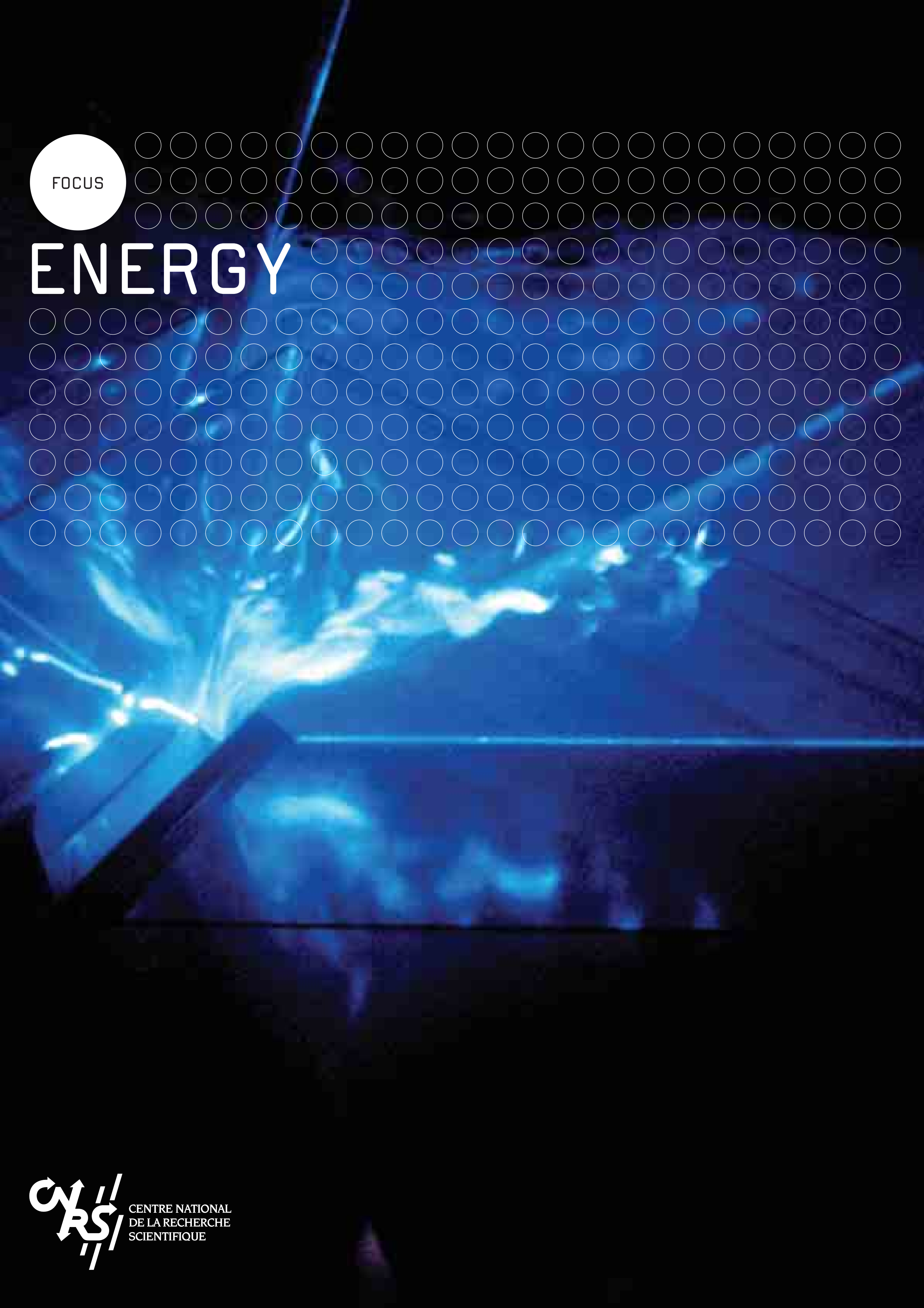
FOCUS

ENERGY



CENTRE NATIONAL
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ENERGY

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The global energy context

Mastering future energy requirements and ensuring their supply is one of the major political issues facing the whole planet. It is made even more difficult by the double challenge facing the human race: firstly, how to meet the energy needs of a world population which will grow even further in coming decades, and a large part of which expects social and economic development involving a greater demand for energy ; secondly, the need to decrease greenhouse gas emissions caused by the use of fossil fuels, and emissions of other pollutant gases, which threaten global climatic and environmental balances. This is the whole issue of sustainable development, where the word "development" is no less important than the idea of our responsibilities to future generations, as implied by the notion of "sustainability", in its three dimensions: economic, social and environmental.

At present, two billion human beings have access to only "traditional" forms of energy derived from wood and animal waste. At the same time the average consumption of an American is 14 MWh a year, while that of a European is 6 MWh and that of a Chinese or an Indian around 1 MWh a year. Furthermore, 85 % of energy needs are met today by fossil fuels (coal, oil, gas), all producing greenhouse gas emissions. Even despite the fact that the first measures to limit gas emissions within the framework of the Kyoto Protocol, which aims for an average 5 % reduction between 2008 and 2012 compared with emission rates for 1990, will not be met, the energy demand is expected nearly to double by 2050 because of emerging countries such as China, India or Brazil, whose main energy reserves are coal-based.

The issues behind energy-production methods and their fair distribution are therefore critical for the human race. Sustainable development implies a double approach in this context: steps must be taken firstly towards reducing energy consumption, and secondly towards replacing fossil fuels with new sources of energy. Production methods depend on political decisions directly influenced by energy availability and costs, population growth and economic development, decisions made even more difficult because, as history has shown, if energy consumption increases along with gross domestic product, these two figures become to some extent unrelated and their ratio can fluctuate significantly from one country to another.

CNRS - research and action

Research in the energy sector is therefore an essential component of any sustainable development policy. Only research can come up with technological solutions leading towards a new approach to the use of alternative sources of energy, without a priori exceptions: fossil energies, renewable energies, nuclear energy. It will also have to integrate basic research in the field of human and social sciences, which will have to deal with risk analysis, economic forecasts and energy-access methods, as well as technical adaptability and social acceptance. The role of human and social sciences is all the more important given that we do not at present have a common universal model for the "value" of energy for human beings and societies.

Since the first oil crisis in 1973, the CNRS (French National Center for Scientific Research) has been working on structured research in the field of energy. The successive programs (PIRDES, PIRSEM, ECOTECH, ECODEV) identified two main targets: thermal and photovoltaic solar energy and the optimization of energy conversion processes to improve energy efficiency. An important part of the research effort has also been devoted to industrial combustion and thermal engines. Furthermore, a general program (PACE) relating to the processing and future of radioactive waste, and innovative solutions for new reactors, has been undertaken in partnership with the CEA (French Atomic Energy Authority) and relevant manufacturers. Significant scientific and technological headway has been made in all these areas.

In response to the new requirements of the energy demand, CNRS embarked in 2001 upon a major study program alongside the research organizations involved in the energy sector, the French Ministry for Research, and industry. An interdisciplinary program, *Énergie*, resulted from this project. This program, which will be discussed in further detail in this publication, is based on five main subjects: new resources (solar and biomass energy), conversion (nuclear and waste processing), energy carriers (electricity, hydrogen, heat), uses (domestic, engines, fuel cells) and socio-economic impacts. Naturally, a scientific and technological watch will still be maintained on the other sectors.

The scientific community has been structured and organized around each of these areas. Over a hundred researchers and professors, and just as many doctoral students, are working on these different topics. Their common objective is to make headway in scientific and technological knowledge to overcome current problems, discover innovative concepts and invent acceptable reactor systems for the future. The cost of energy is a major issue, whatever its source, for member countries of the OECD (Organization for Economic Cooperation and Development), and especially for developing countries. To make energy costs acceptable, CNRS must work in partnership with industrialists, offering them new potentials, and accompanying them in their research and development work once the markets have been created. Markets will be opened through joint action between research organizations and industrials, pooling their knowledge and technology to respond to the populations energy demand. CNRS will be one of the first key actors in the ambitious national and European program currently in the preparation phase.

Resources

Context and issues

Energy sources, or primary energy, come in different forms: fossil fuels (coal, oil, natural gas), mechanical energy (hydraulic, wind, waves/tide), radiant energy (solar energy), and nuclear energy. The planet's supply (75 % of fossil origin, 10 % using biomass and renewable energy, 15 % in the form of electricity of hydraulic and nuclear origin) will become critically low over the next thirty to fifty years, especially the supply of fossil fuels. These are largely responsible for the CO_2 emissions polluting the atmosphere, and for the climate change. Society is therefore confronted with the necessity of substituting fossil resources with non-polluting renewable energy sources.

Certain renewable energy types (wind, hydraulic energy) have already reached maturity with their basic research phases essentially complete, requiring only technological supervision. In addition to supporting progress by exploiting these renewable energy types, for sustainable development and environmental protection, research efforts now need to focus on photovoltaic-generated electricity production, biomass and geothermal energy. These areas will require the most significant scientific and technological breakthroughs.

The photovoltaic electricity market is growing fast (35 % per year), despite relatively high costs and performance levels that still need considerable improvement. CNRS is involved in particular in research efforts on thin-film deposit techniques and on innovative processes such as organic PV cells.

The exploitation of biomass by pyrolysis and gasification is based on thermochemical conversion. It must be improved to attain high-quality biomass gasification as a means of generating bio-fuel quality hydrogen synthesis gas. Enzymatic and micro-biological transformation of wet-processed biomass residues is another process under development at CNRS. Research into bio-fuel/bio-ethanol production in the short-term, and into bio-diesels in the medium-term, is being conducted in parallel with research on biological production of hydrogen.

Thermal photovoltaic and solar energy

Energy generated via a photovoltaic process, based on the conversion of solar radiation into electricity, is seen to be strategic for sustainable development. It is therefore essential to maintain and even increase not only market stimulation measures, but also the associated research and development effort. CNRS has initiated research activity on existing or emerging materials and also accompanies the technological development of French companies in the photovoltaic sector.

Solar electricity today ...

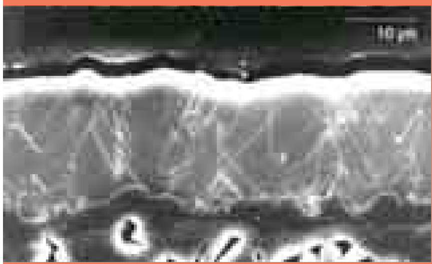
To lower the cost and increase the effectiveness of existing technologies based on crystalline silicon modules, CNRS researchers are working on the phenomena of impurity diffusion, purification of materials and passivation of structural defects. Ultimately, the aim is to facilitate the integration of photovoltaic components into electricity networks, aiming for a cost of 0,10 euro/kWh. A number of processes have already been transferred to industry. The target for the future is to obtain returns on cell conversions in the order of 18 to 20 %, by making efficient use of raw materials in industrial processes with an emphasis on thin plates (< 100 µm in thickness).

... and in the future

Promising alternatives investigated by CNRS laboratories, in the framework of industrial development, concern the use of thin layers of semiconductor materials (crystalline and amorphous silicon, chalcogenides) on various substrates (glass, metal, ceramic). Research work is focussed on crystallogenesis, transport properties and the manufacture of test cells. The use of low-cost polymer-based organic materials is also a consideration in the area of photovoltaic conversion. Work based on polymer films (polythiophene, polyacetylene) combined with interconnected networks of fullerene derivatives has had promising results. Further investigations are needed to better understand the photovoltaic element at a fundamental level and to develop the technique.

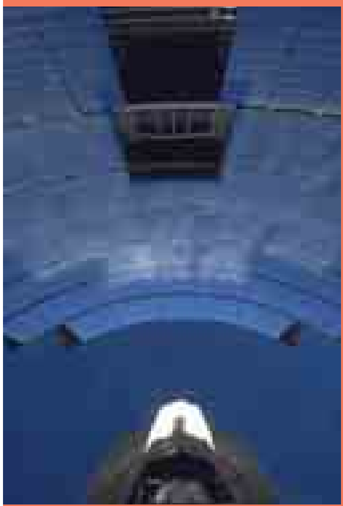
Conversion of solar radiation into heat

Thermal solar energy has aroused renewed interest thanks to developments in a new generation of higher-efficiency low-temperature sensors. These increase the rate of conversion of radiation into electricity or heat in the photovoltaic sensors to which they are sometimes linked. High-temperature solar electricity production is also promising: CNRS teams are developing new concepts for transporting and storing heat for its conversion into electricity. The use of solar energy concentration systems also enables testing of thermochemical hydrogen production cycles, and high-temperature water electrolysis.



Silicon film with 20-µm thickness on ceramic substrate. Savings in material (low cost) and very large surface-area (for roofs) are the major advantages of thin-layer solar energy cells.

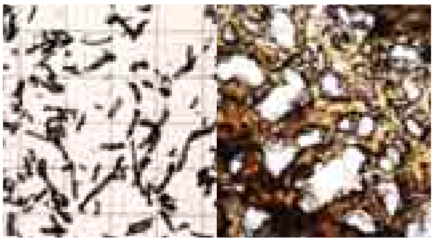
Installation of Photowatt modules within the framework of the HipHip project.



The Odeillo Four Solaire (Solar furnace), designed to concentrate solar radiation.

Pyrolysis - gasification of biomass for energy and chemistry

Biomass is a plentiful renewable source of energy which does not generate greenhouse gas build-up. It can be transformed at a high temperature by various pyrolysis – gasification processes. Vegetation biomass is transformed into products, mainly gaseous, which can then be used to produce heat, electricity, fuel substitutes or hydrogen. The future industrial development of such technologies requires research activities covering the full process chain, from the production of biomass to downstream energy use.



1/ Virgin cellulose particles.
2/ Cellulose particles exposed for 1/10 th of a second to intense heat. The formed liquid phase leads to their agglomeration. This phenomenon must be taken into consideration in designs for reactors.

The process of thermal degradation of biomass

The composition and structure of biomass are very complex and strongly depend on underlying type (forests, crops). The variable reactivity results that it can produce will require in-depth study. CNRS teams are endeavoring to comprehend in detail the intimate mechanisms of pyrolysis of the components of biomass (cellulose, lignin, hemicellulose). The problems result from the strong coupling that exists between the chemical processes and heating (slow or fast), the type and state of biomass (size, humidity, composition). The intention of this research is to control the thermal behavior of biomasses from different sources, in terms of product composition, notably gaseous.

Fast pyrolysis process of biomass. The cyclone reactor used, with a volume of 0.5 L, can transform 1 kg of sawdust per hour, into pyrolysis gas or oil.

High-temperature reactors and cleanliness of effluents

These processes are carried out in high-temperature reactors where the primary reactions described above are followed by secondary processes, the scale of which depends on operating conditions and on the type of reactor: hydrodynamic, heat and mass transfers, capacity. The effluents must also have a minimum level of impurities taking account of their ultimate purpose. The chemical engineering skills of the CNRS teams are put to use in researching reactors that are best suited for this most important aspect of biomass. The need to purify the products has also entailed research in the cracking process of by-products (tars), as well as the efficient elimination of dust particles, aerosols and alkalis. The aim of all this work is to design, using reliable scaling laws, industrial-scale processes that are clean and selective.

Reactor in which cellulose or lignin pellets are exposed to brief controlled heat fluxes.

Management and profitability of industrial processes

All stages of each process must be integrated into the methodology of proceeding from the resource (biomass) to the end-use of effluents. It is essential to discover solutions suited to the most favorable combination between type, availability, transport and storage of biomass, the processing capacity (local or centralized units), energy optimization, the type of downstream use that is envisaged (heat, electricity, fuel, chemistry), geopolitical and socio-economic data.

Bio-fuels

Bio-fuels come from a renewable raw material that constitutes a "sink" of CO_2 by photosynthesis, a positive factor in the fight against greenhouse gases. Two types of bio-fuels can contribute in the short and medium term: bio-ethanol (petroleum) and methyl esters (diesel). In the longer term, biological hydrogen production is a promising area into which CNRS has already started research.

Bio-ethanol and methyl esters

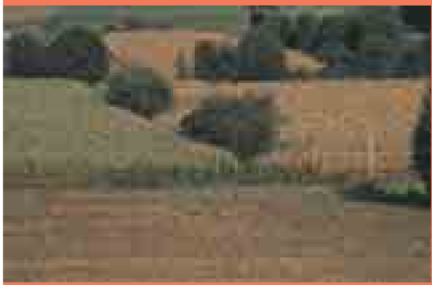
These biofuels have significant scope for progress. Research conducted by CNRS on bio-ethanol especially concerns the enlargement of the spectrum of sugars fermentable in ethanol, the use of new raw materials and the design and production of more powerful biocatalysts. This molecular physiology and microbiological approach will increase the performance of the ethanol-producing micro-organisms, generally yeast. Research into biodiesels, some of which (canola methyl esters) have already been marketed, is currently evolving towards enzymatic transformation as an alternative to chemical methods, and towards perfecting oilseed plants by altering their lipidic composition for a better quality of fuel.

Photobiological production of hydrogen

Algae can be used to produce hydrogen from the photodissociation of water. This reaction is limited however by the extra-sensitivity of hydrogenases with regard to oxygen. Two methods are being investigated to overcome this problem. Firstly, the separation in time (and/or space) of the production of hydrogen and the photolysis of water. Secondly, the creation of hydrogenases that are not sensitive to oxygen by site directed mutagenesis. This will only become possible with a better knowledge of the structure and functioning of the enzyme (crystallography). Understanding the functional and structural relationship of the hydrogenase will also allow the design of biocatalysts and artificial catalysts by a biomimetic approach.

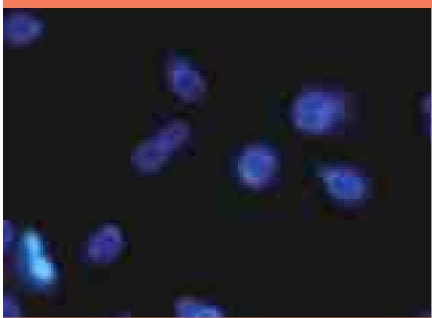
Potentialities

The new regulatory environment envisages an increase in the marketing of bio-fuels throughout Europe with a market-share of 5.75 % by 2010. Meeting this forecast would entail a bio-fuel demand of 3 Mtoe in France and of 18 Mtoe in Europe (Mtoe: Million tons oil equivalent). The significant value in France of agricultural or forest "biomass" resources would allow the dedication of a land area of 4 million hectares to the active cultivation of energy crops, contributing an annual production of 10 Mtoe. This situation, which is quite realistic, could generate a 24-million-ton saving in CO_2 emissions by comparison to the use of fossil energy.



Cereal crops, a new raw material for producing the fuels of the future.

Pilot laboratory for the production of bio-ethanol.



Ethanol-producing yeasts in growth.

Conversions

Context and issues

Seen from the perspective of their ultimate use, primary energy types require conversion (in a different form of energy) or transformation (evolution of the same form of energy). The combustion of fossil resources and waste, as well as nuclear fission, are the main processes involved in these conversions: the heat produced drives electricity-producing turbines. Heat exchangers are needed to extract heat from the core of the reactors and to transfer it to the turbines. They have long been the subject of multi-disciplinary study at the CNRS within the framework of generic research. They are one of the key economic factors of the processes and research is directed towards multifunctional exchangers integrating new materials.

Nuclear fission, which does not create greenhouse gas emission, nevertheless produces radioactive waste requiring treatment and end-of-use storage. Within the framework of the PACE program (program for the electronuclear cycle end-point), CNRS is developing solutions capable of improving waste-disposal and storage safety. The organization also works on new methods of production for the nuclear energy of the future (less polluting nuclear processes) and provides support to the CEA (French Atomic Energy Authority) on the ITER project (thermonuclear fusion project).

Energy conversion by combustion often has low efficiency levels, leading to the production of greenhouse gases (CO_2, CH_4) and polluting gases, and the discharge of high levels of energy in the form of heat, which ought to be recycled. The need to optimize the integration of processes leads to research on ways to maximize useful energy and on concepts of coproduction. To this end, criteria based on the quantity and quality of energy used are being developed by the CNRS school of thermodynamics to determine the exergetic efficiency, a far more precise basis for analysis than energy efficiency. CNRS favors the development of these industrial processes of the future with two imperatives: the minimization of the production of greenhouse gases as well as their destruction at the source or their storage.

Accumulation and storage of waste

Prompted by the Bataille law on nuclear waste management, CNRS set up the interdisciplinary PACE program, dedicated to research on the downstream side of the nuclear power cycle. The goal of this program is to minimize the contamination and environmental impact of nuclear waste. Part of the work aims at coming up with solutions for increasing the safety of long-term accumulation (research on materials) and storage of nuclear waste (geo-sciences).

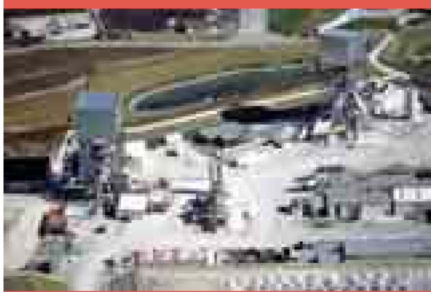
Accumulation and storage of nuclear waste

No process of transmutation can entirely eliminate the volume of waste inevitably generated by industrial processes. Modern waste management will involve careful segregation of the more or less mobile radiotoxic elements (plutonium and heavy elements, iodine and cesium) that result from the phenomenon of nuclear fission. CNRS teams contribute to research into chemical compounds that can selectively extract these elements from the irradiated fuel, either for their specific storage, or for their transmutation. By studying the natural analogues, these teams are making progress towards understanding the sorption mechanisms of these elements on solids, or their discharge and migration into the geosphere and biosphere. They are working on developping and assessing new solid compounds whose confinement properties will not be destroyed, in the long term, by radioactivity and the resulting high temperature.

Monazite is a rare earth mineral (natural analogue), which usually contains thorium or uranium. Its grains act as a perfectly sealed system for these nuclei, despite factors of erosion and transportation.

Storage in deep geological formations

CNRS teams are involved in drilling work (to depths of more than 500 m) for the wells of the Meuse/Haute-Marne underground laboratory. Here one relies on geological material to confine the radioactive elements. The laboratory has to study the geomechanical, geophysical and geochemical conditions needed for the storage of radioactive waste in deep geological layers (in this case, clay).
The task of CNRS is to record the initial state of the site, the nature and state of the traversed rock layers, to determine and characterize the damaged zone, and to assess the retention capacities and healing properties, as well as the absence of fracturing. These characteristics depend largely on the presence and properties of the water in the vicinity of the site, whose underlying history on a geological scale is supplied by the isotopic analysis of interstitial waters. The difficulty in collecting ground water, linked to the very low permeability of the site's clay, makes it essential to develop specific techniques. Knowing the porosity and the permeability of the zone in question gives important indications on potential radioelement migration outside the site. Disturbances induced by the drilling of wells are identified, monitored and quantified. Finally, the absence of any faults and seismicity in a site planned to hold radioactive waste over a time scale on the order of one hundred thousand years must be established.



Drilling devices for the two wells at the Meuse/Haute-Marne site.

Waste processing

One of the elements of the Bataille law recommends the search for transmutation processes for radioactive waste. This would entail the reactor-transformation of elements with low energy content and a radioactive half-life of tens of thousands of years into elements with a much shorter half-life, which would make their radiotoxicity far more manageable. This research work comes under the second section of the PACE program.

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Component of a modern accelerator: supraconductor cavity made of niobium. The importance of the cleanliness of the surface explains why the work is being carried out in a clean room.

Waste incineration ...

Nuclear reactors currently function by the fission of uranium-235, which is present in 0.7% of natural uranium. The production of energy is inevitably accompanied by the production of radioactive and radiotoxic elements. In the long run, and schematically, the most dangerous of these are the isotopes of plutonium, along with those of neptunium, americium and curium, three elements known as minor actinides. Their half-life, the duration over which their activity decreases by half, can reach several tens of thousands of years. The production of these wastes is due to the high concentration of uranium-238 in the heart of reactors. In the past decade, research has been carried out on the disposal of these nuclei via transmutation, that is by bringing about their fission in reactors specifically designed for this purpose. These dangerous nuclei would then be transformed into nuclei with much shorter life spans, which would quickly become harmless. For safety reasons, linked to the neutronic properties of the elements which are to be transmuted, incineration reactors will have to be subcritical: to maintain the chain reaction, they would have to be fed continuously by an external source of neutrons created by a phenomenon known as spallation, by means of a powerful accelerator beam. This is the concept behind the hybrid reactor.

© CEA.

The GENEPI accelerator (right) produces neutron pulses at the end of the pipe at the center of the fuel (in blue). This is a method for studying sub-critical devices.

... in hybrid reactors

Such a subcritical system will call for numerous innovations, in both physics and technology. Research and development on high-intensity proton acceleration is being conducted at CNRS. The objective is to develop a laser beam whose power can reach 1 Megawatt. Work is currently underway in basic nuclear physics, on the parameters specific to spallation reactions, as well as in physical chemistry, on the materials of a target capable of preserving its physical integrity for years. Numerous experiments have measured the rates of the reactions, little understood to date, that take place in this type of reactor, the damage brought about by elements produced within the materials of the spallation target, the incineration capacities and the very peculiar neutron behaviour of a subcritical reactor (monitoring and safety). Finally, the material must be found for the transmutation matrices that contain elements to be incinerated and that are placed in an intense stream of neutrons. These studies are supported by the European program 'Euratom'. The construction, on a European level, of an experimental hybrid reactor is currently being discussed. Scheduled to be operational by 2015, it will have to demonstrate the technical feasibility of waste incineration.

Nuclear energy of the future

The CNRS applies its skills in fundamental research and its methods of scientific expertise to the evaluation of nuclear energy production processes, since the least polluting processes are needed to respond to the challenge of sustainable development for the 21st century.

Production of nuclear energy and sustainable development

If nearly 75 % of the world's energy production today derives from fossil fuels, nuclear energy will be required to play an increasingly important role in the future, not only for the production of electricity without the emission of greenhouse gases, but also for other forms of energy (heat, hydrogen, desalination of sea water). However necessary, the extension of current reactors based on the uranium cycle can only be a transient solution, because of the inefficient use of the resource and the fact that the fuel cycle is never terminated. For nuclear energy production to reach the objectives set for it, researchers must optimize the use of resources, propose a reliable waste management system, and improve the safety of reactors. CNRS, in close collaboration with the CEA (French Atomic Energy Authority), has undertaken the study of extremely innovative reactors, dedicated either to the incineration of waste produced by current uranium-based processes, or to the sustainable production of energy by using the thorium cycle, which generates fewer transuranic elements, eliminating the need for hybrid-reactor incineration and burning a lower quantity of fissionable material.

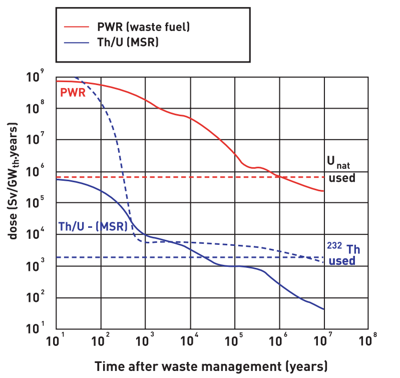
Nuclear energy of the future

These new options for the nuclear energy of the future, based on the optimal use of uranium (fast spectrum, gas-cooled reactors) and thorium (epithermal spectrum, molten-salt reactors), should between the two of them supply 20 % of global production by 2050. Minimizing the production of waste, they promise optimized management of current waste, with the used fuel supplying part of the new fuel.
A system optimized for the use of thorium would be a molten-salt reactor, in which the liquid fuel circulates, which is also the heat carrier. This system presents such theoretical benefits that it is being studied and documented as thoroughly as possible. CNRS is beginning experiments intended in particular to validate the key point of partial, but continuous reprocessing of the fuel. These experiments are conducted in national (EDF, CEA (French Atomic Energy Authority)) and international (European Union master programs) collaborative programs.

Prospects

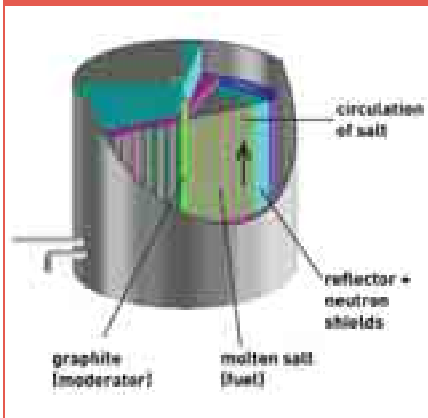
The current outlook is towards validation studies for both types of nuclear reactors discussed above, which appear to be highly complementary. The work of CNRS concentrates especially on thorium-fuelled reactors, which are highly flexible and minimize waste. Additional work is being conducted on the inevitable transition from current to future nuclear energy: methods of deployment, evolution of inventories and the management of waste fuels.

Radiotoxicity of actinides discharged by different cycles in equilibrium



DR.

The comparison of the two curves shows that at all time-scales, the Th/U cycle (blue) produces far less radiotoxic material than the current U/Pu cycle (red).
The dotted curve shows that the danger associated with fission products disappears after approximately 500 years.



© LPSC Grenoble, O. Meplan.

In a molten salt reactor (MSR) based on the Th/U cycle, the liquid fuel circulates in a block of graphite where it undergoes fission.
It can then be externally processed

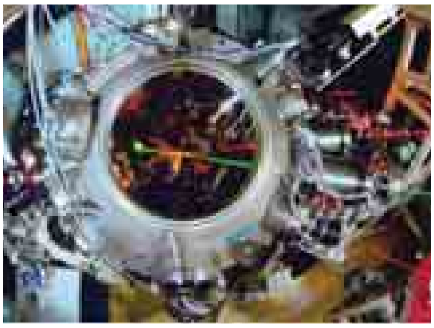
Controlled thermonuclear fusion

Controlling thermonuclear fusion is an objective with much potential since it involves reproducing on earth a phenomenon already at work in the stars: the fusion of light elements accompanied by a high discharge of energy, producing no greenhouse gas emission and no long-lived radioactive waste. Deuterium and lithium, "fuels" for the fusion, are plentiful in sea water, which would guarantee the availability of resources and national energy independence. France has begun working on the construction of large machines (ITER tokamak, megajoule laser) corresponding to both the processes, magnetic and inertial, of controlled thermonuclear fusion.

In this experimantal facility of the Plasma Physics and Technology Laboratory (LPTP) a plasma with toroidal configuration is created to study plasma turbulence in conditions similar to those of large tokamaks, and to develop associated diagnostic techniques.

The magnetic confinement process

In this process, a mixture of deuterium and tritium, in a hot plasma state, is confined by magnetic fields in machines known as tokamak reactors. France is a candidate for hosting the international ITER project, a very large-size tokamak. One of its objectives will be to control, over long time-periods (500 seconds), plasmas producing fusion energy ten times greater than the energy injected. CNRS, whose excellence in the field of hot plasma physics is internationally recognized, is involved in the basic physics of this major project. CNRS laboratories, in association with the CEA (French Atomic Energy Authority), are working on plasma stability, properties, and heating as well as on the development of appropriate diagnostics. This work concentrates on the understanding and control of plasma – wall interactions, turbulence and its impact on thermal transport, the generation of continuous current, as well as the dynamics of suprathermal populations in the thermonuclear regime. The ITER project should also enable researchers to examine other related areas of interest for a future experimental reactor, and to involve disciplines such as material physics and nuclear physics ...



In this experimental facility at LULI, six high-power laser beams can be focused on a target of several hundred microns, in order to study laser-plasma interaction, equations of state and the atomic physics of hot, dense plasmas.

The inertial confinement fusion process

In the "inertial" fusion process, laser beams or particle beams compress a mixture of deuterium and tritium enclosed in a capsule, thus producing a dense and hot plasma. The thermonuclear combustion of this plasma occurs in less than a billionth of a second. CNRS has been supporting basic research on this process for over twenty years now, in matters of theory, numerical modelling and experiments. The organization operates a high-power laser facility, the Laboratory for the Use of Intense Lasers (LULI), which is also a major European instrument. The experimental work carried out at the LULI facility focuses on high-intensity laser-plasma interactions, non-linear or relativistic, aiming for the analysis of laser heating, thermal transport, hydrodynamics, the equations of state of hot, dense matter, the atomic physics of hot plasmas and highly-ionized states in conditions close to those found in stellar plasmas.

CO_2 combustion and capture

Combustion remains the most widely used means to convert energy for use in transportation, industry and the tertiary sector, but it contributes to a significant share of environmental degradation at a planetary level, by releasing greenhouse gases and large quantities of pollutants (nitrogen oxides and sulphur oxides, dioxins, particulates) into the atmosphere. The optimization of energy yields, the reduction and even the capture of chemical pollutants, for the protection of the environment and human health, remain the priorities to be reached, along with the permanent concern for the safety of the facilities.

Optimizing combustion

Basic studies in the fields of fluid mechanics, heat transfer and chemistry are essential in order to improve our knowledge of physical phenomena associated with combustion. To address industrial concerns, CNRS laboratories are currently investigating the ability of systems to accept new fuels produced from biomass, refinery residues, coal, and industrial or domestic waste. For that purpose, the gasification or pyrolysis of these fuels seem to be the most appropriate processes for obtaining clean combustion of the synthetic gases formed (CO and H_2). The optimization of such processes often leads to unstable flame regimes that can impair the operation of devices and even lead to their deterioration. Data acquired by CNRS in partnership with manufacturers are used to develop innovative, clean, efficient and reliable combustion processes for engines, industrial and domestic furnaces, incinerators and gas turbines. These systems are designed to be coupled with a separation unit for the capture and sequestration of carbon (or of CO_2) upstream or downstream of the combustion chamber.

Swirl-stabilized burner flame.

CO_2 Capture

At present, four main methods of capture are possible: cryogenics, gas – liquid absorption, adsorption on active carbon or on zeolites, membrane separation. CNRS has undertaken several research projects on adsorption and on membranes, bringing together researchers from several scientific disciplines to work in three main directions: the development of new materials, the design of selective membranes and high-density modules, and the development of hybrid processes combining filtration and catalytic transformation. These processes are intended for the recovery *in situ* of the CO_2 produced during industrial combustion, prior to storage. For that purpose, experimental studies and modelling in laboratories and on technological platforms will allow a better grasp of the combination of physical phenomena involved, a vision of the industrial process to be implemented and an assessment of the techno-economic impact.

Study of a combustion regime of natural gas with high re-circulation of burnt gases.

Energy carriers

Context and issues

An energy carrier must be appropriate for its task, easy to store and transportable with minimum loss from the point of view of both quantity and quality of energy, and lastly it must be fully suited for its intended ultimate use, all of this in acceptable safety conditions. CNRS is currently working on three carriers of the future.

The most widely used carrier is electricity, thanks to its ease of use. Managing electricity will become crucially important within the framework of the deregulation of the energy market (2006): new production technologies and new network architectures will lead to large-scale problems of connection, congestion, control of the economic viability of planned development and finally, acceptability. CNRS is committed to resolving these problems, with a particular focus on storage.

The hydrogen carrier is very promising, since its final conversions do not involve the production of greenhouse gas. A significant gain in productivity can be obtained by catalytic methods, the use of thermochemical cycles, electrolysis at high-temperature or from renewable energy sources, and finally by photocatalysis or photobiology. The introduction of this carrier, converted to electricity within fuel cells, requires dynamic storage systems with high mass and volume capacity: metal hydrides and carbon nanomaterial processes are to be developed gradually.

With regard to the heat carrier, the main obstacles arise from quality loss during conversion or transformation. The focal point of current research is the temperature level of the heat, inside heat exchangers and during transport in the form of sensible or latent heat, and finally during the storage/de-storage phases.

CNRS has the objective of fully mastering these three carriers, which will require intense multidisciplinary research to remove the associated obstacles.

Electricity

The production of electricity is today concentrated around very high-power units. The deregulation of the energy market and the production of electricity via renewable energy sources will change this and contribute to the massive development of decentralized production at lower power. This type of production will contribute to reinforcing the reliability of the energy supply and will represent for emerging countries the opportunity to access electricity faster and at lower cost.

Decentralized energy production: transport and distribution

The introduction of low or medium power units at different points along the network, characteristic of "active distribution", will significantly change the energy flow in the network. It will also entail further research such as the use of protection and piloting devices suitable for one-way energy flow. CNRS is dealing with the promotion of a safe energy flow management system for these future networks, without which the electric system will not be fully operational. This management requires interdisciplinary research in areas such as interconnections, distribution reliability, the distributed control of decentralized units and the development of new architectures, the economic viability and acceptability of which have not yet been proven.

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Windmill.

Connecting to the network of intermittent energy

The diversification of electricity sources, which certainly includes intermittent, renewable energy sources (wind, photovoltaic) and production systems distributed over numerous sites, raises problems of connecting to the network. Power electronic devices must be capable in such a context of supporting high voltages (20 kV), which will involve research on components and on the architecture of converters. Another field of original research concerns the switching of high currents by limiting the losses and drops in voltage on the output of fuel cells and photovoltaic devices. Finally the use of high-temperature supraconductive materials within cables or protective casing is also being studied for specific applications.

Storing electricity

Electricity storage, which is impossible in the current context, will be required at certain points in the network to minimize intermittent supply. High-power buffer batteries and, for example, super-condensers will be needed for that purpose. Another aspect of electrical energy storage is being considered for low power, small scale applications. This involves electrochemical, mechanical or even electromagnetic methods which make it possible to maintain the energy supply whatever the operating conditions of the production units (lack of wind or sun, disconnection of a supplier). In the case of land transportation, high-capacity batteries are being studied as storage elements for the electric engines of hybrid vehicles.

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Electric power lines in the Dijon region.

Energy carriers

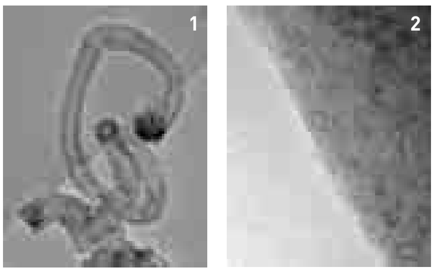
Hydrogen

Hydrogen seems to be a promising potential – carrier to respond to energy supply issues of the future because it is suited to the majority of primary energy sources for its production (fossil hydrocarbons in the short-term, and renewable resources in the medium-term). Downstream, it appears to be an ideal source of chemical energy for fuel cells, internal combustion engines and in the field of pollution control.

View of a catalytic process of hydrogen production on a structured reactor, from the nanoscopic scale (monolith crosspiece in honeycomb covered with its catalytic layer – figure 1) to the laboratory reactor (equivalent to a power of 1 kW – figure 3), *via* the overall structure of the monolith (figure 2).

Hydrogen production by chemical and catalytic processes

Low-cost hydrogen production currently exists for large tonnages on industrial sites. However, the investment is prohibitive when the quantity of hydrogen to be produced is small (< 500 m^3 /h), as is the case for fuel cells and on-site applications (range 0 - 300 m^3 /h). Besides, current production techniques make use of fossil energy sources, and therefore release carbon dioxide that is harmful to the environment.
For the short and medium-term (5 to 15 years), CNRS is setting out to prepare future production processes for sustainable development (bioproduction of hydrogen, gasification of biomass, thermochemical cycles, advanced electrolysis based on the use of renewable energy sources), as well as improving and innovating on existing technologies (reforming of hydrocarbons and gasification of carbon). Indeed, demand is strong for low cost, low-flowrate, compact reformers with powerful kinetics that are compatible with several fuel-types, for localized or on-board applications.
In the long term (15 to 30 years), CNRS intends to develop new solutions and technologies for hydrogen production in large quantities, centralized or delocalized and most importantly low-polluting. The cycle times in this domain are lengthy and, as is already the case in the United States and Japan, it is essential to begin research and development (R&D) immediately on these new areas in order to reach maturity in approximately twenty years.



1/ The catalytic decomposition of ethylene dissociated at 600 °C on an iron-copper catalyzer leads preferentially to carbon nanofibers (2 µm in length, 70 nm in outer diameter).
2/ Close-up of the previous photo. Observation of carbon planes in a nanofiber.

Hydrogen storage

CNRS is conducting research on various methods of storage with the aim of producing realistic prototypes and developing them industrially. “Liquefied H_2” and “high pressure” (> 70 MPa) methods are operational; however there are still problems linked to cost, structural and material damage, and safety. No satisfactory solution has been found for automotive applications, and CNRS is working on two potential methods that involve materials with a high storage capacity: low pressure (0.2 MPa) adsorption/reaction in intermetal alloys and adsorption on medium pressure (10-20 MPa) carbon nanostructures. The obstacle is being able to obtain these materials and their associated storage systems whilst also satisfying criteria of volume and mass capacity, of mechanical behavior of the materials, and of economic and energy costs. Success in this area will depend on design, synthesis and characterization of new materials, on a better understanding of the phenomena of the interaction between hydrogen and materials, and on mastering the production and use of materials in reservoirs as well as the dynamics involved in storage/withdrawal using these reservoirs. Theoretical and experimental work is also being carried out at microscopic (molecular) and macroscopic (reservoir) levels.

Heat

Heat, in the context of the energy demand in France, represents over 80 % of fossil-fuel consumption. The management of thermal energy, with its storage and transport functions, including the minimization of thermal losses and of energy quality (the temperature level), is an essential area for progress from the point of view of resources and for environmental conservation.

Optimizing heat exchangers

The compactness of exchangers requires thorough in-depth studies of the physics of phase change in new fluids, with convection, at high temperature and in a confined environment. Two-phase flow behavior must also be taken into account, which leads to problems of distribution and fouling. CNRS is designing multifunctional exchangers and developing thermal micro-components in order to resolve the thermal issues of new energy technologies in dynamic operation, particularly fuel cells and the related problem of hydrogen storage.

Thermal solar energy and needs in the residential habitat and the tertiary industry

Low-temperature thermal collection, associated with the photovoltaic process, could fulfil thermal needs for habitats and the tertiary industry at low cost. In the future, it will integrate storage units with low-flowrate exchangers or heatpipe as well as systems dedicated to heat management. CNRS is working on liquid and solid sorption processes capable of increasing the quantity of heat introduced, raising its thermal potential or producing cold, all the while including the storage function and significant power variations. The processes will be integrated into advanced home automation, which will ensure the balance between real needs and resources.

Local management of thermal energy resources and demand

The development of the co-generation of heat and work, and the existence of sources of thermal energy, such as incineration plants, which are used inappropriately, or not used at all, mean that new methods need to be considered for transporting heat. Indeed, the urban heat networks, transporting hot water or steam in the form of sensible heat, cannot be extended in length without a risk of significant thermal loss. The cold distribution networks, in the form of latent heat, must still be perfected to attain acceptable savings on commercial or residential sites. A long-distance transport method design, property of CNRS, enables a real interconnection between resources and demand: the circulation of a gas in a closed circuit, using endothermic and exothermic reactions with carefully selected solids, ensures the transport of heat or cold. The storage function is integrated into these new processes. The implementation of such a process would ensure a fit between local and regional resources and demand, with an adequate economy.

Tested on this cycling test bank, the solid-gas thermochemical system developed by CNRS makes it possible to generate cold using heat, rather than electricity. This process has numerous benefits: complete autonomy, reduced footprint and total absence of sound or vibration.

Uses

Context and issues

Analysis of the evolution of the final consumption of energy per sector shows that in Europe the residential–tertiary sector represents approximately 40 %, transportation approximately 32 % and industry 28 %. A large increase in consumption is anticipated by 2020, in particular for the first two sectors. Energy consumed for transportation comes exclusively from petroleum, whereas for mainly from petroleum and natural gas, it comes housing. The detailed analysis of factors of progression in CO_2 emissions underscores the importance of developing innovative solutions, with acceptable cost conditions, essentially in these two areas.

Research conducted by CNRS in these strategic domains partially follows the 2001 conclusions of the Parliamentary Office for the Assessment of Scientific and Technological Choices, concerning two essential programs for housing ("South-Facing" program for intelligent bio-roofs) and for transportation ("earth–energy" program for independent bio-fuels).

The first program seeks to increase the energy performance of buildings and the search for new energy sources, and even their hybridization (thermal solar energy, photovoltaics, functional materials, surface geothermal energy) both for new and existing buildings. This should lead to the concept of low-energy-consumption housing.

The second program targets a growth in bio-fuel production, while accelerating scientific and technological progress in the combustion of these fuels in the aim of decreasing consumption and greenhouse gas emission. Research in this field is being conducted in partnership with oil industries and automotive manufacturers. Finally, in the transportation and housing sectors, an important research effort is devoted to fuel-cells as new electricity and heat generators: membrane cells for transportation and solid electrolyte cells for stationary co-generation systems. These cells are the solutions for the future, due to their non-polluting character, if the hydrogen supply can be controlled and costs can be lowered drastically.

Housing

Our increasing standards of comfort have created more demands on the environment. Dressing habits have changed, the population lives much longer and its metabolism slows down with age. The energy consumption dedicated to immediate comfort in our daily habitat, which is already the main factor of consumption in France, can only increase in the future. CNRS research actions include new buildings, but their main thrust is directed toward the rehabilitation of existing buildings, which represent the major part of the construction activity in France.

Surface geothermal energy

The integration of the underground, which has a thermal mass with a quasi-constant temperature throughout the seasons, is a source or sink of heat that is currently unexploited for the thermal management of buildings. New tri-thermal systems combining dynamic heat sources such as solar energy, surface geothermal energy with constant supply from deep underground, or variable supply via 'Canadian' wells for outside air renewal are currently under development in the aim of ensuring very high energy independence and controlled requirements. Such systems must be implemented rapidly in current residential and tertiary sectors.

Bioclimatic housing

Research on bioclimatic housing investigates the relations between buildings and their immediate environment, with a view to optimizing architectural design and energy consumption. The integration and optimization of passive or active solar energy components into buildings, the quest for innovative processes capable of improving energy transfer from these components to building interiors, in the context of an approach of high environmental quality, are also at the heart of the concerns of CNRS research teams. Research tools integrating a socio-economical approach are favored, and effective energy management methods integrating all the internal and external interactions in the habitat are still to be found.

Outer walls and interior of the building

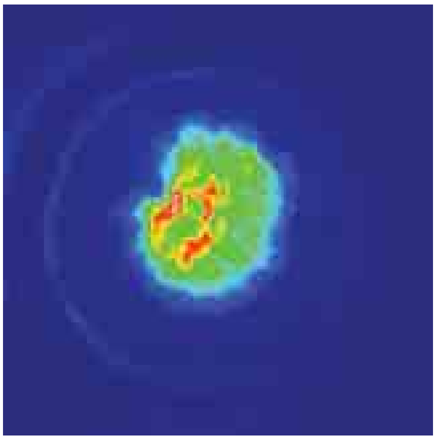
The outer shell of the building evolves towards more developed systems, such as double-skin devices, which appear to improve insulation performance while allowing the integration of a variety of systems (photovoltaic sensors for example). Research into novel components integrated into wall systems is underway. In these devices and inside buildings, natural or controlled ventilation and management of air movement are also determining factors. Research is underway in laboratories with the aim of better understanding the mechanisms of these movements in order to model and control them in such a way as to create optimal conditions of comfort whilst minimizing energy consumption.

A unique example of the use of the double-skin concept with an integrated photovoltaic device at the Cévennes Tourist Office.

Visualization of air movement within buildings (in the vicinity of an air vent on the photo) contributes to understanding turbulence and provides better ways to control heat transfer.

Clean and efficient car engines

Over the next twenty years, the internal combustion engine will still be the main source of power for automobiles. For this reason, environmental issues are of great importance to motorists, on three levels: reducing pollutant emissions from combustion in line with 2005 standards and to combat the greenhouse effect, reducing consumption and decreasing levels of noise pollution.
Scientific issues are leading to the development of two main areas of research.



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Combustion in a direct fuel injection engine.

New modes of combustion

For several years now, the combustion of lean mixtures with stratified equivalence ratio, accompanied by direct injection, is the work-horse of researchers, aiming in particular to reduce the production of nitrogen oxides. This leads to combustion instabilities, which have not yet been fully controlled, and require further research into ignition conditions.
The scientific challenge of the coming years will be 'homogenous' combustion, a method without flame propagation, where the mixture is directly auto-ignited by compression, leading to a high reduction in nitrogen oxide emissions. The process requires basic research on the aerodynamics of the mixture and is strongly dependent on the chemical kinetics of the fuel used. These kinetics remain a key point in defining new fuels and the use of biofuels. Research should focus on fuel composition and the preparation of the mixture, combustion, processing of effluents and interactions with structures. Several CNRS laboratories are already working in these areas. They are equipped with simulation resources, and experimental and metrological devices. There is also an operational platform located in Haute-Normandie, for testing with real engines.
The sound emitted during the process (a constant and controlled knocking sound) is a significant advantage for this new combustion process.

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Stabilization of a flame using plasma.

Use of plasmas for combustion and pollution abatement

Pulsed plasma discharges generated in gases at pressures above or equal to atmospheric pressure, are remarkable converters for transforming electrical energy into chemical energy in the form of active radicals. These systems are characterized by low energy costs because the thermal channels of energy consumption do not come into play. Two fields of application are currently under development at CNRS. A fuel mixture is ignited by cold plasma where the direct creation of radicals provides the conditions for the ignition of poorly-controlled lean mixtures. This research should be conducted together with research into ignition kinetics. Other studies concern pollution abatement in diesel exhaust particle filters using properties of the plasma discharges which are naturally oxidizing. Encouraging experiments on test-engines have shown that these plasma systems can be an alternate solution in resolving environmental issues.

Fuel cells

Fuel cells allow the chemical energy produced by combustion of a fuel in oxygen to be transformed directly into electrical energy, without thermal combustion. Benefits of this conversion method include a reduction of the harmful effects on the environment (no emission of noxious gases, low noise levels) and efficiency greater than 40 %, going as high as 90 % when operating in co-generation.

Fuel cells, a promising alternative

Depending on the type of electrolyte and fuel, and the operating temperature level, there are several types of cells, two of which are the subject of important European and international research. CNRS is focussing on such technologies: PEMFC cells (cells with protonic polymeric membranes, 80 to 100 °C) operating at low temperature and SOFC cells (molten carbonate fuel cells, 600 to 700 °C) known as high temperature cells.

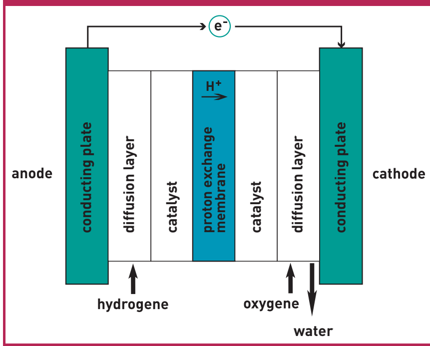
PEMFCs could replace thermal engines in transportation and electric storage cells in portable electronic equipment (which would be beneficial due to factors such as instant rechargeability, 5 to 10 times more energy density, 2 to 5 times more autonomy). A hydrogen/oxygen cell element provides constant voltage of the order of 1V. Researchers are investigating combinations of these elements (parallel, series ...) and the addition of electronic interfaces to regulate voltage, and if required, to transform voltage into alternating mode. Furthermore, developments in microelectronic technologies have made it possible to produce electric current densities ranging from 70 to 100 mA/cm^2 for microcells. SOFCs would allow stationary energy production with minimal pollution and a high electrical efficiency, significantly enhanced by co-generation technique. Already, 5 to 10kW units have been shown to produce domestic electricity and heat (or cold) from natural gas.

Long-term prospects

Numerous problems for each of these applications (membranes, catalysts, interconnection materials) still need to be resolved before marketing becomes a possibility. New cell core components need to be developed, and new concepts of heat and fluid management have to be implemented in cell cores. Finally, the problem of fuel supply still needs to be solved, in particular hydrogen availability for PEMFCs.

Reliability and lifetime issues, especially for stationary applications, are important concerns. CNRS researchers are also working on the possibility of producing recyclable cells from available material, working towards sustainable development in this area: this is not currently the case, especially due to the unpredictable economy of platinum.

Various marketing research studies have forecast a major introduction of this technology starting in 2010 and a significant market, in the order of a dozen billion euros, from 2020 to 2030. The future of this technology is therefore that of a vital intermediary goods for the world.



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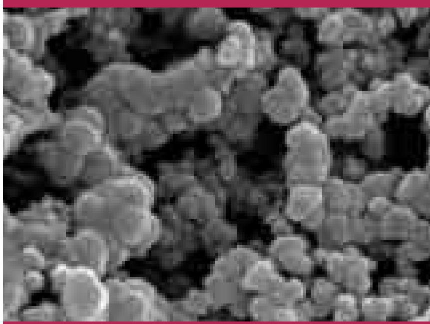
Operating diagram of a PEMFC fuel cell.



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SEM (Scanning Electron Microscopy) image of a PEMFC fuel cell electrode obtained by plasma spraying (CataPulP).

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Reactor for developing fuel cell electrodes, CataPulP (catalysts by plasma spraying).

Socio-economic impact

Context and issues

Under the influence of several major transformations – climatic change (linked to the additional greenhouse effect which is the subject of international negotiations on conservation issues in the interests of "worldwide public benefit"), re-concentration of energy supplies in a sensitive geopolitical zone, deregulation or liberalization of energy markets, in particular electricity, and finally the acceleration of industrial development processes – humanity is faced with considerable changes in matters of energy. The Intergovernmental group of Experts on Climatic change (GIEC) outlines in its third report that leading up to 2050, if concentrations of greenhouse gases are to be stabilized, global emissions must not exceed half of current emission levels. Research programs on energy will have to come up with major solutions to meet these imperatives.

Since the first energy crisis in 1973, CNRS has long been involved in human and social sciences research on energy. This strong momentum must be maintained in order to assess, in association with engineering sciences, distribution possibilities for energy technologies when faced with radical emission restrictions. Furthermore, public policies must be implemented with a view to accelerating the process of converting our energy systems to meet objectives.

The new conditions will entail research work concerning the evolution of companies towards energy systems subjected to these restrictions, in all fields of human and social sciences: technical and economic feasibility for global power at low emission levels ; national measures of public policies (enabling European objectives as well as those of the Kyoto Protocol to be met) ; evolution of the energy demand in the long-term and understanding the links between energy systems and economic development ; environmental and transport issues ; incentives and obstacles to innovation in the energy sector ; the question of citizen acceptability of subsurface disposal of nuclear waste, energy savings and renewable energy resources.

Evaluation and prospects

In the domains of energy assessment and prospects, CNRS researchers are confronted with new challenges. The energy perspective sees its time horizon moving further away – we know for example that issues linked to the greenhouse effect must be considered over the very long-term – and they are becoming more complex due to the very moderate implementation of public policies both nationally and internationally (climate convention).

Evaluation and comparison of technological processes

The problem researchers are faced with is testing how this reorganization of energy systems can take place within the context of transforming economies and business, which are increasingly confronted by the demands of sustainable development, in terms of climatic restrictions, safety of installations and basic energy supply to the population. These constraints can be overcome only through change, slow by nature, in consumption behaviour and by an in-depth reorganization within and between the various sections of energy systems.
For socio-economists, one of the priority research areas is to compare the perspective routes of change in consumption which are in turn determined by changes in the structure of economic activity, industrial processes, technological choices and reduction policies in final energy demands. They must then deduce from these the development of the structure for production of primary energies depending on the choice between fossil energy (with or without sequestration of CO_2), renewable or nuclear energy. In the same vein of thought, CNRS researchers are analyzing the conditions for developing new industrial processes for energy transformation, the enhanced value of multi-energies (co-generation) and the connection of these processes for energy uses, particularly through decentralized production.

Prospects in the energy sector

Energy prospecting requires the development of complementary simulation models. Firstly, sector-based models capable of showing the technological structure of energy systems and their coherence and dynamics must be designed followed by models ensuring the homogeneity of energy scenarios. With this intention, CNRS researchers integrate into the models parameters such as the balance between goods and service exchanges, industrial competitiveness, financial constraints and incentives (taxation, pricing, subsidies, R&D, standards), thereby making it possible to understand technology deployment and changes in consumer habits. The research work is structured by feasibility analyses. Initially, the researchers determine the requirements to change the current situation and transform society into one with a low greenhouse gas emission profile, and then study ways of meeting that objective. The prospective approach therefore consists in defining a desirable future in the long-term and developing models to achieve that result.

Participatory governance and acceptability issues

Reorganizing energy systems and changing economies and societies necessitate taking into account the requirements of sustainable development. Today, in order to meet these challenges, studies must be conducted from a socio-economical and even sociological viewpoint in addition to research of a purely technological nature. Thus, energy labelling (how citizens perceive energy saving) and the use of renewable energy types, or on the contrary, the constraints related to collective risks (subsurface waste disposal) have given rise to citizen acceptability issues.

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Microhydraulic dam.

Citizen acceptability of renewable energies

A branch of research in human and social sciences consists in identifying the obstacles to introducing new 'renewable' energy resources. Sociologists conduct qualitative studies, which are an essential preliminary to better understanding why these types of energy have such a poor image. The economic context therefore has considerable impact on the hierarchy of collective preoccupations of dominant energy (low-cost) versus secondary energy (thought to be more expensive). Sociologists have determined that, even if they appear non-polluting, renewable energies are discredited in the eyes of potential users by a certain amount of qualifying terms. A lack of investigation on their representativity, voluntary or involuntary confusion as regards the choice of vocabulary, a lack of notoriety or structural and institutional constraints to their distribution all contribute to citizens refraining from opting for renewable energy. To remedy this situation, CNRS researchers are conducting studies to reintegrate these energy types in the discussions on resources.

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Lisor T 91 sample tube. This device, designed for studying various structural materials subjected to radiation, in contact with liquid metals and under mechanical constraint has been developed within the framework of the Gédéon Research Grouping (waste management through new options from the PACE program).

Sociological analysis of waste management

Nuclear waste management constitutes a significant field of analysis for CNRS researchers. In particular, the origin and history of the problem, its formulation, its various appearances on the agenda of the authorities, and finally, its "politicization" following controversy about the choice of a technical solution (subsurface disposal), presented as an "unavoidable necessity", had to be re-examined, which resulted in the intervention of actors that had previously been left out, i.e. members of parliament and local ministers. A public debate on the subject and the passing of an original law in 1991 revived research in this field. The resulting wider-spread mobilization of the scientific community led to the development of a wider range of potential choices and conceivable scenarios for waste processing or storage.

This example highlights the role played today by citizen controversies on the presentation and political management of public problems. Certain authorities have become increasingly unavoidable for the formulation of policies as a result. For example, the OPECST (French Parliamentary Office for the Evaluation of Scientific and Technological Choices) is regularly questioned about issues (i.e. nuclear) that were previously treated confidentially and principally in a regulatory fashion. This system has led to the implementation of new consultative procedures, the aim of which is to make certain technological projects acceptable by rewarding the network of actors involved and by favoring decision reversibility.

Public policies and negotiations

This field of research includes economic and technological questions as well as a quest for equity between the various countries. Researchers can help communities to determine how efforts to reduce greenhouse gas emissions can be shared (and therefore the cost thereof) between the various countries and present and future generations.

International negotiations

The question of the policies that need to be adopted and measures that need to be taken arises as soon as quantified objectives are set internationally as regards gas emissions. Some of the research work conducted over the past years involves the choice of the mode of coordination, i.e. price versus quantity, permits versus taxes. Thus, during the discussions preliminary to the Kyoto Protocol, the countries involved chose to favor an approach based on quotas combined with the issuing of negotiable permits rather than a tax-based approach, for both political and diplomatic reasons. Much research still needs to be carried out to define the long-term standards that will enable this mode of coordination to function without distortion (i.e. rules on the attribution of quotas for newly subscribed countries, practical rules on permit exchanges, etc.). CNRS researchers are also interested in studying how to associate countries that have not subscribed with the Protocol (re-association of the United States or subscription of developing countries). Thus, various mechanisms have been proposed to implicate developing countries in the reduction of gas emissions prior to their actual participation in the Protocol. These issues raise the problem of the future of the Protocol, which is a research subject in itself.

Energy innovations and public policies

CNRS research aims to determine the economic and sociological barriers that have resulted from the introduction of new techniques and innovation dynamics. It is an important objective that will enable inciting measures to be developed for use by authorities to stimulate technical change.

Analysis of the mechanisms of technological distribution aims to improve the understanding of economic and social hurdles. This consists in in-depth, sector-based analysis of precise technological domains, i.e. renewable energy, energy transformation techniques and biomass exploitation methods, which will be extended to carbon capturing techniques.

Researchers also study simulation tools, energy innovations such as voluntary agreements, adoption subsidies, market enlargement by public demand, administered purchasing tariffs, green certification and green pricing to determine the efficacy thereof, whether the regime is a monopoly or competitive.

Evaluation of the efficiency of research and development strategies for sustainable development is based on comparative analysis of the efficacy of national innovation systems involving public action as well as company innovation strategies according to anticipated environmental measures and energy prices.

Strategy and prospects

Analysis of the determining factors of the energy demand implies taking into account four criteria, i.e. energy independence, the impact on the environment of carbon emissions in the context of climate change, the increase in demand, not only in developing countries aspiring to increased industrialization, but also in countries belonging to the OECD and finally, the foreseeable decrease in fossil resources in the second half of the 21st century. The answer to the first three criteria is all the more difficult as the energy demand is expected to double in 2050, which implies dividing current CO_2 emissions by four to stabilize the atmospheric concentrations thereof. To achieve this, four conditions need to be respected, i.e. energy must be saved, energies that do not give off CO_2 must be developed (renewable or nuclear energy), CO_2 must be captured and stored when fossil energies are used and energy efficiency must be increased.

Research has a key role to play in each of the above domains, in proposing new solutions or identifying scientific inconsistencies and technological hurdles. Research continuity must be ensured by establishing achievable implementation deadlines. Furthermore, a global approach based on the mixing of energies must be used for research. This should lead to the development of a range of new technologies that meet the criteria of economic efficacy, social acceptability and environmental protection.

If demand is considered in the short term, significant efforts must be made as regards electricity supplies, housing and transportation. Energy requirements of the residential – tertiary sectors can be considerably decreased by making use of solar energy, surface geothermal energy and new materials, combined with novel architectural designs.

Regarding transportation, progress can still be made to increase the return of combustion engines, the principal form of engines that will be used within the next fifteen to twenty years, and to manage gas emissions. A marked effort must be made to develop hybrid engines, with gas becoming the fuel of captive transport fleets. The production of bio-fuels is an interesting alternative to petroleum. Problems derived from this include the acceptability of agriculture for industrial purposes and the perfect management of forests. Vehicles must be made lighter (new materials, calculation of structures, etc.) and transport modalities must be revised in order for these research efforts to remain valid.

As regards electricity, the development of renewable energy resources leads to decentralized production with low-power generators, and for certain sources, intermittent production. This gives rise to problems relative to storage, to the distribution networks and to linking up with the major European and national networks.

Wind energy (already exploited) can be further developed. However, waste and biomass combustion results in the co-generation of electricity and heat. Transporting this form of energy over long distances is a crucial research point. Even if high-power natural gas plants are a very interesting alternative, nuclear energy cannot be ignored in the short term. Very active research on waste processing and on new generation reactors may offer acceptable solutions for society. These reactors must be safe, reliable, resistant to the risk of nuclear proliferation, economical and sustainable. Finally, the ITER program on thermonuclear fusion must be commenced as soon as possible to enable a solution for the future to be envisaged from 2050 onwards.

In the medium term, i.e. from 2015 to 2020, two types of production systems (photovoltaic and hydrogen) may become exploitable on condition that research be intensified, leading to technological breakthroughs.

Photovoltaic production, the cost of which decreases year by year, will be used increasingly for decentralized energy production and combined with thermal solar energy for residential–tertiary sector requirements.

The hydrogen sector undoubtedly has a future if its production (using natural gas, then electrolysis, thermochemical cycles, or even micro-algae), storage for future use and transport can be mastered. Mastering the use of fuel cells and in particular, the decrease in their cost, irrespective of whether they are stationary or portable, still requires major research and technological efforts. However, hydrogen is the energy carrier of the future given that fuel cells do not emit greenhouse gas and that they have the potential to be used for the production of electricity and heat (with a very high overall turnover) and as vehicle engines. The capture and storage of CO_2, which form an integral part of the CNRS program, will mostly be carried out within the framework of the "CO_2 club" initiated by the ADEME (French Agency for Environment and Energy Management and coordinated by the BRGM (French Bureau of Geological and Mining Research).

Thus in the long term, the response to the four criteria could be a combination of different energy resources including renewable ones (solar and wind energy), hydrogen, thermonuclear fusion (if the results of this process prove convincing) and fossil fuels. Two conditions are necessary to achieve this. Firstly, human and social science researchers must become involved in the resolution of regulatory problems, in the evaluation of innovating technological sectors and in the internal and external costs on the new routes for better technological governing, as well as in new lifestyles that are energy saving. This research represents an essential condition to the acceptance by society of necessary changes. Secondly, strong partnerships must be established between French public research bodies and European and international research organizations and companies in order to cover preliminary research and technological development for a given subject.

Research must provide solutions without any prejudice whereas industrial partnership which, essential to technological development, must open markets by meeting the demands of countries of the OECD and developing countries.

For further information:

Website for the Énergie program: www.imp.cnrs.fr/energie
Website for the PACE program: http://pace.in2p3.fr

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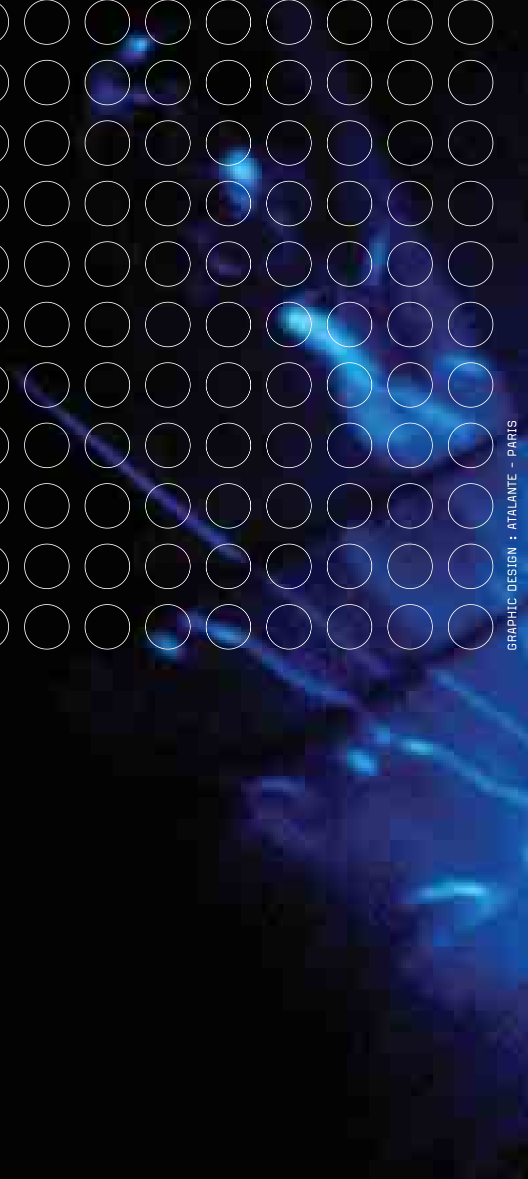

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