IV. THE RATIONAL USE OF ENERGY

The hunt for the "negawatt"

Rationalising the use of energy means using less for a given service. The search for energy efficiency aims to do this right from the initial design of systems, processes and equipment, throughout all stages of production and distribution, as well as in the final use of electricity, whether in heating or cooling systems. It requires an in-depth knowledge of the basic phenomena involved. The CEA has built up expertise in numerous fields, particularly in thermohydraulics and in heat exchangers in connection with its nuclear activities. Side by side with industrialists, the CEA is putting its know-how to use in the hunt for the best way to get rid of the "negawatt", i.e. the unused megawatt.

CEA/GRETh

Industrial plate-fin heat exchanger. The development of heat exchanger technology plays a particularly important role in the rational use of energy in industry.

Goals, challenges and solutions in the hunt for the "negawatt"

More in the news than ever, the rational use of energy involves a range of technological developments in all sectors of activity. These rely on a better knowledge of basic phenomena involved in the main sectors: particularly mechanics, electronics and thermohydraulics, and an increasingly precise modelling of the processes.

Essential and far-reaching requirements

The rational use of energy requires the development of clean and efficient technologies to produce electricity, cooling and heating, increase industrial output and limit energy consumption in transport and construction. It meets current requirements not only on a national and regional level but also on a European and worldwide level.

National aspect

The energy independence of a country, the availability of its fossil energy supplies and the quality of the environment will be greatly compromised in the future if current trends in terms of energy consumption growth continue. The quality of the air in large cities, the rate of exhaustion of fossil resources and changes to the climate depend heavily on our capacity to use energy better. In 1990, France discharged the equivalent of 144 million tonnes of carbon into the atmosphere (box A, ***The greenhouse effect***). Without appropriate measures and at the current rate of increase, this figure would rise to 175 million tonnes in 2010. As a result of the Kyoto conference in 1997, France agreed that in 2010 it would not exceed the 1990 level of emission. The rational use of energy is also a tool in the fight against unemployment because it is often a matter of replacing imported energy by local grey matter. In addition, the gradual application of tax on CO_2 emissions encourages companies using a large amount of fossil energy to optimise their processes. This creates a national outlet for service industries (eco-industries) using the new efficient and clean technologies. The export of products, technology and competence is an increasingly important element for employment in the energy sector.

The importance of a strong policy in favour of the rational use of energy was underlined in the report from the Commissariat général du Plan (table).

In France, research and development in energy efficiency is advancing through innovation-based partnerships between all those involved, both public and private, from the world of research and from industry. Restricted to 2.5% of the public research budget, the potential for growth is great. The CEA, with its wide experience in R&D on thermal equipment in nuclear reactors, is a natural and credible partner in the struggle to optimise all processes.

World aspect

World energy consumption should increase by 50% over the next twenty years. In this context, strong competition already exists between countries offering clean, efficient technology. This competition must be intensified through more research and development so that attractive energy savings are brought to bear.

European aspect

The Green Book for an EU energy strategy(1) describes the means of intervention in favour of a rational energy policy: financial support for R & D activities as part of the 5th framework programme for technological research and development – the rational use of energy being one of the four key actions – financial incentives for co-operation with developing countries to take account of the impact of their energy control policies on global evaluation, regulations to restrict the increase in energy consumption and to encourage the use of efficient, clean technologies.

Regional aspect

Recent discussions between National and Regional government bodies in France have shown the importance of regional policies for sustainable development. Particularly sensitive to the economic aspects, local representatives are focussing on creating business and jobs, particularly in service industries, linked to a regional policy in favour of the rational use of energy.

The example of GRETh

A strong policy for the rational use of energy will help a solution to be found to the social, environmental and economic problems connected with energy. Its technological aspect is an important element. More than fifteen years ago the CEA and Ademe set up GRETh, an organisation responsible for finding ways to improve the heat exchangers that transmit over 80% of the nation's energy. Having built up a relationship based on confidence with many industrial companies (see box) it is able to fulfil its dual role as translator of industrial requirements into applied research and distributor of newly acquired knowledge.

total consumption (MTEP)	1997	S1 2020	S2 2020	S3 2020
industry	58	73	70	62
transport	50	79	72	59
domestic	93	125	113	98
total	204	280	258	222

Table. Evolution of energy consumption in France between 1997 and 2020 according to three hypotheses: S1 "free market", S2 "controlled economy", and S3 "state intervention for protection of the environment" (Source: Commissariat général du Plan).

(1) Energy for the future: renewable energy sources COM(96) 576 of 20/11/96. A *green paper* on the availability of energy supplies in the EU was adopted on 29/11/2000.

Scientific and technological obstacles

The development of clean, efficient technology requires much interaction between scientists and engineers, between science and technology, as well as between research and industry in order to find the right economic/environmental balance.

The scientific and technological obstacles differ depending on the sector (see the articles below), although all sectors are looking to do the same thing: produce transferable knowledge and technology, which involves taking into consideration market requirements and economic restrictions. This is why research programmes must be set up and carried out with constant reference to industry, GRETh model being a rather good one. The action of this organisation is proof of the continuing work and success of the CEA in this field.

Rational production of energy comes first

Deregulation of the energy production sector has had the effect of greatly modifying the principles of the main industrial companies involved who must in future reason in terms of global services provided to their customers. They are therefore led to propose solutions combining the production of electricity and heat (**cogeneration**), and even cooling (tri-generation) with increased efficiency. But there are many problems to be got over. For the recovery of energy at high temperatures, for example, modelling of radiative exchanges in vapours and the design of innovative ceramic exchangers are promising fields of investigation. For elimination of pollution by classic thermal power stations, constraints exist in the extraction of submicronic particles: solutions are based on electrostatic systems or thermal equipment using thermophoresis mechanisms.

Beyond this elementary work, global analysis of systems can be used to assess the advantage resulting from progress on one of the components to be measured: that of dynamic simulation using software tools incorporating physical laws resulting from analytical experiments.

Innovative geometry and advanced materials for industry

The introduction of new components in heat transfer equipment in order to improve efficiency of industrial manufacturing processes or to reduce waste can cause complex problems in understanding the physical mechanisms. Improved surfaces may result in condensation or boiling or particle fouling. These subjects require investigation through practical experiments or computer modelling. Technological aspects concern surface design enabling intensification of heat transfer and restricting fouling in various types of equipment such as boilers, **Volatil Organic Compounds** (VOC) condensers or electrostatic filters. The solutions proposed usually combine innovative geometries and advanced materials.

Innovative solutions for transport

Nowadays, many new complex systems are being investigated: hybrid systems combining heat and electric engines, heat engine pollution control, components and sub-systems for reducing both consumption and emission, domestic heating and air conditioning systems. All require improvements in both modelling of physical phenomena and in design of economically viable original solutions. It is an active and leading field of research enabling the marketing of innovative solutions that are often later used in other sectors. With regard to the components combined in electronic units for the control of power systems (whose development is important for improved control of electricity demand), technological breakthroughs are possible where the thermal aspects are concerned.

Ambitious research for domestic and general use

New cooling technologies need to be developed to respond to the rapid changes in regulations. The design of thermodynamic machines is highly dependent on fluids used and basic studies have to be carried out on the condensation and evaporation of

The CEA-Ademe partnership for GRETh

Making technologies cleaner and more efficient is of major importance to our economy. It is one of the main aims of Ademe (Agency for the environment and control of energy).

Heat exchangers have been identified as one of the main technological components to be improved in the field of technological resources and prevention of atmospheric pollution.

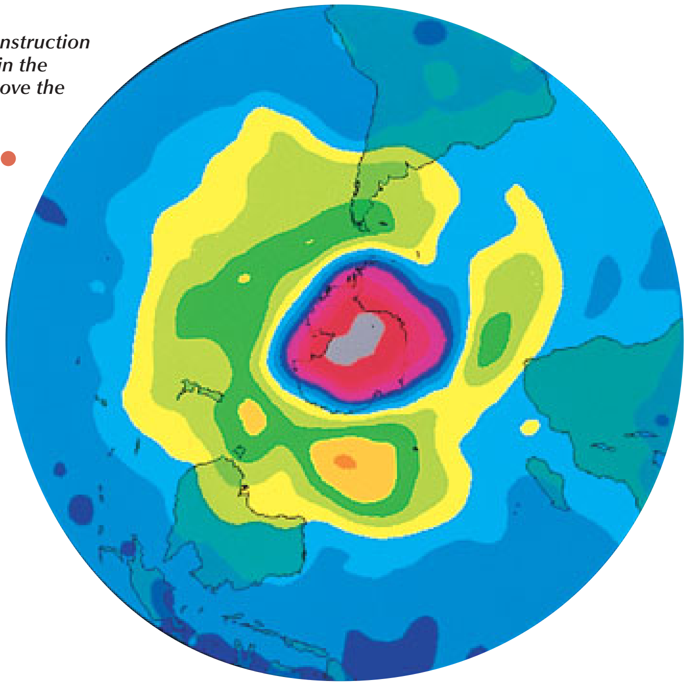
The main objective of public policy was to create an environment favourable to companies in the field of medium technology, comprising small and medium-sized businesses with a modest amount of internal R&D activity. The AFME, then Ademe, with its main partners – the CEA, EDF, CNRS, Cetim (Technical centre for mechanical industries), the IFP (French petroleum institute) – and of course industrial companies themselves, promoted an active Science-Technology-Industry-Market group to study all aspects of heat exchangers. GRETh, with its club of members, over 85% of whom are French manufacturers, through its various combined activities and research-based training, has concentrated efforts on the weak point in the network: that separating the technology available to the CEA from the group of manufacturers. The results of more than fifteen years, mainly satisfactory, led Ademe to renew its partnership with the CEA in April 1999 to support the development of GRETh.

Gérard Chaumain
Ademe

The industrial companies involved in GRETh

The members of the GRETh industrial club (more than 110 organisations) are actively involved in developments in energy control and environmental protection. They belong to the **industrial** sector (energy production: EDF, GDF, Dalkia, Vivendi (CREED), Alstom, CNIM, Pillard; the mechanical engineering sector: Alfa-Laval, Vicarb, Barriquand, Packinox; petrochemical: TotalFinaElf, IFP; the chemical sector: Air Liquide, AGA, Nordon; the ferrous and non-ferrous sector: SEPR (Saint-Gobain), Le Carbone Lorraine, Pechiney; food: Danone (CIRDC), Actini, (FCB), the **transport** sector (Valeo, Alstom transport, ECIA, Delphi), the **building, refrigeration, heating, air conditioning** sectors (CIAT, Chaffoteaux, LGL - Lennox group) and the **engineering** sector (Technip, SGN).

Coloured reconstruction of the change in the ozone layer above the South Pole.



NOAA/SPL/COSMOS

complex mixtures on improved surfaces and on system aspects: the study of innovative thermodynamic cycles, the impact of transients on reliability and the incorporation of new thermal components (fuel cells) are new and ambitious research subjects.

More refined understanding of mechanisms

The development of efficient, clean technologies requires special modelling and experimentation tools. For the former, a deeper understanding of the physical mechanisms involved and the simulation of expected performance can reduce product design and development time. Laboratory experiments followed by full-scale practical tests with precision equipment will confirm the suitability of proposed solutions and ensure that the requirements of availability, reliability and safety insisted on by users are met.

In addition to these technological aspects, there are other restrictions relating to the introduction of these innovations in the traditional industrial sectors: in view of the economic risks and safety requirements a highly conservative attitude is understandable. One non-negligible advantage of the CEA in its transfer and support of industry lies in its wealth of experience in the nuclear sector.

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Cooling technology versus the greenhouse effect

Cold production represents an obvious challenge to the use of energy: 10 to 15% of the electrical energy produced in industrialised countries is used for this. The use of cooling fluids for this purpose involves a wide range of sectors: construction, transport, food, farming, chemical and mechanical industries. CFC (chlorofluorocarbon) and HCFC (hydrochlorofluorocarbon) type fluids are the subject of the Montreal protocol (1987) because of their destructive effect on the ozone layer. For several years, European directives have imposed a halt on the production of the former and a severe restriction on the use of the latter. The HFC (hydrofluorocarbon) fluids that have replaced traditional fluids are also greenhouse effect gases and are subject to the 1997 Kyoto protocol (box A, *The greenhouse effect*).

The drastic reduction in refrigerant fluid emission is undoubtedly the driving force behind future technological developments, to which the CEA contributes by meeting the needs of industrial companies. These emissions have many causes and are produced at different stages in the life cycle of a cooling system: when the refrigerant fluid is being produced, when the machine is being built and used and, of course, at the end of its service life. Analysis of the conditions necessary to reduce emissions shows the importance of machine design and component technology. Beyond the rules of good practice in terms of equipment maintenance, assembly and installation, the development of new technologies appears to be a necessity. Thus, technological breakthroughs to be given priority must include a threefold objective. They must first strive to improve the energy performance of equipment by guaranteeing its integrity (towards zero leakage) and by minimising the quantity of cooling fluid used. They must then encourage the use of fluids with a low greenhouse effect such as **hydrocarbons** or, paradoxically, carbon dioxide (CO_2) whose contribution to the greenhouse effect for the same volume emitted is several hundred or even thousand times lower than that of an HFC fluid. Finally, alternative technologies based on the principles of **absorption** or **adsorption** must be developed.

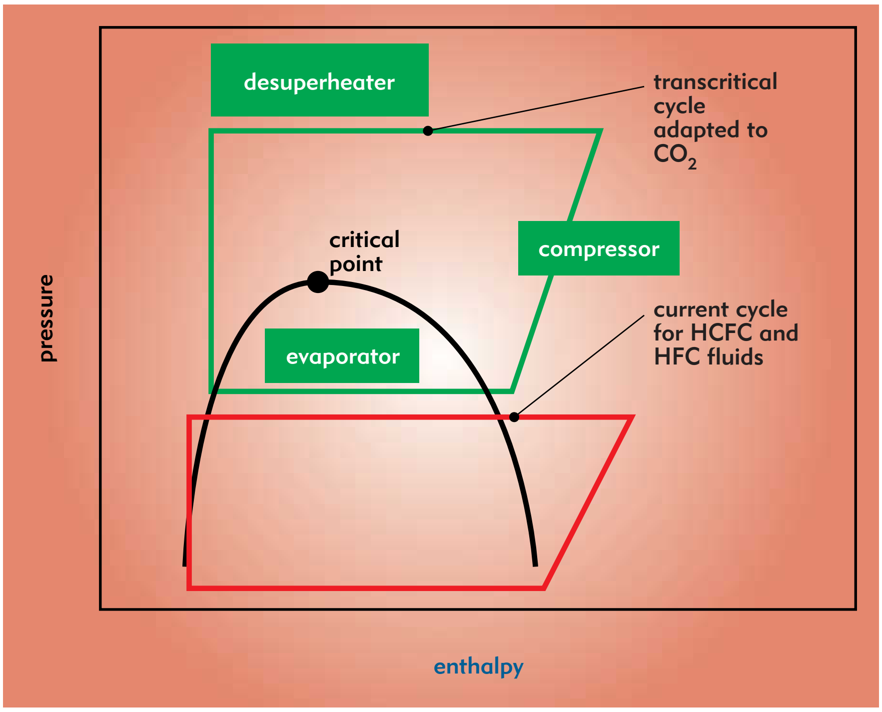


Figure. Diagram of the transcritical compression cycle (called Lorentzen cycle) for CO_2 compared with the current cycle for HCFC and HFC fluids.

Reviewing the cold chain

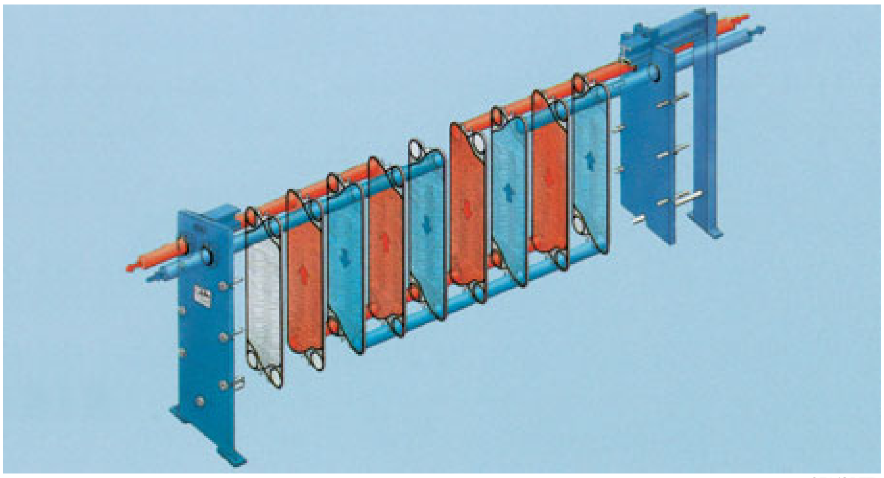
Agricultural-food industries and the distribution of food products are the first sector affected by the new cooling technologies: refrigeration, at the basis of what is traditionally called the cold chain, is of major importance both for economic and health reasons and owing to the energy load and the refrigerant fluids used.

Changes to regulations are urging this industry to commit itself to technical choices whose main priority is to reduce fluid charges. Strategies to be adopted are simple in principle but the difficulties of design and production are numerous. One of them, and not the least, is an increased sensitivity to fluid loss into the atmosphere. This involves reducing the fluid charge while improving its confinement.

There are two priorities behind efforts to reduce refrigerant fluid charges. The first is the focus on monoblock systems (indirect cooling), which have low levels of specific charge(1) (<0.2 kg/kW of cold produced) compared with separated systems. This is seen in the systematic use of an intermediate heat transfer circuit between the device requiring cooling and the cooling machine. The "diphasic" heat transfer fluids may soon be more widely used. They consist of a liquid transporting phase together with particles containing a material changing between liquid and solid phase(2) at a fixed fusion temperature (between 0°C and - 40°C depending on the type of material).

The second focus is on components such as compact exchangers (see *Compact exchangers: an ecological and profitable innovation*). The different types of exchanger are characterised by highly varying specific charges: plate exchangers and cylindrical

(1) Volume of refrigerant fluid contained in a cooling machine necessary to obtain a refrigerating capacity of 1 kW.
(2) Structures receiving phase changing fluids are **microcapsules** containing paraffin, the transporting fluid is a saline solution, or **gels**. In this case, an aqueous solution is poured into a polymer carrying structure, with the carrying fluid being an organic fluid.



CEA/GRETh

An example of a compact exchanger for a cooling cycle.

CIAT-CEA: working together for the future

Manufacturers of air conditioning systems and heat pumps have had to adapt the way they develop new products owing to new environmental requirements. To cope with the rapid changes to regulations on refrigerant fluids, they have set up a strategy based on a highly reactive approach to product development and optimisation. Hence, European manufacturers must follow a series of procedures when developing new technologies. They must be ready to control a wide variety of fluids, whether HFC, hydrocarbons or ammoniac, use heat transfer fluids more often and apply techniques such as co-generation, absorption, and adsorption more widely.

The company CIAT is of course well aware of these aspects and their associated drawbacks. It knows that when faced with such situations success is not easy to come by. Among the measures taken to defend its position, one was to set up working relationships with R&D teams. Its ongoing partnership with the teams from the CEA/Grenoble, and in particular the GRETh, and both the human and material resources it possesses, are obvious assets for a company such as ours.

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exchangers with small diameter tubes, which require only small charges of refrigerant, are attracting interest.

The energy efficiency of cooling systems can be greatly increased by the use of tri-generation, i.e. electrical production accompanied by recycling of the heat emitted by refrigeration (absorption pumps).

Renewed air conditioning

The renewal of technologies also concerns building and domestic air conditioning. The growing demand for comfort has led to a steady increase in the use of small air conditioning systems in homes and medium to large power systems in the business sector. Abandoning HCFC22 in the short term is encouraging the use of "new" fluids such as hydrocarbons and possibly carbon dioxide for low power devices. These fluids need further technological development in relation to exchangers, compressors and more widely the architecture of systems.

The use of compact exchangers can be damaging if certain precautions are not taken. It is therefore important to reduce homogeneity defects in the refrigerant fluid distribution at the entry to the evaporator and to take into account the lubricating oil, whose relative weight in the fluid charge becomes predominant. The effect of the oil may be associated with the refrigerant fluid’s soluble phenomenon, as this modifies the active charge of the fluid, or even its composition in the case of **zeotropic mixtures**, and undermines evaporator performance.

Sudden changes in operating conditions can also have negative effects on the machine's reliability, more marked as the inertia of the system is greatly reduced by the use of compact equipment.

New way to manage energy in cars

The incredible growth of automobile air conditioning in Europe – the highest sources of refrigerant gas emission are usually the USA and Japan – calls for a substitution of HFC by carbon dioxide in a transcritical compression cycle (see figure) where the compressor discharge pressure (when the fluid is at the supercritical state) may reach values higher than 140 bar. The technological developments required by this change are all the more complex owing to developments in motorisation techniques (**hybrid** in particular) for which it is necessary to find new ways to manage mechanical, thermal and electrical energy.

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Recovery of chlorofluorocarbons from used refrigerators in Paris.

S. de Luigi/GAMMA