

Energy Density and Liquid Fuel

We're used to measuring energy efficiency in miles per gallon; however, as the range of fuels that can be used in cars broadens, we need to consider the **energy density** of a fuel. Energy density tells you how much energy the fuel contains per kilogram of fuel and the volumetric energy density tells you how much energy the fuel contains per volume of fuel.



The combustion of a kilogram of ethanol produces about 2/3 the energy produced by the combustion of a kilogram of conventional gasoline. The mass densities are also different: there are more molecules of ethanol in a liter than there are of gasoline in a

liter, so that has to be taken into account.

Even though there are slightly more ethanol molecules in a liter, you still find that gasoline containing ethanol (E10) will decrease your gas mileage relative to 100% gasoline.

The American Le Mans Series encourages the use of alternative fuels. To make the race fair, cars using different types of fuels have different-sized gas tanks so that everyone has the same amount of energy per tank. This module investigates how you analyze which fuel is going to be most economical.



Pre-Race Prep

Related Standards

National Science Education Standards

- A.8.1.A. Identify questions that can be answered through scientific investigations.
- A.8.1.D. Develop descriptions, explanations, predictions and models using evidence.
- A.8.1.E. Think critically and logically to make the relationships between evidence and explanations.
- B.8.1.A. A substance has characteristic properties, such as density, a boiling point, and solubility *that are independent of the amount of the sample*.
- B.8.3.B. Energy is a property of many substances and is associated with heat, light, electricity, mechanical motion, sound, nuclei, and the nature of a chemical.
- B.8.3.B. Energy is transferred in many ways.
- E.8.2.E. Perfectly designed solutions do not exist. All technological solutions have trade-offs, such as safety, cost, efficiency, and appearance.
- E.8.2.F. Technological designs have constraints. Some constraints are unavoidable, for example, properties of materials, or effects of weather and friction; other constraints limit choices in the design, for example, environmental protection, human safety, and aesthetics.
- A.12.1.C. Use technology and mathematics to improve investigations and communications.

- A.12.1.D: Formulate and revise scientific explanations and models using logic and evidence.
- A.12.1.F: Communicate and defend a scientific argument.
- A.12.2.D: Mathematics is essential in scientific inquiry. Mathematical tools and models guide and improve the posing of questions, gathering data, constructing explanations and communicating results.
- A.12.2.E: Scientific explanations must adhere to criteria such as: a proposed explanation must be logically consistent; it must abide by the rules of evidence; it must be open to questions and possible modification; and it must be based on historical and current scientific knowledge.
- B.12.2.F: Carbon atoms can bond to one another in chains, rings, and branching networks to form a variety of structures, including synthetic polymers, oils, and the large molecules essential to life.
- B.12.3.B: Chemical reactions may release or consume energy. Some reactions such as the burning of fossil fuels release large amounts of energy by losing heat and by emitting light. Light can initiate many chemical reactions such as photosynthesis and the evolution of urban smog.
- B.12.5.B: All energy can be considered to be either kinetic energy, which is the energy of motion; potential energy, which depends on relative position; or energy contained by a field, such as electromagnetic waves.
- F.12.6.B: Understanding basic concepts and principles of science and technology should precede active debate about the economics, policies, politics, and ethics of various science- and technology-related challenges. However, understanding science alone will not resolve local, national, or global challenges.
- F.12.6.D. Individuals and society must decide on proposals involving new research and the introduction of new technologies into society. Decisions involve assessment of alternatives, risks, costs, and benefits and consideration of who benefits and who suffers, who pays and gains, and what the risks are and who bears them. Students should understand the appropriateness and value of basic questions—"What can happen?"—"What are the odds?"—and "How do scientists and engineers know what will happen?"

National Council of Teachers of Mathematics Standards

To be added

Prerequisite Concepts

- The **MASS DENSITY** of a solid is the mass per unit volume.
- The mass density of a liquid or gas must be specified for a particular temperature and pressure because the mass density changes as the temperature and pressure change.
- Dimensional Analysis – the ability to manipulate quantities based on understanding the units that must result and the physical meaning of those units.

Essential Questions

- How do you compare the energy in different fuels?
- What considerations need to be made to determine whether a fuel is a viable alternative for a specific type of transportation?

Enduring Understandings

- The energy density of a fuel is a fundamental measurement of how much energy the fuel molecules contain.
- The volumetric energy density of a gas or liquid fuel depends on the temperature and pressure of the fuel.
- Real-world problems rarely have clear-cut solutions. Solving these problems requires making compromises.
- Gaseous fuels may offer high energy density, but low volumetric energy density.

Key Knowledge and Skills

Students will...

- Understand the distinction between energy density and volumetric energy density;
- Understand that the energy density is proportional to the number of molecules, so that compressing or liquefying a gaseous fuel changes its volumetric energy density, but doesn't change its energy density.
- Explain the challenges posed by gaseous fuels in terms of storage at different temperatures and pressure;
- Make a scientifically based argument for and against specific types of fuels based on their energy densities.

Materials Needed

Per group: A copy of the table "Energy Densities of Fuels"

Background Information

- *Crew Chief Notes: Energy Density*

Related Modules

Coming Soon

Pre-Race

We usually measure the energy efficiency of cars in miles per gallon; however, a better figure of merit is the energy density of a fuel because the number of miles you get per gallon depends on the efficiency of the car, but also on the type of fuel being used. **ENERGY DENSITY** is the amount of energy stored in a given *mass* of fuel.

$$\text{energy density} = \left(\frac{\text{energy}}{\text{mass}} \right)$$

The **VOLUMETRIC ENERGY DENSITY** is the amount of energy stored in a given *volume* of fuel.

$$\text{volumetric energy density} = \left(\frac{\text{energy}}{\text{volume}} \right)$$

The two types of energy density are related to each other by the **MASS DENSITY**, ρ :

$$\frac{\text{energy}}{\text{volume}} = \left(\frac{\text{mass}}{\text{volume}} \right) \left(\frac{\text{energy}}{\text{mass}} \right)$$

$$\text{volumetric energy density} = \rho \quad (\text{energy density})$$

Energy density is given in megajoules per kilogram, $\frac{MJ}{kg}$ in SI units. The volumetric energy density is given in megajoules per liter $\frac{MJ}{L}$ or megajoules per cubic meter $\frac{MJ}{m^3}$, depending on the magnitude of the numbers involved ($1000L = 1 m^3$). The energy density of food can be expressed in kilocalories per gram $\frac{kcal}{g}$. (1 kcal=

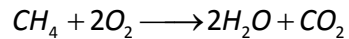
Lower and Higher Energy Density

Energy density values are usually measured for specific blends of fuel. For example, not all street gasoline contains the same fuel molecules, therefore, one type of gasoline may have a different energy density than another, even though they are both "gasoline".

You are likely to encounter two types of energy densities: The higher heating value (HHV) and the lower heating value (LHV). The difference between them (for your enlightenment!) is that the lower heating value assumes all the water is in the vapor state at the end of combustion. The HHV assumes that all of the water is in the liquid state at the end of the combustion. Since the process of going from gas to liquid releases energy, the HHV is always greater than the LHV. Typically, engine manufacturers rate their engines using the LHV, which makes the engine look more efficient than if they used the HHV. All of the energy densities in the table are LHVs. We don't distinguish between the two in the module, but just in case you decide to try to find information about a fuel we haven't included...

Combustion

Fuels combust when mixed with oxygen. For example, methane combusts according to:



Less energy is stored in the reactants (on the right) than in the products (on the left). The difference between those energies is the energy available to power the engine, for example. Chemists use energy density per mole, but that's not a meaningful unit to most people.

Start Your Engines...

- A. Use the table of energy densities to find the volumetric energy densities for conventional gasoline, E85 and E10.**

- B. How much energy does a 13.0 gallon (49.2 L) tank hold when filled with conventional gasoline?**

C. How large a tank would you need (in L) to hold the same amount of energy you found in part B if the tank were to be filled with E10?

D. How large a tank would you need (in L) to hold the same amount of energy you found in part B if the tank were to be filled with E85?

- E. If a car gets 21.0 miles per gallon (8.92 km/L) using conventional gasoline, what would the mileage be if the same car were using E85 (assume that the car has the same efficiency for both fuels)? Express your answer in terms of miles per gallon.**
- F. A commuter drives the car mentioned in part D an average of 39 miles every day. The car has a 13.0 gallon (50.375 L) gas tank. If the driver needs to fill the tank once every seven days using conventional gasoline, how often would she have to fill the tank if she were using E85?**

G. If gasoline costs \$3.00/gallon and E85 costs \$2.10/gallon, which fuel is the better bargain?

Extension A: Liquid Propane vs. Gasoline

If liquid propane can be bought for \$2.62 per gallon and gasoline costs \$3.10 per gallon, which is the better value?

Extension B: Miles per Gallon

Does the efficiency of the car make a difference in the mileage? In other words, is it more economical to switch to E85 in a car that gets 21.0 miles per gallon than it would be for one that gets 40 mpg?

Extension C: Blending Fuels

- A. **British Petroleum introduced a racing fuel for the American Le Mans Series that is 20% butanol by volume and 80% ethanol by volume called iBE20. What do you predict the energy density of this fuel is in MJ/L?**

Extension D: The Energy of a Single Reaction

A. How much energy is released in the combustion of a single molecule of ethanol?