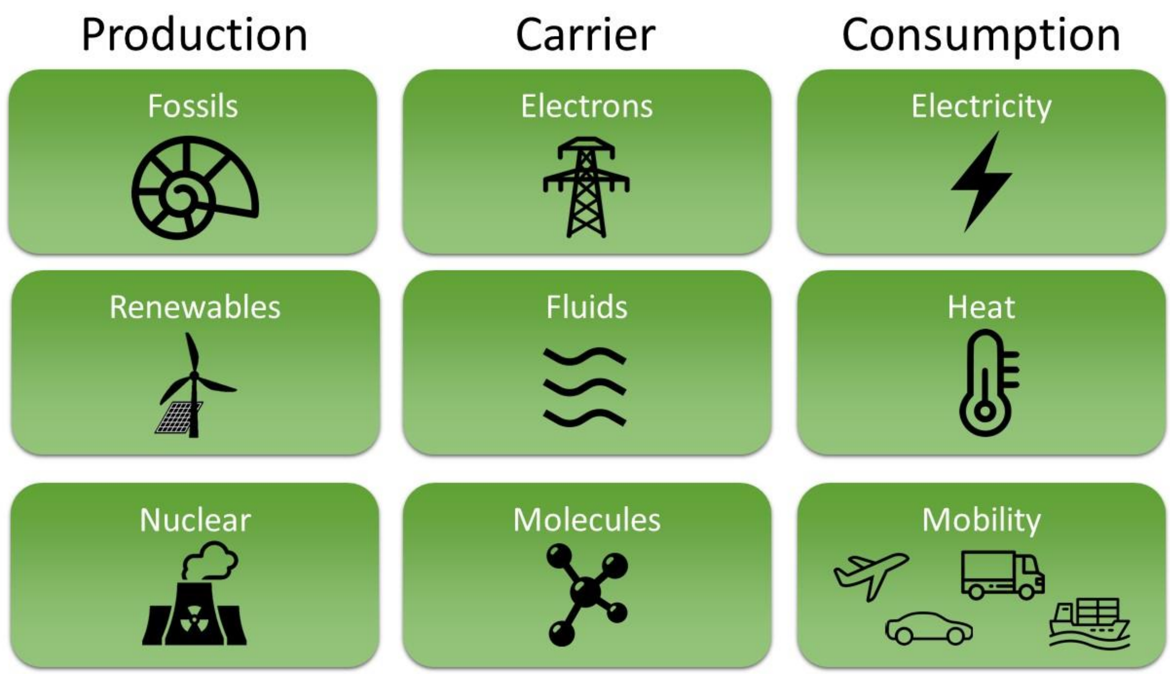
Electrons, fluids, molecules

Energy isn't rocket science if you divide it into groups of 3.

First there are the 3 phases: production, carrier and consumption. And each phase is divided into 3 groups:



We are used to thinking of production - the sources of energy - in terms of its 3 groups: fossils, renewables and nuclear. And the 3 consumption groups are familiar too: electricity, heat and mobility.

But we are less used to thinking about how energy is transported from one place to another - the substances or phenomena that are called energy carriers. They too fall into 3 groups: **electrons, fluids and molecules**.

Fundamentally, humans have made only 3 discoveries that have transformed our species: fire, agriculture and the steam engine. But there is a 4th discovery with a potential that we have hardly begun to exploit – the energy of nuclear fission.

With current technology, nuclear energy suffers from 3 problems: safety, cost and waste. And we currently transport this energy almost exclusively through a single carrier - electrons. But electricity forms only 19% of the world's energy consumption - the remaining 81% is consumed in the form of heat and mobility, where fossil fuels dominate the market.

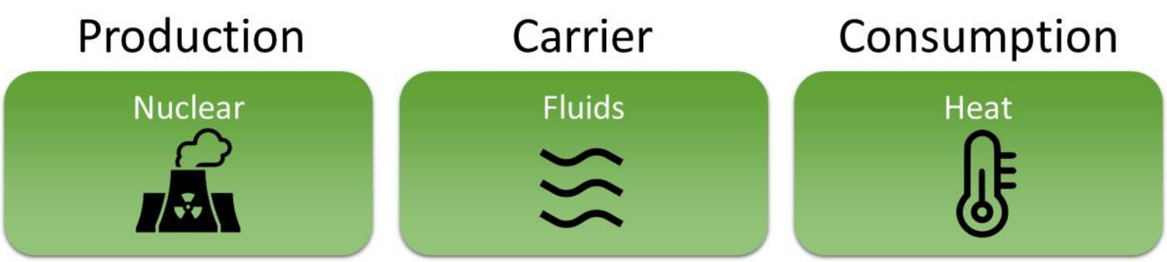
There is a fundamental question about the future of nuclear energy: **Should we change the technology which supplies it or the way it is consumed?** For a long time (and particularly in

France), supporters of this energy have promoted "all-electric" consumption - to cite 3 examples: electric heating, the electric car and electrical industrial processes. But despite all their advantages, electrons suffer from 3 major drawbacks as a carrier: the inflexible nature and cost of their distribution, the impossibility of large-scale electricity storage, and the difficulties of integrating them into mobility systems (for humans and goods).

Residential heating is not fully electric because the cost of fossil fuel solutions remains attractive. Similarly, not much industrial heat runs on electrons because it is cheaper to burn fossil molecules. Cars are not all electric because batteries are heavy, expensive and bulky.

To realise its full potential, nuclear power must follow the 3rd way - change the supply technology **AND** the way it is consumed. Granted, we can decarbonise certain sectors with more electrification - especially with an electricity supply like France's that is 90% carbon-free thanks to a mixture of renewables and nuclear. But the real challenge is to be able to deliver nuclear energy through the other two carriers: hot and cold **fluids**, and **molecules**.

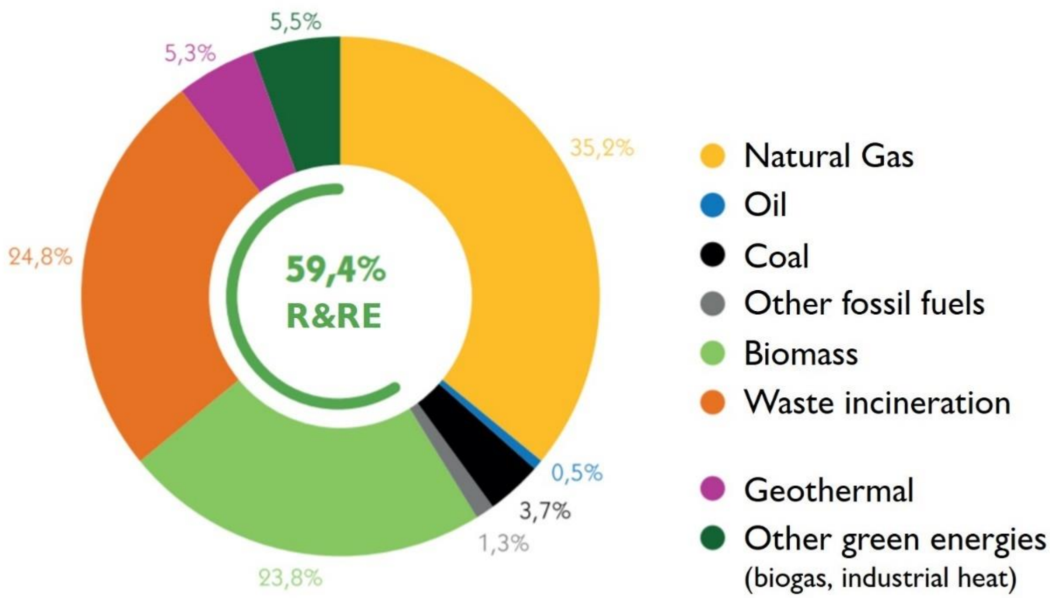
For massive planetary-level energy decarbonisation, nuclear technology must change fundamentally, in 3 ways: It must produce energy that is **hotter, closer and cheaper**.



Leningrad nuclear power plant's district heating network supplies a town and an industrial park.

Nuclear cogeneration is nothing new. In 2019, 79 nuclear reactors were used for desalination, district heating or industrial heat, with 750 years of experience operating these reactors, mainly in Russia and Ukraine. When some of the heat produced by the nuclear reaction is not transformed into electricity, the overall efficiency of the plant is improved. But even in Russia, nuclear power accounts for only 0.3% of the energy supplied through district heating networks.

A 2015 study found that district heating had great potential to decarbonise heat consumption, provided that its networks are supplied with renewable or nuclear energy. The study proposed (and costed, at more than a billion euros) a connection between the Nogent-sur-Seine nuclear power plant and the Paris district heating network, a distance of 90km. But no such project has seen the light, and the biggest contributor to the 25.6TWh of heat supplied in 2019 through France's 798 heating networks was fossil methane.



Energy production sources for district heating networks in France in 2019. Total: 25.6TWh

Regulators around the world demand that nuclear power plants be located at a minimum distance from densely populated urban areas, because they fear that an accident could cause a radioactive cloud, with fallout onto city populations. And indeed, this risk - even though it is extremely low - is not zero **with current pressurised water reactor technology**. Putting distance between power stations and cities is in direct conflict with the use of the fluid carrier because of the high cost of transporting fluids over distances greater than a few tens of kilometres. But with a molten salt reactor the products of the nuclear reaction that are most harmful for humans remain trapped in chemically stable liquid salts. By **eliminating the hazard** of radioactive contamination, the door is open for dialogue with regulators on the siting of small modular molten salt reactors close to cities.

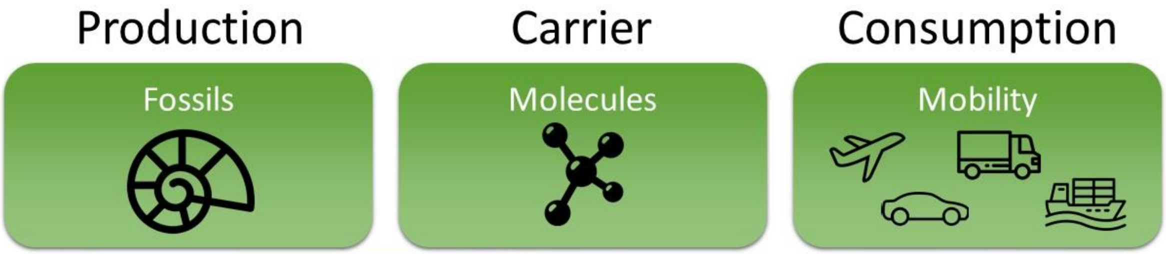
The fluid carrier offers a second opportunity. France already has 24 cooling networks which supplied 0.96TWh to 1,339 buildings in 2019. Supplying these networks with nuclear energy would enable thermally comfortable buildings, using carbon-free energy.

As you will have guessed, there is a third opportunity. The molten salts leaving the tertiary loop of a nuclear island at **650-700°C** are themselves an excellent fluid carrier for transporting heat. Within a radius of a few kilometres around such an island there would typically be a thermal energy storage device (tanks of molten salt) to enable load following of intermittent renewable energies, a facility for turning the heat from the molten salt into electricity, or an industrial park with energy-hungry producers of products like steel, petrochemicals or glass. A new reactor can be located close to an existing industrial site, or these industries can move their production close to a reactor. By comparison, the nominal temperature of the water leaving an EPR reactor vessel is 330°C, which is of much less interest to industrial customers.

The third carrier is **molecules**, which transport their energy in chemical form. When they have been delivered to a consumer a chemical reaction (most often combustion) frees their energy to perform useful work.

Hydrogen (H_2) is currently a fashionable molecule. It is an energy carrier whose combustion or use in a fuel cell releases only water, which eliminates pollution at the point of consumption. In September the French government launched a plan financed to the tune of 7 billion euros, stating that "Given its low-carbon electricity mix, France has key assets for manufacturing carbon-free hydrogen. "

However, 95% of the hydrogen produced in the world uses a fossil fuel source, the most common process being fossil methane steam reforming. It is this process that is used to supply France's first hydrogen bus route (although most of the CO_2 produced is captured using Cryocap technology).



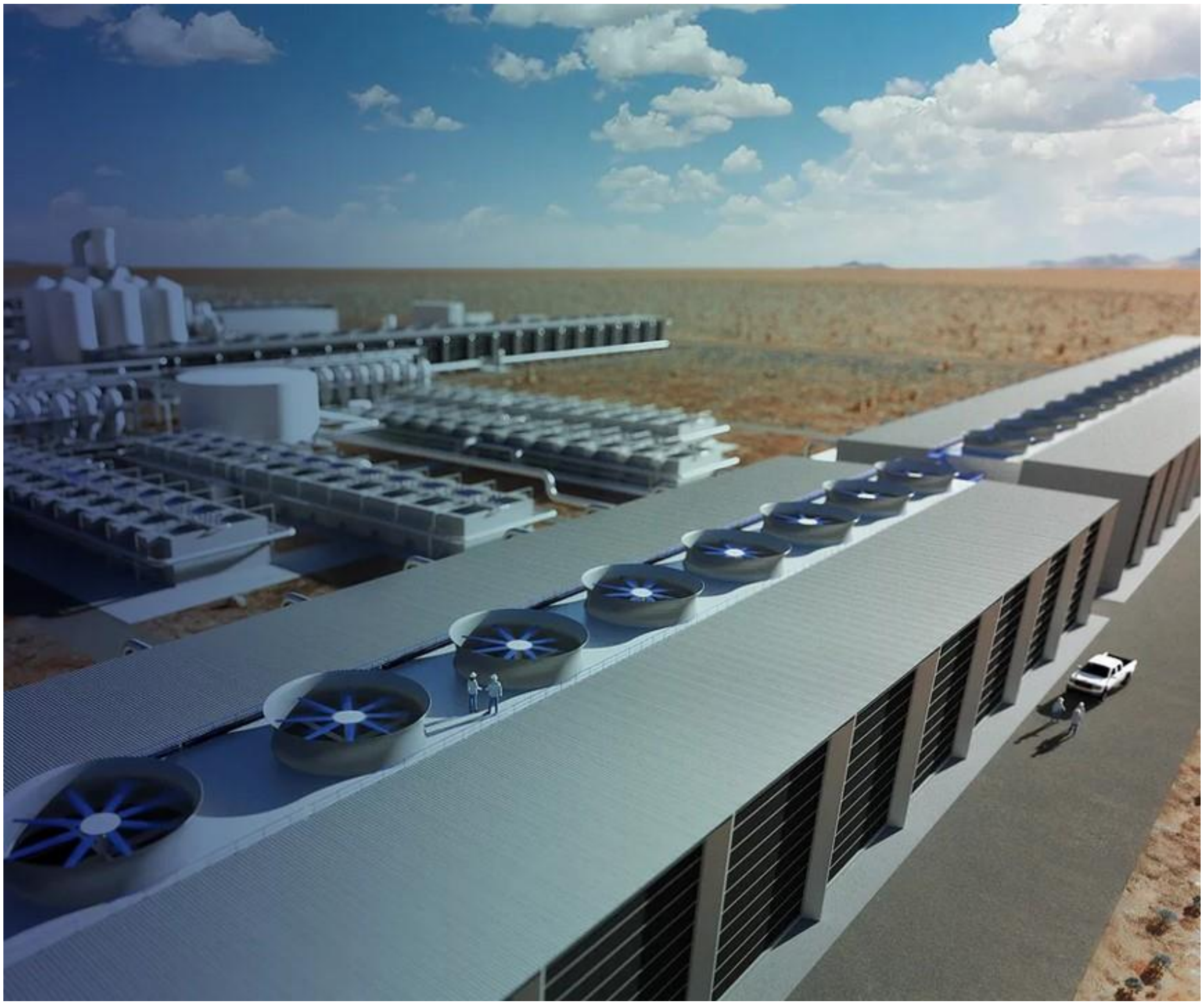
Hydrogen production by steam methane reforming

Hydrogen bus

Completely decarbonising the production of hydrogen requires a combination of a carbon-free energy source and a process for manufacturing the molecule that together produce H_2 cheaper than existing fossil fuel-based processes. 3 examples of sources would be renewable energy, nuclear energy from current reactors or 4th generation nuclear energy. 3 examples of processes would be electrolysis of water, high temperature electrolysis or one of the thermochemical cycles.

The simplicity of molten salt reactor concepts, and hazard pruning of their fault trees, means that the 3 factors mentioned above (hotter, closer, cheaper) can be brought together to produce carbon-free hydrogen competitively. This is a very, very big deal because once this molecule is available it is possible to manufacture many other molecules which would be the keys to decarbonising difficult sectors such as heavy mobility, agriculture or petrochemicals.

In particular, combining carbon-free hydrogen with CO_2 captured directly from the atmosphere would make it possible to manufacture molecules for which the carrier distribution technology and network is already available, such as methanol or synthetic fuels. In parallel with the development of advanced nuclear technologies, direct air capture technologies are progressing. For example, the 1pointFive plant in Texas will be the largest in the world once operational, capturing up to one million tons of atmospheric CO_2 per year. Construction is due to start in 2022.



The 1pointFive facility will use technology developed by Carbon Engineering

In a report published in December, Tractebel - the engineering subsidiary of Engie - give their vision of the rise of nuclear technology 2.0. The report identifies industrial sites such as the integrated steelworks at Dunkirk which would be "ideally suited to welcome a multipurpose Small Modular Reactor demonstrator", and concludes that in the future SMRs (including those operating with molten salt liquid fuels) will be “at the core of integrated, multi-energy carrier ecosystems”. A chapter in Engie Research’s 2020 report on emerging sustainable technologies also explores SMRs.

The Tractebel infographic illustrates their vision and identifies the 3 energy carriers.

In the last century, fossil fuels dominated the market for three reasons:

1. They occupy the 3 consumption sectors: electricity, heat and mobility.
2. They are cheap. **And** (things always seem to come in threes):
3. They utilise the 3 energy carriers: electrons, fluids and molecules.

The start of the third millennium is dominated by the climate change problem. To solve it, humans need new and fundamentally different technologies to realise the full potential of nuclear energy.

John Laurie, [Fission Liquide]

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