Bus

Resources:

Energy Efficiency and Renewable Energy
http://www.fueleconomy.gov/

National Energy Educational Development
http://www.need.org

Energy Efficiency and Renewable Energy
http://www.eere.energy.gov

Kentucky Clean Fuels Coalition
www.kentuckycleanfuels.org

U.S. Environmental Protection Agency
www.epa.gov

National Renewable Energy Laboratory - Department of Energy
www.nrel.gov

Alternate Transportation Fuels
http://www.need.org/needpdf/AlternativeFuels.pdf

Energy Correlation to National Science Education Content Standards
http://www.need.org/needpdf/Correlations.pdf

Project Ideas

1 What is the heat content of two alternative fuels?

Learning Objective: You will be able to measure the amount of heat absorbed by water during the combustion of methanol and ethanol in a calorimeter.

Controls and Variables: Volume of water, temperature change in heat sink (100 ml of water), mass of fuel used, and heat content of two fuels.

Materials and Equipment: Economy calorimeter; alcohol burners; ethanol; methanol; & thermometers.

Safety and Environmental Requirements: Safety glasses should be worn at all times. The frame of the economy calorimeter retains heats and care must be taken when moving after testing.

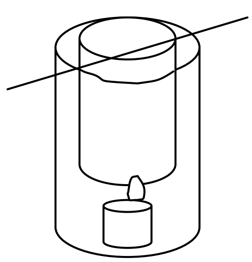
Suggestions:
- Determine the number of chemical bonds in methanol (5) and ethanol (8).

- Correlate the heat content of each fuel related to the number of chemical bonds.
- Students explore why the obtained heat values fall below the actual heat values (ethanol = 7089 cal/g and methanol = 5426 cal/g).
- Do a balance of equations for the combustion of methanol ($2CH_3OH + 3\ O_2 \Rightarrow 2CO_2 + 4H_2O$ + energy) and ethanol ($C_2H_5OH + 3\ O_2 \Rightarrow 2CO_2 + 4H_2O$ + energy).
- Determine the oxygen to fuel ratio for each fuel and how this ratio would change the volume of carbon dioxide produced.

Places To Purchase:
Calorimeter:
https://www1.fishersci.com/wps/portal/HOME
($25.60, economy food calorimeter)

https://www.freyscientific.com
($21.95, economy food calorimeter)

A homemade calorimeter can be made by using two different size cans with holes through the top of both cans to suspend the smaller can over the flame with glass stir rod. The larger can is a tube and the smaller can opens only on top, to hold water and take temperature readings (Note diagram below).



Wickless Leakproof Burner
https://www1.fishersci.com/wps/portal/HOME
($14.00, holds 100cc of fuel)

https://www.freyscientific.com
($13.65, holds 100cc of fuel)

Flint Glass Alcohol Lamp
https://www.freyscientific.com
($6.25, 8 oz. capacity)

https://www1.fishersci.com/wps/portal/HOME
($6.35, 8 oz. capacity)

Ethanol
https://www1.fishersci.com/wps/portal/HOME
($10.80, 1 liter)

https://www.freyscientific.com
($8.35, 1 liter)

Methanol
https://www1.fishersci.com/wps/portal/HOME
($5.15, 500 ml)

https://www.freyscientific.com
($6.65, 500 ml)

2 What is the economically best choice between purchasing a hybrid or a typical gasoline engine automobile?

Learning Objective: You will be able to show which type of engine is the most economical in the long run between a hybrid and typical gasoline engine.

Controls and Variables: The different variables for each automobile will be the initial cost, the operating cost (gasoline price), and the miles per gallon of fuel. Constants should be the amount of driving that would be done in each automobile.

Materials and Equipment: Pen, paper and access to the Internet for research.

Safety and Environmental Requirements: None

Suggestions:

- The payback period is the length of time you must own an energy-efficient vehicle before the decreased operational costs make up for the difference in initial purchase price. Calculate the payback period for a Honda Civic (Hybrid) vs. a Honda Civic (Gasoline) using the following figures:

    Honda Civic (Hybrid)
    Initial Cost: $19,650
    Tax Incentive: $1500
    Miles per Gallon: 48 mpg
    Honda Civic (Gasoline)
    Initial Cost: $17,260
    Tax Incentive: $0
    Miles per Gallon: 40 mpg

	Hybrid	Gasoline
Initial Cost	$19,650	$17,260
Tax Incentive	$1,500	$0
Fuel Economy	48 mpg	40 mpg
Difference in Initial cost	(+) $2390	
Difference in cost after tax incentive	(+) $890	
Fuel economy at a gas rate of $2.10 per gallon for one year at 10,000 miles	$438/year	$525/year
Amount of time till hybrid savings exceed gasoline initial savings	10.2 years	

- Investigate the rate at which hybrid vehicles have been decreasing in initial cost. What might be some factors for this decrease? Do they expect hybrid vehicles to someday have a lower initial cost then gasoline engine vehicles?
- Research other types of alternative fuels. Is a hybrid more cost efficient then compressed natural gas (CNG), hydrogen fuel cells, propane, or biodiesel?

3 Determine a plan for large number fleets of automobiles to transition for traditional gasoline engines to alternative fuel engines.

The mayor of a large city in your area has asked your class to develop a plan to reduce emissions created by his fleet, including school buses, public buses, sanitation trucks, police, emergency vehicles, and the city fleet of automobiles. Divide the project into six parts and in each part develop a plan to present to the mayor, listing recommendations and costs for each type of vehicle and the rationale for each recommendation.

List the recommendations of each part by vehicle category. Where there are several recommendations, debate and defend recommendations until a consensus is reached.

Learning Objective: You will understand different forms of alternative fuels as well as a greater understanding of citywide economics.

Controls and Variables: None

Materials and Equipment: Pen, paper and access to the Internet for research.

Safety and Environmental Requirements: None

Suggestions: Invite area experts to visit the classroom to discuss alternative fuel vehicles.

Present your findings in a formal report to be sent to your local mayor.

4 Quantify the relative amount of CO_2 given off by the methanol vs. ethanol during the combustion process.

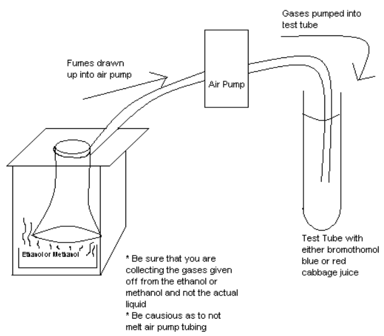
Utilize a fish aquarium pump to pull samples of exhaust fumes from above the calorimeter experiments (done in project idea one) and let it pump the collected gases into a test tube of bromothymol blue solution or red cabbage juice to determine the relative CO_2 content. (Bromothymol blue will change from blue to green to yellow in the presence of CO_2.)

Learning Objective: You will be able to test for the presence of CO_2 in the combustion of ethanol and methanol and qualitatively compare the two amounts.

Controls and Variables: The different amounts of ethanol and methanol that are used can either be held constant or varied depending on the experiment. Hold the solution of bromothymol blue or red cabbage juice constant through each test.

Materials and Equipment: A fish aquarium air pump with tubing, air pump in sealed container with inlet and outlet air tubes, two test tubes, scale to determine mass of fuel consumed, material from project #1, bromothymol blue solution or red cabbage juice, and stopwatch.

Safety and Environmental Requirements: Safety wear (goggles, lab apron, heat resistant gloves), well ventilated area for burning, and waste container. (Do not pour ethanol or methanol down the drain or into garbage.)



Places to Purchase:
Bromothymol Blue, 0.04% in Ethanol
http://www.baddley.com/ ($12.00 – 125 ml)

http://www.clarksonlab.com/salesaz.htm ($14.95 - 5 g powder reagent)

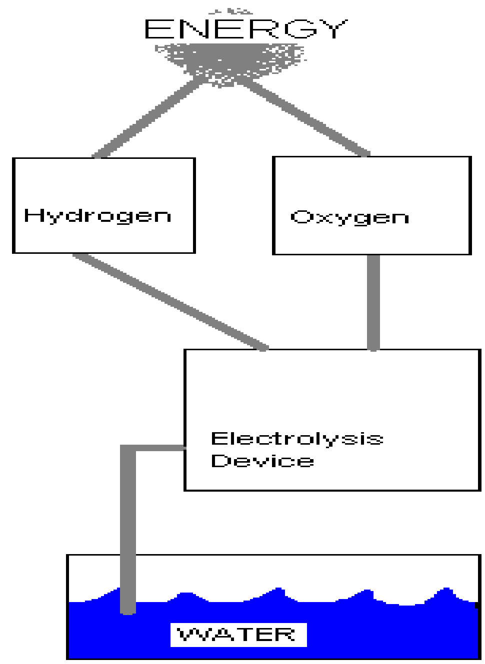
5 What goes into building a hydrogen fuel cell car?

There are many different available models of hydrogen fuel cell cars that can be bought. Try just using the basic parts to build a unique hydrogen fuel cell vehicle.

Learning Objective: You will be able to understand the hydrogen fuel cell process of how water (through electrolysis) is turned into power to run a motor.

Controls and Variables: A simple hydrogen fuel cell vehicle kit will give all the components necessary; everything else is up to you.
Materials and Equipment: Hydrogen fuel cell vehicle kit, some power tools may be necessary when building custom vehicle bodies. You will also need smooth surface to run the vehicles on.

Safety and Environmental Requirements: Safety protection should be taken when building the cars from scratch. You also require protection from small electrical circuits and a moving motor.



Suggestions:
1. See who can build the fastest vehicle by changing wheels and axis, body types, and gear sizes.

2. Determine the efficiency of the hydrogen fuel cell.

Places to Purchase:
Hydrogen Fuel Cell Kits
http://electronickits.com/kit/complete/solar/fuelcell.htm
(~ $125)

http://sciencekit.com/category.asp_Q_c_E_427448
(~ $220)

References:

http://www.nap.edu/readingroom/books/nses/html/

http://www.nrel.gov

http://www.fueleconomy.gov/

http://www.need.org/needpdf/AlternativeFuels.pdf

Photo References:

http://www.need.org/needpdf/AlternativeFuels.pdf