The Second Law of Thermodynamics

The second law of thermodynamics states that you can move heat from a hotter place to a colder place without doing work, but that you need to work to move heat from a colder place to a hotter place. [1]

Application of the second law of thermodynamics helps explain the various ways in which engines transform heat into mechanical work, as for instance in the gasoline engine of a car or in a steam turbine.

Efficiency measures based on the second law of thermodynamics take into account the quality of energy — unlike efficiencies based on the first law of thermodynamics which take into account only the amount of energy. The first law of thermodynamics states that energy is conserved even when its form is changed, as for instance from mechanical energy to heat. By contrast, the second law of thermodynamics allows us to know how well an energy system performs in terms of the quality of the energy.

In 1824, a French physicist, Nicholas Léonard Sadi Carnot, described the most efficient (ideal) engine for converting heat to mechanical work. This maximum theoretical efficiency, called the Carnot efficiency, allows us to compare how well any particular real-world energy-using system is performing relative to the maximum theoretical performance.

The temperature at which energy is available is a good measure of its quality — the higher the temperature of the energy, the more mechanical work we can theoretically get out of it. Thus a kilogram of steam at 1,000 degrees Celsius will produce more mechanical energy than steam at 500 degrees Celsius other things (such as pressure) being equal. Energy at 20 degrees Celsius provides a comfortable living environment, but is essentially useless for producing mechanical work in everyday situations.

Let us consider the example of a natural gas heating system that provides warm air for heating a building. (This example could also apply to systems that provide hot water for heat.) A typical natural gas heating system degrades the heat of natural gas from possible temperatures over 1000 degrees Celsius to about 50 to 80 degrees Celsius. Thus, while most of the quantity of energy in the natural gas is transferred to the air that is used to heat the building, the capacity of the natural gas to do work has been almost entirely wasted. Hence a typical natural gas home heating furnace has a high first law efficiency, often around 85 or 90 percent, but a low second law efficiency of only a few percent (depending on outside temperature). Measuring this system using the second law of thermodynamics allows us to see that the initial natural gas input could be used more efficiently and to greater benefit if its heat were not wasted.

For example, one could use natural gas as a hydrogen source for fuel cells to generate electricity at 60% efficiency (second law). The electricity could then be used to "pump" the heat from the cold air outside up to the desired room temperature. (A heat pump uses electrical energy to pump up the energy present in outside air or soil to room temperature and transfer it into a building. [2]) Another way of describing it is as an air-conditioner in reverse that blows warm air into a building rather than out of it. In moderate climates this could improve efficiency of natural gas use by four times or more. In colder climates, heat from the earth, which is warmer than the air, could be pumped up to the desired room temperature, with similar efficiency improvements.

Use of gas engines to generate electricity and waste heat for heating and cooling (called a cogeneration system) can provide similar increases in efficiency. Higher efficiencies could also be achieved with heat exchangers (devices that takes energy from a warmer medium to a cooler medium, such as a boiler that transfers energy from hot gas to cool water) that are more efficient than those available today. Theoretically, the efficiency of fuel use in space heating applications could be increased ten to fifteen fold relative to typical present-day systems in the United States.

There are, of course, practical problems associated with using such systems, so that they are not always economical. For instance, practical applications would depend on factors such as the amount of heat, hot water, air-conditioning and electricity needed, whether the electric generation system can be connected to a grid, and the cost of small-scale generators. However, over the last two decades, new technologies have evolved to enable far more widespread economical use of cogeneration than the level of current use of this system.

Claims that increases in energy use — meaning use of primary fuels — are the only way to increase the services that energy provides are not based on a careful consideration of the vast potential for increases in energy efficiency even in the so-called “advanced” industrialized countries. By the yardstick of the second law of thermodynamics, the world’s energy system is very inefficient. Therefore, great increases in the services that energy provides, such as heating, cooling, or lighting, are possible even while final use is kept constant or even reduced.

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Notes:

1. The second law of thermodynamics can also be stated in terms of entropy. Entropy is a measure of disorder in a system. Since it takes work to increase the orderliness inside a closed system, an increase in order corresponds to a decrease of entropy. Hence, the second law of thermodynamics can also be expressed in terms of entropy: A decrease in the entropy of a system requires an input of work into that system. ? Return
2. In practice, all materials contain some amount of thermal energy. Even frigid air or ice have a considerable amount of thermal energy in them. Zero thermal energy — that is no random motion of atoms or molecules — is achieved only at a temperature known as absolute zero, which is equal to about -273 degrees Celsius (about -460 degrees F). An absolute zero temperature cannot actually be reached by any practical device. ? Return