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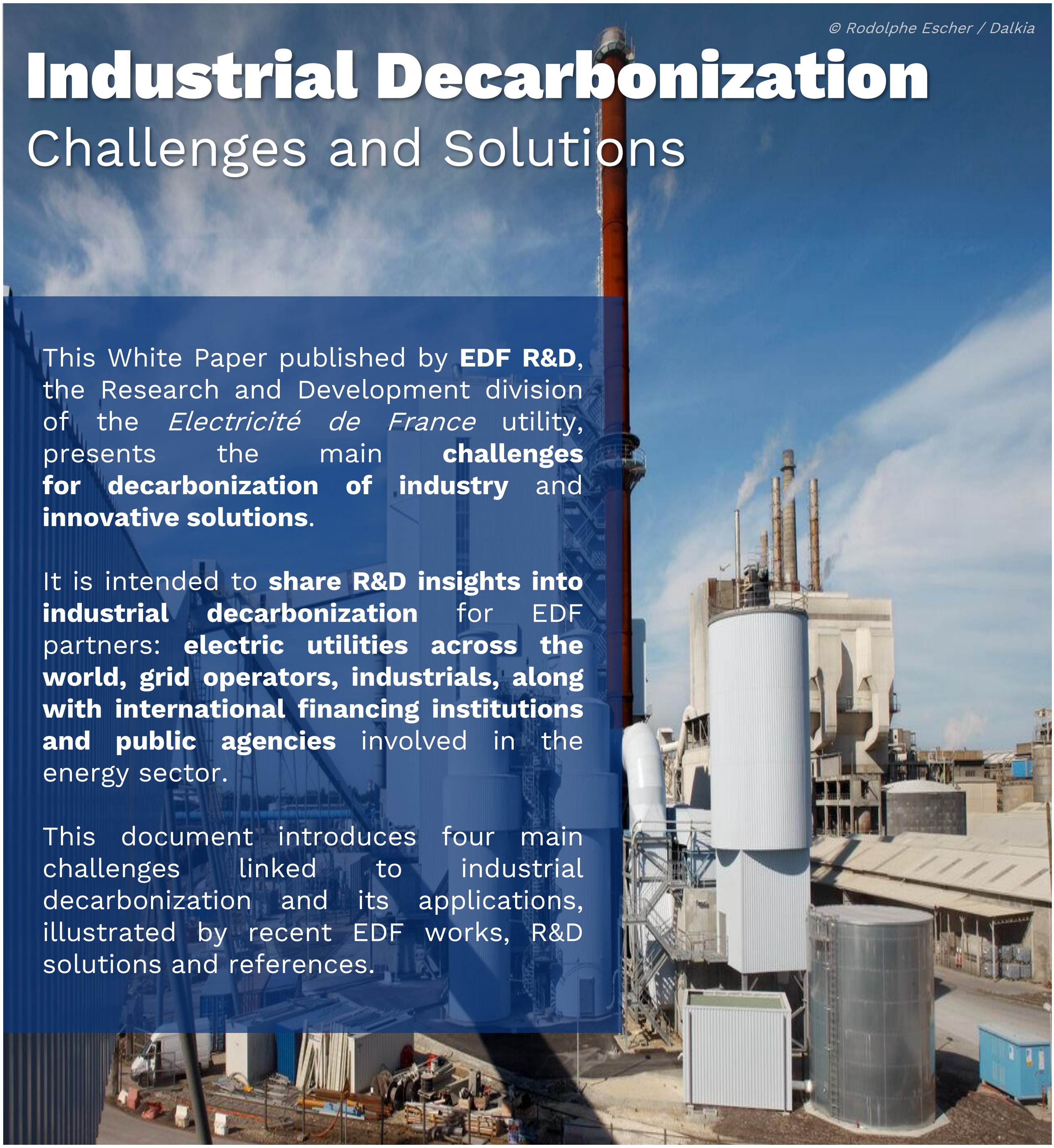
R&D WHITE PAPER



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Industrial Decarbonization

Challenges and Solutions

This White Paper published by **EDF R&D**, the Research and Development division of the *Electricité de France* utility, presents the main **challenges for decarbonization of industry** and **innovative solutions**.

It is intended to **share R&D insights into industrial decarbonization** for EDF partners: **electric utilities across the world, grid operators, industrials, along with international financing institutions and public agencies** involved in the energy sector.

This document introduces four main challenges linked to industrial decarbonization and its applications, illustrated by recent EDF works, R&D solutions and references.

Decarbonization of Industry: Context and Challenges

Adopted on an international scale by the Paris Agreement, and on a European scale by the European Green Deal, commitments to carbon neutrality by 2050 require credible and effective solutions. Decarbonizing industry is a key factor in this transition. In fact, according to the International Energy Agency (IEA)[1], industry is the world's second largest emitting sector worldwide after electricity generation and before transportation and buildings. In France for example, to achieve the carbon neutrality targeted by the French National Low-Carbon Strategy, the industrial sector must reduce its CO2 emissions by more than 80% by 2050, i.e., from 80 Mt/year to 16 Mt/year. Decarbonizing industry is therefore becoming a real challenge.

The bulk of industrial GHG global emissions come from 4 major sectors being iron and steel, chemicals, non-metallic minerals, and non-ferrous metals. Emissions from industry totaled 9.0 Gt worldwide in 2022 according to the International Energy Agency (IEA). As the industry sector is highly concentrated with a few major emitting industries, each decarbonizing action will therefore have a significant impact.

The main part of industrial greenhouse gas emissions comes from **energy uses**. Most of the CO2 emissions from these industrial sites come from thermal equipment (industrial boilers, furnaces, etc.) using fossil fuels. The solutions that can be implemented to successfully reduce CO2 emissions are:

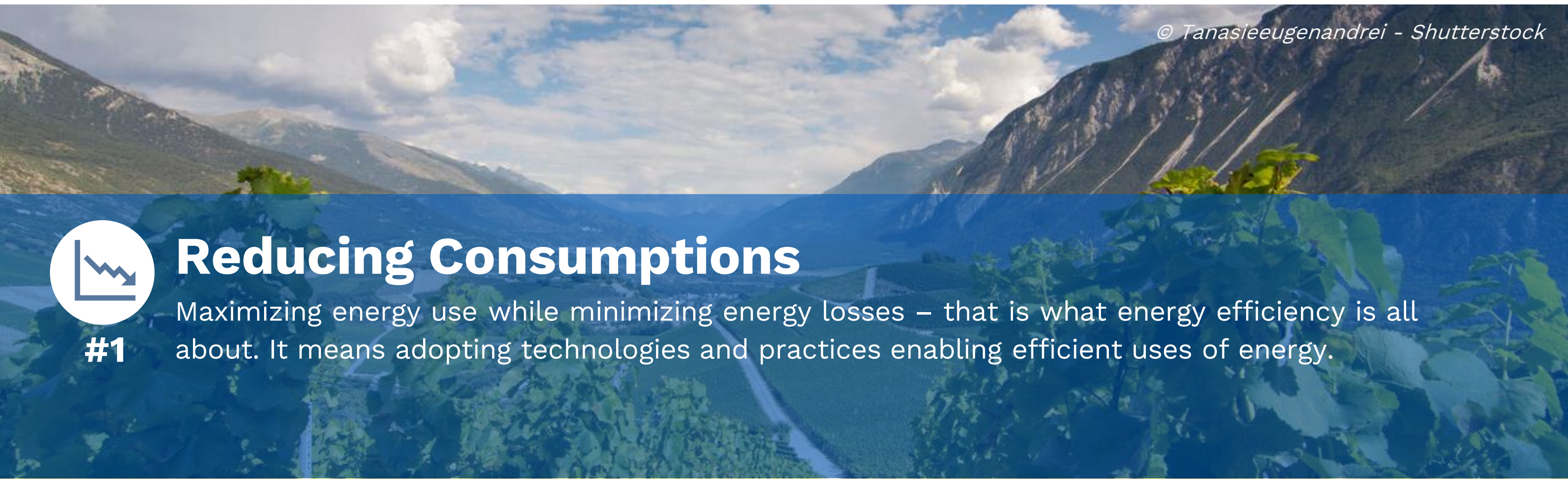
- Energy-related: by replacing fossil fuels, the main sources of GHG emissions, with low-carbon energies (electricity, biomass, biogas, low-carbon hydrogen) to power processes. Electrification appears to be one of the major levers.
- Technological: by developing technologies using low-carbon sources. Some using electricity as a decarbonized vector are already mature such as high temperature heat-pumps or electric furnace.
- Products-related: by altering the composition of certain products to make them less emitting. For example, in cement manufacturing, by replacing the main component, clinker (a highly emitting material), with other less emitting constituents (such as clay, pozzolana, blast furnace slag, ashes) while preserving the same overall properties.
- Industrial symbiosis approaches: creating synergies between manufacturers in a given area to exchange waste heat, water or waste products that can be transformed into a resource for other stakeholders in the area.

In short, industry needs to **reduce** its consumption thanks to energy efficiency, and to **replace** fossil fuels using equipment with electrical equipment. Another challenge is to decarbonize through **territorial synergies**. Nevertheless, despite those solutions, some industries will remain CO2-emitting. That is why, another challenge is to **capture** residual CO2 for **storage and use**. EDF R&D researchers are committed to achieving these goals by carrying out research, testing and demonstrations on all these different fronts.

Decarbonizing industry represents a real challenge, given the heterogeneous nature of the sector and the complex technical and economic constraints it faces. Decarbonization will only be possible if all levers are activated together: reduction, replacement, capture, territorial synergies. That is why, EDF R&D is working on this and has developed genuine technological and sectorial expertise in order to accelerate the deployment of the most effective and economic solutions.

This White Paper explores various solutions, both mature and under development, that could contribute to the decarbonization of industry. EDF R&D has developed several tools, backed up by its knowledge of industrial processes and performance optimization. Hence, it can provide precise figures to companies wishing to improve their energy choices. EDF R&D researchers can provide expert answers to questions about technical and economic feasibility, and possible timeframes.

[1] - IEA, 2022 survey



Reducing Consumptions

#1

Maximizing energy use while minimizing energy losses – that is what energy efficiency is all about. It means adopting technologies and practices enabling efficient uses of energy.

Existing solutions

First and foremost, to decarbonize industry, we need to reduce consumptions through energy efficiency initiatives. EDF R&D develops tools for auditing, optimizing consumption and improving performance, and offers support to factories in their transition.

EDF R&D is looking at all the components of the industry of the future. Researchers are developing solutions that will enable industrial customers to improve their performance and decarbonize their activities through energy savings, driving a transformative shift across all factories towards enhanced operational efficiency and sustainability.

One of the solutions developed is the **Sprint Factory** offer from EDF R&D, focused on improving industrial performance as a basis for developing energy efficiency. It enables massive analysis of all types of industrial data (process, raw material, quality, etc.), not just energy data, using tools that combine EDF R&D solutions and sometimes leveraging external software.

EDF R&D has also developed a solution for optimizing electric motor fleets. Electric motors account for 70% of industrial customers' electricity consumption. According to the French Environment and Energy Management Agence (ADEME), more than half of these motors can be optimized to save between 5 and 30% of industrial electricity consumption. Considering this, EDF R&D has developed the **Motorboard** offer. It stands as an innovative solution that allows for the diagnosis of electric motors fleet, providing a clear understanding of usage costs. It serves for optimizing electrical consumption by implementing appropriate eco-efficient solutions. In the near future, the tool will allow to track progress over time and facilitate predictive maintenance. This audit is carried out using wattmeters designed by EDF R&D, with measurements being analyzed by a software based on EDF R&D expertise.

Furthermore, with nearly 80% of equipment controllers in industry either incorrectly set or becoming unsuitable over the years, leading to over-consumption, optimizing control appears to be a very important lever for obtaining savings. With this in mind, EDF R&D has designed the **EAC** (Easy Advanced Control) **solution**. EAC includes advanced control laws, patented by EDF, which have been implemented in a standalone control box. EAC can be used on compressors for refrigeration and for compressed air, pumps, valves, fans, etc. These control laws perform far better than conventional controllers, and offer greater stability for installations: lower maintenance costs, longer service life, improved product quality, etc.

EDF R&D researchers are also working on a **highly innovative air distribution system** (reversible hot/cold) that will improve working conditions for factory employees while reducing energy consumption. Industrials have already shown interest in this concept and manufacturers as well.

All these tools are at the service of decarbonization and industrial performance.

Easy Advanced Control

The EAC **Plug & Play** unit, easy to use, can be installed in place of an old PID-type regulator or in a new setup. Configuration and start up are simplified through the "auto-tune" function.

Motorboard offer

The Motorboard offer includes the Motorbox wattmeter and the EDF Viveco data analytics platform.

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Substituting Fossing Fuels

#2

Electrification can play a major role in the decarbonization of industries; starting today through greater adoption of already available technologies, and tomorrow through technological and cultural breakthroughs.

Existing solutions

The second axis of industrial decarbonization supported by EDF is the substitution of fossil energies by low-carbon energies. All studies and scenarios looking at ways of achieving carbon neutrality in Europe see the electrification of industry as a major lever for reaching this goal, resulting in a doubling share of electricity in industry's energy mix. Electrification could reduce industrial emissions by up to 50%.

In particular, electrification is an effective lever for decarbonizing industries for which it is difficult to use other solutions, such as ferrous metallurgy. Today, steel production is responsible for 5.7% of GHG emissions in Europe, as it relies on the intensive use of coal and gas. EDF R&D has therefore turned its attention to this issue through the **European Siderwin project** (H2020). Siderwin aimed to develop an electrochemical process for the electrolytic decomposition of iron oxides into metal plates and oxygen gas. By replacing coal with electricity, this innovative technology reduces the sector's direct CO_2 emissions by 87%.

Another major challenge is energy consumption in the form of heat. The majority of industrial energy consumption is linked to thermal needs and is mainly produced from fossil fuels. In France industrial heat accounts for around 236 TWh of total industrial consumption, with about half of it being waste heat. As a result, the recovery of waste heat appears to be a major lever to be activated. Pioneers in this field, EDF R&D and Dalkia, an EDF subsidiary, have developed an industrial demonstrator through the **Transpac project.** Transpac is a high-performance heat pump installed by Dalkia at a paper manufacturing facility, resulting from research conducted by EDF R&D teams. EDF R&D has demonstrated its innovative capacity by designing this high-temperature heat pump, a powerful tool for decarbonizing industrial processes through electrification and waste heat recovery. The results speak for themselves:

- Heat pump coefficient of performance (COP): 4
- Hot air production at 140°C with double the performance of a conventional heat pump.

These results are the fruit of a collective effort involving industrial, academic and institutional partners.

All the reports published in recent months on carbon neutrality have placed great emphasis on industrial heat pumps. In fact, the IEA report recommends installing around 500 MW of heat pumps worldwide every month over the next 30 years to achieve carbon neutrality.

EDF R&D also works with Dalkia to extend current utility supply offers and associated energy performance contracts to the industrial process, by adding a decarbonization component, notably via solutions such as industrial heat-pumps, mechanical vapor compression (MVC), electric furnaces and boilers or pyro-gasification. This project has a strong focus on **partnerships** with manufacturers and stakeholders in the relevant sectors, networks of industry stakeholders such as Allice alliance (Industrial Alliance for Competitiveness and Energy Efficiency), technical centers, etc.

BAMBOO EU project

As part of the Bamboo project, EDF R&D is working with **various European partners** on a steam heat pump demonstrator. They are studying its application to a cold rolling process at the pickling line. Steam is used to heat the acid required for treatment. This project, among others, is enabling EDF R&D to develop genuine **sectoral** (paper, non-metallic materials, chemicals, etc.) **and technological expertise**.

TRANSPAC, world's first highly efficient heat pump

EDF R&D's high temperature heat pump lab allowing for testing of heat pumps up to 1MW and 150°C. © Lutt Julien, CAPA Pictures

Develop Industrial Symbiosis between Industrial Sites

#3

Fostering a circular economy among industrial sites represents a visionary approach to resources management and sustainability. This concept represents a strategic leap toward an interconnected industrial landscape and transcends the conventional notion of energy flows waste.

Existing solutions

To address the issue of limiting resources, EDF's R&D is also focusing on the implementation of different organizational modes within industrial park, which can either be traditional, connected to neighboring cities, or industrial-port zones. The idea is to move from a linear economy to a circular economy. The objective is to valorize the wasted flows from industries, such as fatal heat or wastewater, by turning one industry's waste (or outgoing flows) into another's resource. In this way, energy and material flows are optimized, reducing the impact on local resources and the environment, notably reducing CO_2 emissions. Such organizations are called "eco industrial parks".

EPIFLEX® approach capitalizes on 10 years of R&D work. It is structured around 6 steps and based on a set of tools and methodologies designed to set up collaborative projects between industrial sites towards an optimized way. To design circular economy solutions in an industrial zone, EDF R&D has developed two complementary tools, designed to be adapted to all types of industry. They are used in two main stages:

- The first one enables pre-targeting of material flows vectors and determines which industrials are relevant in the area. The tool provides information on all industrial sectors to identify processes that would be compatible with the waste heat available in the industrial zone. This defines the study perimeter and the initial study issues (heat and resources requirements, waste heat and resources, etc.). This step allows for assessing the current situation by describing the main flows, notably energy and CO2, in and out of each industry.
- The second one designs industrial symbioses and verifies the technical feasibility and economic profitability of the synergies identified above. By modeling real data on industrial site flows (incoming and outgoing) and proposing valorization technologies, the tool optimizes industrial eco-park design, minimizing the capital and operating costs of the entire solution.

During the process, the approach combines techno-economic analyses with territorial animations to stimulate dialogue, and to promote stakeholder buy-in and territorial anchoring of solutions.

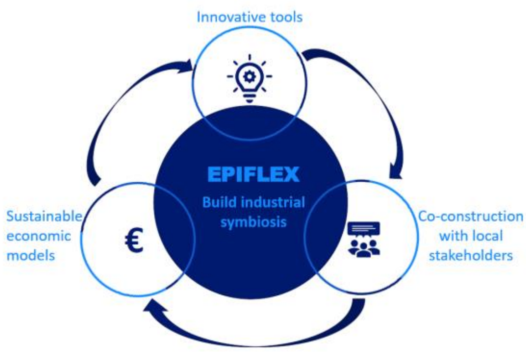
The design of energy recovery networks between industrial sites represents a major energy efficiency and decarbonization initiative, since it leads to the substitution of local production resources (e.g. gas boilers) by unused waste heat flows from neighboring industrial sites. These symbioses enable the power of intra-site production resources to be reduced, or even eliminated if external inputs are sufficient. Renewables means of production can also be proposed to complement available neighboring flows. All theses proposals contribute to the decarbonization of the industrial zone.

EPIFLEX® approach being generic and replicable, studies have started in several interested territories.

The example of Dunkirk (France)

EPIFLEX has been applied to the industrial harbor area of Dunkirk (France), in partnership with various industrial and institutional players.

About twenty major industrial sites have been modeled, and solutions have been identified to support the decarbonization of this territory, the largest emitter in France. Thus, one of the proposed industrial eco-park solutions could avoid 43kt of CO_2 emissions through the valorization of up to 1.3TWh/year of fatal heat, and save 1.5 million m3 of water annually through better water resource management.



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Capture Residual CO2 for Storage and Use

#4

Technical progress in the field of residual CO2 capture will play a key role in the decarbonization of large industrial sites which are intrinsically CO2 emitters. Carbon capture can be combined with a storage and/or reuse process, which would contribute to a considerable reduction in C02 emissions.

Existing solutions

Despite energy efficiency, electrification initiatives and industrial symbiosis, some industrial processes, such as cement and steel production, remain intrinsically CO_2-emitting. Only a change in chemical processes could reduce their emissions, but such a change is not always possible. Therefore, fatal emissions will remain. **Carbone Capture** therefore appears to be the only solution for achieving complete decarbonization. Once captured and transported, the CO2 can either be sequestered permanently – we are talking about **Carbone Capture and Storage** - or used by being converted into a by-product (like e-fuels) – we are talking about **Carbon Capture and Use.**

EDF has been involved in CO2 capture for over 20 years.

In 2014, EDF has already successfully installed and operated an industrial capture pilot in a thermal generation plant in Le Havre. It consisted of isolating CO2 from industrial fumes by chemical absorption. It allows the decarbonization of the plant at the electricity production side. Thanks to this project, EDF has gained experience, both in engineering and operation of a capture process, which has undergone full-scale testing.

Then, EDF R&D has focused on decarbonizing industry by running **industrial CCU - Carbon Capture and Use projects** on cement plants where the CO2 results from the manufacturing process itself. Indeed, the cement industry is responsible for 7% of global emissions. According to the International Energy Agency (IEA), by 2030, CCUS should contribute to reducing CO_2 emissions from the cement sector by 47%. In this context, EDF is involved in several projects such as **HyNoVI** (see details on the right) and **Take Kair,** both in collaboration with cement manufacturers.

Post-combustion CO2 capture from industrial flue gases using solvent absorption is currently one of the most mature processes. The main challenges of this process are to achieve solvent absorption using a minimum of energy and limiting the ageing of the solvent used. The capture rate of this type of process is around 90%. It is also possible to capture CO2 before combustion (pre-combustion capture) or to drastically increase the concentration of CO2 in the flue gas to facilitate capture (oxy-combustion), but these processes are less mature and more complex to implement, especially for existing plants.

EDF R&D and EDF engineering teams are directly involved in the capture and use phases of the CCUS chain. EDF Group, through R&D, keeps an active watch on transport and storage global activities. EDF also participates with partners in CCUS project deployment.

HyNoVi project

Hynamics, an EDF Group subsidiary specializing in low-carbon hydrogen production, has teamed up with Vicat, a French cement manufacturer, to **integrate a CO2 capture solution** on Vicat's industrial site to create the first low-carbon methanol production chain in France. The CO2 from cement production is captured at the furnace exit and combined with H2 produced by 330 MW of electrolysis (according to Vicat's ambition). In the end, this process should **capture 40% of the cement factory's emissions** while producing a quarter of France's methanol needs.

CO2 Lab at EDF R&D Lab 'Chatou' (France)

The CO2 Lab is a **unique CO2 capture** laboratory in France. Flexible, it is designed to test **various capture technologies** across a wide range of flue gas types (CO2, N2, O2, and pollutants). Thanks to its mobile nature, it can be **deployed directly on site**. Equipped with four slots, the laboratory also supports the integration of **external modules**.

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EDF R&D offers a **wide range of services and training courses** for international partners and clients, professionals or scientists.

Several areas of research are open to customers willing to **benefit from EDF R&D analysis, expertise or lab testing**. EDF R&D services span across three major domains: **Smart Home, Regions and Companies and Low Carbon Generation**.

The **Institute for Technology Transfer (ITech)** is a training organization to share practices, expertise, and innovations based on EDF R&D activities.

Various training courses are available on **renewable integration, smart grid solutions, microgrids, grid integration, energy storage, energy efficiency, control and communication technologies, etc (see EDF R&D ITECH catalogue).** Training is provided by EDF R&D leading experts in these key domains.

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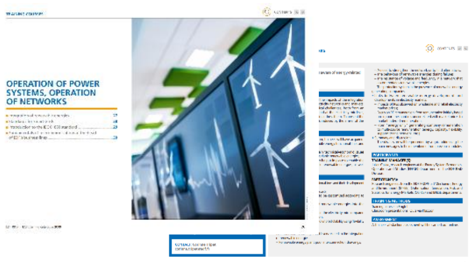

EDF R&D: DARE TO LOOK TOWARDS THE FUTURE AND INNOVATE AT PRESENT

EDF R&D carries out **research for all EDF Group entities**, helping them improve performance and prepare the future integrating innovative technologies and solutions.

EDF R&D has **three Labs in France, six abroad** (China, Germany, Italy, Singapore, UK, USA) and a **R&D representative office in Brussels**.

OUR 4 SCIENTIFIC PRIORITIES

1. **DECARBONISING OUR CLIENTS' USES THANKS TO ELECTRICITY**
2. **STRENGTHENING THE PERFORMANCE OF OUR GENERATION ASSETS**
3. **INVENTING TOMORROW'S ENERGY SYSTEMS**
4. **ACCELERATING DIGITAL TRANSFORMATION**

EDF Lab's facilities in Saclay, one of EDF R&D research centers.

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