# Chapter 2
# Energy I: General Issues

*The history of man is dominated by,*
*and reflects, the amount of available energy.*

Frederick Soddy

*The scientist discovers a new type of material or energy*
*and the engineer discovers a new use of it.*

Gordon Lindsay Glegg

**Abstract** Energy is the basis of everything. It is the dominant fundamental element of life and society. Its movement or transformation is always followed by a certain event, phenomenon, or dynamic process. Energy is used by humans to acquire useful minerals from earth, and construct technological creatures (buildings, transportation systems, factories, machines, etc). The energy used by end users in our society comes from exhaustible sources (coal, fuel oil, natural gas), non-exhaustible (renewable) sources (hydroelectric, wind, solar) or from alternative sources (bio-alcohol, biodiesel, liquid nitrogen, hydrogen). In this chapter, we provide a historical tour to the energy and thermodynamics studies and developments, accompanied by an exposition of the fundamental aspects of energy. These aspects include the energy concept itself, the energy types, the energy sources, and the impact of energy generation and use on the environment.

**Keywords** Energy · Energy types · Kinetic energy · Potential energy
Evidence of energy · Available energy · Sensible energy · Latent energy
Chemical energy · Nuclear energy · Energy sources · Exhaustible/renewable energy sources · Reversible/irreversible process · Fossil/non-fossil fuels

## 2.1 Introduction

*Energy* is the most fundamental prerequisite for all living organisms on Earth and engineered (man-made) systems to live, operate, and act. It is one of the most important physical concepts discovered by human. In the elementary textbooks, energy is defined as the "*ability to do work*". To do all things we do, we need energy. More generally, things can change because of energy. For example, by



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taking concentrated energy in the form of oxygen plus food, we can perform both the unconscious synthesis of the complex biological substances required for our bodies and our conscious physical and mental work, returning to nature-diffused energy as body heat and less-concentrated-energy substances.

Using energy, we can acquire from the Earth useful minerals, construct powerful complex machines, etc. The energy used by end users in our society (car manufacturers, wind turbine makers, dairy farmers, and so on) comes from fossil sources (coal, fuel oil, and natural gas), and electrical energy generated using fossil, nuclear fuel, and renewable-energy sources (wood, hydroelectric, wind, solar, etc.). Humans need energy to walk, to run, to read a book, to think, and even to sleep, and so on. Nearly all buildings (homes, offices, etc.) need energy for lighting, air conditioning, water heating, space heating, and lift systems. To run our office equipment (computers, printers, fax machines, etc.), we need energy. Energy is used to light our cities, power our vehicles, industrial plants, trains, airplanes, etc. In general, we buy energy, we sell energy, try to conserve energy, convert energy, and so on. Energy can be transferred from one place to another and can be transformed from one form to another. Every time energy moves or changes form, a certain event takes place (e.g., something moves, gets warmer or cooler, breaks, falls down, and so on). Therefore, to understand the processes that occur in natural and man-made systems, we must study energy's behavior, i.e., what happens when energy moves or changes form.

This chapter gives a brief exposition of the basic issues of energy, namely the energy concept itself, energy types, energy sources, and the impact of energy on the environment, including a tour of the principal historical landmarks of energy and thermodynamics.

## 2.2 What is Energy?

Energy is a physical concept that cannot be defined in the usual concrete way. Actually, most of the authors in physics, energy, and thermodynamics bypass the definition and describe energy through the physical and mathematical properties of its various manifestations [1–8]. The term, "*energy*" comes from the Greek word "*ενέργεια: energeia*" (action, activity, operation) and "*ενεργός: energos*" (active, working). Aristotle used the term "*ενέργεια*" to clarify the definition of "*being*" as "*potency*" (δύναμις-dynamis: force) and "*action*" (energeia). The elementary definition of energy as "*the ability to do work*" is more a property, a characteristic of energy, than a definition, and applies only to mechanics. In [7], energy is introduced as follows: "While it is difficult to define energy in a general sense, it is simple to explain particular manifestations of energy". In [8] it is stated that, "Energy is inherent in all matter. Energy is something that appears in many different forms that are related to each other by the fact that conversion can be made from one form of energy to another. Although no simple definition can be given for the general term energy, E, except that it is the capacity to produce an effect, the various forms in which it appears can be defined with precision". *Richard Feynman,* a famous physicist and Nobel Laureate, in his lectures on Physics (textbook) [4, 7] introduces energy by saying:

> It is important to realize that, in physics today, we have no knowledge of what energy is. We do not have a picture that energy comes in little blobs of a definite amount… There is a fact, or if you wish, a law, governing natural phenomena that are known to date. There is no exception to this law; it is exact, so far we know. The law is called *conservation of energy;* it states that there is a certain quantity, which we call *energy,* that does not change in manifold changes which nature undergoes. That is the most abstract idea because it is a mathematical principle; it says that there is a numerical quantity, which does not change when something happens. It is not a description of a mechanism or anything concrete; it is just a strange fact that we can calculate some number, and when we finish watching nature go through her tricks and calculate the number again, it is the same!

Following *David Watson* [9], energy can be described in a general way as follows: "*Energy is a property or feature of matter that makes things to move or change condition (state), or has the capability (potential) to make things to move or change*".

In all cases, if anything moves, changes state, or happens, there is an energy change, i.e., either a change of energy form (e.g., kinetic energy of wind or water falling energy to electrical energy) or a change of location (e.g., heat flow from one object to another object). Without energy, nothing would ever move or change or happen. The "changes of condition" include all possible changes in nature, such as a change in chemical composition due to a chemical reaction, change of thermodynamic or systemic state, change of phase (solid to liquid, liquid to vapor, and vice versa), changes in pressure, change of the position of a mass, and so on. Energy "feeds" earthquakes and volcanoes, "powers" bacteria, and "drives" tornadoes, typhoons, and tidal waves. Cosmologists have attempted and are attempting to explain the origin of our universe (cosmogony) via theories that are based on energy. Today, the theory that is accepted by most cosmologists is the *Big Bang* theory. The Big Bang consisted of an explosion of space with itself, different than the explosion of a bomb, the result of which is the outward propulsion of fragments. At the very beginning after the Big Bang (about 15 billion years ago), there was only an extremely hot plasma soup, which began to cool at about 10 into—43s after creation. At that time, an almost equal (yet asymmetrical) amount of matter and antimatter existed. These materials collided and destroyed one another, creating pure energy, but with an asymmetry in favor of matter, with the discrepancy growing larger as the universe began to expand. As the universe expanded more and more, and so cooled, common particles called *baryons* began to form that include photons, neutrinos, electrons, and quarks and became the building blocks of matter and life, as we know it [10–13]. Generally, all the cosmological and astronomical phenomena of galaxies, stars, nova, etc., are large-scale transformations of matter into energy or manifestations of energy movement or the transformation of potential energy into kinetic and radiant energy [14].

The Big Bang model of "cosmogony", like other scientific cosmogony models, is supported by the abundance of the "light elements" hydrogen and helium found in the observable universe, and by other evidence such as the movement of galaxies away from us (Hubble's Law), etc. Cosmogony is an area where science and theology meet in their effort to explain the *"supernatural*" event of the cosmos' creation [11, 15].

In our observable world, energy is the ultimate agent of change, the mother of all changes [6]. Therefore, to study energy, one must learn how it behaves and what it can do. Using this knowledge, humans build all human-made systems: numerical machines, manufacturing systems, power plants, computers, robots, control systems, aircraft, and so on.

## 2.3 Historical Landmarks

The history of energy and thermodynamics represents a substantial part of the history of physics, chemistry, and science. Here only the principal landmarks will be presented. More extensive presentations can be found in [1–3, 6, 16–21, 22–31].

**Ancient Times** The ancients related heat with fire. The Egyptians viewed heat as related to their origin mythologies. In ancient Greece (fifth century BC), *Empedocles* formulated his four-element theory according to which all substances derive from *earth, water, air,* and *fire*. It appears that the fire element of *Empedocles* is probably the principal ancestor of the *J. J. Becher Combustion theory* (1669) that was further developed and renamed as *phlogiston theory* by *Georg Ernst Stahl* (1694–1734). Phlogiston theory was later disapproved by *Antoine Lavoisier,* who discovered *oxygen* and proposed the *caloric theory*. The Greek philosopher *Heraclitus* expressed his famous proverb: "*All things are moving*" ($\sim$500 BC), and argued that the three fundamental elements of nature were *fire, earth,* and *water*. For the above proverbial expression, Heracletus is known as the "*flux and fire*" philosopher. Furthermore, *Leucippus* and *Democritus* formulated the first philosophy of *atomism* which is considered today as the primary link between thermodynamics and statistical mechanics. Atomism was further developed to the subsequent *atomic theory,* which was validated in the twentieth century by the experimental proof of the existence of *atoms*. Another stepping stone that inherently stimulated the development of modern thermodynamics seems to be a "poem" of *Parmenides* entitled "*On Nature*"in which he postulated that a *void* (today's *vacuum*) could not occur in nature. It was *Otto von Guericke* who proved Parmenides' postulation through his vacuum pump, incorporated into his celebrated "*Magdeburg Hemispheres*".

**1676–1689** *Gottfried Leibniz* developed the precursor to the energy concept with his *vis viva* (living force) quantity defined, for a system of interacting objects, by the sum [37, 38] :

$$\sum_i m_i \upsilon_i^2$$

where $m_i$ stands for the mass and $\upsilon_i$ for the velocity of the $i$th interacting object. Leibniz observed that, in many cases, *vis viva* was the same before and after the interaction. Newton developed the concept of *momentum* given by:

$$\sum_i m_i \upsilon_i$$

which is conserved in all interactions (*conservation of momentum law*). It was later established that both quantities are conserved simultaneously (e.g., in elastic collisions).

**1776** *John Smeaton* publishes the results of his experiments on momentum, kinetic energy, and work that supported the conservation of energy.

**1802–1807** *Thomas Young* uses for the first time the term *energy* (from the Greek ενέργεια–energeia) to replace Leibniz's *vis viva*. Young defined energy as $E = m\upsilon^2$.

**1819–1839** *Gustave Coriolis* and *Jean-Victor Poncelet* recalibrated *vis viva* as:

$$\frac{1}{2} m\upsilon^2$$

which determines the conversion constant for *kinetic energy (vis viva) into work*. *Coriolis* used the term *quantity of work* (quantité de travail) and *Poncelet* used the term *mechanical work* (travail mecanique). The precursor to "*potential energy*" is the term *vis mortua* (dead force) and the term "*ergal*" used by *Clausius,* who showed that the energy $U$ of a system is equal to *vis viva* $T$ plus *ergal* $J$ (i.e., $U = T + J$), and that the energy $U$ remains constant during any motion (conservation of energy). The term *potential energy* was introduced by *William Rank* in 1853 [39].

**1824** *Sadi Carnot* publishes his work "*Reflections of the Motive Power of Fire*" in which he studies the operation of steam engines using caloric theory. Through the development of the concept of *reversible process* (and postulating that such a process does not actually occur in nature) he discovers the concept of *entropy*. He stated that in, all heat engines, *work* (motive power) can be produced whenever a "*fall in caloric*" occurs between a hot and a cold body. Carnot proved that if the body of a "*working substance*" (such as a body of steam) is brought back to its original state (temperature or pressure), at the end of a complete engine-cycle (known as *Carnot cycle*), no change occurs in the condition of the "working body". Here is exactly where the development of the classical entropy concept was founded. Carnot defined the *efficiency* of an engine and proved that the upper bound of efficiency is set by his ideal engine (known as *Carnot engine*) (see Sect. 3.6.2).

**1834** *Emile Clapeyron* provides a graphical and analytic formulation of Carnot's theory which facilitates very much its comprehension.

**1842** *Julius Robert von Mayer,* a German surgeon, states for the first time the *mechanical equivalence principle of heat,* but he does not provide at this time a quantitative relationship between the two [40].

**1843** *James Prescott Joule* discovers the *mechanical equivalent* of heat (independently from Mayer) in a set of experiments on friction consequences, and formulated the first version of the *First Law of Thermodynamics*. His most well-known experiment used the now called *"Joule apparatus"*, a falling weight attached to a string causing a paddle immersed in water to rotate. He demonstrated that the loss in gravitational potential energy of the falling weight was equal to the gain in thermal energy (heat) of the water due to the friction with the paddle. Actually, the work of Joule received much wider attention, and the mechanical equivalent of heat is today known as *Joule's equivalent* (see *wikipedia*, mechanical equivalent of heat).

**1847** *Herman von Helmholtz* provides an alternative statement of the *First Law of Thermodynamics* (conservation of energy).

**1848–1849** *Lord Kelvin (William Thomson),* a British mathematician and physicist, develops further the concept of absolute zero and extends it from gases to all substances. He also coins the name "*thermo-dynamics*" in the framework of his studies of the efficiency of heat engines.

**1850** *Rudolf Clausius* develops further Carnot's formulation of the *Second Law*, and explains fully the properties of the ratio $Q/T$ (without giving it a name).

**1865** *Rudolf Clausius* presents the modern macroscopic concept of *entropy* as the dissipative energy use of a thermodynamic system (or "*working body*") of chemical species during a state change. This was in disagreement with earlier considerations based on Newton's theory that heat was a non-destructible particle possessing mass. Clausius also originated the term *enthalpy* as the total heat content of a system.

**1871** *James Clerk Maxwell*, a Scottish mathematician and physicist, formulates *statistical thermodynamics*, a new branch of thermodynamics that deals with the analysis of large numbers of particles at equilibrium (i.e., systems with no occurring changes) for which one can define average properties such as temperature $T$ and pressure $P$.

**1872** *Ludwig Boltzmann*, an Austrian physicist, formulates the Boltzmann equation for the temporal development of distribution functions in phase space, using the constant "*k*" known as *Boltzmann's constant*. In 1948, Boltzmann's definition of entropy was properly transferred by *Claude Shannon* (1916–2001) in the modern field of *information theory*.

**1874** *Lord Kelvin* provides a new formal statement of the *Second Law*.

**1876** *Willard Gibbs* publishes a long paper: "*On the Equilibrium of Heterogeneous Substances*", in which he introduces the *free energy equation* (now known by his name) that gives the amount of "*useful work*" attainable in chemical reactions. This equation is the result of studying phase equilibria and statistical ensembles and is considered as a grand equation of *chemical thermodynamics*.

**1884** *Boltzmann* uses thermodynamic considerations to derive the *Stefan-Boltzmann* blackbody radiant flux law (discovered in 1879 by Jozef Stefan, according to which the total radiant flux from a blackbody is proportional to the fourth power of its temperature).

**1906** *Walther Nernst* develops and formulates the *third law of thermodynamics*.

**1909** *Constantin Caratheodory* presents an *axiomatic formulation* of thermodynamics.

**1927** *John von Neumann* presents the concept of "*density matrix*" and establishes the field of *quantum statistical mechanics*.

**1961** *A. Rényi* presents a generalization of Boltzmann–Gibbs entropy which depends on a parameter "$\alpha$". A similar type of entropy for non-extensive processes is introduced by *C. Tsallis* in 1988.

**1976** *Elias P. Gyftopoulos* (MIT) with *G.N. Hatsopoulos* presents a unified quantum theory of mechanics and thermodynamics, and later (1984), with *G. P. Berreta,* derives a new equation of motion for general quantum thermodynamics, which covers both reversible and irreversible processes.

## 2.4 Energy Types

Energy exists in a variety of types or forms. Any and every human activity is based on the conversion of some energy type into another. In general, energy determines the quality of the processes and changes that occur on Earth and in the Universe, including both the material processes and the thinking ones. Energy is actually the measure of a physical or biological or man-made system; more specifically, it is the measurement of a substance's movement. The occurrence of the substance movements in several forms and their interrelationships and connections inspired the development of the energy concept as a common aspect for measuring them.

The nomenclature of the various types of energy can be based on the following features [32]:

- *How energy is perceived* (e.g., mechanical energy, electrical energy, radiation energy, etc.).
- *What carries the energy* (e.g., thermal energy).
- *The source of energy* (e.g., solar energy, wind energy, geothermal energy).

The energy that is available may not be in the required form. In order to obtain the form needed, the proper conversion must be performed. It should be noted, however, that not all available energy can be converted into another form of energy.

The major well-known types of energy are the following:

### 2.4.1 Mechanical Energy

Mechanical energy is distinguished in *kinetic and potential energy* to position and elasticity.

**Kinetic Energy** The energy stored in an object due to motion. An object of mass $m$ and linear velocity $\upsilon$ has kinetic energy equal to:

$$E_{k,\upsilon} = \frac{1}{2}m\upsilon^2$$

An object of moment of inertia $J$ and angular velocity $\omega$ has kinetic energy equal to:

$$E_{k,\omega} = \frac{1}{2}J\omega^2$$

**Potential Energy** The energy stored in an object due to its position, which is equal to the work done against a given force that changes its position from a reference position. It is given by the work of the force, with a minus sign, i.e.:

$$E_p = -\int \mathbf{F} \cdot d\mathbf{s}$$

where $\mathbf{F}$ is the force vector, $\mathbf{s}$ is the displacement vector, and $''\cdot''$ stands for the scalar (inner) product of $\mathbf{F}$ and $d\mathbf{s}$. From the above relationship, it follows that $\mathbf{F} = -dE_p/d\mathbf{s}$ i.e., $\mathbf{F}$ is the negative derivative of the potential energy$E_p(s)$.

**Elastic Potential Energy** The work needed to expand or compress a spring or any other mechanism that is governed by Hook's law:

$$F = -kx$$

where $x$ is the compression or expansion displacement and $k$ is the elastic constant of the spring. In this case, the *elastic potential energy* is found to be

$$E_{p,x} = \frac{1}{2}kx^2$$

for a linear spring, and

$$E_{p,\theta} = \frac{1}{2}k\theta^2$$

for a rotating spring with expansion or compression angle displacement $\theta$.

**Work–Energy Theorem** If a net constant force $F$ is applied to an otherwise free particle (object) of mass$m$, which has velocity$\upsilon_0$, it will accelerate with a constant acceleration $''a''$ given by Newton's law$F = ma$. The velocity of the particle at time

$t$ will be $\upsilon = \upsilon_0 + at$ and the change of position (displacement)$\Delta s = \upsilon_0 t + (1/2)at^2$. Now

$$\Delta E_{k,\upsilon} = \frac{1}{2}m\upsilon^2 - \frac{1}{2}m\upsilon_0^2 = \frac{1}{2}m(\upsilon_0 + at)^2 - \frac{1}{2}m\upsilon_0^2 = ma\left(\upsilon_0 t + \frac{1}{2}at^2\right) = (ma)\Delta s$$
$$= F \cdot \Delta s = W$$

This says that the change $\Delta E_{k,\upsilon}$ in kinetic energy is equal to the work $W = F \cdot \Delta s$ done by the force $F$ on the mass$m$, which is the so-called *"work–energy theorem"*.

## 2.4.2 Forms of Potential Energy

In general, potential energy appears in several forms, not only in the above mechanical forms. Potential energy is the energy in the matter due to its position or the arrangement of its parts and includes the following:

- Gravitational potential energy
- Chemical potential energy
- Electrical potential energy
- Magnetic potential energy

**Gravitational Potential Energy** This is the energy of objects due to their position above the ground. When an object is lifted or suspended in the air, work is done on it against the pull force of gravity. When the object succumbs to the force of gravity falling towards Earth, it converts potential energy into kinetic energy.

**Chemical Potential Energy** This is the internal energy associated with the various forms of aggregation of atoms in matter (for the internal energy, see Sect. 2.4.3). For example, the chemical arrangement (makeup) of gasoline makes it a good fuel-energy source, which, when burned (combusted), releases large quantities of energy that can, e.g., move an airplane. During combustion, chemical bonds are broken and reformed, transforming gasoline into by-products such as water and carbon dioxide, releasing energy.

**Electrical (or Electrostatic) Potential Energy** This is the potential energy $U$ stored[1]. in a given configuration of point electrical charges or in a given electrostatic field distribution. $U$is equal to the work $W$ needed to bring the charges one by one, slowly, from their infinite separation (i.e., from the zero reference) to the given configuration.

Examples of this type of energy are the following: (i) A battery has chemical potential energy along with electrical potential energy. Turning on a device that is

[1]In many cases the expression "the energy stored" is avoided because energy may be erroneously depicted as a substance contained within a substance.

battery-powered, the electrical potential energy stored in the battery is converted into other forms of energy, such as light, sound, mechanical energy, or thermal energy; (ii) A power plant or hydroelectric dam maintains electrical potential energy due to the spinning generator; (iii) A solar cell stores electrical potential energy similar to a battery, as long as sun rays are impacting on it.

**Magnetic Potential Energy** This is the potential energy $E_{mp}$ of a magnet. It is equal to the work of the magnetic force (torque) done to realign the vector of the magnetic dipole 'moment'**m**. Thus, if **B** is the magnetic field vector, $E_{mp}$ is given by:

$$E_{mp} = -|\mathbf{m}| \cdot |\mathbf{B}|$$

In the case of an inductor via in which a current $I$ is flowing, $E_{mp}$ is equal to:

$$E_{mp} = \frac{1}{2} L I^2$$

where $L$ is the *inductance* of the inductor.

## *2.4.3 Internal Energy in Thermodynamics*

Internal energy is the sum of all microscopic forms of energy in a system. It can be considered as the sum of potential and kinetic energies of the molecules of the object and involves the following subtypes of energy not including the kinetic energy of the system (body) as a whole [33–46]

- Sensible energy
- Latent energy
- Chemical energy
- Nuclear energy

In particular, the sum of the sensible and latent internal energy is called thermal energy.

### 2.4.3.1 Sensible Energy

This is the part of the internal energy in the system due to the kinetic energies of its molecules (particles). It is the heat (or thermal energy) provided to the system (body) when the heat is not used to change the state of the system (as in the latent heat). The sensible energy is actually the heat that changes the temperature of the system. The sensible energy is transported in three distinct ways, namely, via conduction, convection, and radiation (or their combinations). Convection (heat or mass convection) is the motion of molecules within fluids (liquids, gases). In fluids, convection occurs via diffusion (random motion of particles) and advection (heat transfer by the macroscopic motion of current in the fluid). Heat convection is distinguished by two principal types as follows:

- *Free or natural convective heat transfer* caused by the circulation of fluids due to the density alterations produced by the heating process itself.
- *Forced convective heat transfer* which takes place passively due to fluid motions (current) that would occur independently of the heating process. Forced convection is sometimes called *heat advection*.

#### 2.4.3.2 Latent Energy

This is the part of internal energy associated with the phase (state) of the system. It is the amount of energy in the form of heat that is absorbed or released by a chemical compound during the process of changing phase (solid, liquid, and gas). The concept was coined by Joseph Black (starting in 1750) and the name latent comes from the Latin latere (= hidden) [46]. Today, in place of latent energy, we frequently use the term enthalpy. The two typical latent heats (or enthalpies) are as follows:

- Latent heat of fusion (melting)
- Latent heat of vaporization (boiling).

#### 2.4.3.3 Chemical Energy

Chemical energy is the internal energy due to the arrangement of atoms in the chemical compounds. It is produced via reactions that take place when the bonds between the atoms loosen or break and create new compounds. The chemical energy is released in the form of heat. Reactions that release heat are called exothermic. In general, exothermic reactions consume oxygen, and, when the bonds break or loosen, oxidation occurs almost instantly. Chemical reactions that need heat to occur usually store some of this energy as chemical energy in the bonds of the newly generated compounds. Chemical energy is a source of energy easy to assess and very efficient to store and use. The chemical energy contained in food is converted by the human body into mechanical energy and heat. The chemical energy in fossil fuel is converted into electrical energy at power plants. The chemical energy stored in a battery can provide electrical power via electrolysis.

As we will see in Sect. 2.5.3, chemical energy can be used in several ways to obtain alternative renewable-energy sources very useful for the future survival of humans.

#### 2.4.3.4 Nuclear Energy

Nuclear energy is the energy due to the strong bonds within the nucleus of the atom itself. It can be released via fission (splitting) or fusion (merging together) of the nuclei of atoms. When a nucleus is split apart, a tremendous amount of energy E is released, in both heat and radiant-energy forms, according to Einstein's matter–energy equivalence equation $E = mc^2$, where m is the (converted) mass and c is the speed of light.

A nuclear power plant employs uranium as fuel, the atoms of which are split apart in controlled, nuclear chain reactions, through appropriate control rods. In a chain reaction, the particles released by atom fission go off and strike other uranium atoms, splitting them. If a chain reaction is not controlled, then an atomic bomb may be obtained under particular conditions (e.g., pure uranium-235 or plutonium, etc.). The nuclear fission creates radioactive by-products that may harm people. Therefore, very robust concrete domes are constructed to contain the radioactive material, in the case of an accident. The large amount of heat energy released by a nuclear reaction is fed to a boiler in the core of the reactor. The boiled water around the nuclear reactor core is sent to suitable heat exchangers that heat a set of pipes filled with water to produce steam. This steam is passed via another set of pipes to turn a turbine that generates electricity.

Fusion is the process of merging (joining) together smaller nuclei to make a larger nucleus. Through the fusion of hydrogen atoms, the sun creates helium atoms and gives off heat, light, and other radiation. The difficulty of controlling nuclear fusion within a confined space is the reason why, at the moment, scientists have not yet succeed in constructing a fusion reactor for generating electricity. It should be noted that nuclear fusion creates less radioactive material than fission.

### *2.4.4 Evidence of Energy*

Mechanical motion, thermal energy, sound, and light cannot easily be classified as kinetic and potential energy since they always contain a combination of the two. For example, a pendulum has an amount of mechanical energy that is continually converted from gravitational potential energy into kinetic energy, and vice versa, as the pendulum oscillates back and forth. Thermal energy consists of both kinetic energy (the sensible energy) and the latent (phase-dependent) energy. An *LC* electric circuit is, like the pendulum, an oscillator (electric oscillator), and its energy is on average equally potential and kinetic. Therefore, it is arbitrary to characterize the magnetic energy as kinetic energy and the electrical energy as potential energy, or vice versa. The inductor can be either regarded as analogous to a mass and the capacitor as analogous to a spring, or vice versa. Likewise, the sound is made up of vibrations and contains both kinetic and potential energy. Extending the reasoning about the *LC* electric circuit to the empty space electromagnetic field, which can be regarded as an ensemble of oscillators, we easily verify that radiation energy

(energy of light) can be considered to be equally potential and kinetic [7]. This interpretation is used when we are interested in the electromagnetic Lagrangian which involves both a potential energy and a kinetic energy component. Now, in empty space, the photon (which is massless, has electric charge, and does not decay spontaneously in empty space) travels with the speed of light,$c$, and its energy $E$ and momentum are related by

$$E = pc\,(p = \text{magnitude of momentum vector } \mathbf{p})$$

The corresponding equation for particles that have mass $m$ is as follows:

$$E^2 = p^2c^2 + m^2c^4$$

where $mc^2$ is the so-called rest energy. At speeds much smaller than $c$, the kinetic energy of the particle is found to be equal to $p^2/2m$ [47, 48]. This expression is used when we are interested in the energy-versus-momentum relationship. The formula $E = pc$ says that the energy of a photon is purely kinetic. The above two, apparently different, results about the energy of light are actually consistent. In the first, the electric and magnetic degrees of freedom are transverse to the direction of motion, while in the second, the speed is along the direction of motion. In all the above cases, where the energy cannot be classified as pure kinetic or pure potential energy, we say that we have "evidence of energy" [7, 49].

## 2.5 Energy Sources

The energy sources available to humans, besides the perpetual energy of the Sun, are categorized into the following:

- **Exhaustible (non-renewable) sources:** Fossil fuels (oil, coal, natural gas) and nuclear fuel.
- **Renewable (non-exhaustive) sources:** Biomass, geothermal, hydropower, solar, wind, and other alternative non-fossil sources (bio-alcohol, bio-diesel, liquid nitrogen, hydrogen, etc.).

A short presentation of them follows [8, 16–21, 32 47, 48, 50–58]. Detailed technical issues can be found in relevant books (e.g., [59–65]).

### *2.5.1 Exhaustible Sources*

Exhaustible energy sources are finite resources, and eventually, the world will run out of them, or it will become extremely difficult and expensive to retrieve those that remain.

**Fossil Fuels** were formed hundreds of millions of years ago before the time of the dinosaurs (hence the name *fossil fuels*). The age in which they were formed is known as *Carboniferous Period* (from the carbon that is the basic constituent of fossil fuels), which was part of the *Paleozoic Eva* [32]. They were formed from the dead and decayed plants and animals, under the effects of high pressure and high temperature. The dead plants and animals sank to the bottom of the swamps of oceans. They formed layers of the so-called *"peat",* which, over the centuries, was covered by sand, clay, and several minerals, and then were transformed into a form of rock named *"sedimentary"*. As more and more rock piled on top of rock, and weighed more and more, the peat was squeezed by the very high pressures which developed, and the water was ejected. In this way, eventually, the matter became oil, coal, and natural gas.

**Oil** is used to produce petrochemical products (gasoline, petroleum, kerosene, diesel, plastic fabrics) using the distillation method. The reserves of fossil fuels are being depleted at very high rates, a fact that raises strong sustainability concerns. **Oil** supplies about 40% of world's currently used energy (Fig. 2.1).

**Coal** was formed from decomposed plants via the same process (called *coalification*), but it took comparatively less time than that of fossil fuels. Fossil fuels have been used in China from very early times (around 1,000 BC), and oil was in use by ancient Babylonians (about 6,000 years ago). The intensive use of fossil fuels started during the Industrial Revolution. The principal ingredients of coal are carbon, hydrogen, nitrogen, oxygen, and sulphur, but the actual composition varies among the various types of coal (anthracite, bituminous, lignite). It is noted that anthracite is the hardest type and lignite the softest type of coal. It is estimated that, today, coal provides about 28% of the total energy consumed by humans.

**Natural Gas** collects in large quantities and contains mainly methane and some small amounts of butane, propane, ethane, and pentane. It is thinner than air, odorless, and highly inflammable. Its typical use is for cooking in the form of liquefied petroleum. The first discoveries of natural-gas seeps were made in Iran. Natural gas is commonly located near petroleum underground. It is pumped from below ground and transported via pipelines to storage tanks. Since natural gas has no odor, before going to the pipelines and storage areas, it is mixed with a chemical to acquire a strong odor, smelling like *rotten eggs*. This odor is an indication that there is a leak, and so the users of the natural gas evacuate and avoid possible ignition of the gas. Natural gas covers around 20% of the world's energy demand.

**Nuclear Fuel** The basic fuel of nuclear power reactors is uranium (U), a very heavy metal (with a melting point of 1,132 °C). Uranium is mildly radioactive, exists in the crust of Earth and contains abundant concentrated energy. It was formed in *supernovae* about 6.6-million years ago. Today, its radioactive decay provides the principal source of heat inside the Earth, causing convection and continental drift. Uranium is 40 times more abundant than silver. It is primarily used for the production of electricity from nuclear plants, but it is also used for marine propulsion and in medicine for cancer treatment via the production of

**Fig. 2.1** Two examples of technology for oil-field extraction (http://www.inn-california.com/valleys/images/ca0159.jpg, http://www.amroll.com/artman/uploads/1/oil.jpg. The reader is informed that Web figures and references were collected at the time of the book's writing. Since then, some of the urls may not be valid due to change or removal by their creators, and so they may no longer be available

radioactive isotopes. The various processes that are used for the production of electricity from nuclear reactions are collectively called the *"nuclear fuel cycle"*. The nuclear fuel cycle starts with the mining of uranium and finishes with the disposal of the nuclear waste. With the reprocessing of used fuel as a source for nuclear energy, the stages constitute a *"true cycle"* [33]. In a number of areas on Earth, the concentration of uranium in the ground is adequately high so that the mining and use of it as nuclear fuel is economically feasible. In these cases, we say that we have *uranium ore*. The uranium ore can be recovered by *excavation* or in *situ* techniques. The decision as to which technique is to be used is based on the nature of the ore body at hand, and on safety and economic issues. *Vaclav Smil* argues that although the promoters of nuclear energy in the 1970s were saying that, by the year 2000, all electricity in U.S. would come from nuclear fission, the reality of 2008 was that coal-fired power plants produced 50% of the electricity and nuclear stations only 20%, with no operating commercial breeder reactors (The

American, A Magazine (http://www.american.com/archive/2008/november-december-magazine/). Figure 2.2 shows an example of nuclear power plant.

### *2.5.2 Renewable Sources*

Fossil fuels are still the main energy source used for the growth and development of modern industries and the human society, but reliance on them presents a serious problem since they are exhaustible. Renewable-energy sources are energy resources that are naturally replenishing but flow-limited. They produce little or no pollution or greenhouse gases, and they will never run out. Today, about 50% of the energy provided by renewal sources is used to produce electricity. Renewable sources include biomass, geothermal, hydropower, solar, wind, and ocean energy.

**Biomass Energy** Biomass, which is matter otherwise thought of as garbage, has been an important source of energy from the first time humans started burning wood to cook food and warm them- selves in winter. In general, biomass is organic material produced from plants and animals and, besides the release of heat, can also be converted to electricity, biodiesel, ethanol, and methane gas. The conversion of biomass to electrical energy is performed in manufacturing industries, where left-over biomass, like wood waste or paper waste, is burned to produce steam, which is then used for the electricity generation. Waste coming from household and office contains some kinds of biomass that can be recycled for fuel and other uses, thus cutting down on the need for "landfills" into which to put garbage. The two principal ways of using the biomass for energy are the following:

- The biomass is tapped at the landfill for combustible waste products. The decomposition of the garbage produces methane gas which is immediately collected by pipelines that are installed within the landfills. This methane is then used in power plants to produce electricity. This category of biomass is known as *"landfill gas"*.
- The waste wood, agricultural waste, and other organic material from industrial and municipal wastes are collected in large trucks and transferred to a biomass power plant. Here it is properly fed into a furnace where it is burned and generates the heat used to boil water in a boiler. Then the energy of the resulting steam turns turbines and electric generators.

**Geothermal Energy** *Geothermal* comes from the Greek *"γεω: geo"* (earth) and *"θερμότητα : thermal"* (heat). So geothermal means *"earth-heat"* and refers to the energy existing inside the Earth's crust. To generate electricity from a geothermal source, deep wells are constructed and high-temperature water or steam is pumped to the surface of the Earth. Geothermal power plants are built near *geothermal reservoirs* (large areas with naturally hot water). Other uses of geothermal sources include the heating/cooling of houses (heating in winter, cooling in summer). The physics of geothermal energy is briefly as follows. The crust of the Earth floats on

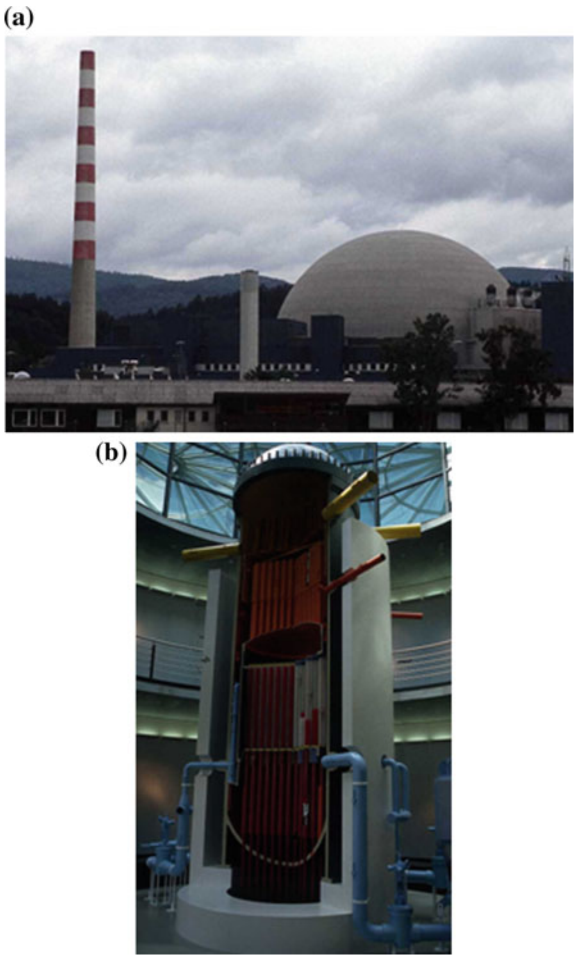

**Fig. 2.2** **a** A photo of a nuclear-power plant (http://www.picture-newsletter.com/nuclear//nuclear-plant-m82.jpg), **b** interior of the nuclear-power plant (http://www.picture-newsletter.com/nuclear/nuclear-power-nv5.jpg)

the *magma* (the hot liquid rock lying below the crust). When the magma comes to the surface of the Earth in a volcano, it is the well-known "lava". The temperature of the rock increases with the depth (about three degrees Celsius for every 100 meters below ground), and so, if we go to about 3,000–3,500 meters below the ground, the temperature of the rock would be sufficient to boil water. Actually, the hot water can have temperatures as high as 150 °Celsius or more (i.e., hotter than boiling water), but, because the water is not in contact with the atmosphere, it does not turn into steam. Hot springs are this very hot water emerging from the ground through a crack.

**Hydropower** was invented in the 1880s, and, for many decades, the moving water was used to turn wooden wheels attached to grinding wheels to grind flour or corn. These *"wooden and grinding wheels"* were the well known "water mills". Water is a renewable resource, constantly replenished by the cycle of evaporation and precipitation. Today, moving water is extensively used for electrical-power generation, the so-called *hydro-electric power* (from the Greek "υδρο-hydro: water" and "electric"). Here, the mechanical energy of the moving (swift-falling or descending) water is used to turn the blades of a turbine. Hydroelectric power plants are built at the place of the water fall or in man-made dams (Fig. 2.3). The electric power generated depends on the amount and speed of the flowing water. In many countries, more than 10% of the total electricity is produced by hydropower.

**Solar Energy** Sunlight (solar energy) can produce electrical and thermal energy by two techniques, namely, *direct* and *indirect*. In the direct, the technique employs *solar cells* or *photovoltaic systems*. In the indirect technique, solar energy is collected by *power thermal collectors* to heat fluid and generate steam, which is fed to steam engines that produce electricity. The varying intensity of sunlight, depending on the location of the system and the weather conditions, is the major drawback of this energy source.

**Solar cells or photovoltaic (PV) cells** are made from *silicon*. When the sun's rays strike the solar cell, electrons are knocked loose and move toward the treated front surface. In this way, an electron imbalance is developed between the front and the back of the cell. Then, by connecting the two surfaces with a wire (or another connector), we make an electric current flow between the negative and positive terminals. Multiple individual solar cells are grouped to form a PV module, and many modules are arranged in arrays that are attached to special tracking systems to maximize the sunlight collection all day long. Figure 2.4 shows an example of a solar-power system.

**Solar collectors** that store heat energy may be "batch"-type collectors, while other kinds of solar collectors use circulated fluid (e.g., water or antifreeze solution) to provide the heat for storage in an insulated reservoir or for direct use. A complete solar-heating system is composed of a collector, a heat-transfer circuit, and a heat-storage device. Three basic plate-collector system types are the *passive breadbox* collector, the *active, parallel, flat-plate* collector, and the *active, serpentine, flat-plate* collector. Flat-plate collectors are usually employed to heat water or housing spaces, and other domestic buildings. To generate electricity, solar-power plants use parabolic solar reflectors of the *"parabolic dish"* or the *"parabolic through"* type. A parabolic dish concentrates the parallel sunlight rays at the focal point of the collecting lens. A kind of solar, reflector, dish concentrator can be also obtained by lining the interior of a cardboard box with aluminum foil. Parabolic troughs are cheaper than the dish. A simple way to make a parabolic trough is to use a sheet of cardboard lined with a piece of aluminum foil. The drawback of solar energy is that it is available for use only during sunny days. During nights and on cloudy days, the solar systems cannot produce energy. For this reason, some systems are of the hybrid solar and natural gas type.

**Wind Energy** Here the wind's speed is used to rotate suitable blades, which are connected to an electrical power generator. The blades of the turbine are connected

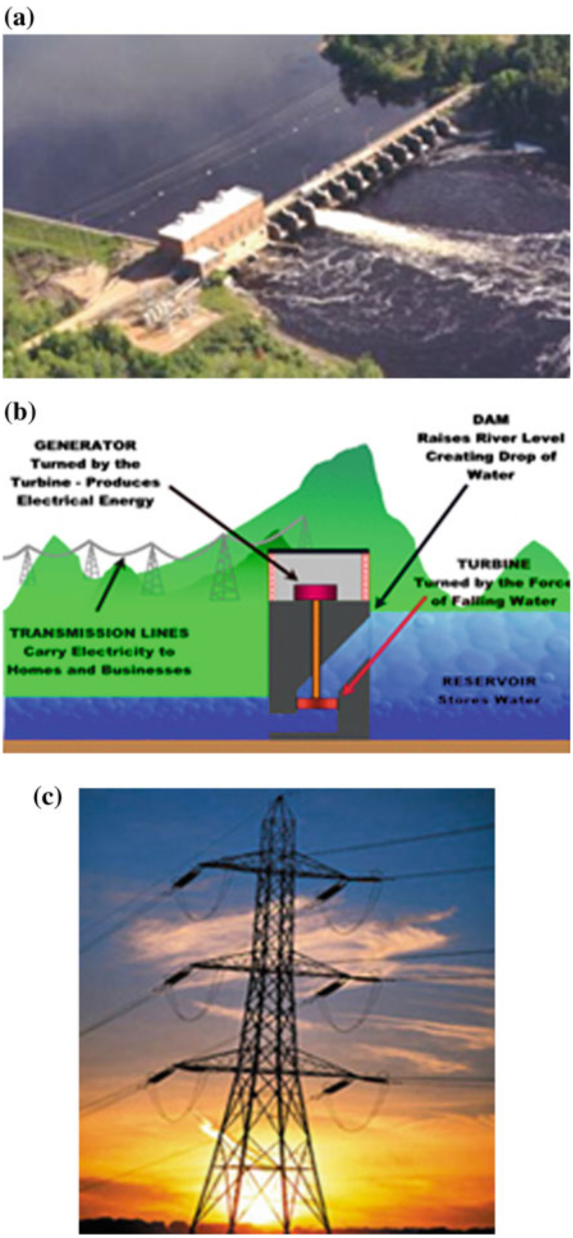


**Fig. 2.3** **a** A hydroelectric power plant example **b** Schematic hydro-power system: turbine, generator, transmission lines (*Source* http://earthsci.org/mineral/energy/hydro/hydro.htm **c** A tower for electric power transmission *Source* http://www.cbc.ca/news/background/poweroutage/electricity_terms.html

to a rotating axis via a gearbox that increases the rotation speed. This in turn rotates an electrical generator. Wind turbines or wind mills are placed in the best orientation in order to make maximum use of wind energy. Wind-power plants involve groups of wind generators (Fig. 2.5). Today, many wind-generator companies

**Fig. 2.4** A photo of a typical solar-power plant (http://www.publicdomainpictures.net/view-image.php?/image=30618&picture=solar-power-plant)

**Fig. 2.5** An example of a wind-power-generator "farm" (http://www.worsleyschool.net/science/files/windpower/page.html)

produce and install wind-power plants appropriate for both domestic and industrial systems. Again, wind generators have the drawback that they can provide sufficient amounts of electrical energy only if installed in windy areas. A wind turbine can provide sufficient power if the wind speeds are higher than 10 to 15 miles per hour, in which case each turbine produces about 50–300 kw.

**OceanEnergy** The ocean provides three main types of renewable energy, i.e., *wave energy, tidal energy,* and *thermal energy*. Of course, the ocean provides non-renewable energy as well, since, in many regions, huge amounts of oil and natural gas are buried below the seabed.

**Wave Energy** The kinetic energy of the moving ocean waves is used to rotate a turbine, and the resulting air circulation turns a generator. In other systems, the up and down motion of the wave is used to power a piston moving a cylinder up and down. The piston is used to rotate an electric generator (Fig. 2.6).

**Tidal Energy** The tides coming onto the shore are trapped in reservoirs behind dams. These reservoirs operate like standard hydropower systems, i.e., when the tide drops, the water behind the dam is let out as in conventional hydroelectric

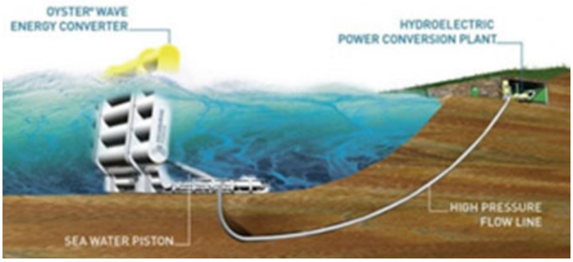


**Fig. 2.6** An example of an oyster system, a type of hydroelectric wave-energy plant (http://www.gizmag.com/tag/wave+power)

plants. In other tidal technologies under development, the natural ebb and flow of water is not changed. For the tidal energy to work efficiently, large tidal variations (at least 16 ft between low tide and high tide) are required, but very few places exist on the Earth with this tidal change. For this reason, tidal systems are of limited applicability. Three examples of tidal-power plants are the 500-kw plant installed on the Scottish shoreline of Islay, the La Rance Station in France (250 MW), which is capable to power 240,000 homes, and the Merrimack River tidal system along the Massachusetts-New-Hampshire border.

**Ocean Thermal Energy** Solar energy heats the surface water of the ocean. Thus the surface layers of the ocean are warmer than the deeper, colder layers. In tropical areas, the temperature difference between surface water and deep water can be very significant. *Ocean thermal energy conversion* **(OTEC)** *systems* exploit these temperature differences. OTEC power systems can work well if this difference is higher than 38 °F, which can occur in tropical regions. There are two types of OTEC systems: *closed* and *open*. A *closed system* converts warm surface water into steam under pressure through several heat-exchange cycles. Cold, deeper water is pumped via pipes to a condenser on the surface. The cold water condenses the steam, and the closed cycle is repeated. An *open OTEC system* turns the steam into fresh water, and new surface water is fed into the system. The generated electrical power is transmitted to the shore. Small-scale OTEC systems have been installed and tested in tropical coasts, but, in general, OTEC technology is far from economically-practical commercial use.

### *2.5.3 Alternative Energy Sources*

Some major alternative nonfossil fuels are the following:

**Bio-Alcohol** Fuels of this category are produced from plant sources. They include ethanol, butanol, methanol and propanol, and (due to their properties) can be used in car engines. The most popular is ethanol which is produced from sugar fermentation. In the US, ethanol is typically produced from corn and is being used extensively as a fuel additive. Its use as a part of a mix with gasoline or as ethanol fuel, alone, is increasing. But, in general, bio-alcohol is not used in the majority of industries because it is more expensive than the derived from fossil fuels. Careful energy analysis has shown that there is a net loss in alcohol use, and further improvements need to be done (use of optimized crops, elimination of pesticides, etc.) to make bio-alcohol a viable renewable fuel. Of course, chemically there is not any difference between biologically produced alcohols and those produced by other sources.

**Bio-Diesel** Bio-Diesel is a renewable fuel for diesel engines produced from natural vegetable oil (such as *soybean oil*) and animal fat by a reaction with an alcohol (such as methanol or ethanol) in the presence of a catalyst. This reaction produces *mono-alkyl esters* and *glycerin,* which is removed. Bio-diesel can be mixed with petroleum-based (normal) diesel fuel in any analogy and used in all existing diesel engines without any modification (or with minor modification). Because glycerin is removed, bio-diesel is different from standard raw vegetable oil. The bio-diesel has reduced the overall emission of pollutants and possesses good lubrication characteristics. Currently, it has been introduced in all types of locomotion all over the world.

**Liquid Nitrogen** This type of fuel can only be used in cars equipped with nitrogen power combustion. These cars have a circuitry similar to electric cars, but the batteries are replaced by nitrogen fuel tanks. Liquid nitrogen is inert, odorless, colorless, non-corrosive, nonflammable, and extremely cold. Nitrogen's concentration in the atmosphere is 78.03% by volume and 75.5% by weight. Although it is inert and does not support combustion, it is not life supporting, since when it is combined with oxygen to form oxides of nitrogen, it may reduce the concentration of oxygen in the air below that needed for life. It is noted that, at low oxygen concentrations, unconsciousness and death may come very quickly and without warning. The use of liquid nitrogen (a *cryogenic liquid*) requires special protective measures (such as a full-face shield over safety glasses, loose-fitting thermally-insulated gloves, long sleeve shirts, trousers without cuffs, and safety shoes).

**Hydrogen** Hydrogen is an energy carrier, like electricity, and may be produced from many sources (water, fossil, biomass, etc.). Hydrogen can be obtained as a by-product of many chemical reactions. The hydrogen fuel cell converts the chemical energy stored in a hydrogen molecule into electrical energy. The most economic method of producing hydrogen is *steam reforming,* which is employed in industries to extract hydrogen atoms from methane ($CH_4$). This method has the disadvantage that, together with the hydrogen, *greenhouse gases* **(GHG)** that are the main cause of global warming are emitted. A second method of hydrogen production is *electrolysis*, a process that splits hydrogen from water. This method does not produce GHG emissions but is very expensive. New methods and technologies are currently under development, e.g. it has been discovered that some *algae* and *bacteria* produce hydrogen. The advantage of hydrogen fuel is that a mass of hydrogen contains 2.8 times the energy in the same mass of gasoline. Although hydrogen fuel is already in use, it's excessively high production cost makes it, at the moment, not commercially viable. Most hydrogen is used in processing foods, refining, and metal treatment. Today, there are many hydrogen-fueled vehicles (buses and cars) powered by electric motors.

The use of renewable-energy sources (including the human-made ones) is steadily increasing because of their environmental advantages, i.e., reduced greenhouse-gas emissions. It is estimated that currently about 20% of the world's energy is produced from renewable sources, with biomass being the dominant renewable-energy source in developing countries.

## 2.6 Environmental Impact of Energy

The production, transportation, and use of energy (of any kind) have a visible, substantial impact on the environment, which includes air and water pollution and solid-waste disposal. This impact takes place at every stage of the energy cycle, from energy-extraction methods to the ways the raw resources are transported and used by humans in the industrial and domestic sectors. In the previous section, we saw that the energy sources are categorized into exhaustible and renewable sources. Therefore, here we will discuss the energy's impact on the environment separately for each one of these two energy categories.

### *2.6.1 Impact of Exhaustible Sources*

Technically, fossil fuels are the incompletely oxidized and decayed animal and vegetable materials (petroleum, coal, and natural gas) that can be burned or otherwise used to produce heat. Up to the Industrial Revolution, most energy sources were used for cooking and heating, with only small quantities used in industry. The Industrial Revolution impelled an increased utilization of conventional fuels (wood and coal) and initiated the development of new ones. Energy consumption is not equally distributed throughout the world. The developed countries, which represent only 20% of the world's population, consume about 80% of the natural gas, 60–65% of the oil, and 50% of the annual coal production [59]. Combustion of these fossil fuels is one of the principal factors contributing to GHG emissions into the atmosphere. But, the most serious long-term economic and environmental problem posed to the world seems to be the high consumption rate of natural sources. As the quantity of these energy resources becomes smaller and smaller, their cost will increase making products that use them much more costly, and nations will fight to maintain access to them. According to [57], the amount of nonrenewable sources remaining available as of 2003 was as follows:

**Oil** About 1000 billion barrels (sufficient for about 38 years)
**Natural gas** Approximately 5400 trillion cubic ft (sufficient for about 59 years).
**Coal** About 1000 billion metric tons (sufficient for about 245 years).

The principal types of harmful outcomes of the conversion of fossil fuels to energy are the following [56–58]:

- *Air pollution*
- *Water pollution*
- *Solid-waste disposal*

**Air pollution** affects the formation of urban smog, acid rain, ozone thinning, and global warming. The main cause of global warming is considered to be the carbon dioxide that is released by the combustion of fossil fuels. Other emissions released by this combustion include carbon monoxide, hydrocarbons, etc. A very injurious gas with long-term effects is nitrous oxide, which is released when coal is burned. About 50% of the nitrous oxide and 70% of the sulfur oxide coming directly from the burning of coal. Smog can cause human diseases and can also affect the sustainability of crops, because smog seeps via the protective layer of the leaves and destroys critical cell membranes. Acid rain (rain which is more acidic than conventional rain) damages lakes, forests crops, and monuments. Today, the least harmful fuel to the environment is natural gas since it releases very little carbon dioxide and other GHGs.

**Water pollution** (surface and ground) can occur during the extraction of oil, coal, and gas that typically exist underground and below groundwater reserves. The drilling process can break the natural barriers between the fossil-fuel and the groundwater reserves. Also, water supplies may be contaminated by fossil fuel during transportation and storage (broken pipes or storage tanks). But water pollution is mainly due to industry which disposes process wastewaters, cooling waters, spent process chemicals, and other contaminants into surface water, either *directly* (by piping them to a nearby lake, river, or steam), or *indirectly* (by adding them to a public sewer which eventually leads to a water body). The treatment of these wastes, so that they cease to be hazardous for human health and the environment, is excessively costly.

**Solid-waste disposal** The conversion of fossil fuels may also lead to accumulated solid waste. Solid-waste disposal also comes from agricultural wastes (such as crop residues or manure from animal feeding), which pose problems in rural areas. Other solid wastes originate from industry (process wastes) and domestic operations (institutional, household, and commercial wastes). The collection, transport, processing, recycling, disposal, and monitoring of waste materials is collectively called *"waste management and control"*.

Other types of environmental impacts of fossil fuels are [48]:

- *Land subsidence*
- *Land and wildlife disruption*

- *Drilling-mud releases*

**Land subsidence** This is due to the large holes left underground when oil and gas are taken out of underground reserves. Naturally, if there is no more mass to support the land above, it can collapse, with serious environmental and property damage.

**Land and wildlife disruption** The process of extracting fossil fuels from the Earth has large-scale infrastructure requirements. These include the construction of new roads, storage tanks, oil and gas wells, and other numerous other constructions. These infrastructure developments are usually done in rural and wilderness areas, and so they have serious impacts on plants, trees, and wildlife in general.

**Drilling-mud releases** These include the drilling fluids or muds employed for lubrication, which contain several harmful chemicals (toxic or non-toxic). The contamination of these muds occurs both in the immediate area of drills and in the wider vicinity due to their subsequent dumping.

**Nuclear energy** Nuclear energy poses a special environmental impact due to the production of long-life (thousands of years) radioactive wastes, either as spent-fuel quantities or as remainders of end-of life, dismantled power plants that have been operated for over 35–40 years.

### *2.6.2 Impact of Renewable Sources*

Although renewable resources are more environment friendly than fossil fuels, they are not appropriate for all applications and places. There are still several issues that must be taken into account from an environmental viewpoint because they are not readily utilizable in their natural forms [58, 63–65]. A brief account of these issues for each kind of renewable energy resources follows.

**Biomass Energy** This category of energy has more serious environmental impacts than any other renewable type of energy, except hydropower. Combustion of biomass releases carbon dioxide into the atmosphere producing air pollution and contributing to global warming. In addition, nitrogen oxides and particulates (soot and ash) are emitted. Unwise cutting of trees and plants (forests, peat, and so on) may lead to sterile soil, through the increased surface run-off and the resulting wind erosion. Another uncertain factor involved in biomass impact is that there is no unique biomass technology. Actually, many technologies exist for energy production from biomass, each with different environmental impacts. The production of energy from biomass needs to be done with care, since the reduction of plants and trees implies that less carbon dioxide is absorbed, thereby increasing the greenhouse phenomenon. Overall, biomass emissions are similar to those of coal-based plants, but with much smaller quantities of sulfur dioxide and harmful metals (such as mercury and cadmium). The most serious impact of biomass-based energy is due to the emission of particulates that must be restricted via suitable filters. Nevertheless, the major advantage of replacing fossil fuels by biomass is that, if done in a sustainable way, it can reduce considerably the emission of GHGs.

**Geothermal Energy** All geothermal-energy-resource types suffer from a common category of environmental concerns. This includes the potential release of water or gas from underground reserves that contain toxic substances, air and water pollution, siting and land subsidence, and noise pollution from the high-pressure steam release. Local climate changes may also occur due to the release of heat.

**Hydropower** In many countries, large and small hydropower plants have a strong impact on fish populations (e.g., salmon, trout, etc.). Young fish are forced to travel downstream via several power plants at the risk of being killed by turbine blades at each plant. To reduce this impact, national laws have been enacted that prohibit new hydropower plants to be installed, enforce a considerable reduction of peak-power output in existing ones, direct water around the turbines during the times of the year when the fish are traveling, use screens that keep fish away from turbine blades, or flash underwater lights to direct night-migrating fish around the turbines. Also, the vast reservoirs needed for large hydropower stations flood broad expanses of farmland, affecting forest and wildlife populations and causing severe changes in the ecosystem and human economic activity. River ecosystem changes (upstream and downstream) can also be caused by the hydropower dams. In modern reservoirs, the mercury naturally existing in the soil is released by chemical reactions. Although existing and new hydropower stations have been modernized to minimize these negative consequences, for environmental protection, it is not anticipated that hydropower will increase in total in the near future by more than 10–20%. On the contrary, it may remain constant or be reduced in the long term due to lessening rainfall, the policies of protecting and restoring perilous wildlife and fish, and the increasing demand for drinking and agricultural water.

**Solar Energy** Solar cells and collectors do not produce waste or gas emissions, but the substances used in photovoltaic cells (e.g., cadmium or arsenic) are hazardous for the humans that are exposed to them. The silicon used in PVs, which is usually inert, might be harmful if breathed in as dust, and so proper protection measures should be taken. Solar systems themselves are manufactured and installed through the consumption of fossil fuels, which produce pollution. But the quantities of fossil fuels needed for this are much smaller than the corresponding quantities consumed for other comparable fossil-based energy systems. Also, the land needed for large-scale power plants (utilities) pose problems similar to other types of energy production.

**Wind Energy** Wind turbines, similar to solar cells, do not pollute the land, water, or air, but they result in visual and sound pollution in the landscape, which may affect wildlife. Wind turbines provide a good solution to the energy needed in agricultural/farming areas, but in other cases they may create difficult conflicts in land use (e.g., in forest areas, tree clearing may be required and, in other places, existing roads have to be cut). In many areas, where large-scale wind-power systems are installed, a massive death or injury of birds due to collisions with the rotating wind turbines or electrocution has been observed. To face this and other similar problems, special measures should be taken, acceptable by the communities concerned.

## 2.7 Violent Manifestations of Earth's Energy

Our exposition of energy' properties and issues is complemented in this section with a short discussion of earthquakes, volcanoes, tornadoes, and hurricanes [66–74]. These violent geological and meteorological phenomena have shown, over human history, severe destructive effects that have killed a huge number of people and destroyed their property.

### *2.7.1 Earthquakes and Volcanoes*

The structure of the Earth involves the core (about 400 miles below the ground), the mantle which is outside the core (about 1800 miles thick), and the crust. The core is made from superheated metals, and the mantle consists of semi-molten and semi-solid rock. On top of the mantle float the so-called tectonic plates (large semi-rigid slabs) that constitute the greater part of the earth's crust and have a thickness of only three to 45 miles. The Earth's continents are the visible surfaces (and land masses) of the plates. In most cases, the edges of the tectonic plates (i.e., the borders between them), which are regions of geological turbulence and create visible fault lines (breaches), extend along the shorelines. The tectonic plates move very slowly (typically less than five inches per year), but there are periods without movement which are signals of danger. This is because, when no or little movement occurs, energy accumulates and is stored that then presses on the plates. When the plates can no longer withstand the tension, they break down and an earthquake takes place. Earthquakes are usually measured using the *Richter logarithmic scale* (or its improvement, called the *moment magnitude scale*). On the average, there is a severe earthquake ($\sim$9.00 Richter), and about 150 moderate earthquakes ($\sim$6–8 Richter) per year (since 2000). Figure 2.7 shows the collapse of houses caused by a strong earthquake in the area of Kobe (Japan).

**Volcanoes** are typically located on the edges of Earth's tectonic plates (e.g., those of Iceland and Japan), but in many cases they are located within the body of a plate, e.g., those of Hawaii (Fig. 2.8). Actually, a volcano is the aperture from which magma and other materials erupt from the ground. But, in common terminology, people talking about volcanoes mean the area around the aperture, where the volcanic materials have solidified. Volcanic eruptions are violent demonstrations of Earth's energy–mass movement. Sometimes, volcanic eruptions start with emissions of steam and gases from small apertures in the ground, accompanied by a

**Fig. 2.7** Collapsed houses in Kobe caused by the 2002 earthquake (http://images.nationalgeographic.com/wpf/media-live/photos/000/002/cache/kobe-house-collapse_262_600x450.jpg)

**Fig. 2.8** The Kilauea volcano of Hawaii (http://www.solarnavigator.net/volcanoes.htm)

dense sequence of small earthquakes. In other cases, magma comes to the surface as fluid lava which either flows continuously or shoots straight up in the form of glowing fountains.

The study of volcanoes, their action, and their products is a multidisciplinary field called "*volcanology*" [69]. A list of the major volcanoes of the world is provided in [66]. It is noted that it may be possible to use nonexplosive volcanoes to harvest geothermal energy, as, e.g., has been done in Iceland [70].

### 2.7.2 Tornadoes and Hurricanes

Normal weather phenomena include wind, clouds, rain, snow, fog, and dust storms. Less common phenomena include tornadoes, hurricanes, and ice storms. Tornadoes and hurricanes are weather phenomena belonging to the class of *natural vortexes*. The atmosphere of Earth is a complex and chaotic system in which small changes somewhere can create large variations elsewhere, see Sect. 8.8 ("*Butterfly Effect*"). The weather is shaped in the stratosphere and affects the weather below it in the troposphere. However, due to the chaotic nature of the atmosphere, it is not possible to specify precisely how this occurs. A tornado is the result of a violent movement of energy (heat) when cool air and warm air meet, forcing warm air to rise very quickly. A tornado consists of a violent windstorm with a twisting, funnel-shaped cloud, usually followed by thunderstorms. Tornadoes in the *Fujita scale* are classified not by their size but by their intensity and the damage they cause. Large tornadoes may be weak and small ones may be strong. An example of a tornado is shown in Fig. 2.9.

*Hurricanes*, known as *typhoons* in Asia, are *tropical storms* or *cyclones* that are much broader than tornadoes (Fig. 2.10). Tropical cyclones are typically formed over ocean water heated to a temperature of 26 °C and lying within about 5° of latitude from the Equator, but they can occur at other places as well. The ocean water is heated and it evaporates taking energy from the ocean. As the warmed air rises, a vacuum is formed from the resulting low-pressure system, and thus tropical storms are created. The formation of tornadoes and hurricanes can be explained by Archimedes principle, the rotational force, and the Coriolis force [72–74]. In particular, the Coriolis force creates the rotation of air around the center (a calm area called the "*eye*") in a cyclonic direction (clockwise in the Southern Hemisphere and anti-clockwise in the Northern Hemisphere). The rising water vapor cools and condenses, releasing latent energy and warming further the surrounding air. Actually, this process is a "positive feedback" process that reinforces the existence of the phenomenon. According to K.M.I. Osborne [74], tropical cyclones help to

**Fig. 2.9** A tornado (http://www.chaseday.com/tornadoes-02.htm)

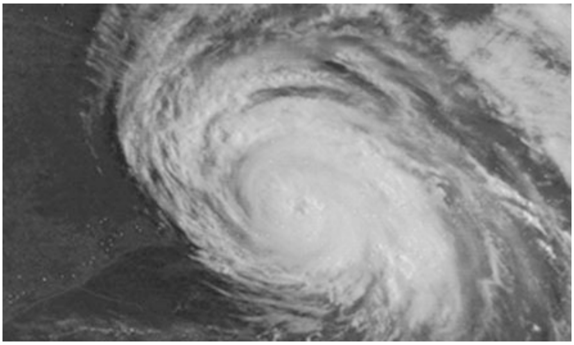

**Fig. 2.10** A satellite photo of a hurricane (Andrew) (http://ww2010.atmos.uiuc.edu/(Gh)/home.rxml)

cool the ocean by drawing heat out and converting it to wind (mechanical energy) and so ensuring that no area of the ocean becomes overheated. The increase of the overall amount of energy in the Earth's atmosphere caused by accumulating GHGs will be followed by the formation of more and more cyclones.

### *2.7.3 Tsunamis*

Tsunamis can be generated whenever large water masses are violently displaced from their equilibrium position, caused by any disturbance. The word tsunami is Japanese written in English and composed of the word "*tsu*" (meaning "*harbor*") and "*nami*" (meaning "*wave*"). Tsunamis are different from wind-generated waves since they have long periods and wavelengths like shallow-water waves. A wave turns out to be a shallow-water wave when the ratio between the water depth and its wavelength becomes very small. The traveling speed of shallow-water waves is equal to the product of the acceleration of gravity (9.81 m/s) and the water depth. For example, in the Pacific Ocean (with a typical depth 4000 m), a tsunami travels with speed about 200 m/s or greater than 700 km/h. The rate at which a wave loses its energy is inversely proportional to its wavelength. Thus, a tsunami can travel (at high speed) long distances with very small energy loss. Figure 2.11a illustrates how an earthquake generates a tsunami. The water column is disturbed by the uplift or subsidence of the seafloor. Figure 2.11b is a photo of an actual tsunami impinging on a shoreline in India.

The tsunami's energy flux (which depends on wave height and wave speed) is almost constant, and so, since the tsunami's speed decreases as it approaches the land, (i.e., water becomes shallower), its height grows to become several meters near the coast. Figure 2.12 shows the tsunami that occurred after an earthquake in Eastern Australia (near Solomon Islands).

A recent tsunami is the 7–20 m tsunami generated by the magnitude 9.0 quake that hit northeastern Japan on March 11, 2011. This tsunami reached Australia, North America, and South America after a few hours.

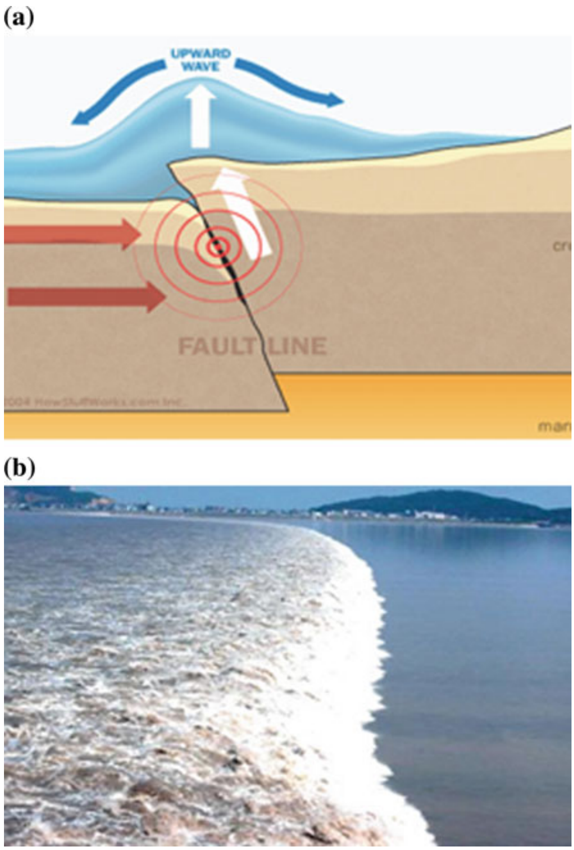


**Fig. 2.11** **a** Earthquake-tsunami genesis (http://static.howstuffworks.com **b** An actual earthquake-generated tsunami (http://www.snopes.com/photos/tsunami/tsunami1.asp

**Fig. 2.12** The Australian tsunami at Lord Howe and Norfolk Islands (http://livesaildie.com/2007/04/02/tsunami-threat-to-eastern-australia)

## 2.8 Concluding Remarks

Energy is the basis of everything and its movement or transformation is always followed by a certain event and dynamic process. For this reason, and the fact that energy cannot be formally defined, David Watson [9] calls energy the "*mysterious everything*". This chapter has discussed the fundamental aspects of energy, viz., the energy types (mechanical, electrical, chemical, and nuclear), the energy sources (exhaustible, non-exhaustible, alternative sources), and the impact of energy on the environment. An overview of the major, violent, natural phenomena of physical energy on our planet was also provided. The actual study of the energy movement and conversion, collectively called "*thermodynamics*", will be the subject of the next chapter. The role of energy in life and its flow in nature, society, and technology will be discussed in Chap. 10.

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