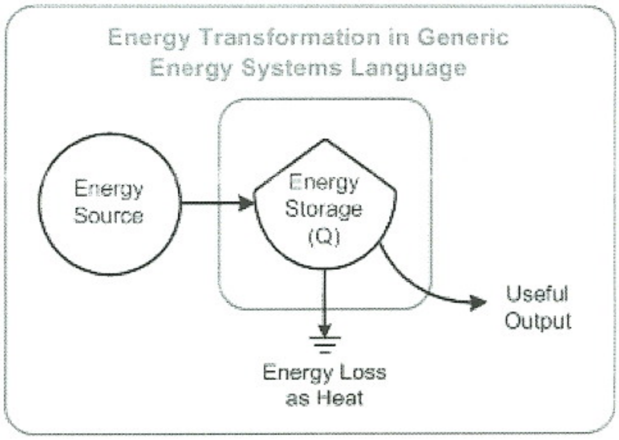
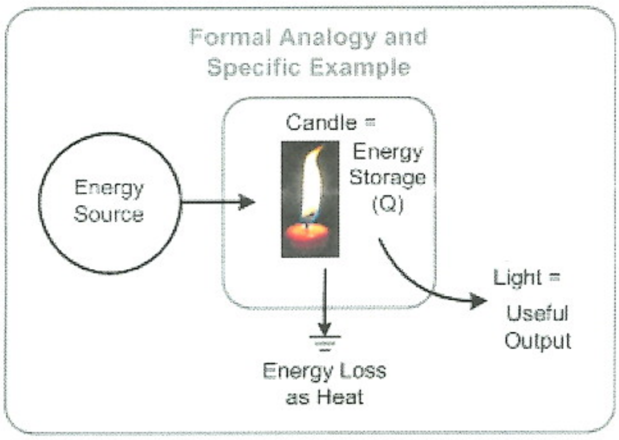
Chapter- 1

Introduction to Energy Transformation



$$\text{Energy Efficiency \%} = \frac{\text{Useful Output}}{\text{Total Input from Source}} \times \frac{100}{1}$$



Energy Transformation in Energy Systems Language

In physics, the term energy describes the capacity to produce changes within a system, without regard to limitations in transformation imposed by entropy. Changes in total energy of systems can only be accomplished by adding or subtracting energy from them, as energy is a quantity which is conserved, according to the first law of thermodynamics. According to special relativity, changes in the energy of systems will also coincide with changes in the system's mass, and the total amount of mass of a system is a measure of its energy.

Energy in a system may be **transformed** so that it resides in a different state. Energy in many states may be used to do many varieties of physical work. Energy may be used in natural processes or machines, or else to provide some service to society (such as heat, light, or motion). For example, an internal combustion engine converts the potential chemical energy in gasoline and oxygen into heat, which is then transformed into the propulsive energy (kinetic energy that moves a vehicle.) A solar cell converts solar radiation into electrical energy that can then be used to light a bulb or power a computer.

The generic name for a device which converts energy from one form to another is a transducer.

In general, most types of energy, save for thermal energy, may be converted to any other kind of energy, with a theoretical efficiency of 100%. Such efficiencies might occur in practice, such as when chemical potential energy is completely converted into kinetic energies, and vice versa, only in isolated systems.

Conversion of other types of energies to heat also may occur with high efficiency but a perfect level would be only possible for isolated systems also.

If there is nothing beyond the frontiers of the universe then the only real isolated system would be the universe itself. Currently we do not have the knowledge or technology to create an isolated system from a portion of the universe.

Exceptions for perfect efficiency (even for isolated systems) occur when energy has already been partly distributed among many available quantum states for a collection of particles, which are freely allowed to explore any state of momentum and position (phase space). In such circumstances, a measure called entropy, or evening-out of energy distribution in such states, dictates that future states of the system must be of at least equal evenness in energy distribution. (There is no way, taking the universe as a whole, to collect energy into fewer states, once it has spread to them).

A consequence of this requirement is that there are limitations to the efficiency with which thermal energy can be converted to other kinds of energy, since thermal energy in equilibrium at a given temperature already represents the maximal evening-out of energy between all possible states. Such energy is sometimes considered "degraded energy," because it is not entirely usable. The second law of thermodynamics is a way of stating that, for this reason, thermal energy in a system may be converted to other kinds of energy with efficiencies approaching 100%, only if the entropy (even-ness or disorder) of the universe is increased by other means, to compensate for the decrease in entropy associated with the disappearance of the thermal energy and its entropy content.

Otherwise, only a part of thermal energy may be converted to other kinds of energy (and thus, useful work), since the remainder of the heat must be reserved to be transferred to a thermal reservoir at a lower temperature, in such a way that the increase in entropy for this process more than compensates for the entropy decrease associated with transformation of the rest of the heat into other types of energy.

History of energy transformation from the early universe

Energy transformations in the universe over time are (generally) characterized by various kinds of energy which has been available since the Big Bang, later being "released" (that is, transformed to more active types of energy such as kinetic or radiant energy), when a triggering mechanism is available to do it. A direct transformation of energy occurs when hydrogen produced in the big bang collects into structures such as planets, in a process during which gravitational potential may be converted directly into heat. In Jupiter, Saturn, Uranus, and Neptune, for example, such heat from continued collapse of the planets' large gases atmospheres continues to drive most of the planets' weather systems, with atmospheric bands, winds, and powerful storms.

Familiar examples of other such processes transforming energy from the big bang include nuclear decay, in which energy is released which was originally "stored" in heavy isotopes, such as uranium and thorium. This energy was stored at the time of these elements' nucleosynthesis, a process which ultimately uses the gravitational potential energy released from the gravitational collapse of supernovae, to store energy in the creation of these heavy elements before they were incorporated into the solar system and the Earth. This energy in uranium is triggered for sudden-release in nuclear fission bombs, and similar stored energies in atomic nuclei are released spontaneously, during most types of radioactive decay. In this process, heat from decay of these atoms in the core of the Earth is transformed immediately to heat. This heat in turn may lift mountains, via plate tectonics and orogenesis. This slow lifting of terrain thus represents a kind of gravitational potential energy storage of the heat energy. The stored potential energy may be released to active kinetic energy in landslides, after a triggering event. Earthquakes also release stored elastic potential energy in rocks, a kind of mechanical potential energy which has been produced ultimately from the same radioactive heat sources. Thus, according to present understanding, familiar events such as landslides and earthquakes release energy which has been stored as potential energy in the Earth's gravitational field, or elastic strain (mechanical potential energy) in rocks. Prior to this, the energy represented by these events had been stored in heavy atoms, ever since the time that gravitational potentials transforming energy in the collapse of long-destroyed stars created these atoms, and in doing so, stored the energy within them.

In other similar chain of transformations beginning at the dawn of the universe, nuclear fusion of hydrogen in the Sun releases another store of potential energy which was created at the time of the Big Bang. At that time, according to theory, space expanded and the universe cooled too rapidly for hydrogen to completely fuse into heavier elements. This meant that hydrogen represents a store of potential energy which can be released by nuclear fusion. Such a fusion process is triggered by heat and pressure generated from gravitational collapse of hydrogen clouds when they produce stars, and some of the fusion energy is then transformed into sunlight. Such sunlight may again be stored as gravitational potential energy after it strikes the Earth, as (for example) snow-avalanches, or when water evaporates from oceans and is deposited high above sea level (where, after being released at a hydroelectric dam, it can be used to drive turbine/generators to produce electricity). Sunlight also drives many weather phenomena on Earth. An example of a solar-mediated weather event is a hurricane, which occurs when large unstable areas of warm ocean, heated over months, give up some of their thermal energy suddenly to power a few days of violent air movement. Sunlight is also captured by plants as *chemical potential energy*, when carbon dioxide and water are converted into a combustible combination of carbohydrates, lipids, and oxygen. Release of this energy as heat and light may be triggered suddenly by a spark, in a forest fire; or it may be available more slowly for animal or human metabolism, when these molecules are ingested, and catabolism is triggered by enzyme action.

Through all of these transformation chains, potential energy stored at the time of the Big Bang is later released by intermediate events, sometimes being stored in a number of ways over time between releases, as more active energy. In all these events, one kind of energy is converted to other types of energy, including heat.

Examples of sets of energy conversions in machines

For instance, a coal-fired power plant involves these power transfers:

1. Chemical energy in the coal converted to thermal energy
2. Thermal energy converted to kinetic energy in steam
3. Kinetic energy converted to mechanical energy in the turbine
4. Mechanical energy of the turbine converted to electrical energy, which is the ultimate output

In such a system, the last step is almost perfectly efficient, the first and second steps are fairly efficient, but the third step is relatively inefficient. The most efficient gas-fired electrical power stations can achieve 50% conversion efficiency. Oil and coal fired stations achieve less.

In a conventional automobile, these power transfers are involved:

1. Potential energy in the fuel converted to kinetic energy of expanding gas via combustion
2. Kinetic energy of expanding gas converted to linear piston movement
3. Linear piston movement converted to rotary crankshaft movement
4. Rotary crankshaft movement passed into transmission assembly
5. Rotary movement passed out of transmission assembly
6. Rotary movement passed through differential

7. Rotary movement passed out of differential to drive wheels
8. Rotary movement of drive wheels converted to linear motion of the vehicle.

Other energy conversions

There are many different machines and transducers that convert one energy form into another. A short list of examples follows:

- Thermoelectric (Heat → Electricity)
- Geothermal power (Heat→ Electricity)
- Heat engines, such as the internal combustion engine used in cars, or the steam engine (Heat → Mechanical energy)
- Ocean thermal power (Heat → Electricity)
- Hydroelectric dams (Gravitational potential energy → Electricity)
- Electric generator (Kinetic energy or Mechanical work → Electricity)
- Fuel cells (Chemical energy → Electricity)
- Battery (electricity) (Chemical energy → Electricity)
- Fire (Chemical energy → Heat and Light)
- Electric lamp (Electricity → Heat and Light)
- Microphone (Sound → Electricity)
- Wave power (Mechanical energy → Electricity)
- Windmills (Wind energy → Electricity or Mechanical energy)
- Piezoelectrics (Strain → Electricity)
- Acoustoelectrics (Sound → Electricity)
- Friction (Kinetic energy → Heat)