Renewable pathways in Europe

In a highly proactive overall context, the various renewable energy pathways are exhibiting diverse patterns of growth within the European Union.

Two major documents set the context for the actions taken by member states with respect to development of **renewable energies**, within the European Union.

The first document is the **European Commission** White Paper which, in 1997, put forward the target of achieving, by 2010, a share of 12% of **primary energy** consumption [1] to be provided from renewable pathways. [2] This target was set as a common objective for all (then) fifteen member states, not giving rise to individual national targets.

The second document, published in 2001, is the European Directive on production of electricity from renewable energy sources. [1] This Directive set the goal

(1) Consumption of primary energy refers to the amounts consumed of fossil energies (oil, coal, and natural gas), nuclear energy, or renewable energies, prior to any transformation into useful energy (hydrocarbon fuel, electricity, heat).

(2) Not taking into account pumped-storage hydropower plants, or non-organic waste incineration plants.

of achieving a contribution from these pathways equal to 22% of gross electricity consumption [3] in the 25 countries inside the European Union, by 2010 (see Figure 1). For that purpose, each member state was set a national target, that set for France standing at 21%. Within this overall context, the various pathways have undergone, within the European Union, diverse evolutions. [4]

The example of wind power

Considering the outstanding growth figures and economic success it has evidenced, wind power is the pathway to set as an example, with respect to development of renewable energies. Since 2000, this has kept to an average yearly growth rate of over 30%, amounting to 29,067 MW by the end of 2003. Trailing far behind the European leaders in this area, namely Germany, Spain, and Denmark, France is making a slow start in making use of its strong wind-power potential (253 **MW** installed by the end of 2003). The country is largely banking on this pathway to meet its target of 21% of gross domestic electricity consumption by 2010 (see Figure 2). In particular, two calls for tenders have been issued (500 MW each), for the development of large inland wind-turbine farms (of more than 12 MW), as well as offshore farms. However, the delay that has arisen in France, as regards this sector, means it may be expected the country will find it difficult to achieve the 21% threshold.

The photovoltaic paradox

Going by the growth indicators for the **photovoltaic** (PV) pathway for European Union countries as a whole, the finding is a positive one. Figures for 2003 show a growth of 36.9% in production of PV **cells** and **modules**, and a rise of 30.3% in installed power. However, if a detailed scrutiny of the patterns is made for individual states, one country, Germany, is found to be sole bearer of a large part of the growth for this pathway. This country alone accounts, in particular, for more than 70.5% of power installed in 2003 within the European Union. The trends for this pathway thus remain fragile, and largely dependent on the various national support programs.

The resurgence of thermal solar power

Making a new start in the latter half of the 1990s, thermal solar power is once more progressing along the trail it had made for itself in the aftermath of the oil crises of 1970s. The momentum, once again, came from
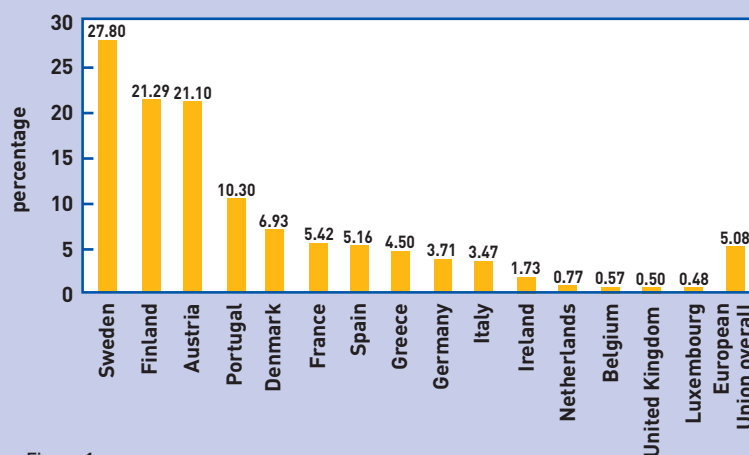

Figure 1.
Ranking of European Union countries according to the share of renewable energies in primary energy consumption, in 2002. (Source: Observ'ER 2004.)
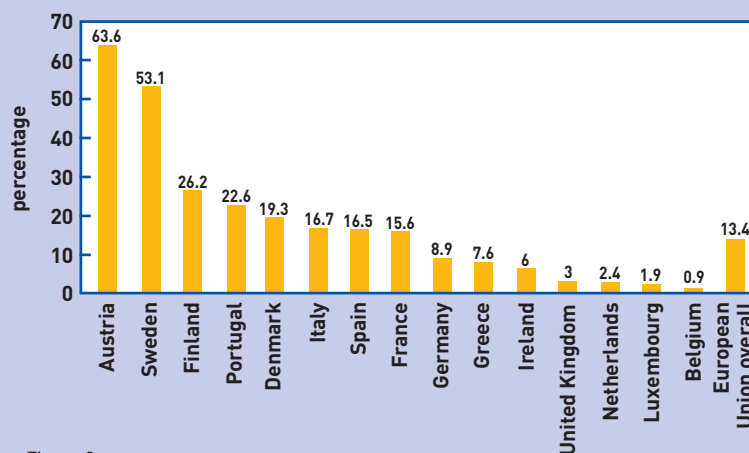

Figure 2.
Ranking of European Union countries according to the share of renewable energies in gross electricity consumption, in 2002. (Source: Observ'ER 2004.)

(3) Gross electricity consumption corresponds to national electricity production, after adding electricity imports, and subtracting exports.

(4) Figures appearing in this paper apply to the 15-member-state European Union.

Germany, which country could point, by the end of 2003, to an aggregate of more than 5 million square meters of collectors installed, out of an overall 13 million for the European Union as a whole. France, bolstered by a national promotion scheme launched in 2000 (the Plan Soleil, i.e. "Sun Plan"), was able to set up a dynamic, making thermal solar power stand out as one of the more popular renewable pathways. Despite such positive results, current growth rate is inadequate, if the country is to achieve the 100 million square meters set by the White Paper.

Geothermal power sets a good pace

Geothermal power refers to an ensemble of highly diverse applications. These may range from electricity-generating sites of several megawatts unit power to heat pumps for individual dwellings. Inside the European Union, growth has mainly concerned thermal applications (whether feeding a network, or individual), particularly in Italy and France. Overall, the growth rate for this pathway should enable the White Paper's 2010 targets to be met, i.e. 1,000 MW electric power output, and 5,000 MW thermal production.

Hydropower, the foundation of renewable electricity

Large hydropower (i.e. installations of more than 10 MW) is known not to offer any further growth potential within the European Union. Nearly all sites that could be put to use are so used, and the 109,000 MW installed (including 23,470 MW in France) are the source for 70% of renewable electricity production in the European Union. On the other hand, *small hydropower* (installations of 10 MW and under) still offers a useful potential, provided local oppositions are overcome, these making for difficulties in the siting of any new plant.

Wood energy, the prime renewable pathway

In the European Union, it is believed 51% of the primary energy provided by the various renewable pathways originates in wood energy (41.8 million toe, out of 81.2 million toe in 2002). France is one of the countries making best use of this pathway (9.1 million **toe** in 2002), mainly for heat production in the industrial, residential and tertiary sectors. The European potential, however, remains large, and substantial efforts will be required, if the target of 100 million toe set by the European Commission for 2010 is to be met.

Biogas: moderate, if steady growth

Development of this pathway is characterized, in Europe, by moderate, if steady growth, of some 9–10% annually. In 2002, 2.8 million toe **biogas** were produced among the fifteen member states, the United Kingdom making a particularly strong contribution (952,000 toe). It should be noted that only part of this production subsequently gives rise to effective value-added use in the form of final energy (electricity, heat, hydrocarbon fuel). Indeed, owing to a lack of economically profitable outlets, about half of the biogas produced within

Phovoir

The European Commission has set itself, for 2010, an ambitious target of 100 million toe for energy uses of wood.

the European Union is burned off in gas flares, **methane** being a particularly harmful gas, in terms of the **greenhouse effect**. For the future, the White Paper is looking to 15 million toe being achieved by 2010, i.e. five times current production.

Biofuels

The **biofuel** sector comprises two separate pathways: ethanol, which, after transformation into **ETBE** (ethyl tertiary butyl ether), is used as an additive in gasoline engines; and biodiesel, used as an additive in diesel engines. In 2003, European production of ethanol stood at 309,500 tonnes, and 1,434,000 tonnes biodiesel. The long-standing leader for both pathways, France has now been overtaken by Germany as regards biodiesel, and Spain for ethanol. A European Directive adopted in 2003 set precise targets for the introduction of all of these biofuels between now and 2010: 2% in 2005, 5.75% by 2010. Current use rate stands at less than 1%.

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A The many states of energy

"Nothing lost, nothing created," as Lavoisier, the father of modern chemistry, wrote in his day. This motto, true as it is of chemical species, applies equally to energy. Indeed, energy is a multifarious entity, which may transform into highly diverse aspects. However, the primary energies that may be directly accessed in nature are limited in number: such are fossil energies (coal, oil, natural gas), nuclear energy, and renewable energies (hydro energy, biomass energy, solar energy, wind energy, geothermal energy, tidal energy). These primary energies are the constituents of what is known as the *primary energy mix* (see Figure 1).
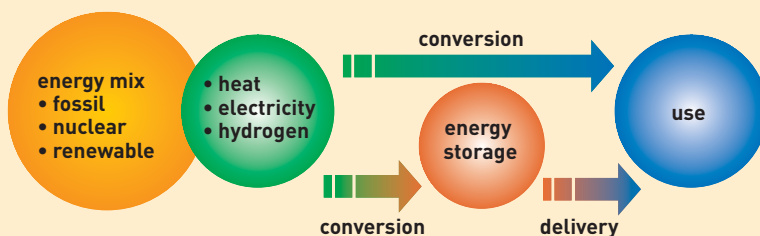

Figure 1.
The energy scheme.

For most applications, energy must be converted to make it compatible with the use under consideration. Of course, nature, highly ingenious as it is, devised the very first energy converters, namely living beings. Plants, through photosynthesis, effect the conversion of radiant light energy into chemical energy. The human body itself allows, in particular, the conversion of chemical energy into mechanical energy, by way of the muscular system. Subsequently, humans went on to invent large numbers of converters (see Figure 2). The first such converter, chronologically, is quite simply fire, converting chemical energy (combustion) into light, and heat. Of more recent origin, a television set carries out conversion of electricity into light energy (pictures) and mechanical energy (sounds). In fact, many energy systems involve a combination of a number of converters, as e.g. a nuclear power station, effecting as it does the conversion of nuclear energy into thermal energy (reactor), then into mechanical energy (turbine), finally through to electric energy (alternator). Unfortunately, the second principle of thermodynamics tells us that any energy transformation carries a cost: a more or less extensive portion of the energy involved is dissipated in the form of unusable heat (through friction in a mechanical system, for instance). In the case of a present-generation nuclear power station, the electric energy generated only amounts to one third of the nuclear energy initially contained in the fuel.

Of course, matters would be altogether too simple, however, if energy could be consumed as and when it is generated, on the very site where it is produced. In very many cases, energy-consuming sites may be far removed from the production site, production and concomitant demand, moreover, not always being matched (as with photovoltaic electricity in nighttime, for instance). Sound energy management thus requires deployment both of an energy distribution network, and of energy storage capabilities.

Energy transport is effected by means of an energy carrier. Currently, the two main such carriers are electricity, and heat. Tomorrow, however, a new carrier may become dominant: hydrogen, this being converted into electricity and heat by means of fuel cells.

Finally, if energy is to be available at all times, it is essential that there should be the ability to store it: to "get it in a can," so to speak. Such storage may take a variety of forms. Energy may be stored in mechanical form (*potential energy*, in the case of the water reservoir of a hydroelectric dam, or *kinetic energy*, in the case of a flywheel), or in thermal (hot-water tank), chemical (gasoline tank, primary and storage batteries), or even magnetic (superconducting coil) form.

Energy management is thus a complex, involved craft, combining production, transformation, transport, and storage. In the current context of energy debate, it is becoming increasingly apparent that, tomorrow, energy networks will grow in size and number, in accordance with a multimodal approach (concurrent management of a number of networks combining diversified energy sources). New energy technologies are thus bound to play an essential part in these developments.
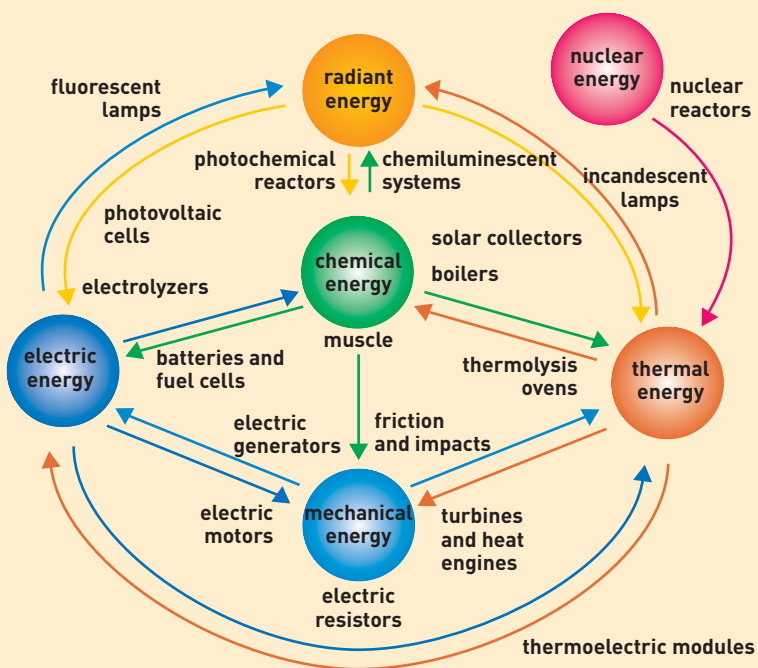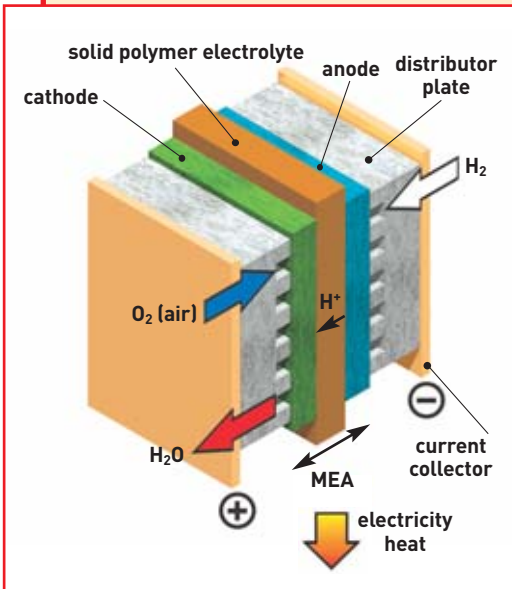

Figure 2.
Conversions of the six main forms of energy, with a few examples of energy converters.

How does a fuel cell work?

solid polymer electrolyte

cathode

anode

distributor plate

H_2

O_2 (air)

H^+

H_2O

MEA

current collector

⊖

⊕

electricity heat

Operating principle of the fuel cell: the example of the proton-exchange membrane fuel cell. MEA stands for membrane-electrode assembly.

The fuel cell is based on a principle discovered quite some time ago, since it was in 1839 that Sir William Grove constructed the first electrochemical cell working with hydrogen as its fuel, thus demonstrating the ability to generate electric current through direct conversion of the fuel's chemical energy. Since the fuel cell has the special characteristic of using two gases - hydrogen H_2 and oxygen O_2 - as its electrochemical couple, the oxidation-reduction reactions occurring inside the fuel cell are particularly simple. The reaction takes place inside a structure (the basic electrochemical cell), consisting essentially in two electrodes (the anode and cathode), separated by an electrolyte, i.e. a material that lets ions through. The electrodes employ catalysts, to activate, on the one side, the hydrogen oxidation reaction, and, on the other, the oxygen reduction reaction.

In the case of an acid-electrolyte cell (or proton exchange membrane fuel cell), the hydrogen at the anode is dissociated into protons (or hydrogen ions H^+) and electrons, in accordance with the oxidation reaction: $H_2 \rightarrow 2\ H^+ + 2\ e^-$. At the cathode, the oxygen, the electrons and the protons recombine to yield water: $2\ H^+ + 1/2\ O_2 + 2\ e^- \rightarrow H_2O$. The principle of the fuel cell is thus the converse of that of water electrolysis. The thermodynamic potential for such an electrochemical cell, consequently, stands at around 1.23 volt (V). However, in practice, the cell exhibits a voltage of about 0.6 V for current densities of 0.6-0.8 A/cm^2. The efficiency of such a fuel cell is thus equal to about 50%, the energy dissipated naturally being so dissipated in the form of heat.

E Storage batteries, cells and batteries: constantly improving performance

Storage batteries – also known as accumulators, or secondary batteries – and batteries – so-called primary batteries – are electrochemical systems used to store energy. They deliver, in the form of electric energy, expressed in watt–hours (Wh), the chemical energy generated by electrochemical reactions. These reactions are set in train inside a basic cell, between two electrodes plunged in an electrolyte, when a load, an electric motor, for instance, is connected to its terminals. Storage batteries are based on reversible electrochemical systems. They are rechargeable, by contrast to (primary) batteries, which are not. The term "battery" may further be used more specifically to denote an assembly of basic cells (whether rechargeable or not).

A storage battery, whichever technology is implemented, is essentially defined by three quantities. Its **gravimetric** (or **volumetric**) **energy density**, expressed in watt–hours per kilogram (Wh/kg) (or in watt–hours per liter [Wh/l]), corresponds to the amount of energy stored per unit mass (or per unit volume) of battery. Its **gravimetric power density**, expressed in watts per kilogram (W/kg), measures the amount of power (electric energy delivered per unit time) a unit mass of battery can deliver. Its **cyclability**, expressed as a number of cycles, [1] characterizes storage battery life, i.e. the number of times the battery can deliver an energy level higher than 80% of its nominal energy; this quantity is the one most frequently considered for portable applications.

Up to the late 1980s, the two main technologies prevalent on the market were lead–acid storage batteries (for vehicle start-up, backup power for telephone exchanges…), and nickel–cadmium storage batteries (portable tools, toys,

[1] One cycle includes one charge and one discharge.

emergency lighting…). Lead–acid technology, more widely referred to as lead–acid batteries, or lead batteries, is also denoted as lead–acid systems. Indeed, the chemical reactions employed involve lead oxide, forming the positive electrode (improperly termed the cathode), and lead from the negative electrode (anode), both plunged in a sulfuric acid solution forming the electrolyte. These reactions tend to convert the lead and lead oxide into lead sulfate, further yielding water. To recharge the battery, these reactions must be reversed, through circulation of a forced current. The disadvantages found with lead–acid technology (weight, fragility, use of a corrosive liquid) resulted in the development of alkaline storage batteries, of higher capacity (amount of energy delivered during discharge), yielding however a lower electromotive force (potential difference between the system's terminals, under open circuit conditions). Electrodes for these systems are either based on nickel and cadmium (nickel–cadmium storage batteries), or nickel oxide and zinc (nickel–zinc storage batteries), or silver oxide coupled to zinc, cadmium, or iron (silver-oxide storage batteries). All these technologies use a potassium hydroxide solution as electrolyte. Lead–acid technologies, as indeed alkaline batteries, are characterized by high reliability, however gravimetric energy densities remain low (30 Wh/kg for lead–acid, 50 Wh/kg for nickel–cadmium).

In the early 1990s, with the growth in the portable device market, two new technological pathways emerged: nickel–metal hydride storage batteries, and lithium storage batteries (see Box on *Operating principle of a lithium storage battery*). The first-mentioned pathway, involving a nickel-based positive electrode and a negative electrode – made of a hydrogen-absorbing alloy – plunged in a concentrated potassium hydroxide solution, allowed gravimetric energy

densities of 70–80 Wh/kg to be achieved. The second pathway had already been targeted by research around the late 1970s, with a view to finding electrochemical couples exhibiting better performance than the lead–acid or nickel–cadmium storage batteries used up to that point. Initial models were thus designed around a metallic-lithium-based negative electrode (lithium-metal pathway). However, that technology was faced with issues arising from poor reconstitution of the lithium negative electrode, over successive charging operations. As a result, around the early 1990s, research was initiated on a new, carbon-based type of negative electrode, this serving as a lithium-insertion compound. The lithium-ion pathway was born. Japanese manufacturers soon made their mark as leaders in the field. Already in business as portable device manufacturers, they saw the energy source as numbering among the strategic components for such devices. Thus it was that Sony, not initially involved in battery manufacture, decided, in the 1980s, to devote considerable resources to advance the technology, and make it suitable for industrialization. In February 1992, Sony announced, to general stupefaction, the immediate launching of industrial production of lithium-ion storage batteries. These early storage batteries exhibited limited performance (90 Wh/kg). Since then, these batteries have seen notable improvement (from 160 Wh/kg to over 180 Wh/kg in 2004), owing, on the one hand, to the technological advances made (reduction in the unproductive fraction of battery weight and volume), and, on the other, to optimization of materials performance. Gravimetric energy densities of over 200 Wh/kg are expected around 2005.

Operating principle of a lithium storage battery

During use, hence during discharge of the **storage battery**, lithium released by the **negative electrode** (<H>: host intercalation material) in **ion** form (Li$^+$) migrates through the ion-conducting **electrolyte** to intercalate into the **positive electrode** active material (<MLi>: lithium-insertion compound of the metal oxide type). Every Li$^+$ ion passing through the storage battery's internal circuit is exactly compensated for by an **electron** passing through its external circuit, thus generating a current. The **gra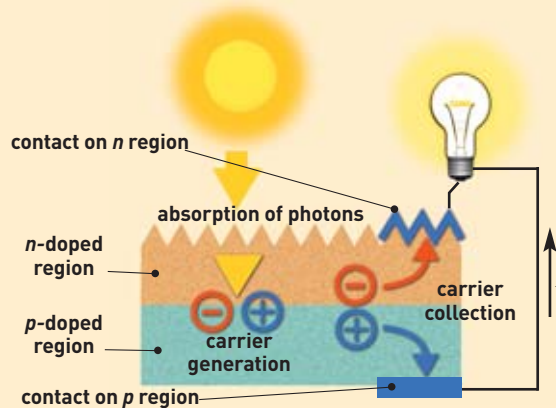vimetric energy density** yielded by these reactions is proportional both to the difference in potential between the two electrodes, and the quantity of lithium intercalating into the insertion material. It is further inversely proportional to system total mass. Now lithium is at the same time the lightest (molar atomic mass: 6.94 g), and the most highly **reducing** of metals: electrochemical systems using it may thus achieve voltages of 4 V, as against 1.5 V for other systems. This allows lithium batteries to deliver the highest gravimetric and volumetric energy densities (typically over 160 Wh/kg, and 400 Wh/l),
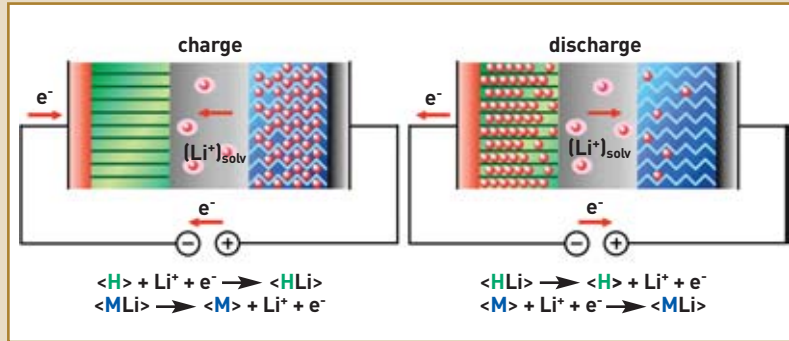
50% greater, on average, than those of conventional batteries. The operating principle of a lithium storage battery remains the same, whether a lithium-metal or carbon-based negative electrode is employed. In the latter case, the technological pathway is identified as lithium-ion, since lithium is never present in metal form in the battery, rather passing back and forth between the two lithium-insertion compounds contained in the positive and negative electrodes, at every charge or discharge of the battery.

charge

$$<H> + Li^+ + e^- \longrightarrow <HLi>$$
$$<MLi> \longrightarrow <M> + Li^+ + e^-$$

discharge

$$<HLi> \longrightarrow <H> + Li^+ + e^-$$
$$<M> + Li^+ + e^- \longrightarrow <MLi>$$

D How does a photovoltaic solar cell work?

The **photovoltaic effect** used in **solar cells** allows direct conversion of light energy from the Sun's rays into electricity, by way of the generation, and transport inside a **semiconductor** material, of positive and negative electric charges, through the action of light. This material features two regions, one exhibiting an excess of **electrons**, the other an electron deficit, respectively referred to as *n-type doped*, and *p-type doped*. When the former is brought into contact with the latter, excess electrons from the *n* material diffuse into the *p* material. The initially *n*-doped region becomes positively charged, and the initially *p*-doped region negatively charged. An electric field is thus set up between them, tending to force electrons back into the *n* region, and holes back into the *p* region. A **junction** (so-called *p-n* junction) has been set up. By placing metallic contacts on the *n* and *p* regions, a **diode** is obtained. When the junction is illuminated, **photons** having an energy equal to, or higher than, the width of the forbidden band, or **band gap**, yield their energy to the atoms, each photon causing an electron to move from the **valence band** to the **conduction band**, leaving behind it in turn a hole, also able to move around the material, thus

contact on *n* region

absorption of photons

***n*-doped region**

***p*-doped region**

carrier generation

carrier collection

I

contact on *p* region

giving rise to an **electron-hole pair**. Should a load be positioned at the cell's terminals, electrons from the *n* region will migrate back to the holes in the *p* region, by way of the outside connection, giving rise to a potential difference: an electric current passes (see Figure).

The effect thus involves, basically, the material's semiconducting properties, and its doping, to improve **conductivity**. **Silicon**, now used in most cells, was selected for the presence of four **valence** electrons in its outermost shell (column IV of the Mendeleyev periodic table). In solid silicon, each atom - termed a tetravalent atom - is bound to four neighbors, and all electrons in the outermost shell participate in the bonds. Should a silicon atom be substituted for by an atom from column V

(a phosphorus atom, for instance), one of its five valence electrons is not involved in the bonds; as a result of thermal agitation, it soon moves to the conduction band, thus becoming free to move through the crystal, leaving behind it an immobile hole, bound to the doping atom. There is electron conduction, and the semiconductor is designated as an *n-type doped semiconductor*. If, on the other hand, a silicon atom is substituted for by an atom from column III (boron, for instance), carrying three valence electrons, one electron is missing, if all bonds are to be maintained, and an electron may quickly move in to fill this gap, taking up the vacant orbital, as a result of thermal agitation. A hole thus arises in the valence band, contributing to conduction, and the semiconductor is said to be a *p-type doped semiconductor*. Atoms of elements such as boron or phosphorus are thus doping agents in silicon. Photovoltaic cells are assembled into **modules**.

Note: In *Organic photovoltaic cells: towards an all-polymer path...*, you will find the operating principle of organic photovoltaic cells (<u>Box, p. 122</u>).

Operating principle of an organic photovoltaic cell

Following absorption of photons by the polymer, bound electron-hole pairs (excitons) are generated, subsequently undergoing dissociation. Owing to inherent limitations in organic materials (exciton lifetime, low charge mobility), only a small fraction of photon-generated electron-hole pairs effectively contribute to the photocurrent. One of the main ideas is to achieve volume distribution of the photogeneration sites, to enhance exciton dissociation. This approach is based on increasing junction surface area, through deployment of an interpenetrating network of the donor-acceptor (D-A) type, effecting transport of holes (P^+) to the anode (indium-tin oxide [ITO]), and of electrons (e^-) to the metallic cathode (made e.g. of aluminum [Al]). While quantum separation efficiency, for photoinduced charges in systems associating a semiconducting polymer (of PPV or polythiophene type) with a fullerene derivative (PCBM), is thus close to unity, the challenge now is to restrict recombination and trapping processes limiting charge transport and collection at the electrodes, to improve overall device efficiency, this currently still being low (less than 5%). The rise of the pathway is also heavily dependent on mastery and understanding of cell aging mechanisms, but equally on mastery of thin-film technologies, to achieve protection of the device against atmospheric oxygen and water vapor.
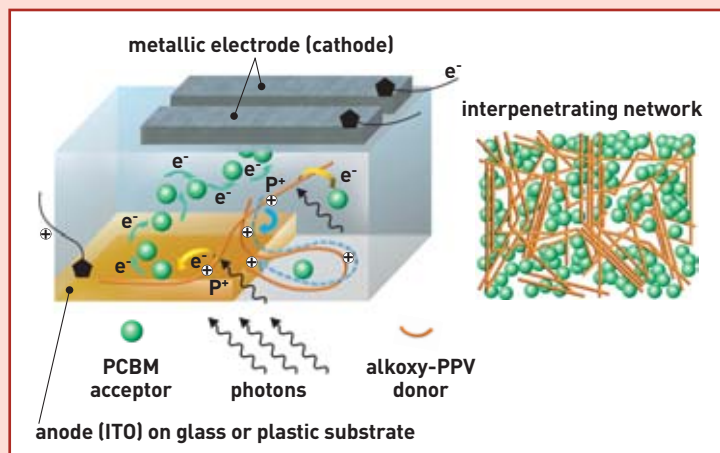

Figure from a presentation by S. Saricifitci (www.lios.at)

The blue dotted line shows the trajectory of holes inside the material.

B The greenhouse effect and CO$_2$

The Sun's energy reaching the ground warms the Earth, and transforms into infrared radiation. Just like the panes of a greenhouse – hence the name given to this mechanism – some of the gases present in the atmosphere trap part of this radiation, tending to warm the planet. Thus, in terms of power, the Earth receives, on average, slightly less than 240 watts/m^2. Without the greenhouse effect, mean temperature on Earth would stand at – 18 °C, and very little water would be present in liquid form. This effect thus has a beneficial influence, since it allows our planet to experience a mean temperature of 15 °C.

However, from the beginning of the industrial era, i.e. for more than a hundred years, humans have been releasing into the atmosphere gases (carbon dioxide, methane, nitrogen oxides, etc.) that artificially augment the greenhouse effect. Since 1750, this increase, with respect to "well-mixed" gases, has amounted to 2.43 W/m^2. Contributing as it does an "additional radiative forcing" of 1.46 W/m^2, carbon dioxide (CO$_2$) accounts for more than half of this "additional greenhouse effect," well ahead of methane (0.48 W/m^2), halocarbons (chlorofluorocarbons [CFCs], hydrochlorofluorocarbons [HCFCs], and hydrofluorocarbons [HFCs]), accounting for 0.34 W/m^2, and nitrogen dioxide (0.15 W/m^2). Further, the ozone in the troposphere exhibits a *positive* radiative forcing of 0.35 W/m^2 (however, it is estimated that depletion of the stratospheric ozone layer observed between 1979 and 2000 has resulted in a *negative* radiative forcing, of 0.15 W/m^2).

This addition to the natural greenhouse effect (155 W/m^2) is small, corresponding to an increase of about 1%. Nevertheless, it is practically certain that this has contributed to the rise in mean temperature, for our planet, of about 0.5 °C, observed over the 20th century (see Figure 1). If nothing is done to curb these emissions, carbon dioxide concentration in the atmosphere (see Figure 2) could double by 2100. From current world consumption [1] of fossil fuels (7,700 Mtoe), the mass of CO$_2$ currently produced may easily be computed: 20 billion tonnes per year!

This could result in a substantial increase in the greenhouse effect, causing, through nonlinear amplifying effects,

(1) European Community, Directorate General for Energy (DG XVII), "Conventional Wisdom" scenario (*European Energy to 2020: A scenario approach*, 1996).

profound alterations in climate. Most models predict that doubling the present carbon dioxide concentration would result, by the end of the 21st century, in a rise in temperature of some 2–3 °C. Some models even yield a bracket of 1.5–4.5°C, meaning dramatic consequences could be foreseen for the environment, such as a substantially rising sea level.

Such figures may seem small, entailing only minor consequences for the climate; that, however, is not the case. To understand this point, one should bear in mind that during the "little ice age," from 1450 to 1880, mean temperature only fell, in France, by 1 °C, on average. Some 6,000–8,000 years ago, as Western Europe experienced a war-

Figure 1. Departures in temperature (ΔT) from the average for the years 1961–1990, over the period 1860–2000, on a global scale (top), and over the past one thousand years in the northern hemisphere (bottom).

■ thermometer readings
■ estimated data
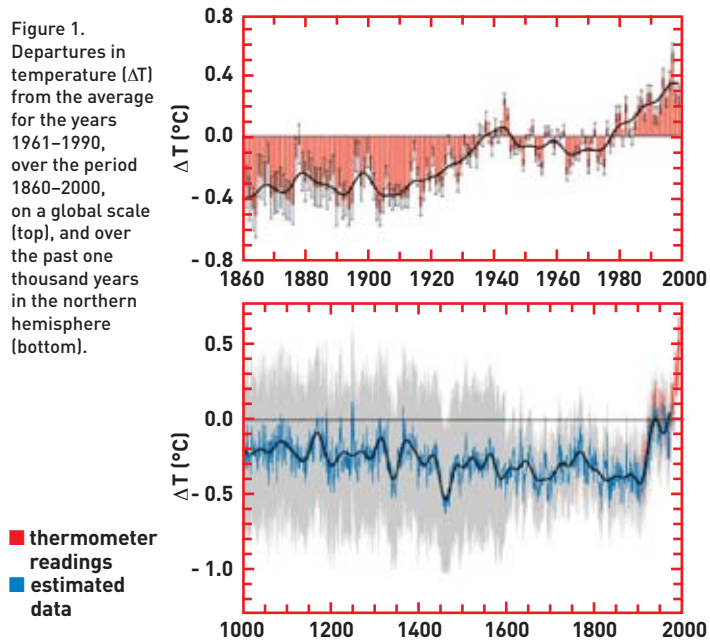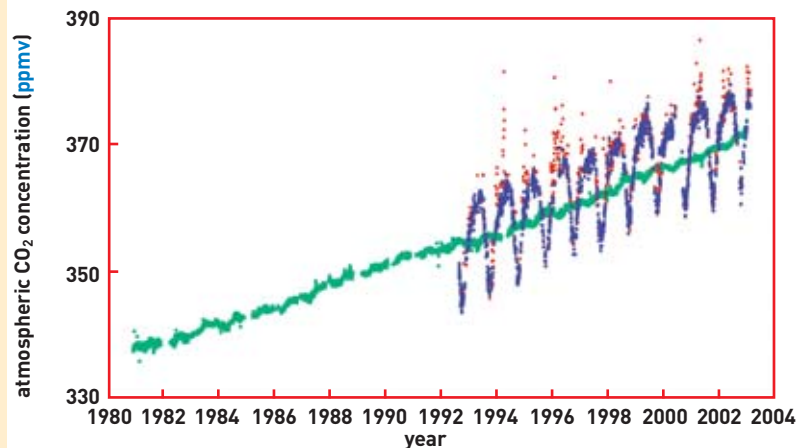
B The greenhouse effect and CO$_2$

Figure 2.
Evolution of atmospheric CO2 concentration since 1980, as measured on a daily basis by the automatic stations of the Climate and Environmental Science Laboratory (LSCE: Laboratoire des sciences du climat et de l'environnement), since 1981 on Amsterdam Island (Indian Ocean), and since 1992 at Mace Head, on the western coast of Ireland.
Readings on Amsterdam Island (shown in green), well away from any direct perturbation of human origin, essentially evidence the constant rise in concentration. The Mace Head site basically measures oceanic atmosphere (under normal conditions, westerly winds: blue). When wind conditions are reversed, the site receives a continental atmosphere, showing a strong excess in CO^2 (red plots), compared to oceanic atmosphere. Over the mean rise in CO$_2$ concentration is superimposed a marked seasonal modulation, due to plant vegetative cycle (chlorophyll photosynthesis), plants being CO$_2$ emitters in winter, and CO$_2$ absorbers in summer.

mer spell, with a mean temperature 2–3 °C higher than it is today, the Sahara was not a desert, but a region of abundant rainfalls. It is not so much the rise in temperature that gives cause for concern, as its rapid variation (in the course of one century). The large variations previously observed in nature all occurred over much longer timescales, for those at least of a global character. Thus, the last glaciation lasted 100,000 years, and the corresponding deglaciation took 10,000 years. The rapid variation we are currently experiencing may induce major, unexpected perturbations in the climate and the ecosystem, which will not always have time to adapt.

From Rio to Kyoto: the major conferences on the global environment

The evolution of the global environment has led to major conferences being organized, starting in the closing decade of the 20th century.
At the Earth Summit, held in **Rio de Janeiro** (June 1992), the United Nations Framework Convention on Climate Change was signed, this setting the goal of a stabilization of greenhouse gas emissions (this convention came into force on 21 March 1994).
At the Kyoto Conference (December 1997), the protocol was signed providing for a global reduction in emissions of such

gases, by an average 5.2% in the period 2008–2012, compared to 1990 levels, for OECD countries and Eastern European countries (including Russia). Reduction targets for the European Union and France are set at 8% and 0% respectively. The ways and means to meet these targets were debated, unsuccessfully, in November 2000 at **The Hague**. Subsequent conferences, held in **Marrakech** (2001), **Johannesburg** (Earth Summit held in August–September 2002), **New Delhi** (October 2002), **Moscow** (September–October 2003), and **Milan** (December 2003) had still not enabled, by 2004, this Kyoto Protocol to be brought into force, until Russia finally decided to ratify the document, at last allowing this enforcement in February 2005.
Under the impetus provided by the United Nations Environment Program (UNEP), the issues raised by substances that deplete the ozone layer in the atmosphere were addressed in **Vienna** (1985), and most importantly in **Montreal** (1987), where the protocol was signed, imposing a reduction in production and use

The Mace Head monitoring station, Ireland.

of chlorofluorocarbons (CFCs). This protocol was specified by amendments adopted in **London** (1990), imposing a ban on CFCs from 1 January 2000, and extending controls to other compounds (including HCFCs), **Copenhagen** (1992), **Montreal** (1997), and **Beijing** (1999).