



—
INNOVATING
FOR ENERGY
+

2021 **ACTIVITY
REPORT**

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IFPEN, THE ESSENTIAL

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DEVELOPING TODAY THE INNOVATIONS OF TOMORROW

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ENCOURAGING AND SUPPORTING INNOVATION

TRAINING TALENTED YOUNG PEOPLE FOR THE ENERGY TRANSITION

OUR MISSION

BACKGROUND

CLIMATE CHANGE
AND ECOLOGICAL TRANSITION

+ CHALLENGES



FOSTERING SUSTAINABLE
MOBILITY



DIVERSIFYING
THE ENERGY MIX

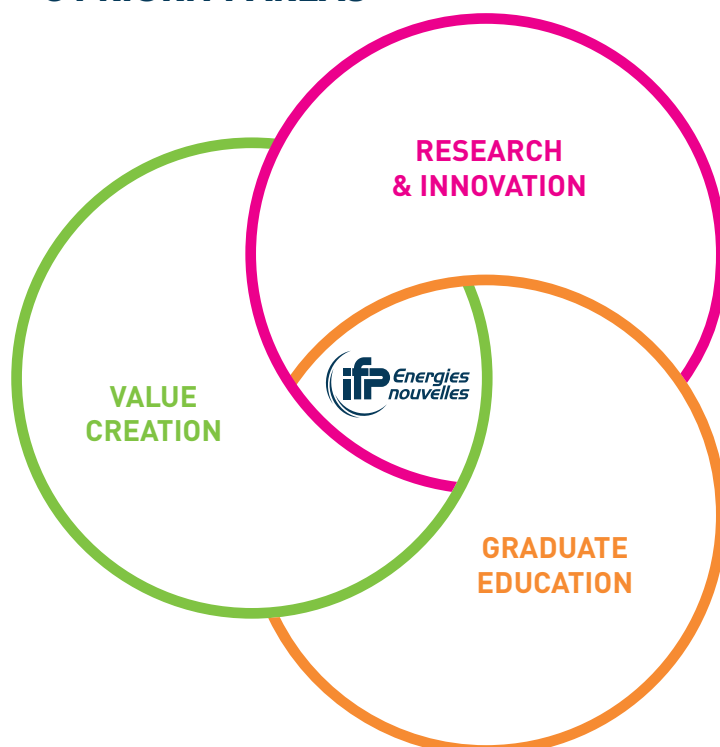


INCREASING ENERGY
EFFICIENCY



REDUCING THE ENVIRONMENTAL
IMPACT OF FOSSIL RESOURCES

+ 3 PRIORITY AREAS



IFP ENERGIES NOUVELLES

IFP Energies nouvelles (IFPEN) is a major research and training player in the fields of energy, transport and the environment. From scientific concepts within the framework of fundamental research, through to technological solutions in the context of applied research, innovation is central to its activities, hinged around four strategic priorities: climate, environment and circular economy – renewable energies – sustainable mobility – responsible oil and gas.

As part of the public-interest mission with which it has been tasked by the public authorities, IFPEN focuses its efforts on bringing solutions to take up the challenges facing society and industry in terms of energy and the climate, to support the ecological transition. An integral part of IFPEN, IFP School, its graduate engineering school, prepares future generations to take up these challenges.

INNOVATION-DRIVEN RESEARCH

The aim of IFPEN's R&I programs is to overcome existing scientific and technological challenges in order to develop innovations that can be used by industry.

Faced with a broad range of open scientific questions, fundamental research at IFPEN is aimed at producing a cross-functional bedrock of new knowledge, concepts and methodologies, a platform for the development of the innovations of tomorrow.

Projects are often conducted within a collaborative environment with academic and industrial partners.

IFPEN's researchers regularly lend their scientific expertise to the public authorities, providing insights to help them in their decision-making process. IFPEN is an active player in numerous projects, technological platforms and networks within the context of the European Horizon Framework Program, and is also contributing to the emergence of a European vision of research in the fields of mobility, energy and the environment.

Applied research programs are structured around four strategic priorities:

- climate, environment and circular economy: reducing the impact of human and industrial activities on the climate and the environment;
- renewable energies: producing energy, fuels and chemical intermediates from renewable sources;

- sustainable mobility: developing efficient, environmentally-friendly solutions for the transport sector;

- responsible oil and gas: meeting the demand for energy and chemical products in a more environmentally-friendly manner.

PUBLIC/PRIVATE FUNDING

IFPEN is funded both by a state budget and by its own resources provided by industrial partners.

VALUE CREATION

IFPEN contributes to the creation of wealth and jobs by supporting the competitiveness of industrial players and fostering the economic development of sectors related to mobility, energy and eco-industry. IFPEN's model is based on the transfer to industry of the technologies developed by its researchers. Innovations are brought to market through close partnerships with industrial players and through IFP Group subsidiaries. In emerging or mature markets, IFPEN thus creates companies or acquires shareholdings in companies of significant potential. In addition, IFPEN supports the development of start-ups and SMEs as part of collaboration agreements, contributing its technical and legal expertise.

GRADUATE EDUCATION, A VECTOR FOR COMPETITIVENESS

In the context of the energy transition, IFP School trains talented young people to take up the technical, economic and environmental challenges facing society, while providing industry with the highly qualified personnel it requires. With an international reach, IFP School provides young graduates with Master's degree programs for the professions of today and tomorrow in the fields of energy, motor vehicles and the environment. Over 500 students from around the world graduate from IFP School each year.

INTERVIEW WITH PIERRE-FRANCK CHEVET

CHAIRMAN AND CEO OF IFPEN



2021: **COLLABORATION AND DIGITALIZATION**

In 2021, IFPEN's teams rose to the dual challenges posed by the economic and health crises - with Covid slowing the pace for the second year running - and conducted fundamental research and applied research to support the ecological transition. Examples include the completion of the 3D CO₂ capture pilot unit at the ArcelorMittal site in Dunkirk, the launch of the industrialization and marketing phase of BioTfuel[®] technology for the production of biojet from non-food biomass, the development of a hydrogen IC engine for heavy trucks, an industrial first in the form of a high-voltage electric machine, and the significant increase in the number of research projects selected at national and European levels.

For IFPEN, 2021 was a year of collaboration and digitalization. Support for SMEs and innovative startups was significantly ramped up: as a result of digital prospection, we more than doubled the number of contracts signed. Moreover, I am delighted with our partnership with Bpifrance. The convergence between our expertise and our networks will foster the transfer of research results via the creation of startups in four key fields of the ecological transition: sustainable mobility, the circular economy, energy efficiency and air quality.

IFP School's profile and reputation have continued to develop thanks to increased digitalization. Our school was also awarded

Despite the difficulties, IFPEN's teams rose to the challenge and continued to spearhead fundamental and applied research to support the ecological transition.

the “Happy at School” label, testament to the well-being of its students. And since June, the new LAB e.NOV™ virtual laboratory has been up and running, giving students access to immersive training modules and paving the way for applications of this technology across the whole of IFPEN.

2021 was also a year of openness and cooperation within the research ecosystem. I am proud of the fact that we were selected to co-manage three priority research programs and facilities (PEPR) initiatives, related to the decarbonization of industry, biobased products and biofuels, and mobility digitalization. The roadmap for the decarbonization of industry was drawn up in record time with the relevant national players, illustrating the recognition of our expertise and our capacity to work with our partners from other research institutes to serve the general interest.

With our sights set firmly on the future, in 2021 we launched the “Horizon 2035” collective strategic approach, the aim of which is to reflect on IFPEN's positioning, activities and trajectory over this time horizon. It might seem pretty bold to take time to reflect in the current circumstances. But it is precisely because we are in a time of crisis that I believe it is right to consider how we intend to bounce back and adapt, as well as the means we are going to employ to do so. Through working groups mobilizing large numbers of employees representative of the diversity that underpins the wealth of our organization, my aim was to consider the direction we want to take in terms of technological choices and to rethink our identity. Initial conclusions and actions to be implemented were defined. This reflection process will continue in 2022, with, among others, the setting up of an energy stakeholder committee enabling players interested in and concerned by the ecological transition to set out their visions.

In this activity report, you will find a representative panorama of the remarkable collective results obtained in 2021 by teams driven by commitment, conviction and enthusiasm.

I hope you enjoy reading this report.



CORPORATE GOVERNANCE

THE EXECUTIVE COMMITTEE*

GENERAL MANAGEMENT



Pierre-Franck Chevet
Chairman and CEO



Catherine Rivière
Executive Vice-President
Research and Innovation



Éric Lafargue
Executive Vice-President
Administration and
Management of
Subsidiaries

BUSINESS UNIT DIRECTORS



Éric Heintzé
Energy Resources



Jean-Pierre Burzynski
Processes



Gaëtan Monnier
Transport



Christine Travers
Education and Training



Nathalie Alazard-Toux
Industrial Development

OTHER MEMBERS OF THE EXECUTIVE COMMITTEE



Véronique Ruffier-Meray
Human Resources Director

* As of 31 December 2021.

THE BOARD OF DIRECTORS*

STATE REPRESENTATIVES

Pierre-Franck Chevet

Chairman and CEO

Frédéric Ravel

Scientific Director of the Energy, Sustainable Development, Chemistry and Processes sector supporting research and innovation strategy at the General Directorate for Research and Innovation, representing the Minister of Research

Alicia Saoudi

Bureau manager, The Energy, Stakeholdings, Industry and Innovation bureau (BEPH) at the Budget Directorate, representing the Minister for Budget

Marie-Solange Tissier

President of the Regulation-Resources section at the High Council for the Economy, Industry, Energy and Technology, representing the Minister of Industry

QUALIFIED MEMBERS

Monique Axelos

Scientific Director for Food and Bioeconomy, Board of Directors Unit, INRAE

François Dassa

Director of Foresight and International Relations at EDF, based in the Innovation, Corporate Responsibility and Strategy Department

Carla Gohin

Director of Research, Innovation and Advanced Technologies at Stellantis

Didier Holleaux

Executive Vice-President Engie

Helle Kristoffersen

President, Strategy Innovation and member of the Executive Committee, TotalEnergies

Hervé Le Treut

Member of the Académie des sciences (French Academy of Sciences), Director of Research at the CNRS (French National Center for Scientific Research)

Sophie Paturle-Guesnerot

Founding partner of Demeter Partners

Axel Plasse

R&D and Marketing Director, Valeo Powertrain Systems, Transmission Systems Product Group, Valeo Transmissions Technical Center

Valérie Quiniou-Ramus

Executive Director Foresight and Research, Ademe (French Environment and Energy Management Agency)

Bruno Sportisse

Chairman and CEO of Inria

STAFF REPRESENTATIVES

Laurent Duval

Sylvie Perrin

WITH THE ATTENDANCE OF

Cyril Bouyeure

Economic and Financial General Controller, Ministry for the Economy, Finance and Recovery, Energy Mission

Philippe Geiger

Government-Commissioner to IFPEN, Energy Assistant Director - DGCE (General Directorate for Energy and Climate) - French Ministry for Ecological Transition

Guillaume Gougoul

Secretary of IFPEN's Central Works Committee (CSEC)

THE SCIENTIFIC BOARD*

Grégoire Allaire

Chairman of the Scientific Board, Professor of Applied Mathematics at the École polytechnique, Senior University Professor

Carmen Claver

Professor of Inorganic Chemistry at Rovira i Virgili University, Tarragona

Christophe Coperet

Professor of Molecular Chemistry and holder of the surface and interface chemistry chair at the École Polytechnique Fédérale, Zurich

Marc-Olivier Coppens

Ramsay Memorial Professor and Head of the Chemical Engineering Department at University College London

Patrick Criqui

Director of research at the CNRS, head of the sustainable development and energy economy team at the GAEL Laboratory of the CNRS and Grenoble Alpes University

Luigi Del Re

Professor at Johannes Kepler University, Linz, Head of the Institute for Design and Control of Mechatronical Systems

Sylvie Dequin

Head of the Microbiology and Food Chain Department at INRAE

Jocelyne Erhel

Director of Research at Inria (French Institute for Research in Computer Science and Automation)

Mohamed Gabsi

Professor and Head of the Electronics-Electrical Engineering Department at the École Nationale Supérieure de Paris-Saclay

Anke Lindner

Professor of Physics at Paris Diderot University and researcher at the Physics and Mechanics of Heterogeneous Media Laboratory at the ESPCI Engineering School, Paris

Jean-François Minster

President of the Île-de-France Photovoltaic Institute

Christine Rousselle

Professor of Combustion and Optical Diagnostics at Orléans University, IEA Clean and Efficient Combustion TCP Delegate

Marc Schoenauer

Director of Research at Inria

Luc Vervisch

University Professor at the National Institute of Applied Sciences, Rouen (France)

Sophie Violette

Lecturer-HDR (national accreditation to supervise research) Researcher, Sorbonne University – ENS Geology Laboratory

IFPEN 2021 NEWS

IN BRIEF



FRANCE RELANCE RECOVERY PLAN: IFPEN, CO-MANAGER OF THREE PEPRs

When he presented the *France Relance* economic recovery plan on 29 June 2021, the French Prime Minister announced the launch of 13 acceleration strategies for innovation within the framework of the country's fourth Investments for the Future Program (PIA4). The objective: to identify the principal economic and technological challenges of the future and dedicate substantial investments to them. These strategies are accompanied by PEPRs (priority research programs and facilities initiatives), each of which is assigned a leader responsible for steering the program.

IFPEN was chosen as joint leader of the PEPR related to the decarbonization of industry acceleration strategy with the CNRS, the PEPR on biobased products and sustainable fuels with INRAE and the PEPR on the digitalization and decarbonization of mobility with Gustave Eiffel University.

In addition, IFPEN was asked to contribute to the PEPR relating to the Hydrogen acceleration strategy and the PEPR relating to the acceleration strategy concerning recyclability, recycling and reincorporation of recycled materials.

DEPLOYMENT OF HYDROGEN: IFPEN STEPS UP ITS ACTIONS

In 2021, IFPEN's contribution to the hydrogen value chain was reinforced.

The Hydrogen for Europe (Hydrogen4EU) study was published in May 2021. Based on modeling carried out by the partners, IFPEN, SINTEF and Deloitte, the project aims to map out pathways exploring the role of hydrogen in a decarbonized European energy system. In June, IFPEN and the French Corrosion Institute created a research group the purpose of which is to assemble industrial partners in order to gain a better understanding of the behavior of materials in the presence of hydrogen. June also saw the organization of IFPEN's 5th Energy Innovation event, focusing on the conditions for deploying low-carbon hydrogen in the French energy mix. Led by François Kalaydjian, IFPEN's hydrogen coordinator, the round table brought together Hoang Bui, coordinator of the French national hydrogen strategy at the French Investment Secretariat, Catherine Azzopardi, Environment and Energy Director for the Auvergne-Rhône-Alpes region, Adamo Scenci, Hydrogen VP at TotalEnergies* and Gaëtan Monnier, director of the IFPEN Transports Energie Carnot Institute. The replay is available on the IFPEN website. The year also saw the commissioning, in October, of a new 210 kW test bench for fuel-cell systems. Located at the Solaize site, this unique experimental tool, the most powerful in France, will enable IFPEN to accelerate its research into the use of hydrogen-powered fuel cells in electric vehicles, particularly for heavy road vehicles (buses and trucks) and for the rail sector.

*Currently deputy CEO of HRS (Hydrogen-Refueling-Solutions).





TECHKARE
Mind your staff

THE SOLUTION MAKING IT EASIER TO MOVE HEAVY LOADS IN HOSPITAL, LAUNCHES SUCCESSFULLY

In July 2021, IFPEN, via the IFPEN Transports Energie Carnot Institute, announced the creation of TechKare™, a company that offers solutions making it easier to transport heavy loads in hospitals. One such electric solution has been developed to help stretcher bearers move patients, addressing the challenges of mobility in the hospital environment. In particular, the solution makes it possible to reduce musculoskeletal disorders in hospital staff. TechKare™ thus addresses the societal challenges concerning the improvement of working conditions, ageing well and professional equality among hospital personnel.

NB: TechKare™ was created by an employee via the spin-off policy (see 2020 activity report p. 33).



PATENT APPLICATIONS: IFPEN MAKES ITS MARK

In 2021, IFPEN was ranked 3rd among French research bodies filing patents, just behind the CEA (French Alternative Energies and Atomic Energy Commission) and the CNRS, with 198 patent applications filed in 2020 with the INPI (French National Industrial Property Institute, 190 patents filed by IFPEN and 8 by subsidiaries). It should also be recalled that IFPEN is ranked 4th globally for patents relating to low-carbon technologies for the period 2000-2019, in the international rankings of research organizations and universities published in April 2021 by the European Patent Office (EPO) and the International Energy Agency.

In addition, in October the EPO published "Patents for tomorrow's plastics*", a study setting out global innovation trends in the fields of recycling, circular design and alternative sources. Globally, IFPEN sits first among public research bodies in the rankings of institutions filing patents in the field of chemical and biological recycling, with 168 international patent families (IPF).

* Patents for tomorrow's plastics – global innovation trends in recycling, circular design and alternative sources, European Patent Office, 2021.



JEAN-BAPTISTE DJEBBARI LAUNCHES A CALL FOR PROJECTS DURING A VISIT TO THE BIOTFUEL® SITE

On 27 July, Jean-Baptiste Djebbari, French deputy transport minister, went to Venette (Oise, northern France) to visit the biomass torrefaction site, one of the demonstrators for the BioTfuel® project. The visit took place as Bionext and its partners had successfully completed the test programs on the BioTfuel® demonstration units, navigating a crucial step in the development of this technology designed for the production of low-carbon biokerosene (see page 19). During his visit, the minister announced the launch of a call for projects aimed at accelerating the development of a French sector for the production of sustainable aviation fuel. Allocated a provisional budget of up to €200M, the call for projects falls within the framework of the Investments for the Future Program (PIA) and will be financed by the *France Relance* economic recovery program.



"WOMEN IN CCUS": A PROJECT MANAGER AT IFPEN SHARES HER EXPERIENCE AS A WOMAN OF SCIENCE

During the "Women in CCUS" workshop organized within the context of the European C4U project, the coordinator of the European 3D project and IFPEN project manager for DINAMX Vania Santos-Moreau shared her experience as a woman of science with "3D Project: The power of women!". Her presentation gave IFPEN the opportunity to provide an original insight into its CCUS expertise and collective success. The "power of women" promoted by Vania Santos-Moreau stems from the commitment of IFPEN's and Axens' women and men engineers and technicians to the project, as well as the importance of role models within IFPEN: women who have led by example and enabled her to be daring in turn.



PIERRE-FRANCK CHEVET BECOMES THE NEW PRESIDENT OF ANCRE



Pierre-Franck Chevet was appointed president of the French National Alliance for Energy Research Coordination (Ancre) for a period of two years. Appointed, as part of a two-yearly rotating presidency, by the alliance's coordination committee made up of the four founding members (CEA, CNRS, CPU and IFPEN) and the representative of associate members (BRGM), he succeeds Mohammed Benlahsen, president of Picardie Jules Verne University.

He will continue the work of the alliance aimed at reinforcing links and exchange between research organizations, agencies and supervisory authorities; working more closely together in this way will make it easier to achieve national and European energy transition objectives. Pierre-Franck Chevet also aims to "foster a more cross-disciplinary and cross-functional approach with human and social sciences, in order to develop a more in-depth understanding of the problems at hand", which will lead, for example, to the increased development of multi-criteria life-cycle analyses within the framework of the research conducted by Ancre.



FOCUS

The OGST (Oil and Gas Science and Technology) journal, created by IFPEN in 1946, has changed its scope and is now called (from January 2022) STET (Science and Technology for Energy Transition). This new positioning and new name underline IFPEN's strategy resolutely focused on the energy transition. To accompany this change, IFPEN has joined forces with the CEA, the other major French research organization dedicated to energy.



5 IFPEN PROJECTS FINANCED BY THE INFRASTRUCTURE COMPONENT OF THE FRENCH NATIONAL RECOVERY AND RESILIENCE PLAN



Within the framework of the infrastructure component of the French National Recovery Plan, IFPEN is receiving funding for several projects at its Solaize site. The global amount of around €8 million will enable the organization to accelerate its efforts aimed at reducing energy consumption. The projects selected concern the installation of solar panels, the renovation of some ventilation and lighting systems and the insulation and renovation of the ventilation system in one of the buildings. The work, some of which has already started, will continue through to 2023.



A WEBSITE TO UNDERSTAND THE EVOLUTION OF MOBILITY IN THE ÎLE-DE-FRANCE REGION

IFPEN and around thirty other players active in the mobility sector in the Île-de-France region have joined forces to analyze the impact of Covid-19 on the transport habits of the Greater Paris region's residents using. The Mobilité Île-de-France collective, which now wants to share its findings with the general public, has set up a website (www.collectif-transformation-mobilite-ile-de-france.fr) for the purpose. IFPEN has contributed its data from the bicycle mobility observatory.



CATHERINE RIVIÈRE APPOINTED TO THE SCIENTIFIC BOARD OF THE CEA AND THE EXECUTIVE COMMITTEE OF THE EERA

Catherine Rivière, Executive Vice-President Research and Innovation, was appointed member of the scientific committee at the CEA for a period of 4 years, following the proposal of the French atomic energy high-commissioner. She was also appointed for a period of 4 years to the executive committee of the European Energy Research Alliance (EERA), the European association created to support the development of more efficient and less expensive low-carbon energy technologies.



KEY FIGURES

2

Carnot Institutes:
the IFPEN Transports
Energie Carnot Institute
and the IFPEN
Ressources Énergétiques
Carnot Institute



ISO
AWARDED
ISO 9001

certification for their
R&I activities

149



basic patent
applications, including
93
in the field of NETs

More than

500



IFP School graduates

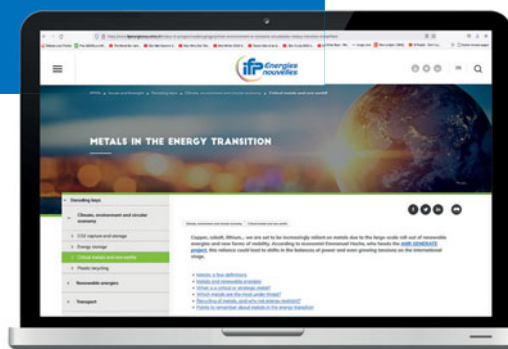
2.5

fold increase in
number of contracts
with startups
and SMEs

FOCUS

Renewable energies and new forms of mobility can be resource intensive. In order to examine in greater depth an issue that tends to be overlooked in energy transition discussions, IFPEN produced "Metals in the energy transition", a series of articles associated with six podcasts. On the agenda: the geopolitics of aluminum, copper, nickel, lithium, rare earths and cobalt.

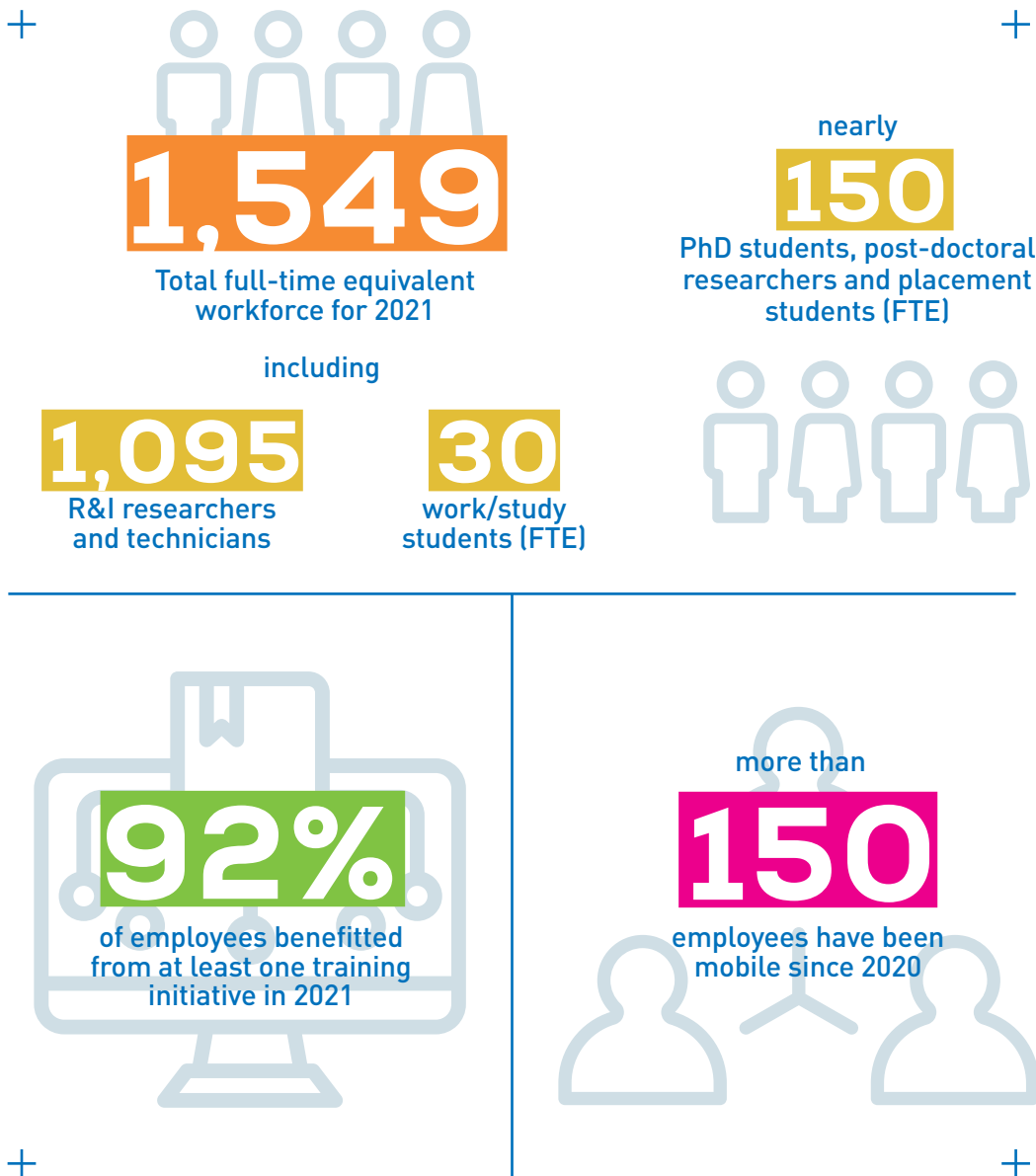
Go to www.ifpenouvelles.com



SOCIAL AND FINANCIAL DATA

SOCIAL DATA

To address the national objectives concerning the ecological transition, making efficient use of the company's resources is an objective that depends on the implementation of a dynamic human resources policy. This policy makes the identification and anticipation of the skills required to develop high-level scientific and technical expertise a priority. Resolutely committed to training the transition's players, every year IFPEN welcomes new apprentices.



FINANCIAL DATA

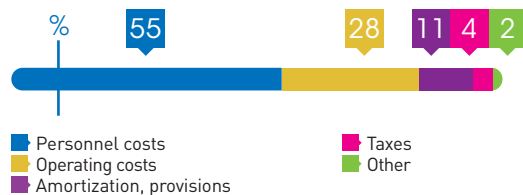
In an unfavorable economic context in 2021 for IFPEN's subsidiaries, own resources fell, primarily as a result of declining royalties.

At the same time, operating expenses fell, primarily due to travel restrictions related to the health crisis.

In spite of the decline in own resources between 2019 and 2021, oil and gas activities remain self-financing via a significant reduction in spending.

BREAKDOWN OF OPERATING EXPENSES

Year end 2021



€262.1 MILLION

including €228 million
for R&I Operating expenses

BREAKDOWN OF OPERATING REVENUES

Year end 2021



€120.2 MILLION

Budget allocation

€147.7 MILLION

Own resources

68%

of budget dedicated to NETs

WEIGHT OF NETS* IN IFPEN R&I IN 2021	%
Total NET	68
Renewable Energies	24
Sustainable mobility	14
Climate, Environment and Circular Economy	12
Cross-disciplinary fundamental research	18

* New energy technologies

DEVELOPING TODAY

THE INNOVATIONS
OF TOMORROW

CLIMATE, ENVIRONMENT AND CIRCULAR ECONOMY

13

+

RENEWABLE ENERGIES

17

+

SUSTAINABLE MOBILITY

21

+

RESPONSIBLE OIL AND GAS

25

+

FUNDAMENTAL RESEARCH SERVING INNOVATION

29

+

CLIMATE, ENVIRONMENT AND CIRCULAR ECONOMY



CCUS: TARGETING PROCESS DEMONSTRATION

IFPEN and IFPEN Ressources Energétiques Carnot Institute's research activities in the field of CO₂ capture, utilization and storage (CCUS) are intensifying in an increasingly dynamic European context. Two capture processes are in the demonstration phase, the DMXTM process based on a demixing solvent that will be marketed by Axens, for which a pilot unit was delivered on the ArcelorMittal site in Dunkirk, and the chemical loop combustion (CLC) process, developed with TotalEnergies, with a demonstrator in China. The demonstration of the DMXTM solutions will be launched in 2022 and the demonstration of the CLC process in 2023. 2021 saw the launch of the PilotSTRATEGY project focused on the evaluation of deep saline aquifer storage capacities led by the BRGM. In addition, IFPEN supports public authorities and industry in the drawing up of deployment strategies as well as the conduct of life cycle analyses and impact studies.



FOCUS

In 2021, IFPEN was chosen alongside the CNRS to manage the PEPR related to the decarbonization of industry acceleration strategy (see page 6).



HIGHLIGHT

CHEERS project: launch of the construction of the CLC pilot unit

At the end of 2021, the Sino-European project reached a crucial milestone with the final decision of TotalEnergies, Dongfang Boiler Group Co. (DBC), IFPEN and Tsinghua University to invest in the construction of a demonstration unit with a capacity of 3 MWth, with a potential for between 4 and 5 MWth in China. Scheduled for 2023, the test campaign will take the technology through to almost commercial maturity (TRL 7).

The CHEERS project has been awarded funding from the European Union's Horizon 2020 research and innovation program through grant agreement No. 764697.

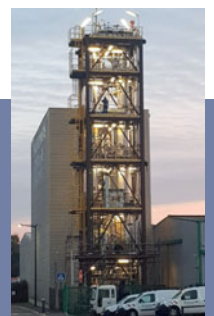


HIGHLIGHT

3D project: the pilot unit for the DMXTM process delivered in Dunkirk

The European 3D project, aimed at demonstrating the performances of the DMXTM process to capture CO₂ in blast furnace gases, reached a key milestone in 2021. The pilot unit, designed by IFPEN and Axens and built by ETCI in Lens, was installed at ArcelorMittal's steelworks site in Dunkirk. By 2026, 125 t of CO₂/h will be captured, i.e., 1 Mt of CO₂/year. By 2030, the European Dunkirk - North Sea cluster could capture, transport and store more than 10 Mt of CO₂/year.

The 3D project has been awarded funding from the European Union's Horizon 2020 research and innovation program through grant agreement No. 838031.



A RANGE OF TOOLS TO SUPPORT AIR QUALITY



Air quality research, conducted jointly by the IFPEN Ressources Energétiques Carnot Institute and the IFPEN Transports Energie Carnot Institute, draws on a stimulating combination of expertise and resources to support communities and local authorities. In 2021, two new air quality tools became available: Real-e™ is aimed at measuring the pollutant emissions from a moving vehicle, and the Flair suite is aimed at monitoring industrial sites, CO₂ capture, transport and storage infrastructure, geothermal sites, etc. In addition, the Gecoair™ ecomobility solution, targeting private individuals, was reinforced by a feature that makes it possible to anticipate bad weather conditions.

HIGHLIGHT



At the start of 2021, the IFPEN TE Carnot Institute and SME Capelec, provider of automotive testing equipment, launched an innovative mobile and connected analyzer, Real-e™ (Real emissions). Real-e™ measures, in real conditions and with a high degree of accuracy, the pollutants emitted by moving vehicles and makes it possible to rapidly identify vehicles that do not meet regulatory requirements. It takes the form of a connected kit containing an exhaust gas analyzer (CO, CO₂, NO_x, PN, NH₃), which samples pollutants continuously, and an onboard diagnostic system that collects the vehicle's parameters. With this system, the development of vehicles and the monitoring of a vehicle fleet are easier, quicker and less expensive than is the case with existing systems.



Interview with:
Pierre Chiquet,
head of Teréga's
Geosciences department

The partnership with IFPEN began in 2017, focusing on the monitoring of all our natural gas storage facilities. With FlairCar™, it was possible to detect diffuse leaks at ground level and in the surrounding air, and determine their origin. Test campaigns only identified biogenic gas production (produced by bacteria from organic matter). In 2021, following field tests of a FlairBox™ prototype, we initiated a collaboration aimed at measuring very low concentrations of the olfactory substance we add to natural gas, THT. The aim of this partnership is to meet regulatory obligations for industrial facilities liable to generate odors in the event of an emergency. Beyond the regulations, these developments will also help us improve our processes when it comes to air quality management.

HIGHLIGHT

Flair: a package of tools to support environmental monitoring and air quality
In 2021, environmental monitoring research conducted by the IFPEN RE Carnot Institute culminated in the development of Flair, a comprehensive range of sensors and software making it possible to explore a geographic zone in order to detect natural or industrial pollutants, visualize them on a map, identify their origin and plot their future dispersal. Applications range from the detection of gas leaks through to the evaluation of air quality, via the study of soil and soil respiration as well as greenhouse gas emissions.

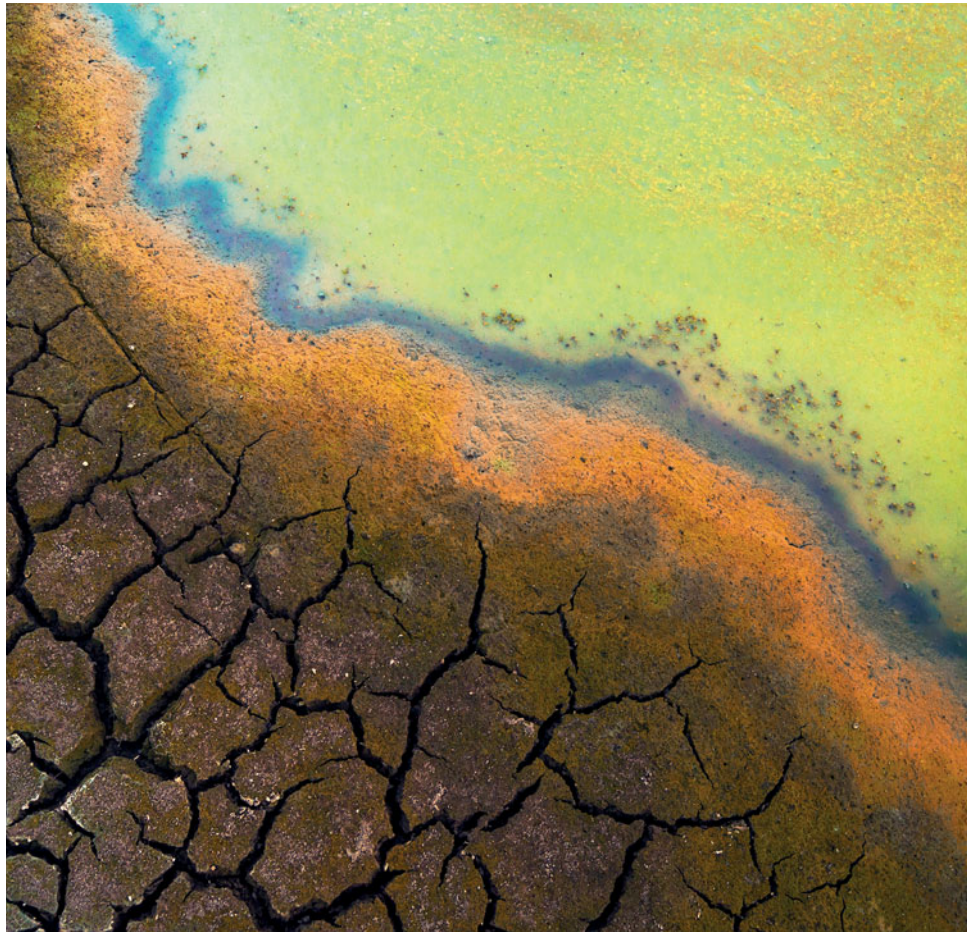




CLIMATE, SOIL AND THE WATER CYCLE: A MINE OF INTERACTIONS TO EXPLORE

Interactions between the soil, the second largest carbon reservoir on earth, climate and the water cycle are increasingly better understood as a result of the numerous studies conducted.

Following on from the roadmap set out in 2020 (see 2020 activity report page 14), the IFPEN RE Carnot Institute pursued three objectives in 2021. Firstly, research focusing on the monitoring of carbon stocks in agricultural and forestry soils was conducted (storing carbon in the ground could help achieve carbon neutrality by 2050). Secondly, studies currently ongoing are quantifying microplastics pollution in soil. And thirdly, research is being conducted aimed at securing access to adequate supplies of high-quality fresh water via management of the resource, the optimization of industrial water use and its treatment and the management of runoff water.



HIGHLIGHT

The VULCAR-FATE consortium and preservation of the biosphere

The international VULCAR-FATE (*Global change impact on vulnerable carbon reservoirs: carbon sequestration and emissions in soils and waters From the Arctic To the Equator*) project was launched in June 2021 within the framework of the “Towards Sustainability of Soils and Groundwater for Society” call for projects issued by the Belmont Forum. Financed by the ANR, the National Science Foundation and the Russian Foundation for Basic Research, and coordinated by the IRD (French Research Institute for Development), it is studying two ecosystems and evaluating the impact of recent climate changes and soil usages in them. Objective: to define evolution scenarios for periods ranging from 30–100 years ahead with a view to adapting local policies. Teams from the IFPEN RE Carnot Institute are characterizing soil organic matter using the Rock-Eval® thermal method and modelling geological processes and water and sediment flows using the DionisosFlow™ simulator.



HIGHLIGHT

Two projects to understand the role of microplastics in soils

The projects selected in 2021 by the ANR and Ademe will study the impact of the presence of microplastics (MPs) in soils. The e-DIP project, financed by the ANR, will evaluate the toxicity of MPs in different soil compartments and their impact on biogeochemical cycles depending on whether they are introduced directly or mixed with organic amendments. The IFPEN RE Carnot Institute will study the direct or indirect (by disrupting microbial activity) impact of MPs on soil organic matter quality using Rock-Eval® methods dedicated to soil studies.

The Plastisol project, financed by the Ademe, will consolidate this study by providing indicators for the presence of plastic matter in soils.



CHEMICAL RECYCLING OF PLASTICS: IFPEN DEVELOPS CUTTING-EDGE TECHNOLOGIES

For nearly ten years now, IFPEN has been conducting research projects in the field of the chemical recycling of plastic waste.

In addition to changes in people's behavior (reducing waste), technological solutions are required to enable the plastics sector to step up chemical recycling alongside mechanical recycling.

Accordingly, IFPEN, in partnership with industrial companies from the plastics sector in order to facilitate a faster transition to the industrial phase, is developing cutting-edge technologies aimed at processing almost all types of plastics as a complement to mechanical recycling, with a view to providing industry with solutions addressing society's expectations and enabling it to comply with public policy relating to the circular economy. IFPEN is placed 5th in the global rankings of patent filers in the field of chemical and biological recycling for the period between 2010 and 2019 (European Patent Office study published in 2021). IFPEN's aim is to be present across the various chemical recycling loops.

For example, projects currently underway relate to the conversion of plastic via pyrolysis. In 2021, research in this field led to the development, in partnership with Repsol and Axens, of the Rewind® Mix process that purifies plastic-based pyrolysis oils enabling them to be directly treated in existing petrochemical plants for recycled plastic production. In addition, demonstration of the Rewind® PET recycling process based on depolymerization, conducted in partnership with Jeplan and Axens, is continuing with a market launch scheduled for the end of 2023. Worthy of note too is the research conducted with a partner on plastics recycling via the dissolution and purification of polyolefins, making it possible to remove additives and pollutants from plastic.



**Interview with:
Wilfried Weiss,
plastic pyrolyzate purification
project manager**



With our partners Repsol and Axens, we have developed a process for the purification of plastic waste pyrolysis oils. The treatment of the impurities they contain, such as silicon, chlorine compounds, diolefins and metals, will enable the direct and undiluted use of these oils in existing steam cracking units. The treatment will then pave the way for the production of chemical intermediates that will be used as a basis for the synthesis of recycled plastics. The Rewind® Mix process was developed at Repsol's and IFPEN's facilities with in-depth testing at pilot scale on high-quality pyrolysis oils. We're going to continue our research to adapt this technology to more challenging feedstock in order to go further in the chemical recycling of plastics.



CRITICAL METALS AND RARE EARTHS, A KEY CHALLENGE

Securing supplies of critical metals has become a major challenge for many industries.

Accordingly, IFPEN is working on projects targeting the development of recycling processes for metals obtained from used catalysts and batteries. The objective is to develop economically viable processes and solutions enabling the recovery and the recycle of metals such as cobalt, nickel and lithium for which demand has grown steadily in recent years.

In partnership with Eramet, IFPEN also developed an adsorbent for the selective and environmentally-friendly capture of lithium in the waters of the Argentinian salt flats. This process integrating the adsorbent was adapted to the geothermal waters of the Rhine basin within the framework of the European EuGeLi (European Geothermal Lithium Brine) project.

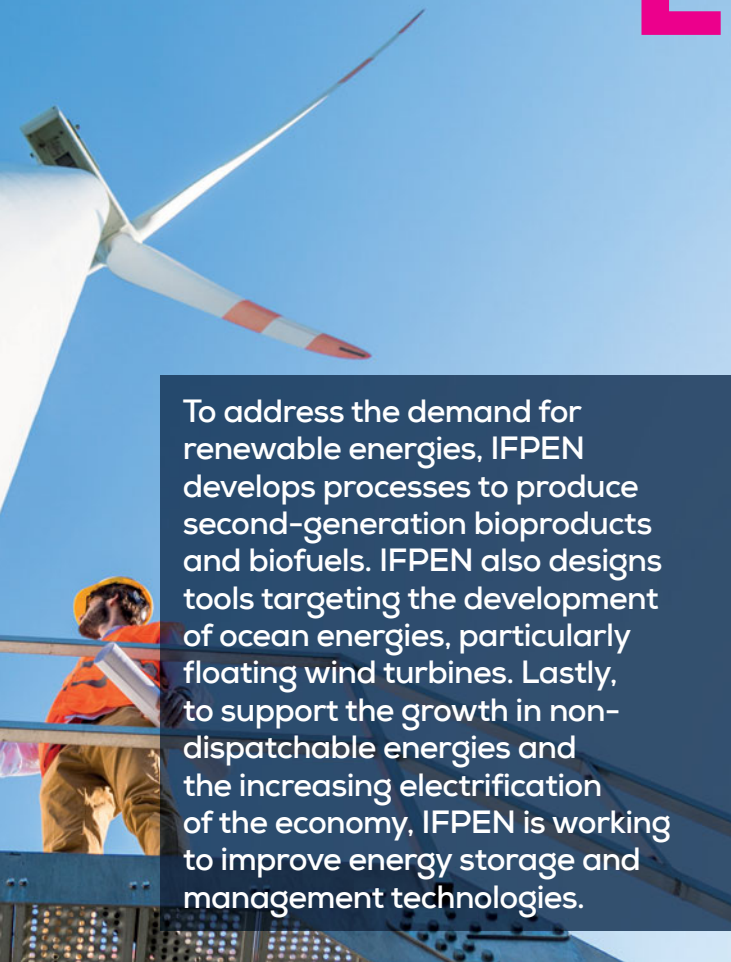


RENEWABLE CO₂ AND H₂ CONVERSION

Alongside biofuels, electrofuels (or e-fuels) are set to play a role in

low-carbon transport (recast REDII Directive and the EU Refuel Aviation project proposed by the European Commission on 14 July 2021). IFPEN is working on a number of options to develop original e-fuel and e-biofuel production technologies and take them forward to the industrial demonstration phase.

RENEWABLE ENERGIES



To address the demand for renewable energies, IFPEN develops processes to produce second-generation bioproducts and biofuels. IFPEN also designs tools targeting the development of ocean energies, particularly floating wind turbines. Lastly, to support the growth in non-dispatchable energies and the increasing electrification of the economy, IFPEN is working to improve energy storage and management technologies.

HIGHLIGHT

WiSE WindField: more accurate wind prediction

In 2021, within the context of the partnership initiated in 2015 with Leosphere, now Vaisala France, a global leader in the use of Lidar technology to measure wind speed, IFPEN finalized the industrial commissioning of the WiSE WindField onboard software solution, which determines the incoming wind from data obtained using a Lidar placed on a turbine. Drawing on expertise in the fields of signal processing and control systems, this solution provides highly accurate real-time wind measurement and fluctuation control, thereby optimizing wind turbine management and performance, resulting in savings and an extended operating life. The increased adaptability of wind turbines to the wind obtained also makes it possible to optimize their design by, for example, increasing the length of the blades, in order to reduce investment costs and maximize energy production.



WIND AND OCEAN ENERGIES: A FRESH BOOST

Offshore wind is strongly encouraged by the European Union, which, in November 2021, reaffirmed the ambition to establish it as a major energy source, the objective being to have installed power of 60 GW by 2030 and at least 300 GW by 2050. Buoyed by this momentum, the IFPEN RE Camot Institute intensified its efforts concerning the design of floaters, wind turbine and wind farm control and the development of a digital twin that optimizes the production and maintenance of a wind farm. In addition, research on the control of wave energy conversion systems continued with a study on behalf of Carnegie Clean Energy on the control of the CETO module.

HIGHLIGHT



Realistic wind fields thanks to Lidar and predictive algorithms

Research was conducted by IFPEN, in partnership with Equinor, aimed at improving the dimensioning and load calculations of floating wind turbines by generating realistic wind fields based on nacelle Lidar measurements. This research was evaluated experimentally with data obtained from the Hywind Scotland wind farm. It led to the publication of a scientific poster at the WindEurope Electric City 2021 conference, with the poster singled out for the WindEurope Poster Award given by the EAWC (European Academy of Wind Energy).

HIGHLIGHTS

IFPEN, Engie Green and Engie Digital develop the digital twin of a land-based wind farm

In partnership with Engie Green and Engie Digital, teams from the IFPEN RE Carnot Institute developed a digital twin of the "Sole du Moulin Vieux" wind farm in the Hauts de France region (northern France), for which 11 years of data are available. Using algorithms combining physical modeling and data science, the mechanical wear of wind turbine components (blades, mast and rotor) was estimated. These algorithms, validated by on-site measurements, provide key performance indicators, such as the estimated loads on components and their lifespan, thereby making it possible to detect failures and underperformance. This digital twin contributed to the development of a new tool: Wind Avatar®.



IFPEN and TotalEnergies conduct a study to evaluate floating wind turbine production

IFPEN and TotalEnergies joined forces to evaluate the impact of a floating wind turbine's movement on its energy production. Two types of floaters were evaluated and compared with a fixed turbine. Differences were quantified and their causes analyzed. The research was conducted using modeling tools developed at IFPEN, particularly DeepLines Wind™ for multi-physical floating wind turbine simulation.



THE DEVELOPMENT OF ENERGY STORAGE AND MANAGEMENT SYSTEMS

The IFPEN RE Carnot Institute is working on the development of stationary energy storage systems with high powers and capacities using an Adiabatic Compressed Air process, and on the development of new materials of future solid-type battery technologies. In 2021, an energy management system prototype integrating battery operation was also developed for the SME BEOGA to study a collective self-consumption solution.

HIGHLIGHT

Ademe TranZAE project: when the energy transition comes to business parks

The TranZAE project, awarded by ADEME in 2021 and led by the CSTB (Scientific and Technical Center for Building), of which IFPEN is a partner via its RE Carnot Institute alongside the CEREMA (Center for Studies and Expertise on Risks, the Environment, Mobility and Urban Planning) and Enedis, will propose a methodology aimed to decarbonize and revitalize France's 10,000 to 20,000 business parks (offices, shops, SMEs), producing renewable energy within the framework of collective self-consumption. A database incorporating cadastral data provided by IGN (National Geographic Institute) and electricity data provided by Enedis will be processed by a search engine created by IFPEN, in order to identify and categorize zones with high photovoltaic, stationary storage and charging station potential, integrating the cost of the technologies as well as the price of electricity and network services.

UNDERGROUND RESOURCES AND USAGE FOR THE ENERGY TRANSITION: THE CONTRIBUTION OF DIGITAL TECHNOLOGY

In 2021, the IFPEN RE Carnot Institute focused its efforts on geothermal energy, underground storage modeling and hydrogen. In the field of geothermal energy, software has been adapted to identify regional potential, make better use of resources and optimize the maintenance of facilities while managing the environmental impact. Storage facilities are simulated taking into account geomechanics, flows and fluid/rock interactions. Lastly, research is focused on hydrogen transport and storage safety based on studies on materials and their corrosion.

HIGHLIGHT


TELLUS: digital technologies serving geosciences

In March 2021, the IFPEN RE Carnot Institute launched TELLUS Share, a community of players from the underground sector led by IFPEN focusing on the theme of digital technology. The role of the community is to evaluate the contribution of digital technologies (data science, artificial intelligence, virtual reality, etc.) to problems related to the underground environment. To do so, the IFPEN RE Carnot Institute set up an ecosystem made up of a multidisciplinary team of geoscientists and digital technology and data science specialists, close partnerships with digital sector players (academics, leading digital sector players, startups). Four industrial partners from the oil and underground storage sectors joined the community for its launch.

HIGHLIGHT

IFPEN a partner of the French Corrosion Institute

In 2021, the French Corrosion Institute and IFPEN signed a framework partnership agreement. Objective: to conduct studies related to new energy technologies and the fight against corrosion, which undermines individual safety, the environment and process profitability by attacking CO₂ and hydrogen capture and storage facilities, geothermal energy facilities and biomass conversion facilities.



REDUCING THE ENVIRONMENTAL FOOTPRINT OF LAND TRANSPORT AND AVIATION SECTORS



Another example of research conducted at IFPEN to reduce the aviation sector's carbon footprint is the development of a process to convert alcohols into light olefins. Atol® technology, developed by IFPEN, TotalEnergies and Axens (the licensing company) is used for both bio-based chemistry or the production of biojet via the Alcohols To Jet process, whereby it is combined with the oligomerization and hydrogenation steps making up part of the portfolio of technologies developed by IFPEN and marketed by Axens.

IFPEN's commitment to the energy transition, in line with French and European public policies, is reflected in the development of eco-efficient technologies for the production of advanced biofuels for the road transport and aviation sectors. Research, launched a number of years ago in the laboratory, relates to the entire lignocellulosic biomass conversion (agricultural and forestry residues) to fuels, based on biotech (bioethanol production) or thermochemical (biodiesel and biokerosene production) processes such as BioTfuel® technology.

Towards sustainable aviation fuels

Tests on demonstration units completed in 2021 validate the positioning of the BioTfuel® technology as an excellent option for the production of sustainable aviation fuels (SAFs), making it possible to reduce greenhouse gas emissions by more than 90% compared with the fossil reference. The technology thus joins the solutions dedicated to Green House Gas emissions reductions for the aviation sector along with aircraft weight reduction, the evolution of engines and traffic optimization.


**Interview with:
Jean-Philippe Héraud,
BioTfuel® project manager**


We have successfully completed the test program on the Venette and Dunkirk BioTfuel® demonstration units, with our consortium partners. This demonstration phase enabled us to validate, develop and optimize the process chain on a semi-industrial scale for several types of biomass, following 1,000 hours of gasification and more than 1,500 hours of torrefaction. So we have reached a crucial milestone in the development of this technology for the production of low-carbon footprint biokerosene. Working with our partners, our focus now will be on research to move to a first industrial reference for the process that is adapted to meet the regulatory objectives set out for the aviation sector, with SAF incorporation targets of 5% in 2030 and more than 50% by 2050**.*

* IFPEN, Avril, Axens, CEA, Thyssenkrupp Industrial Solutions, TotalEnergies.

** Fixed by the French State in 2020 and proposed by the European Commission in 2021 in its Fit for 55 package.



SUPPORTING BIO-BASED CHEMISTRY

IFPEN contributes to the growth of a green economy combining industry and the environment, developing new processes, catalysts and biocatalysts for the conversion of biomass residues into major bio-based chemical intermediates. These technologies address the need to reduce industry's greenhouse gas emissions while diversifying supply sources. IFPEN's research also helps pave the way for the biorefinery of the future, reinforcing synergies between the productions of biofuels and biochemicals.

Research to develop a catalyst and a process for the production of bio-based acrylic acid from lactic acid continued, in collaboration with Axens and an industrial partner. Significant progress has been made with a catalytic formulation demonstrating very good performances.

Within the framework of the BioButterfly project, research conducted on catalysts and the associated process led to noteworthy progress in 2021 accompanied by the construction of a pre-industrial demonstration plant. When commissioned in 2022, this plant will be run to demonstrate the operation of the technology for the production of bio-butadiene from bio-based ethanol. This technology developed by Axens, IFPEN and Michelin will contribute to the production of a tire that is 100% sustainable.

FOCUS

In 2021, IFPEN was selected to jointly manage, alongside INRAE, the PEPR related to bio-based products and sustainable fuels (see page 6).

HIGHLIGHTS

Polyolefin production from waste

Within the framework of its circular economy roll-out project in Japan, Sumitomo Chemical produced the first polyolefin from waste in its laboratory. To do so, it used ethylene produced using Atol® technology, the fruit of a partnership between IFPEN, TotalEnergies and Axens. This process makes it possible to convert ethanol produced from waste into polymer-grade ethylene that will then be converted in Sumitomo Chemical's facilities into polyolefins, a key product for the manufacture of numerous bio-based plastic items.

100% bio-based PET bottles: a global first!

At the end of 2021, Japanese company Suntory announced the successful production of the first 100% bio-based PET bottle prototypes. It used bioparaxylene produced in the TCat-8® pilot unit operated by the American company Anellotech via the Bio-TCat® process developed in partnership with IFPEN and Axens, that converts lignocellulosic biomass into aromatics. Bio-TCat® technology, which is ready for marketing, will enable chemical sector players and brands to achieve their environmental and product sustainability objectives, thanks to its low carbon footprint and its raw material derived from non-food renewable biomass.

SUSTAINABLE MOBILITY



Boosting energy efficiency in transport, improving the environmental performance of powertrains and diversifying energy sources in order to evolve towards clean, low-carbon and increasingly connected mobility are the major challenges associated with sustainable mobility. To support companies, local authorities and citizens, the IFPEN Transports Energie Carnot Institute structures its research around three priorities: electric mobility, connected mobility and mobility with a low environmental impact.



TOWARDS ZERO POLLUTANT EMISSION ELECTRIC MOBILITY

Within the context of the decarbonization of the transport sector, individual mobility is being transformed to become electric with the growth in sales of ZEVs (zero emission vehicles) and the introduction of retrofit. Moreover, the increasing use of light vehicles with reduced power requirements paves the way for simpler and more economical low-voltage powertrains (<60 Volts). The IFPEN Transports Energie Carnot Institute (TE) contributes to this transformation and promotes zero emission mobility via the deployment of low-consumption and highly energy-efficient technologies. In 2021, working collaboratively within a French eco-system, it developed electric powertrain technologies aimed at the emerging retrofit market.

2021: the rapid development of efficient solutions

Our thriving partnership research activities also resulted in the development of a family of efficient electric powertrains, incorporating compact electronics and an original engine cooling solution. These solutions cover a broad range of applications, from the small low-voltage vehicle to vehicles requiring high power.

In order to fuel these partnerships and boost the competitiveness of the industrial fabric, IFPEN designed two new machine topologies for which patent applications have been submitted. These topologies reduce raw material consumption by 30% for equivalent state-of-the-art performances, thanks to improved performance densities. Lastly, 2021 saw the culmination of 2 projects: RefreeDrive and HERA.

Within the context of the European RefreeDrive project, IFPEN developed two electric machines free of rare earths (200 and 75 kW), and an inverter based on silicon carbide (SiC) technology. The inverter has already been the subject of industrial development.

The HERA project, conducted within the framework of the partnership with Punch Powertrain, saw the development of an innovative electric motor and its control system meeting industrial requirements for an electric vehicle's high-voltage transmission (350 V) and high power (150 kW).

HIGHLIGHT



COMUTES²: approaching a new test campaign

At the end of 2020, at the instigation of IFPEN Transports Energie Carnot Institute, the *Consortium pour la Mutualisation de Tests Électriques sur Systèmes de Stockage* (consortium for the pooling of electric tests on storage systems, COMUTES²) launched a first accelerated ageing test campaign, open to all, dedicated to the impact of cold temperatures on the durability of Li-ion batteries. Building on the success of this first campaign which brought together five members - Valeo, Siemens, DGA - Direction générale de l'armement (French defense procurement and technology agency), Hutchinson and EDF - and six partner laboratories* and will be completed in March 2022, COMUTES² is preparing a second test campaign.

Find out more about COMUTES²: <https://www.comutes2.com>

* The consortium's six partner laboratories are: IFPEN TE Carnot Institute, the CEA, Gustave Eiffel University, the laboratoire d'Intégration du matériau au système (IMS, material system integration laboratory), the University of Technology of Compiègne (UTC) and the EIGSI engineering school.

HIGHLIGHT

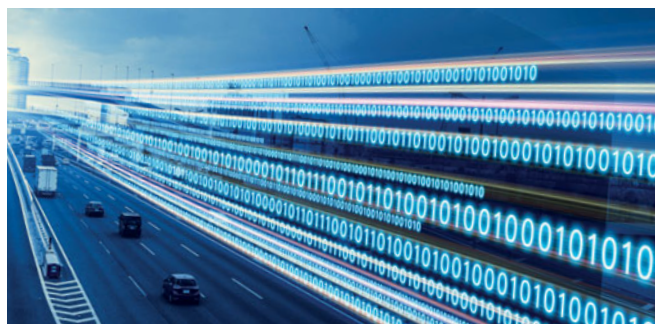


Innovating within a French ecosystem

In 2021, the IFPEN Transports Energie Carnot Institute and French SME EREM pooled their resources and expertise to develop and industrialize innovative electric motors for a broad range of applications. IFPEN is contributing its expertise consolidated by patents relating to the design of the active parts of the electric motor as well as its management. In partnership with EREM and Punch Powertrain France, IFPEN thus developed and approved a first high-voltage motor for electric retrofit vehicle applications, with a high-end application on a classic car.

By pooling EREM's manufacturing tool, IFPEN also developed a low-voltage motor with unrivalled performances (48 V and 40 kW) for use in small electric vehicles. This motor incorporates an inverter developed and industrialized with Punch Powertrain France, which stands apart from the state of the art in terms of its performance density (20 kVA/kg and 20 kVA/L). This powertrain will be marketed in 2022.

**CONNECTED MOBILITY:
MULTI-SCALE/
MULTI-APPLICATION DATA**



IFPEN is contributing to the decarbonization of day-to-day mobility through the development, on behalf of the French State, territories, general public and road professionals, of connected services and applications capable of measuring the environmental footprint of transport (CO₂, energy and pollutants) and thus encouraging improvements in behavior. For example, Gecoair™ is a tool

that helps reduce the environmental footprint of journeys undertaken by encouraging users to travel in an eco-responsible manner.

On the other hand, Geovelo™ is a *Compagnie des Mobilités* application, developed in partnership with the Transports Energie Carnot Institute, for promoting the use of bicycles.

Since 2021, mobility data, as well as a raft of algorithms and digital tools relating to air quality and connected mobility, have been available via around 30 web services provided by IFPEN's partners on the mobicloud.ifpen.fr platform developed by the IFPEN Transports Energie Carnot Institute.

The year also saw a reinforcement of the long-standing partnership between Siemens PLM and IFPEN via - among other things - the increased use and integration of the Real-Driving Emissions component in the Simcenter Amesim. The latter now uses the services available in Mobicloud.



HIGHLIGHT

**Modeling mobility data
in the Ile-de-France region**

In October 2021, the IFPEN Transports Energie Carnot Institute and Paris Ouest La Défense (POLD) launched their new collaborative partnership established within the framework of the *Territoires d'innovation de grande ambition* (TIGA, Ambitious Demonstrators and Innovative Territories) initiative for Ile-de-France, "*Construire au futur, habiter au futur*" (Building in the future, living in the future). Ambition: to capture, analyze and model mobility data for the Paris Ouest La Défense area in order to better understand and anticipate work-related journeys. "IFPEN's long-established presence in Rueil-Malmaison and its expertise make it a key research player across the territory", explains Nathalie Jacquart, economic development manager and POLD project coordinator.

"In concrete terms, our collaboration, which also includes Paris-Nanterre University, will deliver a dynamic map of green flows towards and from the territory's 30 or so third places. The latter are spaces conducive to the development of new modes of production, creation and training related to the professions of the future. And yet they are not well known, not sufficiently developed and not interconnected. Giving an overview of flows to and from these sites will make it possible to propose services and timetables adapted to users, while facilitating interconnections between the sites." IFPEN will construct its analyses primarily on the data provided by the Gecoair™ ecomobility application.



HIGHLIGHT

Mobility Data Hub: towards a national mobility data platform

Placing mobility on an ambitious decarbonization trajectory while integrating changes in behavior depends on being able to better understand, analyze and even predict the movements of people and goods. Mobility data thus represent a key resource. While digital sector players are in possession of a significant proportion of the data, other national players have access to fragmented shares that are highly relevant once a synergy is created between them. Thus, because it now appears necessary to create a trusted third party bringing together these players and capable of processing this data, at the end of 2021, IFPEN, in collaboration with Inria and Cerema, launched the creation of a Mobility Data Hub, the aim of which is to provide all players with common tools making it possible to pool mobility data as well as analyze and anticipate the mobility of people and goods.

NB: the Mobility Data Hub was one of the projects selected for the Propulse program launched by the French Innovation for Transport Agency, announced on 17 December 2021.

HIGHLIGHT

Phoenix: towards a plug-in zero-emission hybrid vehicle

Coordinated by IFPEN and conducted with seven industrial and academic partners*, the PHOENICE (PHEv towards zero EmissionNs & ultimate ICE efficiency) project was launched in 2021. It is aimed at developing a plug-in hybrid vehicle demonstrator with reduced fuel consumption and pollutant emissions. IFPEN will primarily be responsible for the design of the combustion system based on the Swumble™ concept, the design of the after-treatment system, the creation of the engine prototypes and the calibration of the multi-cylinder engine. PHOENICE will help accelerate the transition towards more environmentally-friendly mobility in terms of air quality and the reduction in greenhouse gas emissions.

* CRF/FCA (Fiat Group research center), FEV Europe, Johnson Matthey, Marelli Europe, Garrett Motion France, Politecnico di Torino and In Extensio Innovation Croissance.

This project has received funding from the European Union's H2020 research and innovation program through grant agreement 101006841.

EVOLVING IC POWERTRAINS

In a context in which the transition to electric vehicles is accelerating, research conducted by the IFPEN Transports Energie Carnot Institute dedicated to powertrains is aimed at supporting industry through the changes. Innovations concerning the control of the air loop (air supply system and recirculation of burned gases) and/or the combustion system are explored within the framework of the European Phoenix project in particular (see left).

Launched in 2021, this project aims to improve the efficiency and emissions of a plug-in hybrid vehicle. At lower TRLs, the European Eagle program, which closed at the start of 2021 (see 2020 Activity Report p. 24), and other collaborative studies have made it possible to determine the efficiency and emissions potential of gasoline engines. In the field of natural gas and biogas powertrains, the development of new spark ignition powertrains was launched and is set to continue with the experimental characterization of a new combustion system with efficiency gains of around 10%.

The energy transition relating to the river transport sector is also supported by the IFPEN Transports Energie Carnot Institute. With Voies navigables de France (VNF, the French Waterways Network), a research and development contract is aimed at defining a masterplan for establishing a green river fleet for the Rhône-Saône basin (see page 24). Within the framework of an R&I partnership, a second project is examining boat engine waste heat recovery systems and their navigation potential.



+ FOCUS

In 2021, IFPEN was selected to jointly manage, alongside Gustave Eiffel University, the PEPR related to the digitalization and decarbonization of mobility (see page 6).



+ FOCUS



**Interview with:
Cécile Cohas,
innovation
research mission
manager,
Voies navigables
de France (VNF)**



In order to meet our objective of establishing a green river fleet, we asked IFPEN to work with us. Our partnership takes the form of a research and innovation contract aimed at drawing up prospective scenarios for the establishment of a green fleet in the Rhône-Saône basin by 2050. IFPEN's teams are conducting an in-depth cross-functional study on the theme. In addition to the technical, technological and economic modeling of the solutions under consideration, the study also offers crucial life-cycle analyses to complete the sector-specific data provided by the European Commission. Ultimately, the objective is for these scenarios to be extended to all the basins covered by VNF and lead to the construction of new boats or the retrofit of existing vessels. To ensure these objectives become a reality on the ground, we are once again going to need the support of IFPEN's teams. I would like to see a long-term partnership established with IFPEN, both scientific and technical, enabling us to draw on the expertise of a reference organization for our activities.



IFPEN is working on solutions for the use of renewable or low-carbon hydrogen to reduce the environmental impact of mobility:

- hydrogen used to power a fuel cell that generates on-board electricity for electric vehicles,
- hydrogen used as a fuel in an internal combustion engine,
- integration of low-carbon hydrogen in the production of advanced biofuels, in the form of e-biofuels that can be used by heavy transport (land or sea), off-road vehicles and the aviation sector.

Its researchers have been contributing to the ECH2 project led by Vitesco Technologies since October 2021. Objective: to improve the control electronics of hydrogen fuel cell vehicles and facilitate their large-scale roll-out by reducing their costs and increasing their lifespan. In addition, a new fuel cell system test bench, which with a power of 210 kW is the most powerful in France, was commissioned at IFPEN's Lyon site.

RESPONSIBLE OIL AND GAS

Given the need to increase energy efficiency and reduce CO₂ emissions and pollution generated by industry and transport, while meeting the global demand for mobility, energy and products for the chemicals sector, IFPEN conducts research aimed at producing fuels and chemical intermediates meeting existing standards. At the same time, it develops technologies making it possible to reduce the risks associated with the exploration and exploitation of oil and gas resources.



UNDERSTANDING AND MODELING THE UNDERGROUND ENVIRONMENT

In the current context of the energy transition, industrial players are endeavoring to minimize risks and environmental impacts, employing efficient tools to explore, characterize and produce underground resources.

On a basin scale, the IFPEN RE Carnot Institute reinforces the explanatory and predictive capacity of modeling to understand the dynamic evolution of the underground environment over geological timeframes and manage uncertainties, with a view to identifying drilling opportunities, estimating oil and gas potential, locating fields and reducing exploration risks. On a reservoir scale, research relates to the modeling of complex phenomena in order to characterize and better manage production.



HIGHLIGHT

IFPEN organizes an international basin modeling workshop

The second edition of the Basin Modeling workshop organized by the IFPEN RE

Carnot Institute brought together around one hundred experts from some twenty countries to review the various research avenues in the field. There was a particular focus on new working methodologies, the themes of permeability and flows in faults and fractures, as well as multi-physical and multi-scale problems. A specific session was dedicated to the energy transition.

ifpen
The Science-Innov
Workshops



ENHANCED RECOVERY: A LOWER ENVIRONMENTAL IMPACT

Enhanced oil recovery (EOR) makes it possible to meet demand by increasing the production of existing reservoirs, while limiting drilling operations and optimizing produced water management. In this area, within the framework of the EOR Alliance, IFPEN, Beicip-Franlab and Solvay are developing technologies adapted to different types of reservoir and EOR processes, from formulation research in the laboratory to experimentation in the field. The DOLPHIN 3 JIP, launched at the end of 2019 with six oil industry partners and focused on minimizing the environmental impact of EOR, is pursuing its activities with the conduct of water treatment unit tests on the IFPEN Gas Oil water Separation Platform (GOWSP).

OFFSHORE PRODUCTION: MANAGING THE SEABED ENVIRONMENT

The offshore sector, which accounts for one third of oil and gas production, saw reduced activity in 2021.

Nevertheless, the industry encounters problems that remain critical, such as the significant mechanical stresses present at these depths, corrosion caused by the fluids extracted, the occurrence of hydrate and paraffin plugs, the mixture of fluids of variable composition to be pumped and sometimes separated on the seabed, as well as the cost of installations. To address these challenges, the IFPEN RE Carnot Institute continued its research on the design of offshore drilling equipment, flexible pipes, multi-phase pumps and sensors reducing production risks.

HIGHLIGHT

Partnership with OneSubsea:
tests on a multi-phase pump

Within the framework of a partnership agreement with OneSubsea, tests were conducted on a multi-phase pump enabling production fluids to be brought to the surface without prior separation of the different phases. A transparent prototype used for research on multi-phase flows in pumps was installed at the Lyon site. Following a successful first test campaign, the equipment will remain on site, at IFPEN-Lyon, to enable tests and research on the theme to be continued.

CLEAN FUEL PRODUCTION

Against the backdrop of an accelerating energy transition, the refining sector has to respond to the tightening-up of fuel regulations, as well as the need to adapt to market changes shifting towards more petrochemicals production.

In the field of clean fuels, IFPEN develops catalysts and processes making it possible to meet the strictest specifications while reducing the environmental impact of their production. In 2021, research progress has been recorded regarding FCC gasoline hydrotreatment, catalytic reforming and the hydrocracking and hydro-dewaxing of diesel cuts with the development of a catalyst that improves at the same time, yields, cold properties and fuel quality.



HIGHLIGHT

Catalytic reforming: a new series of optimized catalysts

The Symphony® family of catalytic reforming catalysts, marketed by Axens, has been extended by the addition of a new series for the semi-regenerative process. Catalytic reforming is an essential step to convert crude oil light cuts into fuel components while producing hydrogen. These catalysts, developed as a result of IFPEN's research, offer increased activity and stability while improving reformate and hydrogen yields, thereby helping to enhance the economic and energy performances of the process.

HIGHLIGHT

New FCC gasoline hydrotreatment catalysts

IFPEN's research led to the development of two new catalysts, selective hydrogenation and selective hydrodesulfurization, for the Prime-G+® process marketed by Axens. These developments reinforce a range of solutions adapted to the needs of refining operators for the production of gasoline meeting the strictest environmental standards, as reflected in the 300th reference obtained by Prime G+® technology in 2021.

The eco-efficient fuel production processes developed by IFPEN are designed to contribute to the decarbonization of industry objective, while providing flexibility in order to foster the diversification of refining activities and improve synergies with the petrochemicals sector. In the face of major changes, the refinery of the future, a complete energy hub, will need to have technologies making it possible to treat multiple feeds (including those derived from biomass and plastics recycling) and produce a full range of products including chemicals, fuels, hydrogen, etc.

HIGHLIGHT

**Data and processes**

IFPEN is reinforcing its activities in the field of the processing and capitalization of data generated by high-throughput experimentation as well as data related to the development of technologically complex processes. These activities are aimed, on the one hand, at developing tools for the transformation of research data, facilitating the work of R&I teams and contributing to the improvement in experimentation efficiency; and, on the other hand, proposing new digital services and technologies to accelerate the digital transition of the refining and petrochemicals sectors.

HIGHLIGHT

Two-step hydrocracking catalyst for naphtha production

Researchers at IFPEN finalized a two-step high-pressure process targeting the selective conversion of heavy cuts into naphtha cuts, suitable as a steam cracker feed to produce light olefins. Associated with an innovative zeolite catalyst developed in 2020, it contributes to the expansion of Oil to Chemical complexes.

HEAVY CRUDE AND RESIDUE CONVERSION AND PURIFICATION**The increase in the proportion of heavy and extra heavy oils in the global oil supply and the sustained demand for light products make the conversion of heavy fractions essential.**

IFPEN develops technologies to convert and purify these feeds to obtain cleaner products meeting ever stricter specifications. The solutions developed contribute to the reduction in CO₂ emissions associated with this conversion, while enabling refineries to become more energy efficient.

In 2021, research in the field of deep hydroconversion of heavy residues via ebullated bed hydrocracking led to significant results demonstrating the convertibility of more challenging feeds. Research also targeted the improvement of deep conversion and desulfurization processes for the production of bunker fuels meeting IMO 2020 standards.

Conversion processes play a major role in Oil to Chemicals complexes, aimed at converting a large proportion of crude oil into chemicals. Research conducted in this field includes the development of a two-step hydrocracking process for naphtha production, as well as technology development conducted within the framework of the FCC Alliance, bringing together IFPEN, Axens, TotalEnergies and Technip Energies. The objective of the latter: to increase the flexibility of the fluidized bed catalytic cracking process in terms of feedstock and target a wider range of products, in particular petrochemicals.

PRODUCTION OF PETROCHEMICAL INTERMEDIATES

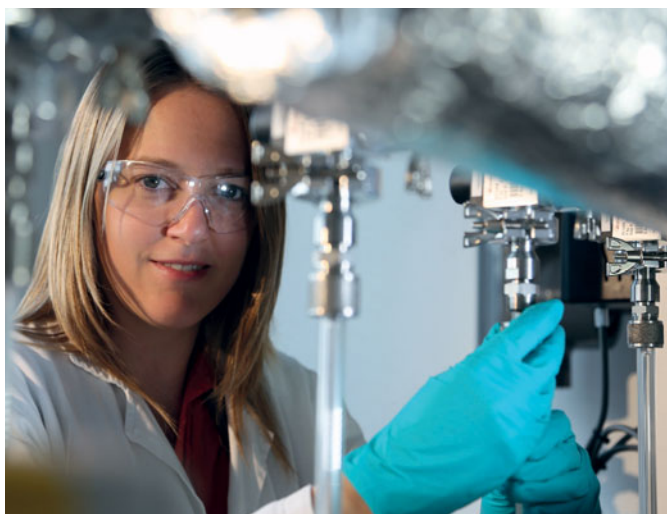
The petrochemicals sector continues to grow, driven by the increase in demand for consumer goods globally.

Base chemicals such as olefins and aromatics are employed to manufacture products used in a variety of sectors: plastics, pharmaceuticals, cosmetics, electronics, automobile, aviation, textiles and agriculture. In order to meet market demand while complying with regulations aimed at reducing the environmental impact of industrial processes, IFPEN develops eco-efficient technologies for the production of petrochemical intermediates and optimizes the performances of existing processes.

Activities conducted in 2021 in the field of aromatics, particularly within the context of research dedicated to improve Eluxyl® technology marketed by Axens, led to the development of new, more efficient xylene separation sieves.

In the field of olefins, research concerned the development of selective hydrogenation and propylene and 1-butene production technologies, with the development of a new process marketed by Axens.

This process also helps encourage the use of new raw materials, such as those derived from biomass, illustrating the profound transformation taking place in the petrochemicals sector.



AN INTEGRATED OFFER FOR GAS TREATMENT AND CONVERSION



The development of gas treatment technologies

is driven by the increase in its consumption, with its contribution to the energy mix forecast to be around 25% by 2040. Research conducted at IFPEN is aimed at offering industry a complete range of technologies to sweeten natural gas or capture CO₂ in syngas production processes and effectively and economically reduce CO₂ emissions at the source. R&I teams are working to improve the efficiency and competitiveness of these solutions, which range from process design through to solvent development, and the development of new packings for absorption columns.

HIGHLIGHT

DimEne-B® : a new 1-butene production process

IFPEN's teams developed a new homogeneous catalysis process, together with the associated catalyst, for the production of 1-butene via the dimerization of ethylene. 1-butene is a chemical intermediate used as a comonomer for the production of plastics. The process, marketed by Axens, also makes it possible to convert ethylene derived from biomass and thus contribute to the production of bioplastics. More energy efficient, its design makes it possible to increase 1-butene production capacity.



FUNDAMENTAL RESEARCH SERVING INNOVATION

In order to ensure the scientific excellence of its research activities and support its innovation ambitions, IFPEN draws on a collaborative fundamental research program, organized around nine scientific challenges. This dynamic approach has already borne fruit. In order to anticipate long-term needs and pave the way for the development of new products and processes, IFPEN permanently adjusts its scientific questions with a view to acquiring new knowledge.



STRUCTURED FUNDAMENTAL RESEARCH

Since 2016, the combined scientific challenges have charted a path for IFPEN's R&I activities, ranging from the understanding of mechanisms on an atomic scale through to the evaluation of the economic and environmental impact of processes and products. They formalize the major scientific questions that need to be addressed in order to prepare the ground for more applied research activities. These challenges are themselves broken down into sub-challenges, corresponding to more specific hurdles that need to be overcome. Between projects, theses, post-doctoral research and partnerships, IFPEN channels multiple resources into removing these hurdles. Fully operational, this organization structured around challenges consolidates a research methodology based on openness, collaboration and knowledge sharing.



NEW ENERGY TECHNOLOGIES AT THE HEART OF CHALLENGES

In 2021, IFPEN pursued its efforts aimed at promoting cross-functionality between challenges on the themes of new energy technologies (NETs) and overseeing the roll-out of the new Climate, Environment and Circular Economy strategic priority within the fundamental research program. For example, the number of theses related to this strategic priority rose from one to seven over the year. Scientific objectives relating to plastic recycling were the focus of new sub-challenges within three of the broader challenges, while those on the theme of "climate/soil interactions and the water cycle" gave rise to new projects. These include the international VULCAR-FATE project, the objective of which is to evaluate the impact of recent climate and land use changes on the water balance and sediment and organic matter transport, as well as on soil decomposition potentially generating atmospheric carbon emissions. Launched in June 2021, it was selected within the framework of the call for projects issued by the Belmont Forum on the sustainability of soils and groundwater for society. The presence of Dr. David Sebag, international environmental geologist, reinforced IFPEN's capacity to characterize soil organic matter for a better description of carbon storage forms.

A consolidated and enriched partnership base

This strategy of openness is reflected in the development of partnerships, old and new, such as the scientific research framework agreement renewed with University College London (UCL) in 2021. The CEA and IFPEN renewed their agreement first initiated back in 2007 to continue to enhance the "Arcane" development and services platform in the field of high-performance computing and prepare to make it open-source. From January 2022, the two partners also agreed to the joint management of the STET (Science and Technology for Energy Transition) journal, formerly OGST (Oil & Gas Science and Technology), an open-access international scientific journal with its focus now shifted towards the energy transition. The pooling of IFPEN's expertise with that of its five partners* in the CARMEN joint research laboratory continues, for its part, to deliver significant results two years after its launch. Lastly, the pooling of fundamental research with private players, be it in the context of bilateral agreements (EDF, Safran, Saint-Gobain, TotalEnergies, etc.), consortiums or Joint Industry Projects (Fugacity and EleTher JIPs), continues to enrich research conducted to overcome various scientific challenges.

* CNRS, ENS Lyon, Sorbonne University, Claude Bernard Lyon 1 University and Strasbourg University.

HIGHLIGHT

BIFROST, an interdisciplinary collaborative project

At the interface of analytical chemistry and data science for the analysis of complex mixtures, the BIFROST (Blind Identification, Filtering & Restoration On Spectral Techniques) project, launched in 2018 with the Marseille Institutes of Mathematics (I2M) and Molecular Sciences (ISM2) within the framework of the Aix-Marseille excellence initiative, was completed in 2021. Combining quantitative analysis and algorithm optimization in signal unmixing, it demonstrated the benefit of associating new NMR (nuclear magnetic resonance) data acquisition methods and applied mathematics.



Interview with:
Sophie Violette,
Lecturer-HDR (national
accreditation to
supervise research)
Researcher, Sorbonne
University – ENS
Geology Laboratory- PSL
University and member
of IFPEN's scientific
board

In the last few years, IFPEN has implemented a complete shift in focus in terms of its oil and gas research programs to encompass new energy and ecological themes. Organizing its fundamental research around scientific challenges has been tremendously beneficial to the reflection process surrounding this change, since it has made it possible to put into perspective the purpose of IFPEN's technologies and their applications.

We should also pay tribute to the revamped Earth Sciences and Environmental Technologies division for the advances it has made in transferring its expertise to NETs, and IFPEN's teams in general for their capacity to adapt and make this shift a reality. The "climate/soil interactions and the water cycle" theme is a prime example of this: its flagship "Critical zone challenges" project required the expertise acquired in deep basins to be applied to surface-related themes, but it also demonstrated the efficiency with which IFPEN's long-established analytical tools have been transposed. One example is Rock-Eval®, capable of reliably, rapidly and cost-effectively characterizing the content of soil organic matter, as well as other numerical tools that will ultimately be able to quantify the anthropic impact on erosion processes. The development of these themes at IFPEN has also been an opportunity to forge academic and industrial partnerships. For example, a new agreement with long-standing partner INRAE involves the pooling of expertise that paves the way for some equally fruitful collaborative projects in the future. Lastly, let's underline the contribution of scientific visitor David Sebag, whose complementary soil science expertise reinforced and galvanized the skills of IFPEN's teams.



Interview with:
Jean Kittel,
physical-chemical
engineer at IFPEN

In 2021, IFPEN further reinforced its presence in the field of corrosion. Partners since 2015 on the basis of complementary know-how and experimental laboratories, and building on knowledge gained through joint research such as that conducted between 2019 and 2021 within the framework of the fundamental research Fugacity Joint Industry Project (JIP) on hydrogen penetration in steels, IFPEN, via its IFPEN Ressources Énergétiques Carnot Institute, and the French Corrosion Institute signed a 5-year framework partnership agreement. The objective? To develop new collaborative research and innovation projects for potential applications to foster and support sustainable industry, built around protecting the environment and individual safety. Advances are set to feed through to innovation in numerous new energy technology fields (geothermal energy, hydrogen, wind, CO₂ capture, storage and utilization), as well as for responsible oil and gas exploration and production. The partnership has already given rise to the launch of the Membership Research Consortium, the purpose of which is to study the behavior of materials in the presence of hydrogen.

HIGHLIGHT

Thermodynamics: when IFPEN anticipates increasing needs in the field of recycling

The objectives of the French Circular Economy law and the needs expressed by industry have established thermodynamics applied to recycling an active research field for which IFPEN's contributions have been significant. For example the EleTher teaching and research chair, launched by IFP School in 2021, is focused on the use of thermodynamic tools to improve the efficiency of recycling processes. To achieve this, it aims to acquire a better understanding of physicochemical phenomena in the aqueous phase. "The chair draws on research conducted by the seven industrial partners in the EleTher JIP, relating to systems containing ionic species and their numerous applications: metal recycling, biomass treatment and CO₂ capture and storage. Two years after its launch in 2019, the results of the JIP concerning data analysis and model calibration have already led to a publication, several reports and webinars aimed at industrial experts. It is likely to be renewed in 2022", specifies Jean-Charles de Hemptinne, chair holder and lecturer-researcher at IFP School. In this context, the 31st edition of the ESAT conference on applied thermodynamics, organized jointly with Mines ParisTech engineering school in July 2021, brought together numerous players in the field. "A community for exchange is necessary to enable those active in the field to discuss the latest research and advances", adds Jean-Charles de Hemptinne. Organized around a 100% virtual format, the conference brought together nearly 300 participants from 37 countries. Against the backdrop of Covid, the format was much appreciated, enabling discussions of the highest scientific quality to take place, despite the circumstances. Several prizes were awarded and a round table dedicated to the chair's theme was organized.



HIGHLIGHT

Complex systems: growing number of collaborative projects for new optimization methods

In 2021, IFPEN continued to reinforce its expertise in the field of the command and optimization of complex systems associated with many of its products and services. Its strategy of openness and knowledge pooling, via collaborative research projects with university and industrial partners as well as other research organizations, continues to bear fruit. The OQUAIDO applied mathematics chair, led by the École des Mines engineering school in Saint-Étienne, which brought together 11 partners including IFPEN, gave way to CIROQUO (*Consortium Industrie et Recherche pour l'Optimisation et la QUantification d'incertitude pour les données Onéreuses*, or Industrial Research Consortium dedicated to the Optimization and Quantification of Uncertainties for Expensive Data). Managed by the École Centrale de Lyon and jointly led by IFPEN, this new consortium brings together six academic partners alongside seven technological research partners to address issues surrounding the exploitation of expensive simulations resulting from major calculation codes. IFPEN also conducts research within the ANR SAMOURAI (Simulation Analytics and Meta-model-based solutions for Optimization, Uncertainty and Reliability Analysis) project launched in 2021 for a period of 4 years. Once again, with six academic and industrial partners, IFPEN is developing innovative optimization methods, based on meta-models, for the design and evaluation of risks specific to complex systems in different fields: renewable and low-carbon energies and low-carbon aviation. These methodologies will enhance LAGUN, an open-source web platform for data exploration and optimization co-developed with Safran Tech.

AWARDS WINNERS IN 2021...



Antoine Fécant, research engineer and project manager at IFPEN, was awarded the French *Académie des sciences* 2021 IMT Young Scientist prize for his work and contribution to the development of research in the field of photocatalysis conducted at IFPEN for the production of low-carbon hydrogen and the utilization of CO₂ in the form of "solar fuels".



Rémi Hocq, PhD student at IFPEN (2017–2019), was awarded the Dufrenoy silver medal by the French Academy of Agriculture for his thesis entitled "*Clostridium beijerinckii* DSM 6423, une souche plateforme émergente pour la bioproduction de solvants" (*Clostridium beijerinckii* DSM 6423, an emerging platform strain for solvent bioproduction).



Julie Guillemant, PhD student at IFPEN (2017–2019), was awarded the French Society of Mass Spectrometry (SFSM) 2021 thesis prize for her work on the "chemometric exploitation of molecular analysis data (FT-ICR/MS) of gas oils (GO) and vacuum gas oils (VGO) for the search for reactivity descriptors".

AND ALSO...



The IFPEN Scientific Board recognized the excellence of **Lina Jolivet's** research activities and awarded her the 2021 Yves Chauvin prize for her thesis entitled "*Apport de la spectroscopie de plasma induit par laser pour la modélisation des procédés de raffinage*" (Use of laser-induced plasma spectroscopy for the modeling of refining processes). Her work is now part of a joint research project conducted with the start-up ABLATOM aimed at adapting the use of this technique to materials for NETs.

FOCUS

Nine projects were selected from the 33 proposals involving IFPEN that were submitted within the context of the ANR's 2021 generic call for projects. This number, in significant increase compared to previous years, illustrates the quality and relevance of the proposals drawn up. These projects will help overcome scientific challenges in a variety of fields including geothermal energy, artificial intelligence, biomass conversion and electric machines.



ENCOURAGING AND SUPPORTING INNOVATION

IFPEN contributes to the development of green industrial sectors and sustainable mobility, speeding up the detection of new energy technology opportunities. To achieve this, IFPEN is diversifying, both in terms of its industrial partnerships and the development of its subsidiaries, and supporting the competitiveness of SMEs and innovative startups, thereby contributing to job creation and local wealth. Underpinning this, IFPEN encourages the expression of a genuine in-house innovation culture.



INNOVATION, THE FOCUS OF IN-HOUSE CHALLENGES

The NET diversification strategy supporting innovation is reflected in the way IFPEN operates.

For example, it regularly organizes a challenge open to employees, IFP School students and employees of IFPEN Group subsidiaries, aimed at stimulating the company's innovation culture. In 2021, progress was made in all five winning projects from the 2020 challenge: for several of them, testing and POC led to a partnership with an SME or an industrial group, or patents being filed. Alongside, a so-called "free creativity" approach is focused on the development of new skills, methodologies and experimental or digital tools. In addition, via its spin-off initiative, IFPEN helps employees seeking to set up their own companies. In 2021, IFPEN helped an employee set up TechKare™, a company that offers solutions making it easier to transport heavy loads in hospitals (see page 7 and the 2020 Activity Report p.33).



SUPPORT FOR START-UPS AND SMES: AN OUTSTANDING YEAR

IFPEN has been actively supporting SMEs and startups spearheading innovation projects with a positive environmental impact for nearly 30 years.

In 2021, the development of digital prospection tools helped publicize IFPEN's support provision more widely, which resulted in the number of partnership agreements signed more than doubling compared to previous years. Companies having joined IFPEN's ecosystem in 2021 propose innovations as varied as the production of bio-based additives for the paper industry (see page 34), AI algorithms for image processing, a system enabling the preparation of span gases, training crows to collect waste, drinking water production from solar panels, serious games for the energy transition and an innovative imaging technique for flow measurements.

IFPEN, a partner of major deeptech events

An illustration of this increased influence, IFPEN signed a partnership agreement with Bpifrance, aimed at supporting the creation and development of technological startups (see opposite). IFPEN is also a partner of the Hello Tomorrow challenge, organized within the framework of the Hello Tomorrow Global Summit, and sponsors the "Energy and Environment" category of the competition, which aims to identify the most promising technological and scientific projects addressing the societal, environmental and industrial challenges of tomorrow. This year, Swiss startup Oxyle, which is developing a solution designed to remove highly persistent organic pollutants from municipal and industrial waste water, won the category.

HIGHLIGHT

Support for FunCell, a company that develops bio-based additives for the paper industry

In 2021, IFPEN began supporting FunCell, a company founded in 2020 and located in Isère (south-east France), that develops bio-based additives for the paper industry. The additives improve the properties of cellulosic materials (paper, cardboard, packaging and hygiene products) and, notably, give them greater resistance to humidity. This innovation could therefore help promote the use of paper packaging as an alternative to plastics. The additives have already been successfully produced in the laboratory and IFPEN will now help FunCell to extrapolate and develop the process at the industrial pilot scale. "We are pleased to be teaming up with IFPEN. We will be able to benefit from their expertise in order to take our technology further and apply it on an industrial scale, since it has obvious potential as regards the eco-responsible packaging market", explains Gilles du Sordet, CEO of FunCell. Awarded a Grand Prize in the i-Lab 2020 competition, the FunCell solution also meets the durability and toxicity criteria of the packaging market.



HIGHLIGHT



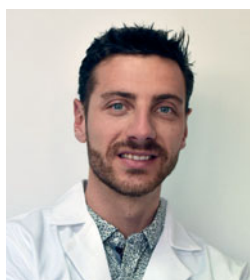
IFPEN and Bpifrance join forces to support greentech startups

At the 2021 edition of Meet'Up Greentech, the annual event of the French Greentech ecosystem organized by the French Minister for the ecological transition, Pascale Ribon, Deeptech Director at Bpifrance, Catherine Rivière, Executive Vice-President of IFPEN and Nathalie Alazard-Toux, President of IFP Investissement, signed a partnership agreement. Under the terms of this agreement, Bpifrance and IFPEN will be mobilizing their resources and expertise to promote the transfer of research results through the creation of startups in four key energy transition fields: sustainable mobility, the circular economy, energy efficiency and air quality. Bpifrance and IFPEN want to converge their respective objectives, in line with the strategic priorities formalized in the Deeptech plan drawn up by the French public authorities: transfer of public research results and support for startups mobilizing disruptive technologies.

NB: IFPEN has been a member of Greentech, the French national network of incubators, since its launch in 2017 by the French Minister for the ecological transition.



Interview with:
Guillaume Lepage,
Technological Development
Manager, Naturamole



We met IFPEN at a French R&D ecosystem event. Among the various SME support mechanisms available, the Boost&Link™ partnership offered by IFPEN appealed to us on various levels. On the technical side, due to its advanced expertise in the field of separation processes and distillation technologies, IFPEN helped us develop a high-yield purification process delivering a high level of purity from an active ingredient derived from renewable resources. Secondly, the service is structured in a straightforward manner, with each step explicitly and clearly defined. Thirdly, the successful revenue model is an undeniable asset: as an SME, we do not need to provide any cash upfront. Building on this success, we plan to turn to IFPEN again for future development projects.

+ FOCUS

In 2021, IFPEN met more than 450 companies and more than doubled the number of contracts signed.



TARGETED PARTNERSHIPS TO DETECT OPPORTUNITIES

To identify collaborative opportunities with SMEs and young innovative companies and optimize intelligence activities concerning new fields, IFPEN can draw on an extensive network of partners: target incubators, innovation support networks and the Carnot Institute network.



FOCUS

Support for innovative start-ups also takes the form of financial participation in investment funds specializing in eco-industries and eco-energies, which invest in young companies and SMEs providing innovative services and technologies.





A GROUP IN TRANSITION

The health crisis and its economic consequences continued to have an impact in 2021.

While the level of activity of IFP Group's main subsidiaries, Axens, Beicip-Franlab and IFP Training, was down compared to pre-crisis levels, the ecological transition did, nevertheless, continue to generate opportunities.

In line with R&I activities, the group's subsidiaries pursued their NET development efforts. In April, for example, Axens acquired FlowVision, a company specializing in nitrogen oxide reduction solutions. It also reinforced its offer in the field of plastic recycling. In September, IFP Training forged a partnership with EIT InnoEnergy, the European innovation institute set up to catalyze and accelerate the energy transition.

The objective: to contribute to the roll-out, in France and Europe, of training programs dedicated to batteries across the entire value chain, from design through to recycling. For its part, Beicip-Franlab provided consultancy services relating to geothermal energy and CO₂ capture to major energy groups.



HIGHLIGHT



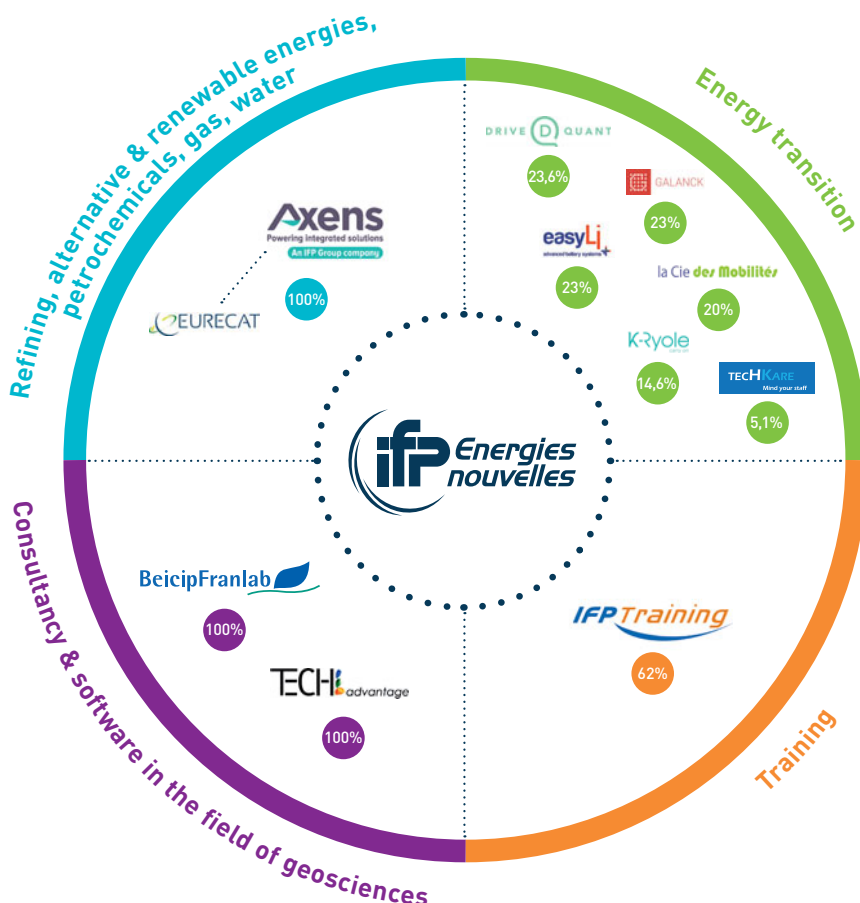
2024 Olympic and Paralympic games: Geovelo™ winner of the call for mobility innovations

The “*Challenge Olympique à Vélo*” (Bicycle Olympic Challenge) project submitted by *La Compagnie des Mobilités* was selected alongside 20 other projects within the context of the “2024 Olympic and Paralympic games” call for mobility innovations launched by the French Ministry for the Ecological Transition. The project, in the “new mobility and active mobility” category, is aimed at encouraging people to use bicycles throughout the 2024 games, thanks to tracking of fans’ and participants’ cycling activity via the Geovelo™ application. The objective: to create genuine emulation and encourage the development of cycling as a long-term mobility option. It should be recalled that IFPEN supports the development of integrated models and services in the application.



PORTFOLIO OF INDUSTRIAL STAKEHOLDINGS*

* As of 31 December 2021.



IFP GROUP CONSOLIDATED ACCOUNTS IN 2021

€882.3 MILLION
Turnover

€36.5 MILLION
EBIT

€12.9 MILLION
Net profit Group share



TRAINING TALENTED YOUNG PEOPLE FOR THE ENERGY TRANSITION



AN EDUCATIONAL AND TRAINING OFFER ADAPTED TO EVOLVING INDUSTRIAL AND SOCIETAL NEEDS

To address the energy and ecological challenges of the 21st century, IFP School provides students with the skills they need to be immediately operational in the fields of energy and sustainable mobility. Via a training offer based on a resolutely innovative teaching model and an extensive partnership network made up of academic and industrial players in France and around the world, the School addresses societal expectations and the needs of industry.

IFP School, which offers applied graduate programs, is recognized for the excellence of its training offer in the fields of energy and sustainable mobility, particularly via its apprenticeship system, introduced in 1996. In September 2021, it opened its own apprenticeship training center (CFA) to provide young people with the skills they need to contribute to the ecological transition, meeting the needs of industry and society as a whole. Reflecting the School's appeal, the new student intake was up with a record 64% of apprentices. In spite of the pandemic, IFP School ensured the continuity of its programs via the implementation of a hybrid format - or digital where necessary - and the development of virtual reality modules.

Being operational in a fast-changing environment

The educational and training offer based on a "learning by doing" approach is continuously adapted to reflect the major energy challenges and covers four fields: Powertrains and sustainable mobility, Energy economics and management, Processes for energy and chemistry, and Georesources and energy. The teaching modules delivered within its ten specialized engineering degree programs prepare talented young people to be immediately operational in a constantly evolving environment, and contribute to the development of new energy and transport technologies. The School's commitment and open-minded approach to energy challenges are illustrated, for example, through the "Innovation and Entrepreneurship" module, dedicated, in 2021, to adapting to climate change, or by the changes made to the Petroleum Economics and Management program, now the Energy Technology Economics and Management program.

Recognition of the quality of teaching programs was reflected in the co-accreditation of the research-oriented master's programs obtained in 2021, two of them with Paris-Saclay University and the third with Lille University.

In addition, graduate and PhD students were once again singled out for awards by professional juries: world champions in the Laurie Dake Challenge organized by the European association of geoscientists and engineers (EAGE); 3rd prize in the Student Challenge organized by the French Automotive Engineers Society; 1st and 2nd prize for the best student article awarded by the French Association of Energy Economists (AEE), etc.

HIGHLIGHTS



IFP School awarded the HappyAtSchool® label 2022

At the end of 2021, the School was awarded the HappyAtSchool® label, which recognizes schools that provide a happy environment for students to live and study in. Five criteria are used: the quality of facilities and protection of the environment, academic teaching, student life, proximity with companies and confidence in the future. Recommended by 91.3% of students from the 2021 intake, IFP School is among the French engineering schools offering the best student experience.

An IFP School student delegation invited to the Élysée

A student delegation attended the presentation of the France 2030 Investment Plan by Emmanuel Macron, at the Élysée Palace in October 2021. IFP School, as an active player in the energy and ecological transition, was asked to contribute to the debate.



To this end, invited students prepared a summary of the intake's ideas and vision relating to the challenges to be overcome and the actions to be implemented, including, for example, the promotion of hydrogen as a "zero-emission" solution, a theme that is an integral component of various programs delivered by the School and developed by LAB e-NOV™ in an on-line training module available to a wider public.

AN EDUCATIONAL APPROACH THAT IS CONSTANTLY BEING REINVENTED

As a specialized graduate school, IFP School is at the cutting-edge of educational innovation. It proposes an agile model, adapted to new digital technology usages, which evolves in line with the expectations of new generations of students and industry. The introduction of soft skills into programs also helps students develop their interpersonal skills to ensure they are prepared for the diversity they will find in the workplace. A key feature of 2020 was the acceleration in the digitalization of programs. 2021 confirmed this transformation with, for example, the renewed success of the MOOCs on tomorrow's mobility and the energy transition. The latter took the form of a module containing a selection of videos, games and webinars, freely accessible to all. A new module on hydrogen and mobility is also planned for 2022.

This capacity to innovate is also illustrated through numerous developments of the LAB e-NOV™, the digital culture laboratory, supporting the School, IFPEN Group and partner companies, as well as through the personalized training paths offered by the School. IFP School allows students to personalize some aspects of their learning experience. For example, they have the opportunity to take elective modules aimed at helping them explore sectors outside their programs or conduct a project, individually or as part of a group, enabling them to crystallize their career objectives.

LAB e-NOV™: A PROLIFIC YEAR IN 2021



2021 brought success for several projects developed by LAB e-NOV™, a physical and virtual space created by IFP School at the start of 2020 to foster the promotion and support of educational and innovation initiatives. The majority of these initiatives are aimed at students, such as virtual reality modules in the field of powertrains (electric and hybrid) and processes. Others are aimed at IFPEN employees: fire drill modules; interactive tools for the virtual tour of two IFPEN sites for new arrivals, and a similar tool to tour a pilot unit; and support for the roll-out of a training program on bullying. Other initiatives included the co-production of video and podcast series. LAB e-NOV™ also continued its collaboration with Axens Academy for the development of e-learning modules and Spocs (Small private online courses), addressing the specific needs of the IFPEN subsidiary's teams.



A SUSTAINED DEVELOPMENT DYNAMIC

In 2021, despite a challenging health context, off-site programs led by IFP School in partnership with IFP Training continued apace.

The second intakes of the Petroleum Upstream Techniques & Economics and Petroleum Downstream Techniques & Economics masters' programs in partnership with *Institut national polytechnique Félix Houphouët-Boigny* (INPHB) were welcomed in Côte d'Ivoire. Also worthy of mention is the 19th edition of the Petroleum Engineering and Project Development master's program, one of IFP School's first spin-off programs, which is based in Nigeria.

This development dynamic was also reflected in the broadening of industrial partnerships to include around twenty new companies operating in the energy transition, finance and consultancy sectors, among others.

The development of IFP School also hinges around the promotion of research activities via the four teaching chairs it leads: Electricity and Digital Transition (EDT); Electric, Connected and Autonomous Vehicles for Smart Mobility (ECAV); Carbon Management and Negative CO₂ Emissions Technologies Towards a Low-Carbon Future (CarMa) within the framework of which agreements were signed with the CNRS and INRAE; and Electrolyte Thermodynamics (EleTher) launched in 2021.

The School also has an active network of more than 16,000 alumni, which contributes to its influence. Its role is illustrated by the activities of the alumni clubs, five of which are outside France, and the participation of its members in IFP School Voices, a series of webinars launched in 2020 that proved so successful that it was continued in 2021. These short-format lectures, aimed at the School's students, graduates and IFP Group employees, tackle topical issues and explore the latest trends and innovations in the energy and powertrain sectors.



Interview with:

**Arash Farnoosh, IFP School,
EDT chair holder, Executive
Master of Management
in Energy program head**



It was against the backdrop of a rapidly evolving sector that we launched the Electricity and Digital Transition chair in 2018. It was becoming increasingly necessary to understand the changes taking place in the energy industry in terms of transport, distribution and production in a world under carbon constraints having recourse to intermittent and non-storable renewable resources. Its results are significant and students have benefitted from it within the framework of the teaching programs: the chair covered technical and economic aspects and management as well as the digitalization of electricity via the digitalization of its tools, in particular, big data, real-time information, artificial intelligence and machine learning methods, an increasingly important component of future electric systems. In addition, publications (12 scientific articles since its creation), conferences and workshops, thesis research on the technical and economic challenges associated with the integration of renewable energies into the network, and, lastly, the arrival of Professor Peter Cowling (University of York, UK), a specialist in optimization and algorithms, contributed further still to the preparation of our students to tackle the challenges facing the sector.

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