April 2022

R&D WHITE PAPER

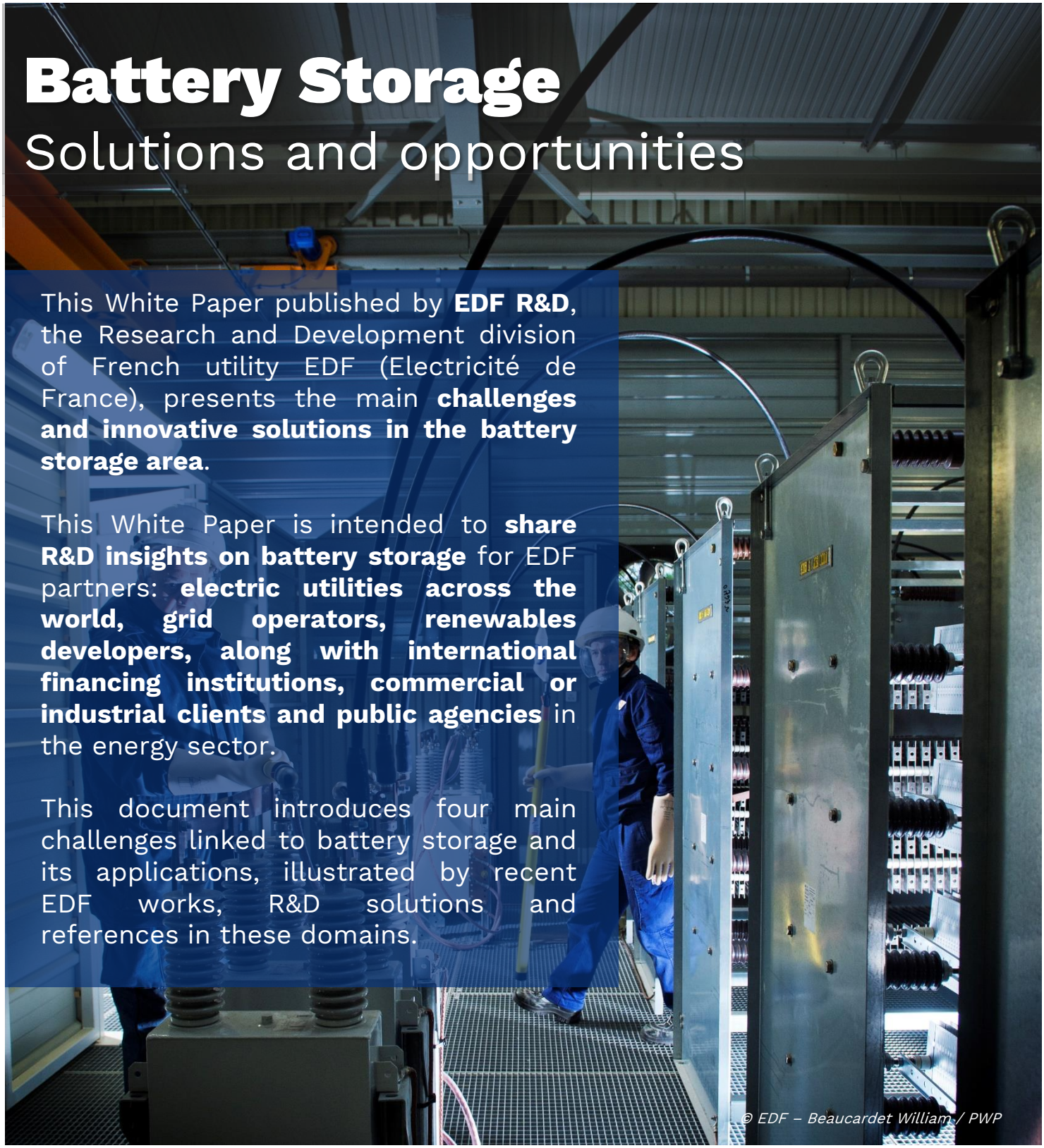
Battery Storage

Solutions and opportunities

This White Paper published by **EDF R&D**, the Research and Development division of French utility EDF (Electricité de France), presents the main **challenges and innovative solutions in the battery storage area**.

This White Paper is intended to **share R&D insights on battery storage** for EDF partners: **electric utilities across the world, grid operators, renewables developers, along with international financing institutions, commercial or industrial clients and public agencies** in the energy sector.

This document introduces four main challenges linked to battery storage and its applications, illustrated by recent EDF works, R&D solutions and references in these domains.



© EDF – Beaucardet William / PWP

Battery storage: context and challenges

© EDF / Jobard Rodolphe

EDF R&D vision of battery storage

Energy storage is gaining momentum and is seen as a key option in the process of energy transition where several services will be fulfilled by batteries. For the last twenty-five years, EDF R&D has been a major player in the energy storage area and has developed significant knowledge and skills to provide the best solutions for EDF storage projects.

In 2018, an Energy Storage Plan was structured by EDF, based on three objectives: development of centralised energy storage, distributed energy storage, and off-grid solutions. Overall, EDF will invest in 10 GW of storage capacity in the world by 2035.

Given the growing importance of stationary storage in electrical power systems, this white paper aims at presenting EDF R&D's experience with batteries across applications, technologies, economics and operations.
This document does not intend to cover other types of energy storage, such as hydrogen, hydraulic, thermal nor electric mobility.

Storage is sometimes perceived through a rather restrictive angle: a straightforward solution to smooth out intermittent generation from renewables. In reality, stationary storage can offer various benefits along the electricity value chain. Being a quite complex domain, battery storage requires sound expertise to overcome its challenges and identify operational applications.

Battery storage uses are wide with many possible applications at different power system scales and for a variety of stakeholders. A thorough R&D analysis of possible applications is required beforehand.
The choice of battery storage technologies requires precise expertise to select the most suitable candidates and ensure that they match the specific expectations of the project (cycles, performance, lifespan...). Experimentations are made at EDF R&D labs to validate their overall performance.
When investing in batteries, the economics of energy storage becomes a key aspect. The investor must ensure that the economic equation is profitable between the value created by the battery uses, its initial investment and the O&M costs over the long run. Novel tools are developed to determine the optimal added value. When the battery is operational, a communication and monitoring system is needed, generating data for the operator and bringing real time visibility on the battery's condition. Data analysis contributes to extend the lifespan of batteries by maintaining their capacity and anticipating any dysfunction.

EDF R&D is working on key storage topics through collaborations with academic partners (CRIEPI, ICMAB, ICCMO, Tsinghua Univ...) and worldwide industrial companies. EDF is also member of several energy storage associations and agencies (ESA, ADEME, RS2E electrochemical storage network...). In addition, EDF is a founding member of EASE, the European Association for Storage of Energy.

© EDF

One of the key words about stationary energy storage is flexibility. Matching generation and demand will imply using a broad range of flexibility levers: flexibility from generation and consumption, from grid development and from energy storage (electric, thermal, inertial gravitational). Storage must then be analyzed as one of the potential components of a flexibility portfolio.

#1

Battery storage applications

Recent technical progress in the field of batteries will play a key role in increasing the uses of storage, particularly in the context of energy transition. Batteries can provide several services in large power systems, distribution grids, microgrids or at customers' premises.

© EDF – Nabil Zorkot

Diversity of applications

Battery storage can act on the whole electrical system and at different levels. It is able to provide several services, such as operating reserve, frequency control, congestion mitigation, peak shaving, self-consumption, security of supply and many more.

Identify and Integrate storage most relevant services into an electric power system is a key challenge. Indeed, there are strong differences between power systems: large interconnected areas, local distribution grids, isolated systems and private networks located behind the meter.

Regulatory contexts applicable to batteries strongly differ across countries. Regulations typically define the scope of application and the possibilities for stakeholders to use batteries (frequency control, congestion mitigation self-consumption...).
To assist investors on the emergence of a storage project, EDF R&D has developed a deep knowledge in regulations for battery uses, applied to different EDF international projects.

In 2018, EDF was involved in new storage applications for the procurement of ancillary services to public stakeholders. EDF R&D supported the West Burton power station in England, integrating a 49MW lithium-ion battery that benefited the whole of UK for solving frequency issues.

In the context of energy transition, batteries can compensate rapid fluctuations of renewables and can increase their share in the energy mix. In French overseas territories, EDF carries out research to find out optimal storage configurations.

The MASERA microgrid testbed in Singapore integrates various battery technologies demonstrating EDF R&D's expertise in storage applications, as recognized by an ISGAN Excellence Award in 2019.

Besides direct economic impacts, storage can also serve several security purposes.
For instance, private clients and public vital facilities (medical, military...) seek for resiliency in case of outage of the public grid. Behind the meter batteries can then provide temporary energy supply as an alternative to conventional gensets.

The development of energy access in emerging countries is also a key driver for new battery applications (solar home system in off-grid power systems, solar pumps for irrigation, light duty vehicles).

Saint-Georges de l'Oyapock

In French Guyana, EDF R&D participated in the design of an energy storage system using lithium-ion batteries. It ensures stability to the grid, allows the connection of new consumers and supervises the entire electrical power system (hydro, biomass and storage).

West Burton power station (UK)

The 49MW battery storage facility at the West Burton power station site was the largest project in the new regulation system that had been set up across the UK. This system improves the stability of the electricity network and enables a rapid response to frequency fluctuations.

Battery storage technologies

#2

Storage solutions are not “one fits all”. The most suitable battery technologies strongly depend on the expected performance, lifetime and location in the power system.

© *EDF* –DASTE ADRIEN / TOMA

An active technological development

There is a strong dynamic in the research and industrial world, leading to diversity in the field of battery technologies. EDF R&D carries out an active technological watch, detecting new trends around storage: emerging technologies and innovations, new manufacturers, M&A in this field, batteries price evolutions...

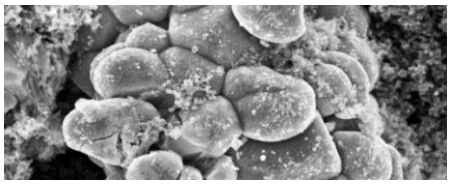
EDF R&D leverages its wide range of scientific partners like CRIEPI in Japan, industrial partners and battery manufacturers. It allows EDF to be at the forefront on the emergence of technological breakthroughs.
EDF R&D is specialised in battery testing for stationary and mobile applications and benefits from a wide set of specific laboratories.
R&D labs are dedicated to test battery materials, cells, modules or full size batteries up to the MW-scale at our smart grid lab.

R&D experts carry out performance assessment tests, charge and discharge cycles, as well as lifespan evaluations. Current research also covers safety protocols, destructive testing and post-mortem analysis for understanding degradation modes inside batteries, detecting potential security issues and evaluating mitigation measures.

It results in an advanced understanding of batteries’ overall performance, domains of application and operational conditions including safety.

For preliminary design stages, EDF R&D has recently developed several modelling and simulation tools for optimal battery sizing and related control systems. These tools rely on accurate mathematical representations of battery technologies, leveraging our deep knowledge in terms of physical behavior (chemistry, materials, electronics...).

The output of these tools can also be used to validate a business plan including an accurate economic analysis.
Through collaborative research projects, EDF R&D benefits from public funding in the field of energy storage (ANR, ANRT, ADEME, H2020, Horizon Europe...).



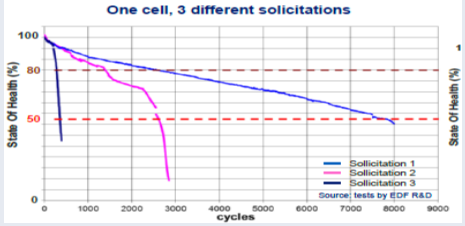
In the context of rapid evolution in the battery area, EDF scientists are looking at several promising battery technologies like lithium metal, solid state batteries, redox flow, silicon anodes, zinc aqueous batteries, sodium ion batteries.

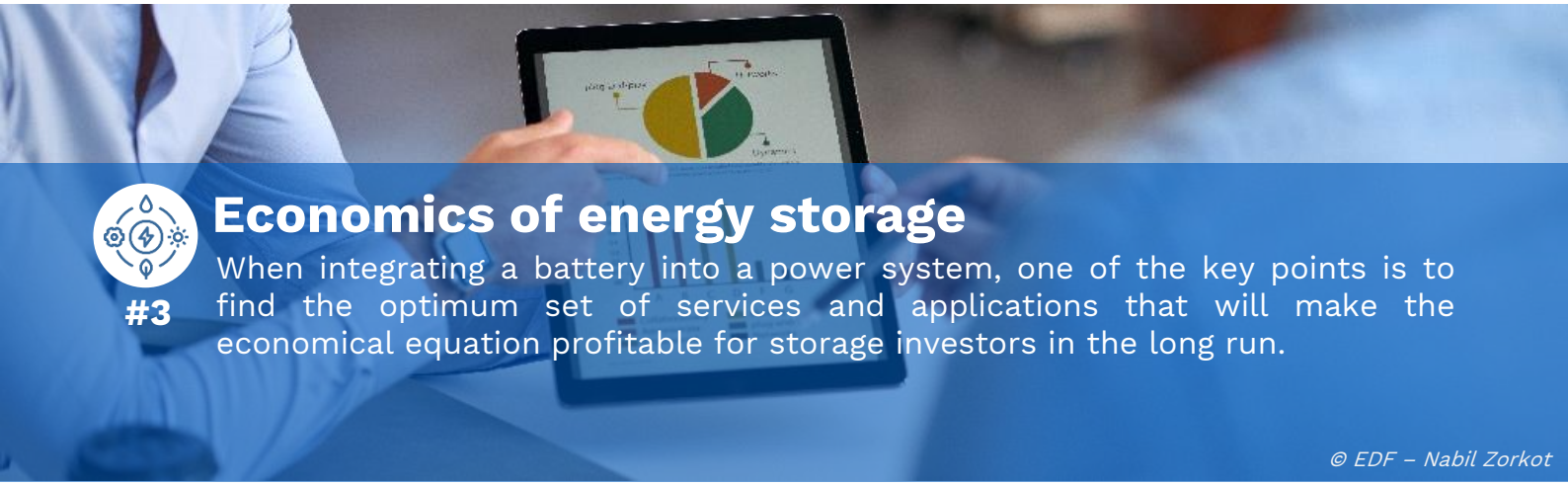
Concept Grid

Concept Grid is EDF R&D’s smart grid platform allowing a wide range of experiments for preparing tomorrow’s networks. Various storage technologies and applications can be tested. Concept Grid allows to create and conduct safely complex testing campaigns which would be impossible to perform in the field. Concept Grid is representative of a French distribution grid, though versatile to be adapted to various clients' needs.

Battery cells testing

The performance of battery cells depends on the uses, environnement and number of charging cycles they go through. R&D lab testing, allows to determine appropriate technologies ensuring expected lifetime, safety and economic returns.





#3

Economics of energy storage

When integrating a battery into a power system, one of the key points is to find the optimum set of services and applications that will make the economical equation profitable for storage investors in the long run.

© EDF – Nabil Zorkot

Towards sounds economic analysis

In battery development projects, EDF R&D leverages its expertise and tools to provide economic analysis and insights ensuring overall profitability for users and investors over a defined period of time.

Even though rapid progress in batteries are reducing storage costs, they still represent a significant investment requiring a precise assessment of costs and revenues over the expected lifetime. Different revenues streams can be exploited for public and private stakeholders: market arbitrage, capacity market revenues, tariff optimisation and ancillary services procurement.
When adding a battery to the grid or at the clients' premises, the economic analysis should also consider potential risks (technological, regulatory...).

When battery economics are challenging, different additive value streams might become necessary. For example, in 2015 the French Venteea demonstrator has shown that a combination of services was needed to reach profitability (congestion resolution, peak smoothing, market arbitration...). These various services can benefit several stakeholders (renewable energy producer, distribution system operator...).
EDF R&D has developed a set of evaluation and simulation tools to support its partners in de-risking projects during the pre-feasibility or feasibility phases.

These tools integrate extensive physical models of batteries (heat transfers, power electronics, components, actual cycling possibilities...) with the ability to represent grid constraints. The outcomes allow to determine batteries sizing and associated control laws, lifespan and economic value (CAPEX and OPEX).

Regarding islanded power systems, EDF carries out research to determine optimal storage applications. For instance, a recent study for Martinique Island showed that the installation of battery storage for primary reserve procurement would optimise the overall cost of generation in scenarios with significant solar inputs.

Combining know-how and specific tools, R&D studies allow to overcome the economic challenges of batteries for multiple applications (behind the meter, grid connected, islanded power systems...).

For the solar self-consumption market, EDF R&D has participated in the development of integrated solutions based on battery to maximise the economic value by combining peak load reduction, tariff arbitration and load shedding.

Umiyolanga, South Africa

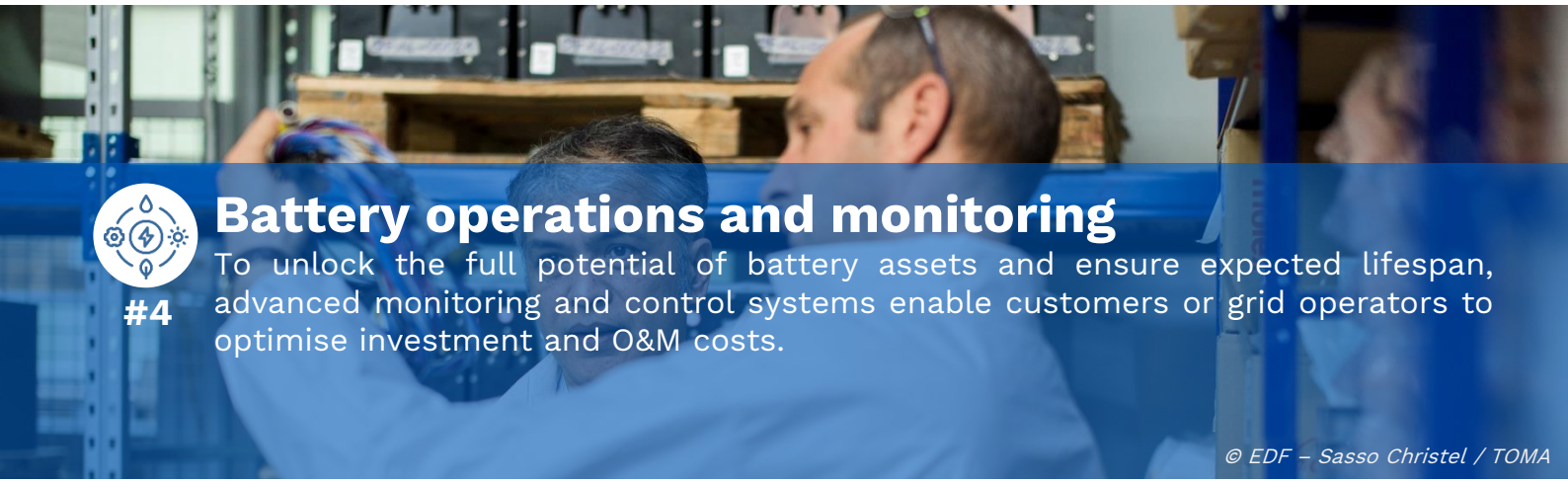
© EDF – Love Silhouette

To reduce load shedding in South Africa, EDF has built a 75MW VPP offer that includes wind, PV, storage and a genset.
In this project, EDF R&D specified the EMS and provided economic expertise through its sizing software in conducting numerous simulations of distributed energy resources.
In the pre-design phase, EDF R&D estimated the battery ageing and ancillary consumption.

EDF R&D storage toolset

© EDF – Detienne Augustin

EDF R&D has developed a set of tools adapted to the different stages of a battery storage project (consultancy, pre-feasibility, detailed sizing...). Advanced R&D tools can handle precise economic analyses by integrating descriptions of physical, electrochemical and electronic elements that compose a battery.



#4

Battery operations and monitoring

To unlock the full potential of battery assets and ensure expected lifespan, advanced monitoring and control systems enable customers or grid operators to optimise investment and O&M costs.

Critical role of real-time controls

Following the identification of uses, battery technology and economic analyses, the next challenge is to ensure optimal battery operations in the long run. For that, continuous supervision of batteries is needed. Monitoring allows anticipation of failures and checks batteries capabilities (state of charge, power, voltage, capacity, etc.). In order to maintain storage services to the grid for several years, controls and monitoring enable to keep batteries in their intended operating range.

This context has led EDF to develop remote monitoring and control solutions. To ensure safety in real-time, battery storage systems can be fitted with sensors feeding control algorithms (EMS, SCADA). Over time, monitoring can generate several gigabytes of data that represents valuable information to be exploited. The data collected also allows the development or enhancement of algorithms that verify system functions (lifetime performance, safety...).

EDF supports its partners and customers by developing solutions and tools for industrial control systems.

These different monitoring tools offer performance indicators and allow battery operators to support their periodic and conditional maintenance operations. For instance, they help to maintain the battery temperature in the ideal operating range. They can monitor charge current and voltage to prevent overcharging, or can even monitor cell balancing. This results in an extended battery lifetime.

Regarding industrial communication systems, a two-level technology platform has been developed by EDF R&D, leveraging the features of the IEC 61850 communication standard at a site level (field station) and at a virtual centralised level (cloud operation). It unlocks full potential of industrial assets, adds agility and enhances cybersecurity and resilience.

EDF provides financial and strategic support for innovative battery monitoring projects. In 2019, an investment was made in the deeptech for measuring the remaining life expectancy of a lithium-ion battery. This technology optimises battery lifespan by notifying when maintenance is required and by providing better management of the state of charge.

The insertion of micro-sensors or optical fibers within battery cells brings new opportunities. In the coming years, access to the monitoring of ageing or safety parameters will be done in real-time, allowing earlier detection of these phenomena.

Operational support for storage systems in Guadeloupe

In 2020, EDF R&D provided its expertise for the verification of acceptance tests of a 5MW/30min stationary battery in Guadeloupe. The operational battery responded successfully to the frequency control service designed by EDF R&D.

Sein Island, Brittany (France)

Sein Island in Brittany is an islanded microgrid based on hybrid generation, transitioning to target 100% renewable energy in the power system by 2030. Today, solar wind and battery storage are drastically reducing the use of diesel gensets, leveraging EDF R&D expertise in storage applications. The battery is optimized by an EDF control system ensuring renewable integration while keeping power system secure and reliable.

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 & 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.

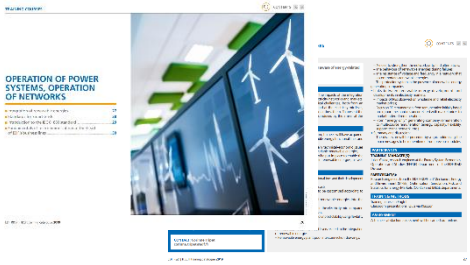
Various training courses are available on **renewables integration, smart grid solutions, microgrids, energy storage, control and communication, hydrogen**...
Training is provided by EDF R&D leading experts in these key domains.

EDF R&D BROCHURE OF SERVICES

Consult the interactive document by clicking on the picture opposite

EDF R&D ITECH CATALOGUE OF TRAINING COURSES

Consult the interactive document by clicking on the picture opposite



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 and six abroad** (China, Germany, Italy, Singapore, UK, USA) and an office in Brussels.

OUR 4 SCIENTIFIC PRIORITIES

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

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

© @EPA Paris-Saclay / DronePress

All elements contained in this document are for public information only.
EDF will not be liable for the consequences of using the information presented in this white paper.

EDF SA
22-30 avenue de Wagram
75382 Paris Cedex 08 - France
Capital de 1 619 338 374 euros
552 081 317 R.C.S Paris

www.edf.com

EDF Research and Development
EDF Lab Paris-Saclay
7 boulevard Gaspard Monge
91120 Palaiseau - France

Contact:
EDF R&D
International & Partnerships
retd-enquiries@edf.fr