

## ENERGY NEEDS AND USAGE

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## ENERGY NEEDS AND USAGE

At present, one of the main problems of our society is the energy crisis and related environmental crisis: we need more and more energy to sustain our way of living, but energy (like water) is not at hand, not when we need, not in the desired form, and its usage generates harmful wastes. The water problem is similar in the sense that both, energy and water, are not consumed (only used; their amount on Earth is constant), but we require water and energy of good quality (potable water, concentrated energy), and we reject them as waste (sewage, and fumes), relaying on the environment to recycle them. We leave aside metabolic energy (to feed us and our animals), and other energy services of use by mankind.

Civilization milestones are often related to energy mastery: our control of fire some 500 000 years ago (artificial light, heating, coking); extended food storage some 12 000 years ago (Neolithic Revolution); development of explosives some 1000 years ago (fire arms); the motive power of fire in heat engines some 250 years ago (Industrial Revolution); and finally nuclear power in the 1940s (for the first time with a capacity to put an end to humankind, if misused).

To satisfy our needs for transport, manufacturing, electrical appliances, and so on, we need secure energy products (availability), economically affordable, and environmentally sustainable. Energy policies are the strategies governments decide to promote or restrain energy production, distribution and consumption. Energetics is the discipline that analyses the utilization of: energy sources, energy transportation, energy storage, and energy consumption. It is sad to realise that there are people without electricity (near a third of the world), and there are people so dependent on electricity that life almost stops without it (problems in multistore-building elevators and trains, blackout in lighting, computers, shopping, banking...; even gas heating or hot-water for a shower at home cannot be used if the boiler is electronically controlled).

Developed societies require a lot of energy; e.g. with our muscular effort, one well-fit adult person would be required full time to keep a 100 W lamp lit. And the energy problem is not only our starving demand, but the associated pollution and shortage.

- Present energy sources are mostly of fossil origin, locally and globally contaminant, and politically strategic, but they are cheap and storable.
- Nuclear energy is presently risky in contamination and war proliferation, has widespread refusal in many societies, is not renewable either, and politically the most strategic; but it is relatively cheap and storable, and might solve the whole problem if nuclear fusion becomes practical.

- Renewable energies (solar energy and its derivatives), seem to be the future because they pollute the less, are inexhaustible, and are not politically strategic (well distributed and not sensitive); but they are presently very expensive, and most difficult to store. We should follow the natural energy paths we have found so efficient on Earth: a distant primary energy source (the Sun), the simplest transportation means (ductless, wireless, by radiation), a marvellous fuel-making process (photosynthesis), and some derivative energies like wind and water flows (optimized with phase-change processes). Hydraulic energy has small growth potential worldwide, but wind power is blossoming. Energetic use of biomass has shown through the ages to be a handy resource to humans, provided it is based on residual biomass and not in conflict with its use for feeding people and animals; current fossil fuels are but accumulations through the ages of decomposed biomass.

Unless we solve the energy problem in an environmentally acceptable way, it may become the major cause for global conflicts (other basic needs like water and food, the cause of many local conflicts, seem no so threatening globally). The panorama is gloomy, but we can point some positive trends:

- There is still some margin in security of supply; power interruptions are still scarce and sporadic, and new energy sources are continuously being discovered. Anyway, some contingency energy storage locally should always be available.
- There is still some margin in affordability; current energy prices are below (in updated currency) the ceiling prices in the 1979 crisis, and large price increases (e.g. oil from 50 \$/barrel in 2007 to 150 \$/barrel in 2008) have been tolerated by global economy. Alternatively, the price of a litre of refined oil fuel is less than the price of a cup of coffee.
- There is still a great margin in efficiency; society is being concerned about rational energy use (but with great differences in demands and acceptance, e.g. related to personal mobility). The rate of increase in energy consumption is decreasing, both in global terms and per production value (energy use divided by gross domestic product).

## The energy concept

Energy is a scalar physical magnitude that is conservative in the evolution of an isolated system, can be considered extensively additive (i.e. the energy of a system is the sum of its parts), and is related to the homogeneity of time through Noether's theorem (the laws of Physics do not depend on time origin). The name 'energy' was introduced by Young in 1807 as a synonym of *vis viva*, and the energy concept was extended in the 1840s to all kind of actions: mechanical, thermal, electrical, metabolic...

Energy has many aspects of interest to humans: scientific (unity of physics), technical (usage), economical (cost), environmental (impact), social (refusal/acceptance), political (strategic dependence)...

The concept of energy is transversal to all branches of Physics, but it is under Thermodynamics that energy takes a central role, relating all other forms of energy to thermal energy and its distribution:

- Equilibrium states (temperature).
- Processes (heat).

Really, what matters most is not energy but energy transfer (work and heat) to satisfy energy services (comfort, lighting, mobility, communications...), besides its storage (energy properly). Moreover, since work can be used for any further purpose (including heating and cooling), and heat cannot fully converted to work, the real measure for usefulness is [exergy](#) (available energy to do work) and not energy itself. Every non-inert system (from biological to just mechanical clockwork) generates entropy that must be evacuated as heat, which must be compensated by an exergy input.

Energy usage is commonly measured in power units. There are low-energy applications (basically for information exchange: 10  $\mu$ W for a pacemaker, 10 mW for an e-agenda, 1 W for a cell-phone, 10 W for a small laptop) and high-energy applications (basically for heating and transportation of matter: 1 kW for a microwave oven, 10 kW for a hot-water heater, 100 kW for a car, 1 MW for a big truck, 10 MW for a train or a small ship, 100 MW for an airplane or a large ship). [See other scales of energy and power, aside.](#)

## Energy [thermodynamics](#)

First law. Energy (as well as mass) is a conservative physical magnitude, and, after use, goes back to the environment (i.e. out of the user-system, as waste heat and waste matter).

$$\left. \frac{dE}{dt} \right|_{\text{ais}} = 0, \quad \text{with} \quad \Delta E \equiv W|_{\text{adiab, closed}} \quad \text{and} \quad \Delta E = \Delta E_m + \Delta U = W + Q$$

Table 1. Energy states in a closed system (control mass).

Stored energy	Flow energy
Potential energy of the microscopic bonds and positions	Work at the frontier
Kinetic energy of the microscopic particles	Heat (by $\nabla T$ at the frontier)

In general, the rate changes in energy for an arbitrary system must comply with the following balance:

$$\left\{ \begin{array}{c} \text{volumetric} \\ \text{accumulation} \end{array} \right\} = \left\{ \begin{array}{c} \text{internal} \\ \text{production} \end{array} \right\} + \left\{ \begin{array}{c} \text{surface flows} \\ \text{diffusive} + \text{convective} \end{array} \right\}$$

$$\frac{dE}{dt} = 0 + \dot{W} + \dot{Q} + \sum_{\text{openings}} h_t \dot{m}$$

where the conservative character of energy stands in the null-production term, energy flows through matter-impermeable surfaces can be in the form of work rate  $\dot{W}$  or heat rate  $\dot{Q}$ , and energy flows associated to mass flow-rates  $\dot{m}$  (through openings in the system surface) are proportional to total specific enthalpy  $h_t$  of the stream at the opening, because the work of forcing the flow (pressure times specific volume,  $p\nu$ ) is added to the specific energy  $e$  ( $h_t = e + p\nu$ ) at each entrance.

Second law. It is not energy what has a price, but available energy (i.e. exergy). How much work can be extracted from an 'isolated' system not at equilibrium, or how much work must be spent to force an 'isolated' system initially at equilibrium to reach a non-equilibrium state? That is exergy, a combination of the amount of energy,  $E$ , and the uncertainty measure of its distribution within a system,  $S$  (entropy). Entropy is a measure of the uncertainty on the state of things (the reason why everybody should bet at 7 in the two-dice game), a measure of how energy and other extensive quantities distribute within available constraints in a thermodynamic system.

$$\left. \frac{dS}{dt} \right|_{\text{ais}} \geq 0 \quad \text{and} \quad \left. \frac{d^2 S}{dt^2} \right|_{\text{ais}} \leq 0, \quad \text{with} \quad dS \equiv \frac{1}{T} dU + \frac{p}{T} dV - \sum_{i=1}^c \frac{\mu_i}{T} dn_i$$

Thermal energy may be defined as the stored energy that flows as heat when two systems at different temperature are brought in contact; it includes sensible energy (growing with temperature, i.e. stored as microscopic kinetic energy), and latent energy (not proportional to temperature for pure substances, stored as potential energy in the physical bonds of condensed matter). The simplest model for internal energy stored as thermal energy is the so called 'perfect calorific substance' (or simply perfect substance

model, PSM), assumed to be known from former courses, and for which the thermal energy change is directly proportional to the temperature change, that is:

$$\Delta U = mc_v \Delta T$$

where  $c_v$  is a constant, the specific thermal capacity at constant volume, and temperature  $T$  is temperature.

Temperature is the measure of the thermal energy level of a system, characterised by the fact that it is uniform in a system at equilibrium, and, when not at equilibrium, temperature gradient forces the flow of heat.

Heat is thermal energy flow (not thermal energy stored), and it is defined by  $Q = \Delta E - W$ .

Greek prefix *therm* means heat (causes and effects, generation and usage), and Latin prefix *temper* means mixed (originally used for '*temperatura caeli*', the sky combination).

## Energy needs

Life is a self-organised system of mass (water, polymers, and trace elements), energy (food and air), and information (from ADN to brain).

Besides metabolic energy, people need energy to procure their welfare: shelter, athermalization (heating/cooling), manufacturing, transportation, communication...

1. Some basic energy resource is a human right (after air, water, food, shelter...). If this basic need is not satisfied, confrontation can be expected. Energy utilization should be secure, safe, clean, and economic affordable.
2. There is a correlation between the GDP (gross domestic product) of a country and their energy use. During industrialisation, the correlation is with primary production, but at a later stage of development it is with the electrical consumption. The explanation is that, at the initial stage of use, production is prior to efficiency, whereas efficiency comes later by optimisation of equipment at source and end-use, and of user practice. Small agriculture cities changed to big industrial cities and then to huge service cities with large differences in living standard. Vertical cities (with many tall buildings) may be more energy-efficient than horizontal cities (with long distance to travel daily), but are more dependent; what can people do in a 10<sup>th</sup> floor without electricity? Economy of scale by centralisation of services (water, energy, heating/cooling, food...) presents some advantages in raw efficiency, but the trend nowadays seems to be changing to decentralised production (to minimise transport and maximise offer/demand matching).
3. The key energy problem nowadays is that, present technology (largely based on fossil fuels), cannot supply clean energy (i.e., safely to the environment, global warming), at affordable economic conditions (energy price must inevitably rise as sources are depleted), and to everybody (it seems we are too-many people for this planet, even just for feeding, not to mention the 20 times more current energy use relative to metabolic needs).
4. In spite of the necessary energy saving of large consumers, humankind at present needs much more energy, since most people still lack reasonable energy allowances.
5. Energy being a basic need, energy planning in the long term is a key political issue (like planning water supply, food and shelter). As for food, all available energy sources should be tried for optimised supply, and diversity preserved as a more healthy mix and for contingency. Public and private research is needed to pave the way for new energy technologies. At present, and in spite of the environmental problem associated, there are no substitutes at site (for the next 20 years or so) for the traditional fossil-fuel-dominated energy technologies.
6. Immediate challenges foreseen are:

- a. Improve energy saving procedures (penalise waste, promote rational use, increase control devices).
- b. Promote sustainable energy technologies: solar, wind, water, biomass...
- c. Improve present technologies: coal reforming, waste-heat recovery...
- d. Develop improved technologies: fuel cells, new thermodynamic cycles...
- e. Capture and remove CO<sub>2</sub> from concentrated sources
- f. Solve proliferation risk of nuclear energy.
- g. Improve waste-fuel processing of nuclear energy.

### **Energy services and energy price**

It must be emphasized that end-user-concern focuses on energy services demanded (e.g. artificial lighting, space heating to at least 20 °C in winter, space cooling to at least 24 °C in summer, refrigerated storage at some 0 °C or below freezing, food cooking, milling, stirring, propulsion for transportation and mobility, communication and computation...), and the user does not care about the means used (amount and type of energy) to achieve the goals (the energy services wanted), except for side effects like cleanliness, readiness, safety, price...

As for other commodities in developed societies, commercial processes are established to make energy available to end-users in a convenient form, when and where needed, at a value added cost (market price, of the order of  $10^{-8}$  €/J for a western city-dweller). Similarly, as for other basic utilities (water supply, sewage, transportation...), there are appropriate public regulations and provisions to guarantee universal access to energy at a rational cost. In summary, what we expect from the energy service is:

- Secure supply in amount, time and location. We need electricity for everything (lighting, communication, boiler controls...), and more during daytime and working hours.
- Economically affordable. The price of all other goods, depend on energy price, because of transport and manufacturing. (Cheap energy is being depleted.)
- Environmentally sustainable in the short and long terms (not compromising our present activities, neither the future ones).

### **Energy installations**

Habitable space, either in permanent buildings or in vehicles, is often provided with permanent or movable energy equipment and facilities to satisfy the energy services demanded by the users: illumination, heating, communications, cooking... Besides, vehicles demand energy for propulsion.

The envelop separating indoors from outdoors may include doors, windows, and different kinds of walls or framework, through which energy flows (intentionally or not, associated to a mass flow or not). Most energy flows are entrance flows, with heat flow usually being an exit flow. Typical energy facilities are:

- Electrical supply, satisfying most energy services.
- Fuel supply, either piped or in batch, satisfying some energy-intensive services (e.g. heating).
- Hot fluids, usually hot water or hot air (e.g. from solar collectors or a centralised supplier).
- More rare facilities may be:
  - Cold fluids, analogue to hot fluids.
  - Compressed fluids (for hydraulic or pneumatic applications).

### **Energy measurement and units**

As said above, only energy flows can be measured, not absolute energy content (which depends on an arbitrary energy reference); e.g. when we say that gasoline has 48 MJ/kg, what we are saying is that 1 kg of fuel, when burnt in air within a thermal bath at room temperature will release 48 MJ of energy. The basic procedure to measure energy is by measuring an amount of mass (or mass flow-rate, or electricity flow) and its change in energy level, thermal or potential.

The SI unit of energy is the joule (J). Many other energy units (Table 2) are in use for the practical expression of energy quantities partly for historical reasons and partly because the small size of the joule demands the use of decimal prefixes or exponential notation (unfamiliar to non-scientists). As a result, the international organisations have used units for energy of a size appropriate for expressing national fuel supplies, and related to the commodities in use. Historically the ton of coal equivalent (tce) was used but, with the ascendance of oil in the 20<sup>th</sup> century, this was replaced by the tonne of oil equivalent (toe) defined as 42 GJ (gigajoules, 1 GJ=10<sup>9</sup> J). Most national balances, and the International Energy Agency, still use this unit (the toe) but the terajoule (1 TJ=10<sup>12</sup> J) is increasingly used in accordance with the recommendations by the International Standards Organization (ISO). At the individual user level, the kilowatthour (kWh) is in widespread use not only for electrical consumption but for fuel energy too (instead of the SI megajoule; 1 kWh=3.6 MJ). When a gross energy quantity and its several energy shares are presented (e.g. in graphics and tables of world or regional primary consumption or electricity generation by source share), it may be advisable to give just the total in absolute energy units, and the shares in percentage of the total.

Table 2. Some energy unit conversions.

Unit	Equivalence		
Tonne oil equivalent (toe)	1 toe	=	42·10 <sup>9</sup> J
Tonne coal equivalent	1 tce	=	30·10 <sup>9</sup> J
Cubic metre of natural gas (STP)	1 m <sup>3</sup> NG	=	40·10 <sup>6</sup> J
Kilowatthour	1 kWh	=	3.6·10 <sup>6</sup> J
Thermie (10 <sup>6</sup> cal)	1 thermie	=	4.2·10 <sup>6</sup> J
Therm (10 <sup>5</sup> BTU)	1 therm	=	0.11·10 <sup>9</sup> J
Barrel of crude (1 bbl=0.159 m <sup>3</sup> )	1 barrel	=	6.1·10 <sup>9</sup> J
British Thermal Unit	1 BTU	=	1.1·10 <sup>3</sup> J
Kilocalorie (Calorie)	1 kcal	=	4.2·10 <sup>3</sup> J
Quad (10 <sup>15</sup> BTU)	1 Quad	=	1.1·10 <sup>18</sup> J
Exajoule	1 EJ	=	1.0·10 <sup>18</sup> J
Electronvolt	1 eV	=	0.16·10 <sup>-18</sup> J
Erg	1 erg	=	0.10·10 <sup>-6</sup> J

Energy conversion from fuels is traditionally based on the lower heating value of the fuel.

## World energy sources

Energy sources can be classified, in terms of the fundamental forces involved, as:

- Nuclear-origin sources: celestial (solar radiation), crust (fission), earth interior (geothermal).
- Chemical-origin sources (fuels to burn in air): biomass, and fossil fuels (from by-gone biomass).
- Physical-origin sources: water reservoirs, ocean currents, winds, ocean waves. Notice that thermal energy, although of a physical nature, originates from chemical and nuclear processes (e.g. from combustion, solar radiation, geothermal decay...).

Energy is abundant on Earth. Globally, the Earth gets from the Sun 10<sup>4</sup> times more energy than the whole present humankind usage, but solar energy is not available at night, not enough for home heating in winter, not directly usable for transportation or refrigeration, and too-much diluted for most applications.

Besides the tiny contributions from the gravitational pull of the Moon and Sun, and the residual nuclear energy in the Earth interior, practically all energy input into our ecosphere is solar electromagnetic radiation, that can be gathered thermally, photonically (biological photosynthesis and photovoltaic cells), or indirectly through the winds, hydrological cycle, ocean waves, etc. Energy input practically equals energy output at every instant on the whole Earth (the space-averaged temperature in the Earth surface is

nearly 15 °C all the time; the worst fear of global warming is a few degrees by the year 2100); and both, input and output, correspond to electromagnetic radiation, but the input is half and half in the visible and the infrared region of the spectrum, whereas the output is mainly infrared.

One calls "primary energy" any kind of energy that has not undergone anthropogenic processing, encompassing not only solar radiation, but its spin-offs: hydraulic energy, wind energy, biomass, fossil fuels (long-term biomass residue), and non-solar-radiation related sources: nuclear energy, geothermal energy and tidal energy. One calls "secondary energy" or "final energy" any kind of energy carrier available to the end-user (homes, vehicles, farms, and industries other than energy-transformation ones). At present, there are just two kinds of final energy forms:

- Electrical energy, flowing through solid conductor wires.
- Chemical energy, flowing through gas pipes, or batch delivered in solid, liquid, or gas form.

Human metabolism needs some 100 W/cap (100 watts per capita), and humankind consumes some additional 2400 W/cap of primary energy (some 300 W of electricity produced from some 900 W of primary energy, plus some 1500 W of end fuels consumed). Most of the energy trade involves fuels, presently, in the past, and in the foreseeable future, as summarised in Table 3.

Table 3. Short summary of fuel share in world energy utilization.

Year 2000		Year 2020 prediction	
Primary energy <sup>a</sup>	Energy carriers (end use)	Primary energy <sup>b</sup>	Energy carriers (end use)
90 % Fuels	84 % Fuels	90 % Fuels	82 % Fuels
6 % Nuclear	16 % Electricity	5 % Nuclear	18 % Electricity
4 % Hydro	Electricity production:	3 % Hydro	Electricity production:
	<ul style="list-style-type: none"> <li>• 66 % Fuels</li> <li>• 17 % Nuclear</li> <li>• 17 % Hydro</li> <li>• (0.7 % Wind, solar...)</li> </ul>	2 % Wind	<ul style="list-style-type: none"> <li>• 65 % Fuels</li> <li>• 10 % Nuclear</li> <li>• 15 % Hydro</li> <li>• 10 % Wind, solar...</li> </ul>

<sup>a</sup>Gross values: 2400 W/cap ( $\rightarrow 460 \cdot 10^{18}$  J/yr=10900 Mtoe/yr); population,  $6.1 \cdot 10^9$  cap; GDP, 6700 €/cap.

<sup>b</sup>Gross values: 3200 W/cap ( $\rightarrow 620 \cdot 10^{18}$  J/yr=14600 Mtoe/yr); population,  $7.6 \cdot 10^9$  cap; GDP, 10000 €/cap.

When dealing with world-wide average energy usage, we must recall how uneven (unfair) the distribution can be: in year 2000 consumption was 12 000 W/cap for USA, 6000 W/cap for EU, 1500 W/cap for China, 1000 W/cap for India, or 300 W/cap for Bangladesh; and there is a third of mankind presently lacking electricity.



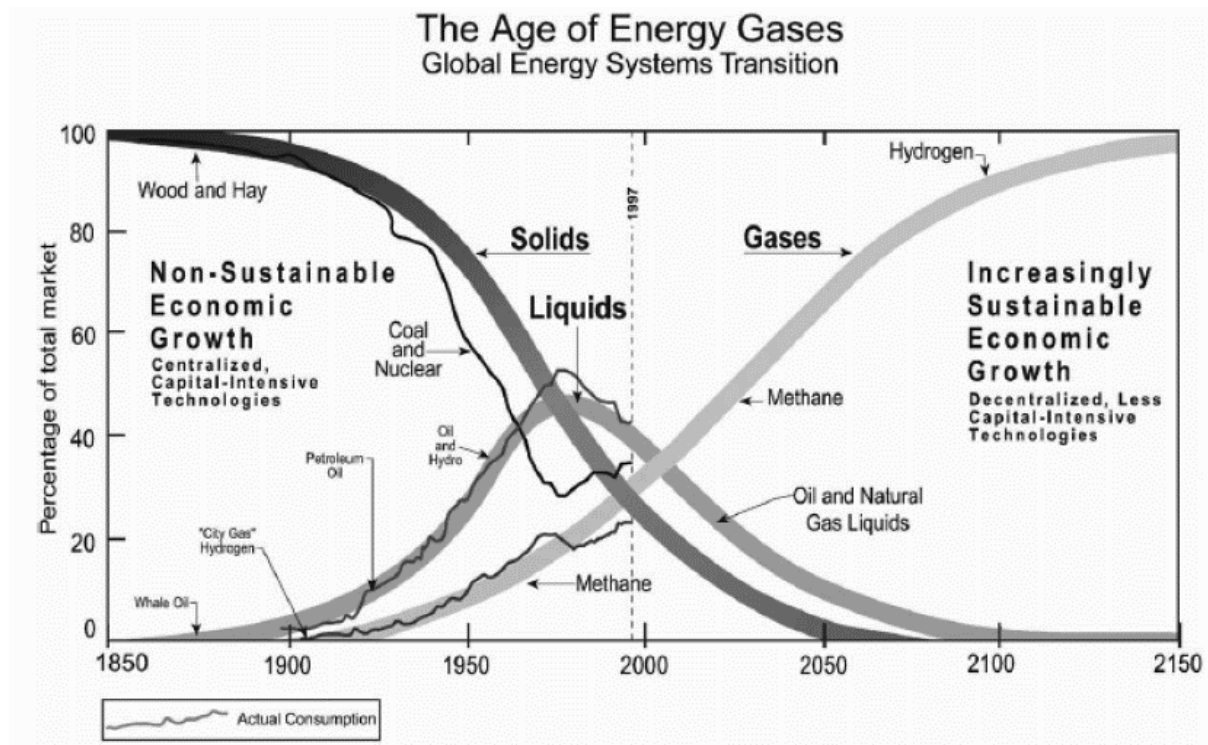


Fig. 1. History of type-of-fuel usage.

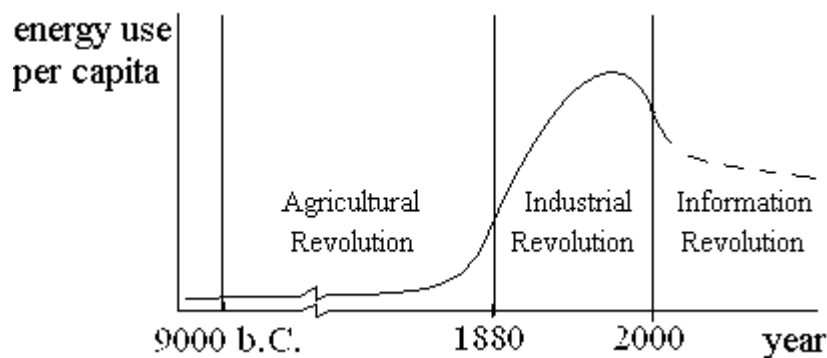


Fig. 2. History of amount-of-energy usage.

## Energy storage

Presently, the most convenient end-user energy-form happens to be electrical energy; it is versatile (multipurpose), easily controllable (simple switch), quite safe to handle (thin flexible wires), and clean (no spills, no fumes, no ashes). But it has the drawbacks of inconvenient sources (environmentally) and inconvenient storage (electricity in the grid must be generated at the same rate it is consumed). Besides, the carrier capacity is not large in comparison (e.g. domestic copper wires of 4 mm<sup>2</sup> section can only provide 24 A of electric current, what limits power to 5.5 kW at 230 V; the same amount of electric power can be produced with a small combustion engine using only 1.3 kg/h of gasoline).

For these reasons, in quantitative terms chemical energy of fuels is the most used and convenient, because energy storage is simply related to mass storage, and natural fuel-sources are more or less adequate: large fossil fuels deposits were found (although they are being commercially exhausted), and renewable fuel sources can be cropped. Future fuels, however, will be synthetic, either to replace similar natural fuels, or to shift to new fuels: hydrogen appears as the best candidate. A compilation of different energy storage systems, ranked by specific energy content (J/kg), can be found in [Table 1](#) aside.

Since the larger share of present world energy production is from fuels (90 %), and they are easily available (fossil or biomass), energy prices are comparatively low, of the order of 10<sup>-8</sup> €/J for a modern city dweller, corresponding to 10<sup>-1</sup> €/kg of coal, less expensive than basic food (1 €/kg of bread). Water



may reach a city-home at  $10^{-3}$  €/kg and air is presently free, although many people in large cities would be willing to pay for good bottled-air or clean-air appliances, as they pay for good bottled-water, for good food and for good energy.

We might imagine a society scarcely dependent on energy, as in pre-industrial civilisations, but nowadays developed societies are based on energy even for their food production (agriculture mechanisation and artificial fertilisation presently allow a mere 5 % of the population devoted to farming to feed 100 % of the population; before mechanisation and artificial fertilisation, 95 % of the population had to be engaged in agriculture). Energy prices are comparatively low at present (e.g. a litre of gasoline costs nearly the same as a litre of bottled water), but there is evidence that we are approaching a [threatening energy future](#):

- Energy usage is the major pollution activity on Earth: toxic fumes, oil spills, nuclear accidents, climate change... Combustion generates some  $25 \cdot 10^{12}$  kg/yr of CO<sub>2</sub>, significantly increasing the greenhouse effect.
- Energy demand will grow a lot in the near future due to:
  - Increasing population (world population doubled from 1960 to 2010).
  - Increasing per-capita energy use (a third of the world population still lacks electricity).
  - Increasing energy needs for new basic demands associated to a crowded world, like water desalination, waste management, migrations...
- Scarcity of fossil-fuel source.

The only way out of this fossil-fuel-dependence (leaving aside nuclear fusion) seems to fall on the efficient storage of energy from renewable sources, mainly solar and wind power. The best storage solution is as synthetic fuels (chemical fuels, synthetic nuclear fuels are out of reach), and hydrogen has been proposed as the ultimate solution because of its clean reaction with oxygen, but it has the big problem of low volumetric storage density. Notice that the greenhouse contribution from any other synthetic fuel can be minimal if CO<sub>2</sub> from the air is used in its production, as for biomass; e.g.  $\text{H}_2\text{O} + \text{CO}_2 = \text{CH}_2\text{O} + \text{O}_2$ . Prospects, however, are ill-fated: most forecasts predict for 2020 a negligible decrease of fossil fuel share in world primary energy, staying around 90 %, and still being dominant in 2050 with some 70 % share. The only way-out of this doom horizon lays is human creativity, guided by a sound education in Thermodynamics and other sciences.

## World energy consumption

[Energy consumption](#) is loosely correlated with gross national product (GDP), but there is a large difference even between the most highly developed countries, such as Japan and Germany (with 6 kW/cap and 40 000 \$/cap) and the United States (11.4 kW/cap and 46 000 \$/cap). In developing countries such as India energy use is closer to 0.7 kW/cap (with 1100 \$/cap). Bangladesh has the lowest consumption with 0.2 kW per person. The US consumes 25 % of the world's energy with a share of global GDP of 22 %, and a share of the world population of 5 %.

Care must be paid when interpreting energy management data because power installed (capability) is sometimes confused with power produced (e.g. in the case of solar energy the latter is a small fraction of the former), primary energy extraction is confused with final energy consumption (in the case of electricity production only a third of primary energy is transformed to useful energy), local and short data series are extrapolated (e.g. half of the world solar energy installed in 2008 took place in Spain: 3000 MW; on a given day, half of the national electricity demand in Spain was from wind origin...).

Electrical energy consumption has been a measure of society development, but there have already been some great failures in prospects:

- The ‘all-electric home’, which started in the 1920s in the USA and peaked in the 1950s worldwide. Experience has shown how expensive it can be the substitution of fuel carriers by electricity in the heating and hot water services.
- The ‘electricity too-cheap-to-meter’, which the nuclear power stations advocated in the 1960s.

Because electrical energy is too difficult to store, advantage in averaging demand needs have pushed electrical grid interconnection and largest-possible power plant design. However, demand for non-grid-connected electrical energy availability is growing. Initially it was for searchlights, radio-transistors and toys, but the widespread use of mobile phones in around 2000 changed it all. Soldiers have to carry several kg of batteries for all their electronic equipment (radio-communication, night vision, GPS...).

At the end-user point, there choices to manage energy consumption are not very wide because appliances (and vehicles, and housing) may cost a lot to replace or refurbish, and the original manufacturers (and builders, and landlords) were pressed by lowering initial price, leaving the operating costs to the end consumer. Fortunately, this third-party-decision-making is being corrected by administrative enforcing of energy-performance information, increasing energy prices, and increasing energy and environmental public consciousness.

## **Energy use and the environment**

Humankind is increasing its per-capita energy usage, and population keeps increasing. Presently, the Earth gets from the Sun nearly  $10^4$  times the world energy consumption, but this cannot be directly used because it is too much widespread. The energy sources actually used at present are mainly from fossil fuels (coal, oil and gas), but they have two big problems:

- Fossil fuel usage, based on combustion, is heavily pollutant (besides the innocuous water vapour often pictured as the visible pollution, large quantities of  $\text{CO}_2$  are necessary released, plus acid  $\text{NO}_x$  gases that may condense, and a variety of un-burnt residues: CO, volatile organic compounds, and soot particles). It was thought to be just a local problem, but its effect on the global climate change seems even a greater problem.
- Fossil fuels are not renewable at the rate they are consumed. Present estimation of reserves range from a few decades for crude oil and natural gas, to a few centuries for coal (which is the most contaminant).

The main difficulties of renewable energy sources are: temporality (the energy is required when the source does not provide it), and spatiality (the energy demand in a location where the renewable source is nonexistent or insufficient), and the answer to both is storability by means of the artificial synthesis of stable and transportable fuels from raw materials taken from the atmosphere: just like natural evolution has developed).

At present, the end user consumes only two kinds of commercial energy: electricity (from the mains), and fuels (piped or batch served to the door). Humankind has no need for specific energy carriers such as coal, gas, oil, wood, electricity, or hydrogen. We need energy services, i.e. lighting, space heating, cooling (refrigeration and air conditioning), transporting goods and people, rotating shafts and other actuators, and control devices (e.g. radio transponders, computing machines). The most important energy carrier has always been a fuel (a chemical reductant) in an oxidant atmosphere, complemented since the 19th century by an electron conductor (electricity), since pneumatic, hydraulic, and mechanical carriers have very poor overall performances. Fuels have always been directly taken from the environment (e.g. wood and fossil fuels) but the time has been reached for artificial fuels, and hydrogen (from renewal sources) seems to form the perfect carrier couple with electricity: a proton carrier with an electron carrier.

We take all our energy from the environment by several kind of extraction processes (fuel mining, wind and solar capture...) which already produces some waste energy while delivering the rest as useful energy to industry, which powers not only all the services we need as end users, but other industries (including the extractive one), and degrading another part that returns to the environment.

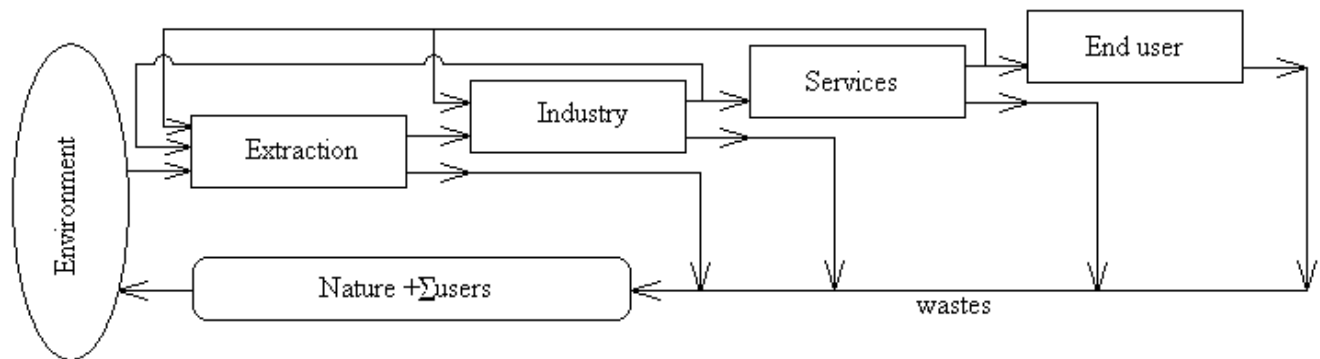


Fig. 3. Energy from the environment to the end user and back to the environment.

Not all energy from the environment can be extracted, of course; Thermodynamics teaches that only exergy, i.e. the part being ‘available’ can be extracted, and that with some inevitable losses in the process (the faster the process, the greater the losses). Besides this thermodynamic limit, there are other practical limitations to energy extraction, some related to available technology (e.g. we do not know yet how to profit from deuterium energy in the oceans), and others related to energy concentration or or variability (like solar and wind energies). From the possible exergy sources ( $\dot{W}$  from tides, water motion and winds;  $\dot{Q}$  from the Sun and Earth-interior; and  $\dot{m}$  from chemical and nuclear fuels), we presently take 96 % from fuels,  $\dot{m}_{fuels}$  (82 % fossil, 8 % biomass and 6 % nuclear), plus 4 % from  $\dot{W}$ -hydraulic, and nearly 0 % from  $\dot{Q}$  (solar and geothermal), as can be seen from Table 4..

Table 4. Availability of useful energy, and actual energy use, by resource type.

Energy source	Availability	Usage
Solar radiation at the Earth surface (60 % of the extraterrestrial 175 000 TW)	105 000 TW	Negligible direct use (solar thermal and solar photovoltaic)
-Hydrological cycle	40 000 TW	1 TW hydraulic energy
-Winds	350 TW	0.1 TW wind energy
-Biomass (photosynthesis)	100 TW	1 TW biomass energy (mainly in poor countries)
Geothermal	25 TW	0.01 TW geothermal energy
Tide	3,5 TW	Negligible
Fossil (fuels plus nuclear).	16 TW	16 TW (96 % of the 17 TW total energy use in 2008).

One may have a look at the European energy targets (EU 7 PM) to see the importance of environmental effects on that:

- Improve energy efficiency throughout the energy system;
- Accelerate the penetration of renewable energy sources;
- Decarbonise power generation and, in the longer term, substantially decarbonise transport;
- Reduce greenhouse gas emissions;
- Diversify Europe's energy mix;
- Enhance the competitiveness of European industry.

It seems that future energy utilization will be based on intermittent renewable sources (solar, wind, hydro) with two energy carriers: electricity and hydrogen. The latter has the advantage of being storable and non-pollutant, but having low density in all known storage and transportation means; some condensed form of hydrogen-rich substance, like methanol, synthesized from renewable hydrogen and carbon-capture-

systems,  $4\text{H}_2+2\text{CO}_2=2\text{CH}_4\text{O}+\text{O}_2$ , has been suggested to cope with this difficulty (and minimise climate change). But the change from our present highly-polluting energy use to a clean energy future is not in the short term; the International Energy Agency prediction of world fuel consumption in terms of type of fuel (Fig. 4) is gloomy: fossil fuels will continue to take the major share of our energy resources.

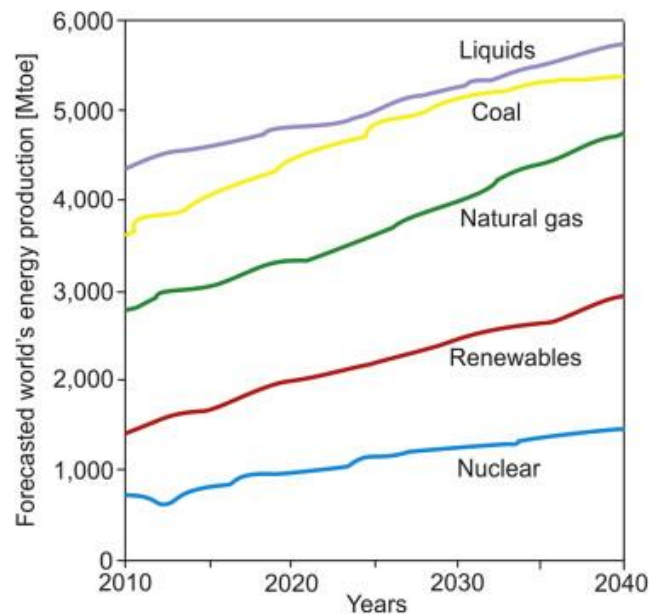


Fig. 4. World energy consumption projection by type of fuel (from [World Energy Outlook 2013](#)). 1 Mtoe= $42 \cdot 10^{15}$  J). Global 2013 consumption  $550 \cdot 10^{18}$  J (13 100 Mtoe).

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