Chapter 1
Energy and Sustainable Development

1.1 Energy is basic in our societies and our lives

Energy is fundamental in our lives. None of us can do anything without energy and in the way same society cannot do anything without energy. Development and energy consumption in a society is typically parallel up to a point. Then energy use is levelling off, even if economic turnover continues to grow. But then the *energy consumption* is already large.

An average person uses about 2.4 kWh per day as metabolic energy from the food we eat, that is, the base for keeping alive. This means that an average person has an effect of about 100 W (or perhaps a little less), like a traditional lamp. For a modern society, e.g. a West European country, the figure for energy use is typically 100 times larger counted per capita. Thus there are enormous amounts

Figure 1.1 Brown coal power plant near Otzenrath Nordrhein-Westfalen Germany, CC Photo: fxp

of energy used all the time for all kinds of purposes: keeping us warm (or cold in some countries), running our industries, for agriculture, for construction, for household purposes, for transport and so on. Still energy use differs much between countries and individuals, and also depends on methods for measuring it. Sweden, e.g. uses each year about 400 TWh for 10 million inhabitants, industries and all kinds of societal needs, so this is actually a little less than this average.

When discussing energy, it is useful to be acquainted with a few fundamentals. Energy is constant in the sense that it is not produced or consumed; it is only transformed from one kind to another, more or less useful for a purpose. Thus a power station transforms energy stored in e.g. fossil carbon, or biomass, or high-level water, into electricity in a generator run by a turbine. The energy produced during a set time period is the *effect* of the power station. The usefulness of the energy – its capacity to do work – is called *exergy*. Electricity has 100% exergy, while the exergy of hot water or gas depends on its temperature: higher temperature means higher exergy. We will come back to that below.

1.2 Kinds of energy

Energy exists in many different forms. *Energy can be stored* as in fossil carbon – coal, oil and gas – or biomass such as wood, biogas or vegetable oils. Stored energy functions as a fuel and can be used in many contexts.

Energy can also be in the form of *flowing energy*. This includes flowing water or wind (flowing air) or the sun (flowing light). Flowing energy on the other hand is intermittent, it needs to be used directly. The transformation of intermittent energy into stored energy is a key difficulty for energy management. Hydropower has a unique capacity here as it can be stored as water in a dam on higher level than the surrounding landscape.

We will discuss energy in three forms: *electricity* (the best) *heat* (mostly hot water) and stored fuel.

Energy is measured, quantified, using many different units. All of these can be converted into each other (See Box 1.1). By tradition *food energy* is measured in calories, *electric energy* is measured in Wh (Watt hours). In *thermodynamics* energy is mostly expressed in Joules (defined as Newton meter). In the world of *fossil fuels* (coal, oil and gas) energy is measured in *litres or barrels of oil* (one barrel = 159 litres) then referring to the amount of energy released when this volume of oil is burnt and heat released.

Since the amounts discussed vary enormously one uses prefixes for practical reasons. Prefixes are kilo (k), Mega (M), Giga (G) or Tera (T) for thousand, mil-

Box 1.1 Energy units and conversion of energy units

Energy is defined via work. *The SI unit for energy* is the same as the unit of work – the joule (J), named in honour of James Prescott Joule and his experiments on the mechanical equivalent of heat. In slightly more fundamental terms, 1 joule is equal to 1 newton-meter in terms of SI base units.

The *British thermal unit (BTU or Btu)* is a traditional unit of energy equal to about 1,055 joules. It is the amount of energy needed to cool or heat one pound of water by one degree Fahrenheit. The BTU is most often used as a measure of power (as BTU/h or BTUH) in the power, steam generation, heating, and air conditioning industries, and also as a measure of agricultural energy production (BTU/kg). In North America, the heat value (energy content) of fuels is expressed in BTUs.

In discussions of energy production and consumption, the unit *barrel of oil equivalen*t (BOE) and *ton of oil equivalent* (toe) are often used. The tonne of oil equivalent (toe) is the amount of energy released by burning one tonne of crude oil, approximately 42 GJ (as different crude oils have different calorific values, the exact value of the *toe* is defined by convention; unfortunately there are several slightly different definitions as discussed below). The *toe* is sometimes used for large amounts of energy, as it can be more intuitive to visualise, say, the energy released by burning 1,000 tonnes of oil than 42,000 billion joules.

The barrel of oil equivalent (BOE) is the approximate energy released by burning one barrel (42 U.S. gallons or 158.9873 litres) of crude oil. The U.S. Internal Revenue Service defines it as equal to 5.8×10^6 BTU. The value is necessarily approximate as various grades of oil have slightly different heating values. 5.8×10^6 BTU59 °F equals 6.1178632 × 109 J about 6.1 GJ (HHV, meaning higher heating value, then referring to an original temperature of 15 ^{o}C), or 1.7 MWh. If one considers the lower heating value instead of the higher heating value, the value for one BOE would be approximately 5.4 GJ. A commonly used multiple of the BOE is the kilo barrel of oil equivalent (kboe or kBOE), which is 1,000 times larger

Natural gas. One BOE is roughly equivalent to 5,800 cubic feet of natural gas or 58 CCF (volume of 100 cubic feet (cf) of natural gas). The USGS (U.S. Geological Survey) gives a figure of 6,000 cubic feet (170 cubic meters) of typical natural gas. Natural gas in the US is sold in Therms 100 cubic feet. One Therm is equal to about 105.5 mega joules. In the rest of the world, natural gas is sold in giga joules (GJ).

Electric energy. The energy unit used for everyday electricity particularly for utility bills, is the kilowatt-hour (kWh); one kWh is equivalent to 3.6×106 J (3,600 kJ or 3.6 MJ). Electricity usage is often given in units of kilowatt-hours per year (kWh/yr). This is actually a measurement of average power consumption, i.e., the average rate at which energy is transferred.

Thermal (heat) energy. The calorie equals the amount of thermal energy necessary to raise the temperature of one gram of water by 1 Celsius (centi) degree, at a pressure of 1 atm. For thermochemistry a calorie of 4.184 J is used, but other calories have also been defined, such as the International Steam Table calorie of 4.1868 J. Food energy is measured in “large” calories or kilocalories, often simply written capitalized as “Calories” (= 103 calories).

Measurement unit prefix and multiples. A metric prefix or SI prefix is a unit prefix that precedes a basic unit of measure to indicate a multiple or fraction of the unit. Each prefix has a unique symbol that is prepended to (written before) the unit symbol. The prefix *kilo*-, for example, may be added to *gram* to indicate *multiplication* by one thousand; one kilogram is equal to one thousand grams. The unit prefix *centi*-, likewise, may be added to *meter* to indicate *division* by one hundred; one centimetre is equal to one hundredth of a meter. The *unit prefix* mega, M, indicate multiplication by 1 million, giga, G, multiplication by 1 thousand millions and tera, T, by million millions, peta, P, by thousand million millions, exa, E, by million million millions. It may also be expressed in terms of 1000, 1000^2, 1000^3, 1000^4, 1000^5 and 1000^6.

lion, billion and trillions. Thus using the prefixes we may express amounts of energy as kWh, MWh, GWh or TWh. The same prefixes are used for the other kinds of energy measures. Thus we may talk about kilocalories, or mega barrels of oil.

It is important to know that energy sources are either renewable or non-renewable. Renewable energy can be renewed endlessly. This is the case with solar energy, or hydropower or wind energy. Non-renewable energy is available in a final amount and will at some point be emptied. This is the case with coal, oil and natural gas. They are called fossil energy sources, since they were formed many millions of years ago and are since then left in the ground and now recovered and used by us, mankind. Peat, recovered from wetlands, are sometimes counted as non-renewable and sometimes as renewable. The time required for peat to form is in the order of a few thousand years; thus depending on how mining of peat is conducted it may be counted as one or the other.

A society being dependent on fossil, non-renewable energy, is not sustainable. There are two reasons for this. First at some point the energy stores will be emptied and the society will stop working because of lack of energy. Secondly, to extract a natural resource from the ground (properly called the lithosphere) and releasing it into our living environment (the biosphere) will cause problems. These problems will grow as the amounts are building up. In the case of fossil energy resources, all consisting of carbon, it is caused by the carbon dioxide formed when the carbon is burnt. Carbon dioxide concentrations are increasing in the atmosphere and in the oceans and causing climate change, ocean acidification and other effects. We will come back to this later in the book.

Today some 83% of the global energy supply consists of fossil carbon: coal, oil and gas. This is not surprising considering that oil has a very high concentration of energy and is thus extremely valuable as an energy source. The access to large amounts of oil from the 1860s and on led to rapid industrialization, urbanisation and economic growth, proving its enormous value as energy. It should also be said that black coal has a very long tradition as energy source in many countries, and has been used even from medieval times. However, this is not sustainable.

1.3 Supply of energy

In many cases *stored fuels* are used in their original form. Thus coal, gas or wood are burnt to produce heat for cooking or heating in a household. Oil is most often processed in a refinery which delivers gasoline, heavy oil, and a number of other products based on oil. These are typically used for transport, for cars, trucks,

Figure 1.2 Hydropower. Akkats hydroelectric power plant in Swedish Lapland. Photo: Hans Blomberg

trains etc. They are of course also used as material in chemical industry which thus is also fossil energy dependent and in this sense unsustainable.

Electricity is the best form of energy for all kinds of mechanical movement such as in machinery, but in fact it can be used for anything. Electricity is also very practical for distribution of energy using grids. In most countries electricity are provided from *power plants*, which often use coal, lignite or natural gas as fuel. The fuel is incinerated to heat water, which is sent to a turbine, which runs a generator producing electricity. As mentioned this is not sustainable as it depends on fossil fuels.

Power plants may be improved in two ways. By using the hot water from the turbines for some purpose, typically district heating, the plant becomes a CHP, a Combined Heat and Power plant, and increases its efficiency from about 40% to about 90%. Secondly it may be improved by using a more sustainable fuel. Best is to use biomass such as wood from energy forests or wood waste (roots, branches etc). Then the power plant turns into a producer of renewable electricity. There are more options such as using household waste, which is an improvement,

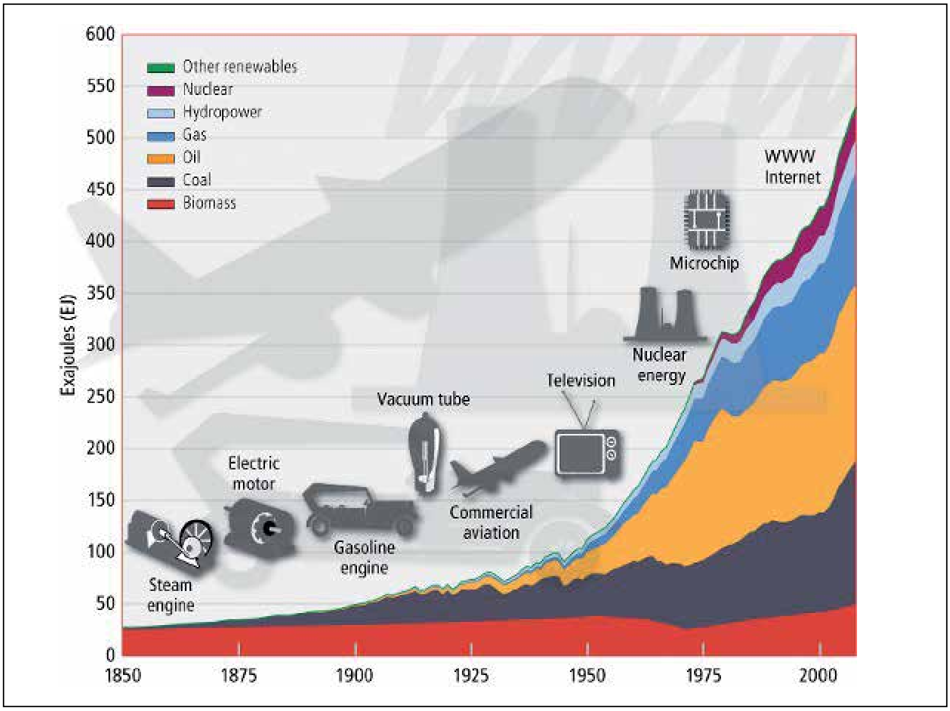

Figure 1.3 World Primary Energy Use: The figure shows the explosive growth of global primary energy with two clear development phases, the first characterized by a shift from reliance on traditional energy sources to coal and subsequently to oil and gas. Hydropower, biomass, and nuclear energy during the past decades have a combined share of almost 22%. New renewables such as solar and wind are hardly discernible in the figure. Biomass refers to traditional biomass until the most recent decades, when modern biomass became more prevalent and now accounts for one-quarter of biomass energy. Source: Grubler A et al. (2012). Chapter 1—Energy Primer. In: Global Energy Assessment—Toward a Sustainable Future, IIASA, Vienna, Austria and Cambridge University Press, Cambridge, UK and New York, NY, USA. (http://www.iiasa.ac.at/web/home/about/achievments/scientificachievementsandpolicyimpact/Sustainable.en.html)

but not completely sustainable since household waste normally has quite much plastics in it.

Nuclear power (NP) is not renewable for the simple reason that uranium is a fossil resource. Even if nuclear power plants can be safer and more efficient (3rd generation technology) than earlier, we are left with the problem of the nuclear waste, which remains toxic and radioactive for many thousands of years. It also appears that NP is too expensive for commercial investments and can only be built with governmental support. Very few NP plants are built today although many are being planned. However they do not emit carbon dioxide, which contributes to global warming, why many concerned scientists promote NP.

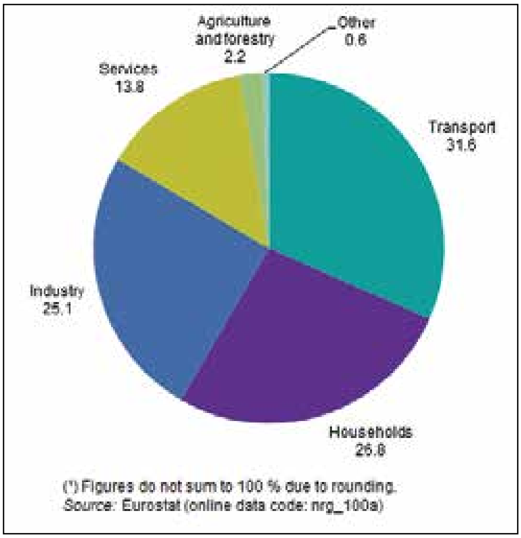

Figure 1.4. EU final energy consumption 2013. Source: http://ec.europa.eu/eurostat

To become a sustainable society we need to change our energy regime completely and rely on renewable resources. *Renewable energy resources* all ultimately come from the sun. The sun makes the water move, the wind blow and the trees and plants grow. In one-way or the other a sustainable society needs to find out how to use the sun well and cleverly. And there is enough for all of us. Humankind uses about 0.1 per mille of the energy content of the sun coming to us every day and minute. Just as the ecosystems found in Nature depend on the sun for its survival, human society needs to do the same thing. To replace the large scale dependency on fossil fuels to renewable energy schemes is perhaps the most difficult part of a transition to sustainable societies.

Renewable electricity is produced from hydropower plants, from wind power stations, and directly from solar cells, either photovoltaic, which directly transfers sun light into an electric current, or from CSP, Concentrated Solar Power, in which the heat of the sun is focused to produce hot liquid producing electricity in a turbine and generator. Hydropower is providing almost all of Norway's electricity and 50% of Sweden's electricity, and a fair share in some other countries. Wind power is very important in Denmark (about 40% of electricity) and Germany. Solar cells are not big anywhere but is increasing fast, by some 40% yearly. Other technologies include small hydropower plants, wave power at the coasts, electricity from running water, and electricity from power stations using renewable fuels such as biomass.

Renewable heat dependent on biomass is important to heat our houses. In the Nordic countries the earlier oil has been almost completely changed into biomass as wood chips, or wood pellets, all renewable biomass. In *district heating* the houses in urban areas are connected to one common power plant. This is much more efficient than a series of individual boilers, not the least because flue gases may be purified much more efficiently. Household waste incineration, the "waste to energy step" in waste management, takes care of waste and avoids landfill. This is seldom fossil fuel free as there is much plastic in household waste. It also requires good flue gas cleaning. Solar panels on the roof, or larger size on fields, may be used for solar heat. This is standard in Southern Europe. Heat pumps use electricity to extract heat from ground or outdoor air. This is up to 4 times more efficient than direct electric heating and is renewable if the electricity is. Heat pumps are important in Sweden.

Renewable fuel is mostly biomass either as solid (wood), liquid or gas. This is most critical for road traffic, which today is almost entirely oil dependent. Bio-ethanol from fermentation of sugar, e.g. sugar beet (1st generation bio-ethanol), or cellulose after hydrolysis (2nd generation bio-ethanol) is renewable if produced in such a way. Today all petrol in the European Union contains 5% ethanol; it may be increased to 10% without technical problems. Some cars and buses use E85 with 85% ethanol. Biodiesel is produced from oil crops, such as rapeseed, after extraction and methylation. It can easily replace standard diesel e.g. in buses and trucks. Production of biogas from anaerobic fermentation of organic waste (households, farms, wetlands etc) is increasing rapidly. In the Nordic countries it is mostly used for city buses. Biogas buses are more silent, less polluting and more sustainable. However transport is best done using an electric motor as it is about 4 times more efficient, less polluting, more silent and cheaper than a traditional combustion motor. The problem is the insufficient capacity of today's batteries.

1.4 Effect and electric power

Effect is the amount of energy transferred from a sending system to a receiving system during a specified unit of time. Effect is measured in Watt (W) defined as Joule per second (J/s) in the SI system. For mechanical energy also Newton meter per second (Nm/s) is used. Formerly horsepower (hp) was also used, for example for the power of car motors. 1 hp = 735.5 W.

Effect can be used for all kinds of energy per time unit. Thus the sun emits 3.92×10^{26} W of radiation energy. A strong car motor delivers some 100 kW of mechanical energy, a 60 W lamp delivers 60 W light and heat. An adult person delivers about 100 W (or a little less) as heat. The amount of energy transferred is received by multiplying the effect by the time.

Electric effect is often called *electric power*. It is the rate at which electric energy is transferred by an electric grid. Electric power is usually sold by the kilowatt hour (1 kWh = 3.6 MJ) which is the product of power in kilowatts multiplied by running time in hours.

1.5 Exergy is the ability to do work

Exergy is the ability to do work. The exergy quantity is defined as the ability to do work. It is present in a material system which can function as an energy supply. Exergy can also be described as composed of two measurable variables, one quality factor and its quantity, the latter being, like energy, measured in joules (J) or kilowatt hours (kWh). Whereas energy is omnipresent, exergy represents a contrast, or a 'tension', and it must be referred to for instance a system and its surrounding. This demonstrates that exergy is an ecological resource concept. Furthermore, since every contrast in natural systems has a tendency to weaken, and in the end to be eliminated, exergy can be consumed! This is in effect an expression for the second law of thermodynamics. It characterizes a relevant resource concept that it can be supplied, distributed, utilized and finally consumed. This is what holds for exergy, quite contrary to energy.

The definition of exergy. The Carnot principle (that can be studied in texts on Thermodynamics) demonstrates that the energy quality for quantities of heat can be calculated by means of a special temperature factor. If the temperature of the surrounding is T_o, a quantity of heat Q with temperature T (larger than T_o) can provide the work

$Q \times (T - T_o)/T$; (T must be expressed in kelvin).

The dimensionless factor $(T - T_o)/T$ measures the quality of the heat Q. This factor can be expressed as percentage or as a fraction, since it varies between zero and one. If $T = T_o$, that is if the two temperatures are equal, no work can be performed and the exergy is zero, all energy is background energy. Only if the surrounding temperature is close to absolute zero, does the factor become one in the limit.

Exergy can do work and is the 'driving agent' of all material processes and all changes of structure in matter. Exergy is a creative force in the small and the large scale. It provides the capability to develop new atomic architecture as well as architecture for humans. The solar flux to the surface of the earth contributes large amounts of exergy. It is exergy, not energy, which in essence sustains life and all evolutionary processes, also in the long and in the short time-scale.

Natural systems are exergy efficient. The exergy theory forms a framework for thinking about resource supply in a way that is relevant to an ecological perspective. It can clearly demonstrate that all physiological systems function with a practically perfect exergy efficiency. But the exergy concept can also be utilized to study very practical matters of housekeeping and energy conservation in a society with high technology. Needless to say, most human constructions operate at a much lower exergy efficiency than natural systems do. Those who want to study the potential of energy conservation measures ought to work within the framework of the exergy theory.

1.6 Energy efficiency – better exergy efficiency

An important starting-point for the discussion of energy efficiency (as it is called by most people today) is that one must consider effective utilization of both the quantity and the quality of energy. The traditional energy conservation measure is to use less energy, to tighten the leaks and to be careful with all kinds of spending.

Exergy efficiency also depends on clever handling of energy quality. High energy quality has in practice some clear demonstrations: mechanical energy, electrical energy and high temperature heat. The quality factor of electric energy is perfect. Electricity can be used for almost any purpose in technological systems, including production of heat. It has a very high 'temperature capacity'. The frequently applied technique of producing low-temperature heat (less than 100 degrees centigrade) by means of electricity is in principle extremely wasteful. Its exergy efficiency is in most cases less than 10 per cent. Therefore one now often defines special applications for electricity, namely, those that concern motion and high temperatures: transportation, mechanical machinery, lighting and hot-steam devices. For heating different sources than electricity should be considered.

Exergy, is the most important natural resource to humans and the society. When reading and using the conventional word energy it should be kept in mind that exergy is the essential part of the energy. In the perspective of human ecology the first and most important energy source is food. It is surprising that most scientists today still do not observe that the food supply to humans is a part of the energy supply to the society. Energy is required also for collecting all other resources, water, minerals etc and for maintaining the whole collective machinery. A modern society develops mechanical structures for housing and performance of various activities such as communications and transportation, farming and industry etc.

1.7 Emergy – an ecological concept for "embodied energy"

To measure the energy content of materials and products, based on an ecological view, for comparison and to make choices, researchers use the special concept of emergy. Different energies and materials can be measured on the same scale using emergy calculations. The following is a basic explanation of emergy principles.

This human energy food chain shows the joules in the units as they are processed from sun to electricity to human work. At each process some energy is used up, lost from the chain. The emergy of each unit is the amount of energy it took to make it: all of them used the whole 20 million joules of sunlight.

For example, think of you, a human. If I put you in an oven, how much heat would I get out of you? That's your energy. But to evaluate the emergy of a human you count all the different kinds of energy taken to make him, from genetics, to tender loving care, to school, trips, everything that has gone in to make him. Your emergy is a much bigger quantity than your energy. UEV (energy unit value) is a related special concept. UEV is the amount of solar emergy joules it takes to make 1 joule of a material or service. The abbreviation for solar emergy joules is sej. Table 1.1 compares energy and emergy for quantities in the diagram in Figure 1.5.

This is a hierarchical concept of value. Power and quality are different from physical quantity. This is a way to quantify the idea everyone has that the value of something is more than just the energy and materials in it. This does not represent the monetary value. Price is not its emergy value; price is just what someone would pay for it. Using emergy as the way of comparing different things on the same scale, its emergy value, we can calculate different choices.

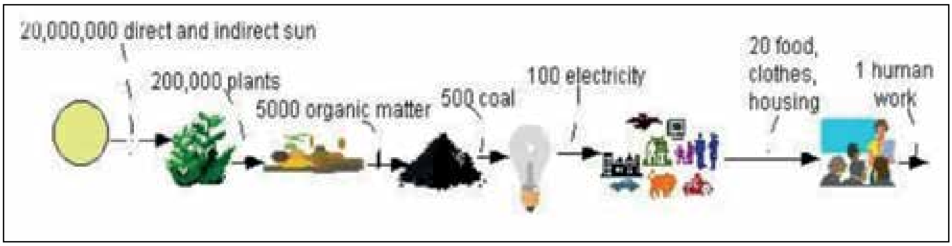

Figure 1.5. Emergy. 20 million joules of direct and indirect sunlight are used to produce each part of this energy chain. 20 million joules is the solar emergy of each component

Table 1.1.**Comparison of energy, emergy and transformity** for quantities in Figure 6.

	Sun	Electricity	Food, housing
Energy	20 E^6 joules	100 joules	20 joules
Emergy	20 E^6 sej	20 E^6 sej	20 E^6 sej

Between 1986 and today, the emergy methodology has continued to develop as the community of scientists has expanded and as new applied research into combined systems of humans and nature has presented new conceptual and theoretical questions. The maturing of the emergy methodology has resulted in more rigorous definitions of terms and nomenclature and refinement of the methods of calculating transformities. There is now an International Society for the Advancement of Emergy Research and a biennial International Conference held on the campus of the University of Florida.

Chapter 1 sources:

Main text Lars Rydén The Sustainable development course of the Baltic University Programme http://www.balticuniv.uu.se/index.php/introduction

Box 1.1 Wikipedia material

On Exergy: Tage Sundström in the Environmental Science book by Baltic University Programme http://www.balticuniv.uu.se/index.php/boll-online-library#environmental-science

On Emergy: A Prosperous Way Down, by Howard T. Odum and Elisabeth C. Odum, 2001 University Press of Colorado, Boulder, see http://emergysociety.org/