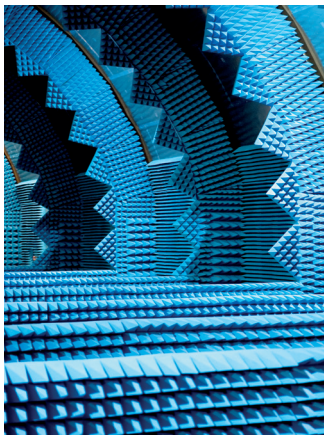
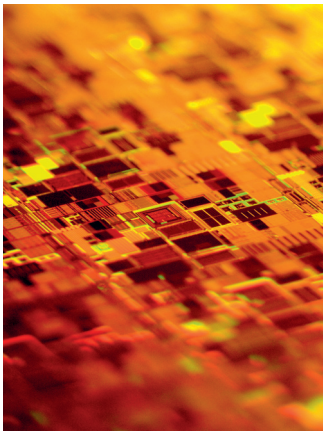
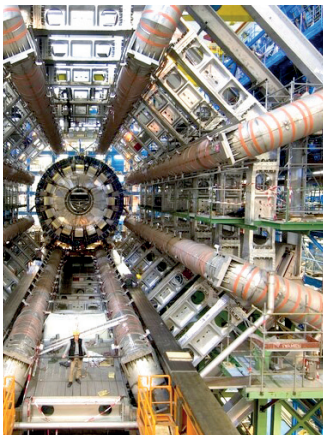
THE ENERGY MIX:
CEA INSIGHTS

TRANSITIONS

ABOUT THE CEA

As France's largest government research organization, the CEA informs public policy and provides public- and private-sector organizations with access to science and technology research so that our society can more effectively navigate the transformations currently underway in energy, health, technology, and global security and defense. This 20,000-person-strong organization possesses nine world-class research facilities across France and engages in partnerships with academic research laboratories and businesses around the globe.

The CEA is a major center for R&D and innovation in:

- **LOW-CARBON ENERGY**
  (NUCLEAR AND RENEWABLE)
- **SECURITY AND DEFENSE**
- **TECHNOLOGY RESEARCH FOR INDUSTRY**
- **FUNDAMENTAL RESEARCH**
  (MATERIALS AND LIFE SCIENCES)

The organization's throughline is research in service of national and European scientific, technological, and industrial sovereignty for a safer, more resilient world for all, now and in the future.

Specifically, we provide public- and private-sector stakeholders with knowledge and innovations vital to building a low-carbon energy system. Our energy-systems research is holistic and integrated. We look at existing low-carbon-energy production technologies like nuclear and solar PV, as well as new emerging/energy technologies; investigate the interactions of different energy vectors in the storage, management, and conversion solutions that will enable tomorrow's grids; and study how circular economy principles can be applied to energy.

Beyond the science, we always consider the technical, economic, environmental, and societal costs and benefits of our research and results.

February 2023.

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BACKGROUND

The time to ramp up our already substantial efforts to transition our energy systems to low-carbon energy sources is now. The growing climate emergency and recent energy crisis have removed any remaining doubt. Turning to clean energy will not only lower greenhouse gas emissions, but it will also reduce France's dependence on oil- and gas-producing countries.

Yes, many questions still need to be answered, but the consequences of inaction are not one of them. We must speed up the energy transition, and we must do it now.

As a signatory of the Paris Agreement, France has committed to achieving net zero greenhouse gas (GHG) emissions by 2050 and has joined fellow EU member states in the European Green Deal in pursuing the ambitious intermediary target of lowering GHG emissions by 55% (from 1990 levels) by 2030. Other significant measures include supporting the development of a low-carbon hydrogen industry and banning the sale of new combustion-engine cars starting in 2035.

Overall energy consumption should decrease due to the growing impacts of energy conservation initiatives and energy efficiency solutions. However, by the 2030s, demand for low-carbon electricity will be massive as electrification picks up momentum. For France to successfully rebuild its industrial economy, this electricity must be cost-competitive.

France is the world's seventh-largest economy and is in an excellent position to transform its energy system. Firstly, it already has a very low-carbon electricity mix (over 90% of its electricity comes from zero- or low-carbon sources) and electricity generation costs are lower than average in Europe. Secondly, it has a highly qualified workforce, an excellent level of technical expertise, and is a leading center for R&D.

Nevertheless, the country still faces four major challenges. It has few raw materials of its own; a significant proportion of its power plants will require refurbishment in the coming decades; the industries needed to shore up the country's energy sector are not sufficiently integrated or, in some cases, non-existent; and, finally, the sector must overcome employer branding and talent pipeline challenges.

The French government is due to introduce or update several key policies in 2023, including the Energy and Climate Planning Act (*LPEC*), the National Low Carbon Strategy (*SNBC*), and the Multiannual Energy Plan (*PPE*). The success of France's energy transition will depend heavily on the targets set by these policies and how well the policies are implemented over the long term.

The purpose of this CEA policy brief is to inform public debate. It sets out the major principles we believe France must adopt to transform its energy systems at the lowest possible risk and cost and reach net zero GHG emissions as quickly as possible.

WHAT FRANCE CAN DO TO REACH NET ZERO BY 2050

1 | DIVERSIFY THE LOW-CARBON ENERGY MIX FOR A SOVEREIGN, COST-COMPETITIVE ENERGY SUPPLY

To achieve net zero by 2050, France must replace fossil fuels—which currently represent more than 60% of the national energy mix—by immediately stopping any new investments in fossil fuels and leveraging all available low-carbon energy technologies. This means:

- Massively rolling out solar, onshore and offshore wind, biomass, biogas, hydropower, and other renewable energy technologies;
- Refurbishing existing nuclear power plants to safely extend their service life;
- Starting a new nuclear program to mitigate the risks and uncertainties of tomorrow's energy mix.

According to a report on France's electricity system completed by national grid operator RTE at the request of the French government, leveraging all the low-carbon technologies currently available is the lowest-cost pathway to a secure energy supply, less dependency on energy imports, and reduced exposure to price fluctuations.

Electrification is not appropriate for all scenarios, unfortunately. Heavy vehicles (trains, ships, planes) and certain industrial processes will require new low-carbon solutions. This is where nuclear—for purposes other than power generation—comes in. Heat, hydrogen, and hydrogen derivatives for the manufacture of chemicals or alternative fuels can all be produced using nuclear energy.

To reduce investments in large-scale grid infrastructure and support the emergence of distributed, local production for self-consumption, it will be important to roll these solutions out at different geographical scales and develop the appropriate production technologies, like Small Modular Reactors (SMRs) and clean hydrogen production units.

2 | BUILD A MORE FLEXIBLE ELECTRICITY SYSTEM AND COMBINE IT WITH OTHER ENERGY VECTORS (HEAT, HYDROGEN)

A more flexible electricity system will be the key to ensuring that the energy supply is optimized, safe, and secure—all vital to moving away from easy-to-store fossil fuels. This can be achieved by:

- Using demand-side mechanisms, in particular consumer incentives and energy monitoring and management systems;
- Boosting dispatchable low-carbon power production;
- Developing electricity storage infrastructure, including Pumped-Storage Hydropower (PSH), stationary batteries, vehicle-to-grid technologies, hydrogen, and heat;
- Increasing transnational grid interconnections;
- Creating a grid architecture that favors local production and demand so that all flexibility resources can be leveraged effectively.

What France's low-carbon energy mix could look like in 2050

Distributed production, storage, and conversion capabilities are orchestrated to supply energy from various low-carbon sources. In this integrated, distributed, multi-energy system, consumers become prosumers.

Each community uses its own, locally-available low-carbon resources (nuclear, wind, solar, biomass) to supply its own energy to meet local demand, which depends on factors like industrial activity, climate, and population.

3 | REDUCE ENERGY CONSUMPTION AND GHG EMISSIONS

To reach the net zero target, energy consumption will have to be reduced drastically through increased conservation and energy efficiency—both of which must become the norm whenever possible. This means rethinking all our activities—including those involving technology—and reducing losses by insulating buildings, for example.

There are two key elements to reducing overall energy consumption: using more electricity (instead of carbon-emitting fossil fuels) and making equipment and processes more efficient.

Imported emissions—from manufacturing activities offshored to fossil-fuel-intensive countries—must also be addressed, as they account for a significant share of France's carbon footprint. Domestic carbon emissions have fallen since 2005, while emissions from imports continue to rise.

Consumers need better information about their actual carbon footprint. Carbon labeling on products, for example, should be encouraged and, perhaps, mandated.

4 | LAY THE GROUNDWORK FOR THE HYDROGEN AND SYNTHETIC FUEL INDUSTRIES

Hydrogen—when produced using zero- or low-carbon primary fuels and processes—offers several advantages. It is an attractive energy vector for industrial process equipment and heavy vehicles. And it can also provide much-needed flexibility. When electricity supply is higher than demand, the surplus can be stored directly in batteries or pumped-storage hydropower plants—but it can also be used to produce easy-to-store hydrogen.

Electric motors and batteries cannot respond to all transportation use cases. For planes, trains, ships, and heavy trucks, it is likely that hydrogen—in massive quantities—and synthetic fuels will be the answer. Hydrogen could also rapidly replace fossil fuels in certain industrial processes, including steel manufacturing and fertilizer production.

In addition, hydrogen can be combined with carbon captured from the atmosphere or point sources using low-carbon energy to form new carbon chains. The science and technology behind processes like this are still in the early stages, and concerns about cost-effectiveness and efficiency need to be addressed. Nonetheless, this type of solution should not be overlooked.

Given the major role hydrogen will undoubtedly play in national low-carbon energy policy, developing hydrogen production (e.g., water electrolysis using low-carbon electricity), transportation, and storage capabilities must be made a priority now.

5 | STRENGTHEN THE CIRCULAR ECONOMY

Increasing electrification and developing new emerging technologies will drive even greater demand for critical materials and resources. Many of these materials are mined and processed in just a handful of countries, which raises vitally important supply chain issues.

Decarbonization alone is not enough. Circular economy principles must also be adopted to save materials and reduce the environmental impact of new technologies.

Regulators, manufacturers, and consumers must all contribute. First, product lifespans must be extended, obsolescence pushed back as much as possible, and end-of-life reuse and recycling encouraged. Products must be updatable, upgradeable, and repairable by design. Complete product composition, assembly, repair, and disassembly information for the entire product lifecycle must be provided by manufacturers.

Similarly, recycling the critical metals and resources used in energy production and storage must be a priority. For nuclear power, the circular economy translates into a closed fuel cycle, which has the benefits of securing the fuel supply and supporting the long-term viability of nuclear energy. The carbon cycle, too, can be closed, by capturing carbon from the atmosphere or industrial processes, and reusing it to make synfuels, which can be used as a substitute for fossil fuels.

The key challenge to building a circular economy around low-carbon energy will be to develop sovereign domestic industries that will ensure that raw materials and value-added processes stay in France and in Europe.

CEA R&D AND INNOVATION: A LONG-TERM COMMITMENT TO THE ENERGY TRANSITION

The CEA's holistic, integrated approach to the energy mix gives us a unique vantage point. We believe that all available options should be utilized to achieve net zero by 2050 at the lowest possible cost to society and in a way that best supports national sovereignty.

Our goal is to help build an energy mix that includes both existing technologies and emerging ones that will reach maturity before 2050. When considering possible solutions, it is important to remember not only the time it takes to bring a new technology from the lab to the market, but also the additional challenges—and potential delays—around public acceptance and market adoption.

CAPITALIZING ON MATURE, PROVEN TECHNOLOGIES (NUCLEAR AND RENEWABLE ENERGY)

France will need an energy mix that includes nuclear and renewable energy based on proven, competitively-priced technologies to achieve net zero by 2050. Combining these two forms of energy makes perfect technical, economic, and strategic sense and supports national sovereignty. Choosing one to the detriment of the other would be a mistake, exposing the country to higher costs and the risk of missing its carbon-reduction targets.

KEEPING OUR EYES ON THE FUTURE

Decisions made now to align the energy mix with the goal of net zero by 2050 will shape the rest of the century. Our science and technology roadmaps must remain focused on innovations with predictable times to market.

New technological advances affecting the supply and demand sides will be made between now and 2050. Consumer lifestyles will also change. We will need to periodically reassess our options and pathways to decarbonization.

We believe that progress will be incremental. But we also believe that looking further ahead will be crucial to avoiding the kind of "stop-and-start" that slows down R&D and hinders public acceptance—which will inevitably compromise the country's chances of reaching its 2050 targets.

Securing long-term funding for research in France will be vital to ensuring we can purchase the lab equipment needed to explore new research avenues and build new industries while making our existing industries more efficient, resilient, and sustainable.

WHAT WE ARE DOING TO ACCELERATE THE ENERGY TRANSITION

Our holistic, integrated approach to energy systems drives nine research focus areas with the capacity to accelerate the energy transition.

1 | INNOVATIVE NUCLEAR REACTORS:
Continue work on the NUWARD SMR project with our French and European partners; develop new reactor concepts and solutions for energy-intensive industrial facilities and communities like Advanced Modular Reactors (AMRs) and SMRs that produce heat or hydrogen instead of—or as well as—electricity.

2 | THE NUCLEAR FUEL CYCLE OF THE FUTURE:
Improve fuel cycle plants by introducing new processes and start adapting plants for a closed fuel cycle.

3 | SOLAR PHOTOVOLTAIC:
Develop high-performance cells and solar panels for a variety of use cases to make ubiquitous, grid-friendly solar a reality.

4 | DEVELOPMENT OF THE HYDROGEN INDUSTRY:
Scale up electrolysis (build gigafactories) and develop hydrogen fuel cells for the transportation industry, hydrogen storage solutions, and hydrogen conversion technologies to produce molecules of interest.

5 | BATTERIES:
Develop new generations of safe, powerful batteries with smart BMSs and optimized characteristics (capacity, charging time, cycles, cost).

6 | SMARTGRIDS:
Build simulation and management tools and create a national open platform for testing innovative smartgrid technologies and services.

7 | THE CIRCULAR ECONOMY:
Develop sustainable, resource-efficient design, manufacturing, and recycling methods and processes for energy system components.

8 | THE INDUSTRIAL ECOSYSTEM:
Help establish a robust industrial economy in France and in Europe, foster innovation through tech transfer partnerships, and shorten development and scaleup cycles.

9 | SOCIETAL, TECHNICAL, AND ECONOMIC ANALYSIS OF SYSTEMS AND SCENARIOS:
Provide insights on the impacts and issues inherent to new technologies and inform decision making.

The CEA makes significant investments in state-of-the-art lab equipment, research facilities, and computing and simulation tools.

Our goal is to help make France's energy mix sustainable, diverse, and sovereign for a secure, affordable supply for consumers and a faster transition to net zero GHG emissions.

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