1
What Is Energy?

It is important to remember that we are energy.
Einstein taught us that. Energy can neither be created nor destroyed; it just changes form.

Rhonda Byrne

You're reading a book. Close your eyes for a moment and remain perfectly still. Under these conditions, you might perhaps think that you're not consuming energy. Well, not quite. For when you breathe, your brain works, your heart throbs, and your body has a different temperature (probably higher) than its surroundings. All this costs energy – energy taken from what you've eaten at this morning's breakfast or at dinner last night, or else energy drawn from the fat reserves that have accumulated in your belly, your hips, or some other parts of your body.

At some point during the week you'll likely participate in some form of sport activities (jogging, swimming . . .), and you'll probably experience a feeling of great well-being. The effort made in such activities stimulates the release of endorphins and neurotransmitters, which induce pleasure. However, after a nice swim your energy content will be lower than before. Don't believe for a minute that the so-called *energizing shower foam* will recharge your battery. In fact, it would be better to have a snack somewhere. If you drive and have to stop to fill-up at the gas station, you will likely complain about the latest fuel price increases. And if you're thirsty, you're likely to buy a bottle of water or a bottle of pop at the seven-eleven – have you noticed that a liter of bottled water costs more than a liter of gasoline? And to think that over 60% of the price of fuel represents indirect taxes (excise taxes, sales taxes, etc. – at least in Europe) that all go to the Treasury (in the case of water, the government takes in only 4–5% . . .). Unfortunately, we seldom pay attention to these hidden taxes, and so we tend not to complain – would it change anything if we did?

Once home, back from a hard day's work, it may be time for a well-deserved snack: perhaps a banana or a kiwi. If you do snack, look at the stickers to see where these fruits came from. You discover that the banana came from Costa Rica, the kiwi from New Zealand. So to reach your table these fruits had to travel some thousands of miles. You eat them with gusto and you feel much better. Next you'll turn on your personal computer to check your e-mail or access the social networks, or otherwise surf the web.

Powering Planet Earth: Energy Solutions for the Future, First Edition. Nicola Armaroli, Vincenzo Balzani, and Nick Serpone.

You can't complain. It's not been a bad day, for in a short time you've achieved much: maybe you read a book, you went for a swim, you went for a drive, you had a snack, or maybe you just chilled out doing nothing at home. You probably don't realize it, but all this was made possible thanks to an enormous availability of energy: for instance, the energy of the cells in your body, the energy from the boiler, the energy from the car's gas tank, the energy of the ship that sailed the oceans to bring you the banana and the kiwi, and not least the electrical energy from the utility network.

If now you asked yourself: what is energy? You'll probably have no idea of how to define this omnipresent entity in your life in clear and concise terms. In fact, it may even prove embarrassing, because we usually like to know only what's around us and tend to be suspicious of that which we don't know and can't see. Don't be too distressed: energy ignorance is widespread, and understandably so. Energy is an elusive concept and only seemingly intuitive. It is so difficult to define that for millennia even scholars gave vague definitions or even completely wrong ones. For instance, the 7th Edition of the *Encyclopedia Britannica* of 1842 defined energy as *"the power, virtue, and efficacy of a thing."*

If we've come to understand the notions of what energy is and what laws and principles govern it, it is mostly thanks to the passionate and prolific insights of a small group of curious men that, since the end of the eighteenth century, dedicated much of their time to this problem: men such as James Watt, Sadie Carnot, Justus von Liebig, James Joule, Rudolf Clausius, William Thompson (better known as Lord Kelvin), Ludwig Boltzmann, Walther Nernst, and Albert Einstein.

Energy and Related Terms

The concept of *energy* is not immediately definable. Before we attempt to understand what energy is, we need to define another concept that precedes it: *work*.

Work can be described as the use of a force to move something. The amount of work depends on how much force is used and the distance the object is moved to. From a mathematical point of view, *work* is the product of *force* $\times$ *distance*.

We do work when we lift a weight against the force of gravity, such as, for example, lifting a crate of apples. The magnitude of the work needed depends on the mass being moved (how many apples are there in the crate?), the magnitude of the gravitational force (whether we're on Earth or on the Moon) and the height to which we want to lift the object to: on the table?–on the shelf above?

Often the mass may be that of our bodies: for example, we do work when we climb the stairs or a ladder. Since the force of gravity is identical in the Italian regions of Valle d'Aosta and Abruzzo, and the mass to be moved is constant over the years (provided we maintained our figure), greater work will be needed to climb to the top of Mont Blanc, 4810 meters, than to climb to the top of the Gran Sasso at 2912 meters in the Apennine mountain chain of Italy.

If you attempted to move an object (for example, a 4-wheel drive SUV with your arms) and were unsuccessful, then you've done no work. In common parlance, however, *work* can mean other things. For instance, a letter carrier and a notary both do *work*. However, from the scientific point of view, the carrier does more *work* than the notary, although you would not intuitively think so from their standard of living. But this has nothing to do with science.

How then, would you describe the ability of a system (for example, a liter of gasoline, a living being, a rock that falls, a car . . .) to do work? What is the parameter that quantifies this ability to do work? We're getting there: the ability to perform work is *energy*, not to be confused with *power*, which describes the rate at which *energy* is transferred, used, or transformed. In other words, *power* refers to the mathematical relationship between energy and time: *power* = *energy*/*time*).

Consider, for example, two athletes with the same body mass that compete in the 100-meter final at the Olympic Games. They both do exactly the same work in this glorious event; the one that uses up even an iota of more power will reach the finish line first. That greater effort or work will suffice to make the difference between an Olympic medal and total oblivion.

From One Energy Form to Another

At this point we can go a little further and free ourselves from the concept of work being purely mechanical, although it may sometimes be just that (the crate of apples). Thus, any process that *produces a change* (maybe the temperature, the chemical composition, speed, or position) *in a certain system* (a living organism, an inanimate object, a car) is deemed to be *work*.

Broadly speaking, the ability to do work manifests itself in many ways; what we define as *forms of energy* go far beyond muscle energy described above. In their diversity, all forms of energy have one common feature: they are always the expression of a system that is capable of exerting a force, which can act against another force.

We can easily locate seven forms of energy, almost all of which we experience daily:

1) **Thermal energy:** radiators that heat our house.
2) **Chemical energy:** natural gas that feeds our gas furnace and/or gas stove.
3) **Electrical energy:** energy that makes electrical appliances work.
4) **Electromagnetic energy or light:** sunlight that makes plants grow in a vase, on a balcony, or on a farm.
5) **Kinetic energy:** energy of a glass bowl falling to the ground (gets broken).
6) **Gravitational energy:** If the glass vase falls from a height of 10 centimeters (about 4 inches) it will likely not break, but if it falls from 2 meters (about 6.5 feet) there's no hope of saving it.
7) **Nuclear energy:** energy from the atom: difficult to see – we'll have more to say on this later.

Table 1 Different forms of energy and various methods with which one energy form can be converted into another energy form.

From \ To	Thermal	Chemical	Electrical	Electromagnetic (light)	Kinetic
Thermal	–	Endothermic reactions	Thermo-ionic processes	Lamps (tungsten wired)	Motor engines
Chemical	Combustion		Batteries	Fireflies	Muscles
Electrical	Electrical resistances	Electrolysis	–	Electro-luminescence	Electric motors
Electromagnetic (light)	Solar collectors	Photosynthesis (chlorophyll)	Photovoltaic panels	–	Solar sails
Kinetic	Friction	Radiolytic reactions	Electrical alternators	Accelerated charges	–
Nuclear	Fission and Fusion	Ionization	Nuclear batteries	Nuclear weapons	Radioactivity

Note: none of the energies in the first column can be transformed into nuclear energy.

The various forms of energy can then be converted from one form to another, but not always. For example, we can transform the Sun's light energy into electricity through a solar panel. However, contrary to what is often thought, we cannot transform nuclear energy directly into electrical energy. Nuclear power plants are nothing more than sophisticated water kettles that convert nuclear energy into thermal energy, which in turn is converted into mechanical energy and then finally into electrical energy.

If you wish to have other examples of energy transformation, think of your typical day and unleash your fancy; you may find some inspiration in Table 1.

Sources of Energy

Energy *sources* are physical entities from which it is possible to obtain one or more *forms* of energy. These sources may be very different:

1) ***Plant and mineral resources:*** in the case of coal, oil, gas, and biomass, the chemical energy is stored in carbon-carbon (C–C) and carbon-hydrogen (C–H) chemical bonds; to free this energy requires a trigger and an oxidizer (oxygen); in the case of uranium, the energy is of the nuclear type and can only be freed by fragmentation (fission) of the atomic nucleus.
2) ***Artifacts:*** If a river were blocked by a dam, it would be possible to transform the gravitational potential energy of water into kinetic, mechanical and electrical energy through a series of pipelines and machinery; similarly, wind turbines can convert the kinetic energy of moving air mass.

3) ***Celestial bodies:*** the Sun is a source of light energy; the Earth is a source of thermal energy (underground) and gravitational energy (the pot that falls).

It's good to remember that energy sources are not sources of energy only – they can also be sources of some useful products. For example, with fossil fuels we can manufacture a variety of useful plastics, fertilizers, and medicines (among others). With a dam, we can control the flow of water in a river; as for the Earth, we need not emphasize that it is useful for many other purposes.

Energy sources are said to be *primary* sources if they are directly available in nature – for example, fossil fuels, sunlight, wind, moving water (as in rivers), vegetation, and uranium. These can be used as such or can be converted into other forms that are referred to as *secondary* energy sources; these are more easily used: for example, products derived from crude oil (fossil fuels in general).

The forms of energy – whether primary or secondary – typically used are referred to as *final forms*; among these are electricity and gasoline. By contrast, neither solar radiation nor crude oil belongs to this group – the latter needs to be refined before use.

The Pillars of the Universe

The first scientific and experimental studies on the transformations of energy date back more than two centuries when machines were used to transform heat into motion, and *vice versa*. Historically (and logically), this branch of physics became known as *Thermodynamics*.

In the nineteenth century, men who laid the foundations of thermodynamics during the years of great technological advancement were mostly British, French and German. They were often driven by the desire to contribute to the development and technological supremacy of their country.

Thermodynamic studies conducted in the second half of the 1800s led to the formulation of some basic laws, or principles, whose validity can be extended to all forms of energy. In other words, without realizing it, the thermodynamicists of that era went beyond their original ambition. They wanted to understand the operation of simple machines and in doing so managed to uncover some of the fundamental pillars that hold the universe together.

The two principles of thermodynamics are so basic that often they are referred to simply as the First and Second Principle of Thermodynamics. Incidentally, the capital letters are not typographical errors. Before illustrating these Principles, it is useful to clarify briefly some of the concepts underlying these Principles, namely *temperature* and *heat*.

Particles in Motion

Thermal energy (or *heat*) is a manifestation of the ceaseless movement with which atoms are agitated – atoms are the submicroscopic particles that make up matter. As for *temperature*, we are all convinced that we know what it is: who has never used a thermometer? However, the concept of temperature is far less trivial than it seems at first. It is rigorously described according to the average kinetic energy of motion of the atoms.

Here we shall limit ourselves to state simply that temperature is a property that defines the direction of the transfer of thermal energy from one system to another. Thermal energy (heat) tends to move from a system of *higher temperature* to a system of *lower temperature*. The process stops when the so-called *thermal equilibrium* is reached, at which point there is no longer transfer of heat energy between the two bodies (macroscopically speaking) since they are at the same temperature.

The *scale* used to measure temperatures is based on a simple convention. You can use whichever scale you like (Celsius, Fahrenheit, Kelvin). Don't be surprised, then, if you find yourself in the United States during a snowstorm and are told that the outside temperature is 32 degrees (Fahrenheit, °F), equivalent to 0 °C (or 273 °K).

Heat (Warmth) – an Exchangeable Energy

Heat is thermal energy that can be exchanged between two bodies of different temperatures. For millennia, it was believed that heat was an intangible fluid (maybe someone still believes it . . .) – but this is not true. When water is heated in a pot, the flame does not directly heat the water but warms the bottom of the pot, which in turn heats the water. This is an example where exchange of heat takes place between three bodies (from the flame, to the pot, to the water).

Atoms and molecules that constitute the flame (which technically speaking is called *plasma*, a very hot form of ionized gas) move, rotate, and vibrate rapidly. These particles collide with the bottom of the pot and stimulate the vibration of atoms of the metal (not their change of position, at least as long as the pot does not melt . . .). This chain transfer process proceeds rapidly until it involves the water molecules inside the pot, starting from the first layer in direct contact with the metal.

If we keep the flame lit, the water will come to a quick boil, and only then can we throw in the pasta. But if the bottom of the pot were perfectly insulated, we would have to resign ourselves to eating uncooked pasta or else starve, as the water will remain cold forever.

You Can't Run Away from Them – the Principles of Thermodynamics

The *First Principle* states that the energy of an isolated system, that is a system that cannot exchange matter or energy with its surroundings, is always the same; it can convert energy from one form to another, but the total amount remains unchanged. Thus the energy of an isolated system – for example, the universe – is always constant.

Objectively, the first principle is good news, though a bit distressing for those who wished to stay on a diet: the energy of the food eaten is either spent through mental or physical exercises, or else it accumulates as fat in various parts of your body (belly, hips, . . .).

The chemical energy stored in the gas tank of a car will take us to some vacation spot by doing work, and so we might believe unknowingly that the engine has literally "eaten" all the energy available in the gas tank. Well it's not really so. If we managed to get to the Stelvio pass (2760 m, Italy), for example, the chemical energy stored in the fuel purchased at the gas station was converted inside the engine in a process involving air – in part – into gravitational potential energy (we and the car are now at a greater height than before), in part as heat emitted by the car exhaust, and in part in the form of friction between the tires and the road.

The mass of fuel was converted to gases, mostly water vapor (H_2O) and carbon dioxide (CO_2), that were discharged into the atmosphere. In this transformation, the initial volume of the fuel increased some 2000 times because the gases produced are much less dense. But since the gas is invisible, we have no guilt feelings of having polluted the air we breathe. We no longer see anything, but energy isn't lost. The unobtrusiveness with which the fuel disappeared is truly amazing.

The *Second Principle* is one of nature's most fascinating laws. The resulting consequences are vast. They can be formulated in various ways, but the most intuitive is probably the following: in an isolated system, thermal energy is always transferred from a body of higher temperature to one of lower temperature.

It's important to point out that the Second Law doesn't say that heat cannot pass from one cold body to a warm one. The way the refrigerator works is precisely for this reason, and there is no doubt that it functions. But the refrigerator is not an isolated system. The Second Principle states that if we want heat to flow in the direction opposite to its natural tendency, then we need to provide power to the system: the refrigerator works only if it's connected to an electrical power outlet.

The *Second Principle* leads us very subtly to the notion that there exists a *hierarchy* between the various forms of energy. Note that every time you do some form of work, you consume energy; the resulting heat is dissipated to the surroundings.

Thermal energy will make its presence felt in any process that involves energy conversion. For example: the car engine and the motor of the refrigerator get hot; our body is warm; without cooling towers, the nuclear power station would undergo a meltdown.

All forms of energy can be transformed completely into heat, that is, thermal energy; the opposite process cannot and does not happen. Every time you convert a noble form of energy into another, for example, electrical energy into mechanical energy, not all the available quantity can be used to accomplish useful work. Inevitably, a part will be degraded into thermal energy forever.

In most cases, this thermal tax is characterized by the thermal environment, primarily the atmosphere and surface waters. This explains why power stations are built near the seashores, near lakes, or near rivers. Even though a power plant is built solidly, it cannot directly convert even half of the fuel's chemical energy into electricity. Most of that energy turns into heat, which is discarded in the immediate vicinity of the power station. Even nuclear power plants have an output that does not exceed 30–35%: only about a third of the heat generated in the reactor is converted to electricity, while the remaining two thirds is relinquished to the environment by the cooling towers, and so is lost. For comparison, a thermo-electrical gas-fed power station that uses combined cycles can reach a yield close to 60% – that is, nearly two thirds of the energy is converted to electricity.

It is unfortunate that no ship sailing on a river can operate its engines using the heat dissipated by the numerous power stations situated on its banks. The reason is that the heat dissipated by the power plants has a much *lower value* than the chemical energy of the fuel. Hence, its exploitation to useful purposes is rather limited. The same applies to a car. A good part of the compact and valuable energy initially stored in the gas tank will be dispersed in a myriad of unnecessary forms of heat – for example, friction, already mentioned earlier. In these processes, the energy of the universe is nonetheless preserved, in keeping with the First Principle, but loses value to comply with the Second Principle. Whoever is still convinced that he can build a perpetual motion machine knows perhaps the First Principle, but obviously ignores the Second Principle.

In more general terms, the Second Principle tells us that a profound asymmetry exists in nature: disorder is obtained in an instant, while to restore order from chaos necessitates time and effort.

Inherently, natural systems tend spontaneously toward disorder. The universe is made this way. Hence, we need to find an explanation as to the reason why this is. The spontaneous and inexorable trend that energy is transformed into its most disorderly form – heat – is one of the many expressions of the general tendency of the universe toward chaos. This is expressed scientifically through a function we call *Entropy*. Though the energy of the universe is constant, the entropy increases. To illustrate this concept, imagine putting a layer of 100 red marbles in a box, then overlay this layer with a layer of 100 blue marbles and then again a layer of 100 green marbles. If we now shake the box vigorously, the marbles will mix. Ultimately a state will be reached at which even if we continue to shake the box for millions of years, it is highly unlikely (in fact impossible) that we will regain the original orderly configuration.

A small reflection tells us that our daily life is a continuous demonstration of the implacable power of the Second Principle: to mess up our room requires but a minute (and a little effort), but to put it back in order, it takes hours of hard work. At this point you might be tempted to think that living beings do not obey the Second Principle. Unfortunately, this is merely an illusion. The tendency toward disorder (entropy) should be measured in relation to the environment that surrounds a given system.

Order represents the extraordinary complexity of all forms of life (even the simplest ones), that are largely balanced by the disorder generated from the progressive consumption of the Sun's energy, from which we are not isolated. But it's not all. For living beings to survive – that is, to remain in an ordered state – they continually produce wastes (a form of disorder) that are discharged into the environment, starting with those physiological ones (pardon the expression – going to the toilet).

The First and Second Principles should be a basic part of the cultural preparation of each of us, just like the alphabet, multiplication tables, the Constitution, and *The*

Divine Comedy. Unfortunately this is not the case. Every day we hear journalists mention that incinerators destroy wastes and produce energy. Economists and union leaders are confident that economic growth has no limits. Environment ministers talk about clean coal. Some scientists deny global warming. Maybe their refrigerator works without being connected to an electrical outlet.

Einstein's Equation: $E = mc^2$

This equation is well known. It is the icon of the twentieth century. It's sometimes seen on T-shirts just as are the names of a pop group or a photo of Che Guevara. This equation defines energy in such a way that anyone can understand it, even if (in fact) it's a little difficult to accept.

$\boldsymbol{E = mc^2}$ means that mass and energy are the same thing albeit under different guises. As the ice melts it turns into water, totally changing its appearance, so is mass a form of *frozen* energy that can be converted into more familiar forms: kinetic energy, thermal energy, and so on.

In the formula, the letter c represents the speed of light in vacuum. Raised to the second power, it has an even larger numerical value. So, since the right and the left hand sides of the Einstein equation must be numerically equal (otherwise, what kind of equation would it be?), and since c^2 is on the side of m, to obtain massive amounts of energy we need only convert small quantities of mass.

Every time you produce energy of any kind, quantities of mass – large or small – largely disappear. This *dematerialization* recalls some improbable science fiction movies and makes us a little bit skeptical. But that's the way it is, folks. The energy consumed in a month from a huge megalopolis – for example, modern London – is comparable to the energy *frozen* in the mass of this book. The unfortunate destruction of Hiroshima and Nagasaki in World War 2 occurred by converting only a few grams of matter into energy; a small amount, but certainly a measurable one.

Nuclear fission allows the conversion of materials into energy very efficiently, but, as we shall see later, it leaves extremely hazardous wastes. A kilogram of uranium in a nuclear power plant can generate 50 000 kilowatt-hours of energy, while 1 kg of coal in a thermal power station produces only 3 kilowatt-hours. Einstein's equation is valid in both cases. The amount of matter that *evaporates* to become energy is dramatically higher in uranium than in coal.

For nearly 5 billion years, the Sun has converted 4.4 billion tonnes of hydrogen every second into electromagnetic energy through nuclear fusion processes at temperatures well above 10 million degrees. A tiny fraction of this endless energy flux lightens our days. Of course, Einstein's equation also suggests that it is possible to convert energy into mass. This has been verified by means of some very complicated experiments. It is possible to create new particles of matter by concentrating huge amounts of energy into a small volume of space.

From Kilowatt-hour to the Barrel of Oil

Units of measurement are the despair of many High School, College, and University students. There are some units that are common and easily understood by all. Others are more difficult to digest. The so-called international system of units (SI) defines the unit of measurement of seven physical quantities: *length* is measured in meters (m), *time* in seconds (s), *mass* in kilograms (kg), *temperature* in degrees kelvin (K), *amount of a substance* in moles (mol), *electrical current* in amperes (A), and *light intensity* in candelas (cd).

All other physical quantities, strange as it may seem, are a combination of these seven units of measure. Some sadistic science teachers like to see students cringe when told that electrical resistance has something to do with kilograms, or that heat capacity has something to do with meters. Many students never understand this and forever drop their scientific studies.

As we had anticipated, energy is not a primary physical concept. It may seem bizarre that, from this point of view, electricity and light intensity are both hierarchically superior to energy, but that's the way it is, folks.

We have already stated that *work* can be expressed as the product of *force* multiplied by *distance* (length). In terms of the size of the physical parameters indicated in brackets we have:

$$[work] = [force] \times [length]$$

In turn, *force* is a parameter derived from the next equation; that is, it can be expressed as *mass* times *length* divided by *time* raised to the second power:[1)]

$$[force] = [mass] \times [length] / [time]^2$$

Accordingly, *work*–that is, *energy*, which represents its quantification–has the following physical dimensions:

$$[work] = [energy] = [mass] \times [length]^2 / [time]^2$$

However, no one is thrilled to have to use a unit of measure as twisted as kg-m^2/s^2 to express a quantity of energy. Fortunately, new units have been adopted for sizes derived from these fundamental parameters, often indicated by the names of famous scientists of the past. For instance, in the case of energy, it was decided that the unit kg-m^2/s^2 could simply be called a *joule* and would be represented by the capital letter J.

By contrast, the watt (symbolized as W) is the unit of power: 1 watt equals 1 joule divided by 1 second (W = J/s). The choice of so honoring Joule and Watt was certainly appropriate, considering the contribution of these two British scientists to the advancement of knowledge in the field of energy.

Unfortunately, the joule is a very small unit of measure. A small field-mouse consumes about 50 000 J per day to survive. The gas tank of a medium-sized car

1) The famous Newton's law $F = ma$ shows that *force* equals *mass* times *acceleration*, which in turn is a change in *velocity* (defined as *length* divided by *time*) per unit time.

Table 2 Some energy units in common use.

Units	Symbol	Value in joules (J)
Calorie	cal	4.19
British thermal unit	BTU	1.05×10^3
Kilowatt-hour	kWh	3.60×10^6
Barrel of oil equivalent	boe	6.12×10^9
Tonne of oil equivalent	toe	4.19×10^{10}

Table 3 Symbols and prefixes of multiples and sub-multiples.

Symbol	Prefix	Factor	Symbol	Prefix	Factor
a	atto-	10^{-18}	k	kilo-	10^3
f	femto-	10^{-15}	M	mega-	10^6
p	pico-	10^{-12}	G	giga-	10^9
n	nano-	10^{-9}	T	tera-	10^{12}
μ	micro-	10^{-6}	P	peta-	10^{15}
m	milli-	10^{-3}	E	esa-	10^{18}

contains over one billion joules of energy. Hence, for convenience we use energy units of much greater magnitude. Among the most common are the *kilocalorie* used to measure heat and the *kilowatt-hour* to measure electrical energy.

Compilation of energy balances in the world often uses other measurement units which are not strictly related to the physical quantity of energy, as indicated in Table 2.

Also commonly used are units of mass or volume of fossil fuels, to which are associated a certain energy content. The most often used is *toe* (*tonne of oil equivalent*), which represents the heat developed by the complete combustion of one ton of oil; also used is its sub-multiple kilogram of oil equivalent (*kgoe*). The barrel of oil equivalent (*boe*) is also greatly used, which corresponds to the energy developed from the combustion of 159 liters of crude oil (approximately 130 kg).

The amount of energy involved in the large variety of natural and artificial processes can vary immensely. For example, for a flea to jump requires a one hundred millionth of a joule; a tropical hurricane develops an energy equal to tens of billions of billions of joules.

Thus, if we wish to maintain the same unit of measurement for whatever energy phenomenon, it would be better to use the conventional prefixes for multiples and sub-multiples shown in Table 3, so as to avoid the burden of many zero digits.

From a Chemical Bond to a Tsunami

Let us now take a short trip on the energy scale starting from two infinitesimal entities that can appear insignificant at first, but that in reality maintain the treasure of fossil fuel energy. We're referring to the chemical bonds between two carbon atoms (C–C) and between a carbon atom and a hydrogen atom (C–H). Each of these bonds contains about 0.7 billionths of billionths of a joule, that is, 0.7 attojoules (otherwise written as 0.7 aJ).

This is small change in the currency of events on which the industrial civilization, the digital age, and the globalization of the economy are based – in short, modernity. To get this money, which too often has literally dictated the price of the economic currency, there's been no hesitation to resort to war, unfortunately.

To hit a key on a computer's keyboard consumes 20 thousandths of a joule (20 mJ). A well-fed adult takes on an average 10 million joules (10 MJ) a day. A kilogram of good quality coal contains about 30 million joules of energy, that is, 30 megajoules (30 MJ).

The annual world consumption of primary energy today is around 510 billion billion joules, that is some 510 esajoules (510 EJ). Of these, four fifths, or about 410 EJ, are from fossil fuels. The largest hydrogen bomb tested so far has developed 240 million billion joules (240 PJ), an energy 3000 times greater than the bomb dropped on Hiroshima (84 trillion joules, 84 TJ).

Each year the Earth receives from the Sun 5.5 million billion billion joules (5 500 000 EJ) of light energy; approximately 2000 EJ are converted into new biomass through the process known as photosynthesis. At this time, it would also be interesting to describe briefly the power in some phenomena, that is, the amount of energy per unit time. For instance, a traditional incandescent bulb absorbs 60 W. A washing machine that works at 60 °C requires approximately 800 W. The engine of a Ferrari Formula 1 car can develop 550 000 watts (550 kW). The four engines of a transcontinental Boeing 747 jumbo jet produce 80 million watts (80 MW) on take-off. By comparison, a violent thunderstorm develops around 100 billion watts (100 GW).

The average quantity of energy consumed every second on a global scale amounts to about 16 trillion watts (15 TW), a value obtained by dividing the annual global energy consumed (510 EJ) by the number of seconds in a year (about 31.5 million). A volcanic eruption can disburse 100 trillion watts of power (100 TW). An earthquake of magnitude 8 on the Richter scale releases 1.6 million billion watts (1.6 PW) and can produce huge oceanic wave surges, thereby generating tsunamis that can bring death and destruction to the mainland. These numbers give you a rough idea of the immense power of nature and of the respect that nature, therefore, deserves from mankind.