



Europe and France: between energy **liberalization** and **environmental** hardening

The energy situation, in Europe, is characterized by gradual liberalization of the sector, and a hardening of environmental conservation measures. A twofold evolution, bringing France to the point where crucial choices have to be made.



Photo: voir

High-voltage line operated by RTE. The French market is currently open, to a proportion of 37%, for gas and electricity, in compliance with European Union targets.

At the root of the present moves to deregulate and liberalize gas and electricity markets, in Europe, there stands the wish to set out common rules for the internal market in energy. This was expressed in two foundational documents, the European Directive of 19 December 1996 concerning electricity, and the European Directive of 22 June 1998 concerning natural gas. Their philosophy is based on the free choice of supplier, for customers in the larger consumption brackets, so-called “eligible customers,” threshold for eligibility being brought down gradually, in stages (see Viewpoint, p. 12). Two new Directives were adopted on 26 June 2003, concerning common rules for the internal market in natural gas and electricity, providing, essentially, for market opening to all non-hou-

shold customers from 1 July 2004, and to all customers from 1 July 2007, thus expanding on the provisions of the earlier Directives of 1996 and 1998. Alongside these documents, organizing the liberalization of the energy market, the European Directive of 27 September 2001 on the promotion of electricity produced from **renewable energy** sources set national indicative targets, country by country, aiming to take the share of electricity of renewable origin, within the European Union, from the 12% it currently stands at, to 22% by 2010. In the environmental domain, Directives have also been adopted to set emission ceilings for large combustion plants, along with national emission ceilings for certain atmospheric pollutants. Finally, the European Directive of 11 February 2004

on the promotion of **cogeneration** based on a useful heat demand has been adopted, as was the European Directive of 16 December 2002 on the energy performance of buildings.

France: specific conditions

France is faced by specific conditions, characterized by the significant share of nuclear power among electricity-generation sources. In 2003, France produced 567 TWh electricity, of which 441 TWh were of nuclear origin. The share of renewable energies, standing at around 16%, means that France ranks as the leading European producer in this respect, however this is mainly due to the share of hydropower. To comply with the new European rules, and achieve the set targets, regulatory instruments have been enacted.

The French Law of 10 February 2000 concerning public service for electricity set in place the legal framework enabling transposition in France of the European Directive of 1996, by opening to competition the eligible customer market (consuming more than 16 GWh, initially, then more than 7 GWh, and finally all professional users from 1 July 2004), and providing for a mechanism for the compulsory purchase, by French national electricity utility EDF and non-nationalized utilities, of electricity generated from energy sources for which growth is sought. The law set out the distribution of responsibilities among actors on the electricity system scene, and set up – anticipating on the European Directive of 2003 – an Energy Regulation Commission, along with regulated tariffs for distribution networks. This law further instated a multiyear programming process for electricity production investments, first implemented by an order of 7 March 2003 setting out targets according to energy pathways, to be achieved by 2007. In this context, calls for tenders are to be published, to enable growth of production resources involving wind-turbines, both on land and offshore, or using **biomass**. This mechanism should ensure optimum achievement of the energy policy targets set out in the European Directive on renewable energies, and compliance with the multiyear programming of investments. Finally, the Law of 3 January 2003 concerning public service for energy opened the natural gas market to eligible customers, transposing the European Directive of 22 June 1998, at the same time modifying the Law of 10 February 2000 on electricity, further specifying some of its provisions.

Outcomes of the great National Debate on energy

A great National Energy Debate, organized by the French government in the first quarter of 2003, enabled five principles to be identified, as guides for a viable energy policy: contributing to economic competitiveness, bolstering energy independence, ensuring environmentally friendly development, safeguarding a right to energy at competitive price, and conformity with international coordination schemes. The conclusions from this debate served in the drawing up of the proposed strategic Orientation Law on Energy, which was approved, on a first reading, by the French Parliament in June 2004. This document reasserts the main goals of French energy policy: safeguarding energy independence,

conservation of the environment, vouchsafing competitive pricing for energy, along with social and regional cohesion, by ensuring access for all to energy. It further transposes a number of European Directives, concerning, in particular, renewable energies and energy performance of buildings, and sets up a market in energy savings certificates. It keeps the nuclear power option open as a prospect, providing for construction of an industrial demonstrator reactor of the EPR type. Finally, it sets out quantitative targets (reductions in energy intensiveness, curbing of **greenhouse gas** emissions, improved energy performance in new buildings...).

Concurrently, market opening was implemented by the Decrees of 18 May 2004 (natural gas) and 23 June 2004 (electricity), making all professional users eligible customers, this involving close to 3.5 million sites. Finally, the Law of 9 August 2004 concerning public service for electricity and natural gas, and electricity and gas utilities allows for modification of the statutes of national utilities EDF (Électricité de France) and GDF (Gaz de France) to limited liability companies (*sociétés anonymes*), at the same time specifying their public-service remit, and transposes the European Directives of June 2003 (legal separation of transport, managerial separation of distribution), while safeguarding the pension funding scheme for employees in the electricity and gas industries.

Indeed, energy policy, in the coming decades, must enable France to take up three major challenges: the drive to curb the **greenhouse effect**, gradual exhaustion of oil and gas reserves in the face of rising world demand, and the alleviation of worldwide disparities in consumption between North and South.

French policy must therefore set itself clear, quantitatively specified goals, such as the reduction by a factor 4 of greenhouse gas emissions by 2050. This should be supported by reinvigoration of a true energy efficiency and energy conservation policy. Potentials for energy savings have already been taken up in part, especially by industry, the only sector for which consumption has declined since 1990. Sector-specific measures, targeting the more energy-hungry goods (heat regulation in housing, energy labeling of equipment, voluntary consumption-limitation agreements for motorists...), have further allowed growth in consumptions to be curbed. New instruments now need to be devised, to carry through the tapping of more diffuse energy saving potentials. The long-term goal may only be achieved through major technological breakthroughs, which must be nurtured by fostering and developing research. Innovation has a fundamental part to play in this. For that purpose, it needs must focus on research aimed at technological breakthroughs with respect to energy production and consumption, and helping make available the new energy technologies (*see A sustained government effort to foster new energy technologies*, p. 13).

Finally, it should be stated that, for France, security of supply can but rely on a broadly diversified “energy mix,” both in terms of types of energy, and origins of supplies.

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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).

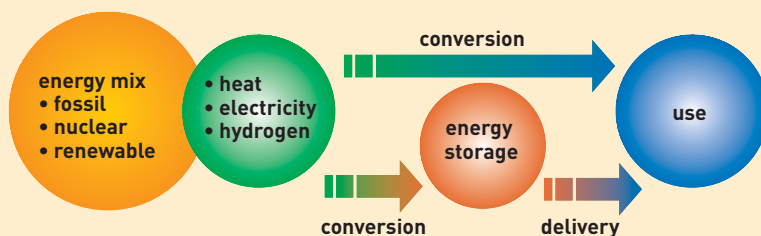


Figure 1. The energy scheme.

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.

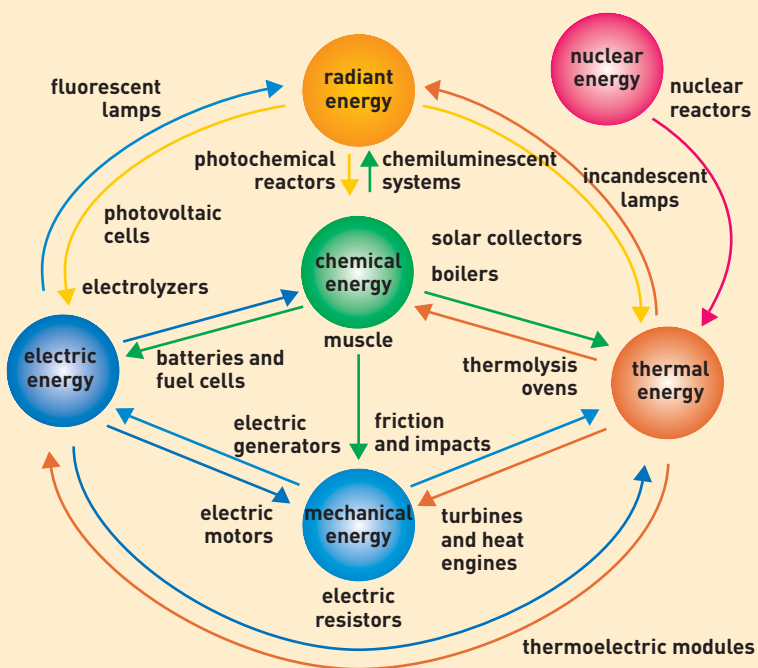
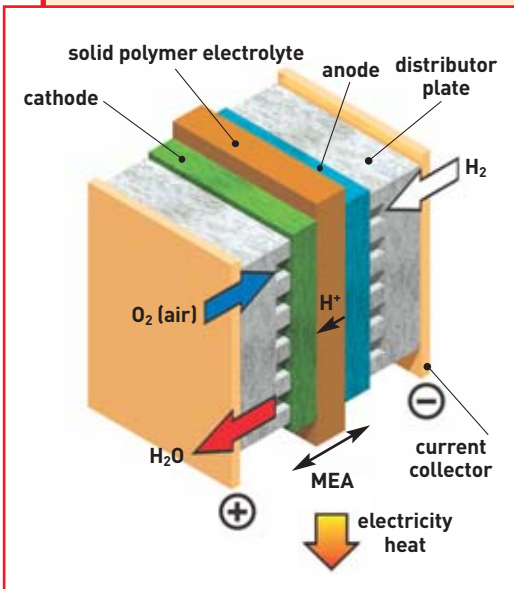


Figure 2. Conversions of the six main forms of energy, with a few examples of energy converters.

C How does a fuel cell work?



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 H₂ and oxygen O₂ - 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: $\text{H}_2 \rightarrow 2 \text{H}^+ + 2 \text{e}^-$. At the cathode, the oxygen, the electrons and the protons recombine to yield water: $2 \text{H}^+ + 1/2 \text{O}_2 + 2 \text{e}^- \rightarrow \text{H}_2\text{O}$. 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/cm². 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,

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

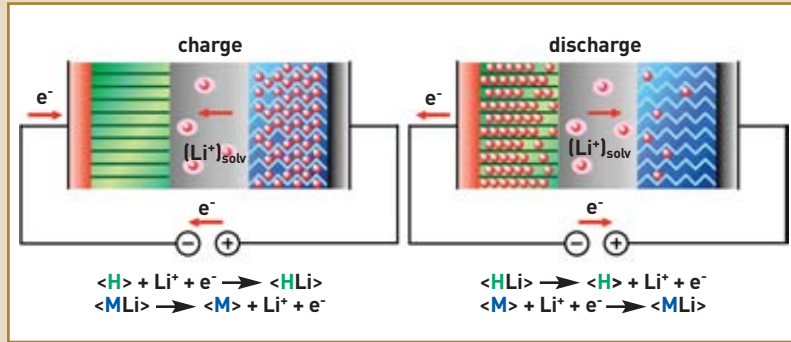
densities of 70–80 Wh/kg to be achieved. The second pathway had already been targeted by research around the late 1970s, with a view to finding electrochemical couples exhibiting better performance than the lead-acid or nickel-cadmium storage batteries used up to that point. Initial models were thus 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.

⁽¹⁾ One cycle includes one charge and one discharge.

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 **gravimetric 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.

B The greenhouse effect and CO₂

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/m²**. Without the **greenhouse effect**, mean temperature on Earth would stand at $-18\text{ }^{\circ}\text{C}$, 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 $15\text{ }^{\circ}\text{C}$.

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 (CO₂) 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, correspon-

ding 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 $0.5\text{ }^{\circ}\text{C}$, 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 CO₂ currently produced may easily be computed: 20 billion tonnes per year!

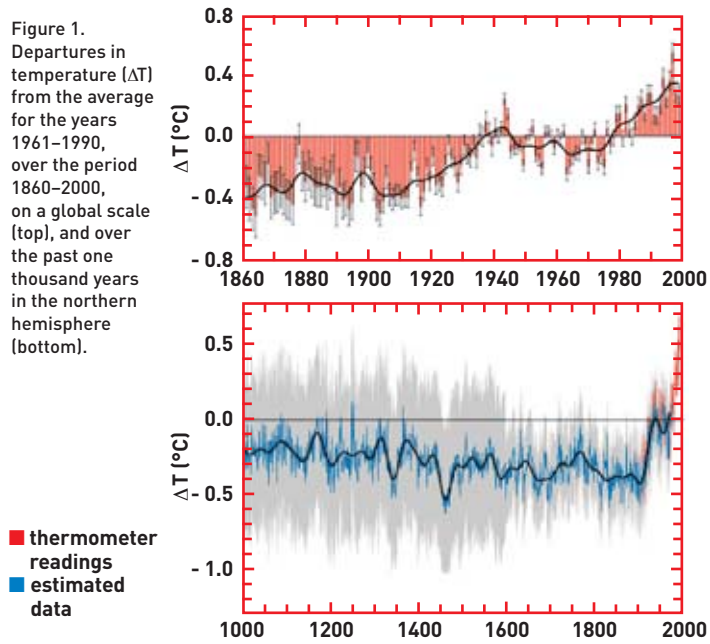
This could result in a substantial increase in the greenhouse effect, causing, through nonlinear amplifying effects,

(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 $2\text{--}3\text{ }^{\circ}\text{C}$. Some models even yield a bracket of $1.5\text{--}4.5\text{ }^{\circ}\text{C}$, 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 $1\text{ }^{\circ}\text{C}$, 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).



B The greenhouse effect and CO₂

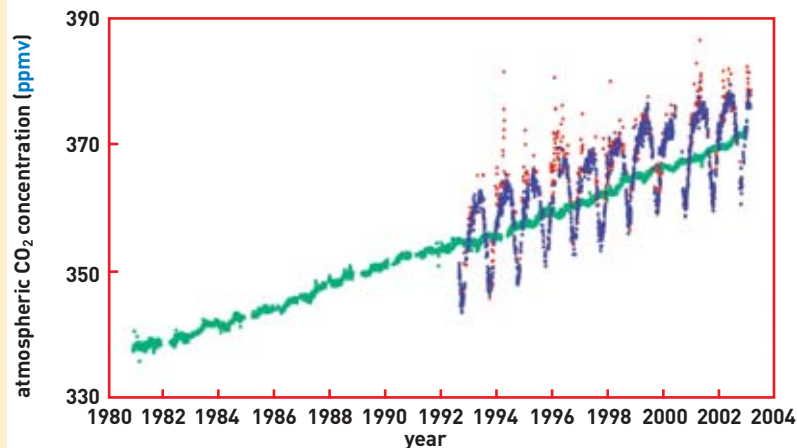


Figure 2.

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 CO₂ (red plots), compared to oceanic atmosphere. Over the mean rise in CO₂ concentration is superimposed a marked seasonal modulation, due to plant vegetative cycle (chlorophyll photosynthesis), plants being CO₂ emitters in winter, and CO₂ 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).