Making the most of nuclear heat

Towards more efficient use of nuclear power stations?

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Recovering some of the waste energy from nuclear power stations for industrial use or district heating offers very interesting prospects for reducing greenhouse gases (GHGs).

To combat global warming, we need to find low-carbon sources of energy. Unlike electricity production, heat production in France generates a lot of CO_2 emissions, because it uses natural gas as its main source of energy. At the same time, our nuclear power plants have to be cooled by massive withdrawals of water from a cold source, because electricity production generates large quantities of heat. The thermodynamic efficiency of converting heat into electricity is relatively low: it varies from 35% for nuclear power to 58% for combined-cycle gas power stations. Wouldn't it be feasible to recover at least some of the waste heat from power stations for our own heating uses?

Energy in the form of heat

In 2018, 50% of the world's final energy was consumed in the form of heat and contributed to 40% of global carbon dioxide emissions [1]. The vast majority of heat production, mainly for residential or tertiary heating and industrial processes, is based on fossil fuels (Fig. 1).

Differentiating heat by temperature is essential, as uses at temperatures below 250°C[a] can be greatly optimised by energy efficiency practices (using excess heat produced by data centres, thermal power stations, factories, in other applications such as district or process heating, etc.). In France, energy consumption for heating purposes below 250°C (space heating, water heating, industrial process heating) accounts for 30% of greenhouse gas emissions. Despite the fact that the law formally obliges certain energy intensive industries to study the possibility of supplying neighbouring heating networks [2], energy symbioses of this type are still rare.

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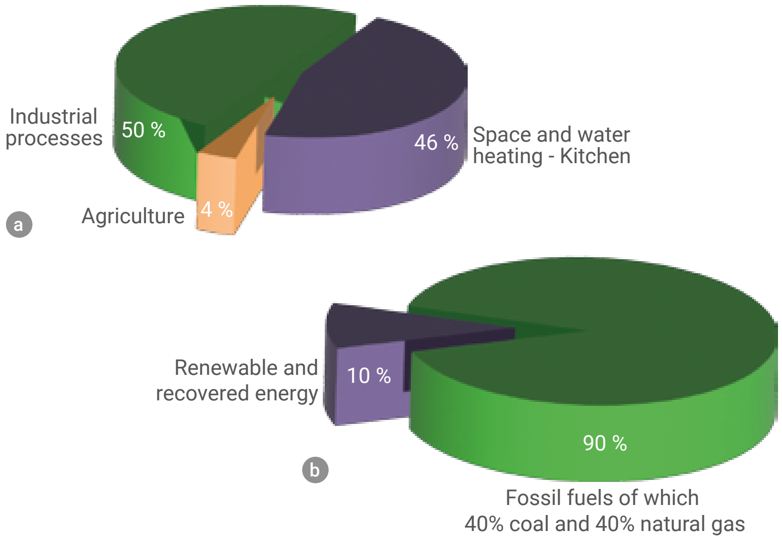

1. Breakdown of heat production worldwide in 2018 (in percentages), by use (a) and by fuel type (b).

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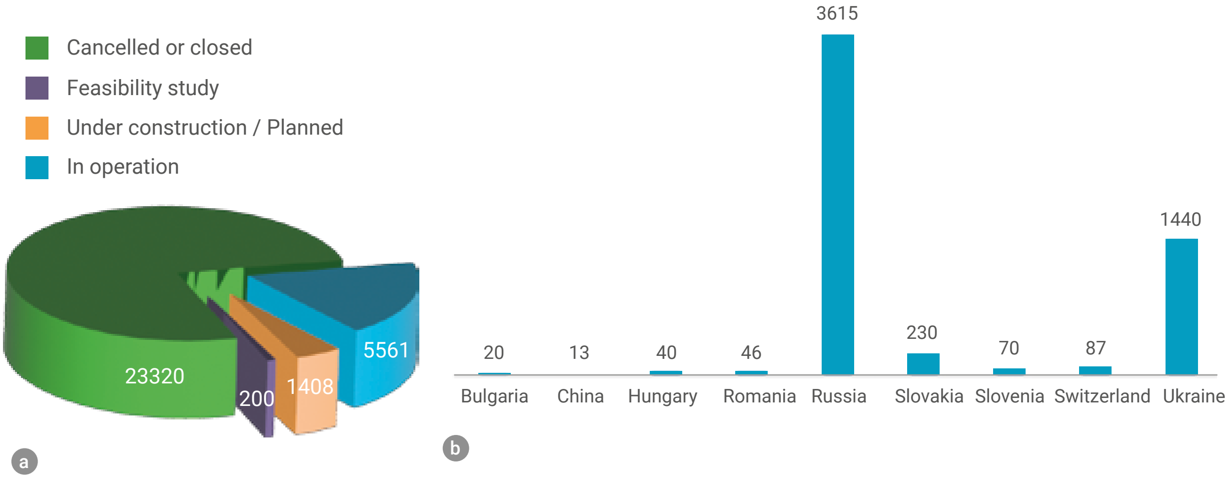

2. Quantity of heat (MWth) **supplied by nuclear power plants to heating networks worldwide.**
(a) Distribution by status.
(b) Distribution by country (networks in operation). In Europe, nuclear power plants account for 0.15% of the heat distributed by heating networks.
Source of data used: M. Lipka and A. Rajewski [7].

Heat production at nuclear power stations

One example of a relevant system - although rarely mentioned - is the recovery of heat produced by nuclear power stations. In a nuclear reactor, the thermal heat from fission is converted into electricity in a steam turbine with a thermodynamic efficiency of around 35%[b]. Two-thirds of the heat produced is therefore released into the environment, into sea water, rivers or the atmosphere (cooling towers). In France, there are a few uses for water discharged at 40°C, known as "warm water", such as fish farming, heating vegetable or horticultural greenhouses, neighbouring swimming pools or crocodile farming, but these applications remain marginal. In fact, the heat from nuclear reactors could be put to much better use [3].

Pressurised water reactors (PWRs, the type of nuclear reactor most commonly used today and likely to remain so until at least 2050) can, however, be designed to simultaneously supply electricity and heat (or even exclusively heat), without compromising the safety of the installation [4]. The heat leaving the steam generator of a pressurised water reactor is available up to a temperature of 280° C, covering a third of industrial needs and all residential and tertiary heating needs, corresponding to 30% of France's total greenhouse gas emissions. Technically, some or all of the heat can be easily recovered in a heat exchanger and transported to the site of use in heat pipes. If the heat is recovered at low temperature (< 120°C), it can be transported over long distances with very low losses (< 2% over 100 km) [3, 5].

In search of ambitious territorial policies

Worldwide, at least 55 reactors have been used as a heating solution since the 1970s (5561 MWth of capacity in operation for heating networks, 65% of which is in Russia and 26% in Ukraine ; see Figure 2). J. Leppänen [6] provides an overview of the different types of reactor used in heating networks.

With the help of OECD experts, we have identified fifteen urban areas in Europe where heating and domestic hot water could be distributed in the form of hot water circulating in heat networks partly supplied by a nearby nuclear power station. Seven of these fifteen systems have the potential to reduce greenhouse gas emissions at a competitive cost [8], the main condition being to have sufficiently large heating networks. Today, several countries, starting with China and Finland, but also the UK and Poland, are considering the option of district heating based on nuclear thermal generation. The Eco SMR project ("Ecosystem for Small Modular Reactors", see also p. 97) should be followed closely, as it brings together industrial and political players from Finland, the UK and Latvia.

The production of steam for industrial ecoparks has also been studied in France [8]. Promising projects have been identified at Gravelines (a parapharmacy plant 0.5 km from the power station) and Bugey (two plants 1.8 km away). However, the overall potential is limited by the distance that often separates plants from nuclear sites. In the future, ambitious regional policies aimed at encouraging relevant industries to locate in areas adjacent to nuclear power stations could have significant economic (10-20% reduction in annual heat production costs) and environmental benefits (between 1% and 4% reduction in France's greenhouse gas emissions) [8].

> **“Pressurised water reactors (PWRs)... can be designed to provide electricity and heat simultaneously... without compromising the safety of the installation.”**

The two main questions that arise when considering the production of heat from nuclear plants are the following:

1- What is the optimum power output of the reactor, in MWth?

2- What type of reactor would best meet the needs of the market?

As far as power is concerned, it will of course be necessary to adapt to the market. The smaller the reactor, the more it will be able to meet the expectations of a large number of users in terms of thermal requirements, financial risk and construction time. On the other hand, the greater the energy delivered, the lower the cost per MWh of heat extracted (economy of scale). Finally, the distance between the nuclear site and the end customer is a factor that will influence the cost of transporting the heat.

As for the choice of reactor type, this will depend on the application and, in particular, the desired operating temperature. For low-temperature district heating, a small, non-pressurised pool-type reactor with enhanced passive safety could suffice. On the other hand, for industrial applications, a standard pressurised water reactor will provide heat up to 280°C. Among the industrial sectors potentially interested are chemicals, pharmaceuticals and the manufacture of starch, malt and plastics.

Preparing the evolution of energy systems

If a plant is planned on a site with potential for supplying heat close to conurbations or industrial sites (*e.g.* Gravelines, Le Bugey, Nogent-sur-Seine [8, 9]), it should be built in such a way that it can be easily modified at a later date to operate in electricity and heat cogeneration mode. For a relatively modest additional cost (provision of sufficient space for the implementation of equipment such as heat exchangers [10]), this would guarantee the future possibility of using the thermal energy currently lost. At the same time, the development of heat networks and industrial ecoparks should be strongly supported through all channels, particularly local and regional.

Furthermore, the amount of heat generated by high-power PWRs often far exceeds the surrounding thermal requirements. It would therefore be worth exploring the possibility of designing lower-power nuclear reactors, such as SMRs (Small and Modular Reactors, see p. 97 and p. 103) for more appropriate heat production.

More generally, it is essential to integrate energy systems into a coherent whole, to achieve overall energy efficiency and offer new technological choices to industry. The energy transition will be based on the complementarity of energies and technologies, on the search for synergies, and not on opposition between different methods of producing or saving energy.

(a) The maximum temperature of water in the secondary circuit of a nuclear reactor does not exceed 300°C.

(b) The higher the maximum temperature of the heat transfer fluid, the higher the Carnot efficiency.

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