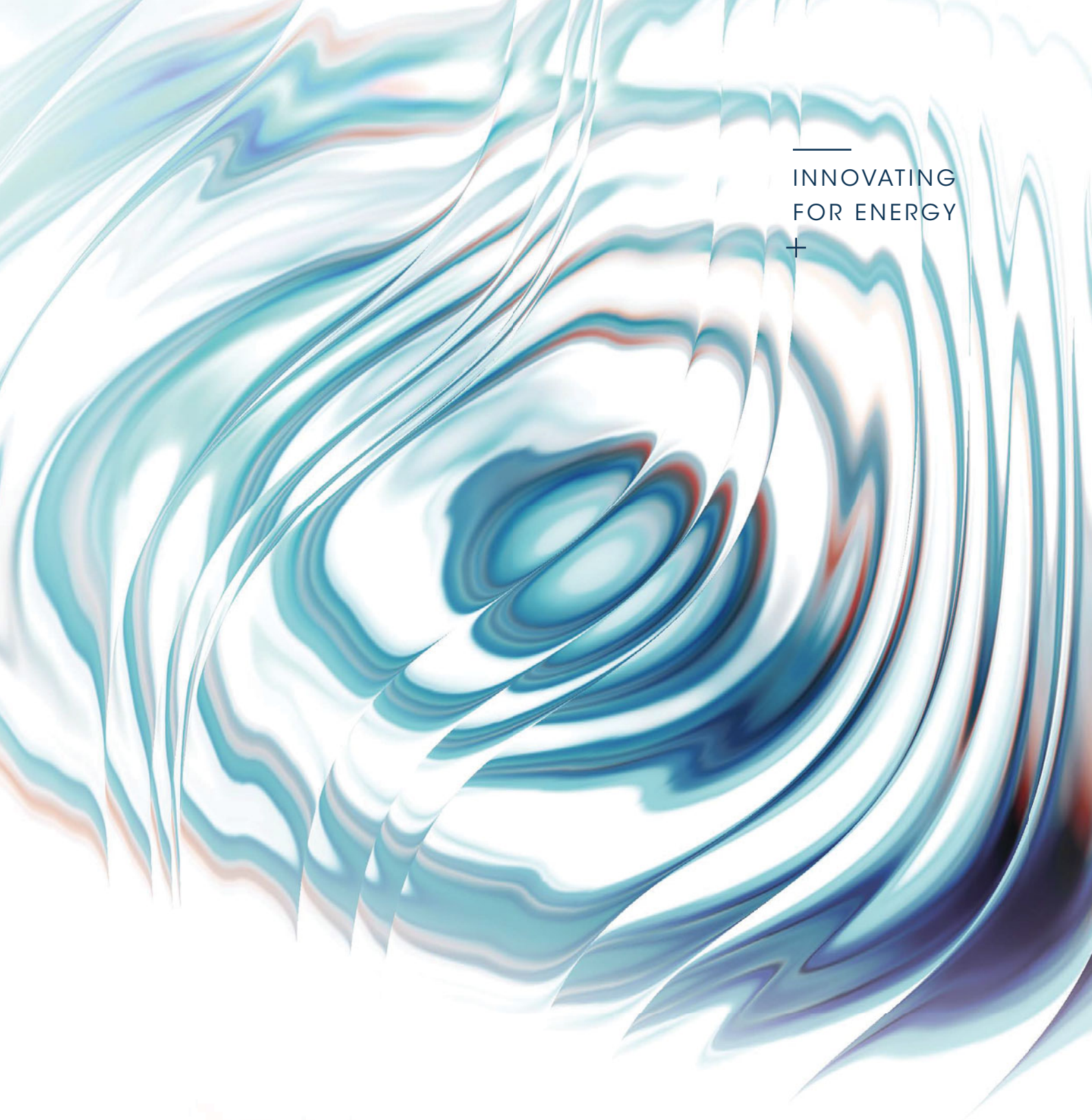


INNOVATING
FOR ENERGY

2022 **ACTIVITY REPORT**

IFP Energies nouvelles

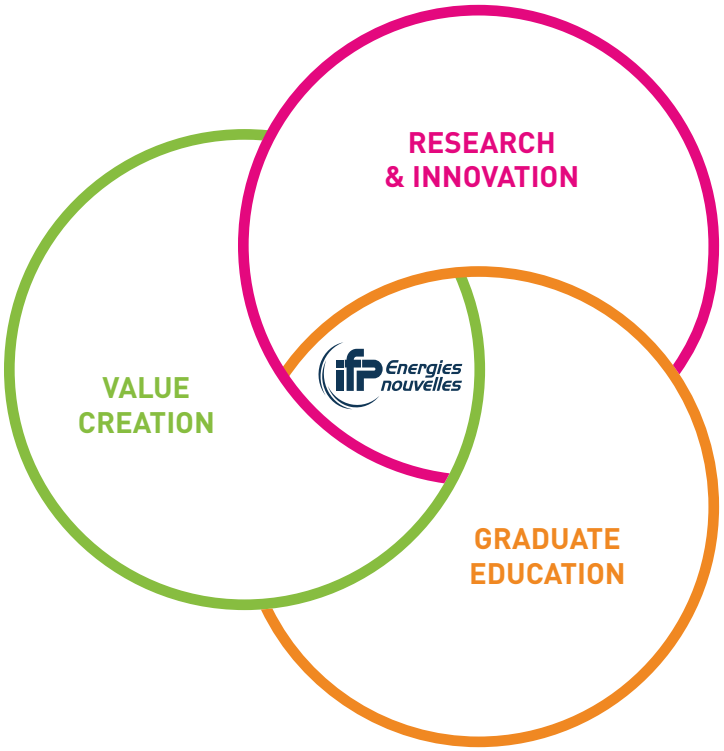
OUR MISSION

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

INNOVATING FOR A LOW-CARBON AND SUSTAINABLE WORLD

IFPEN's ambition is to be an active player committed to the triple ecological, energy and digital transition, an institute that is open to society, and a creator of value and employment that draws on the abilities of its personnel and is a trusted third-party to the public authorities.

In June 2022, the results of our Horizon 2035 initiative, the fruit of a collective reflection process launched in 2021 aimed at drawing up a strategic vision, were presented to the board of directors.

This vision sets out IFPEN's trajectory for 2035 in terms of its research programs and its organization. Thirty-five technologies were analyzed with a view to establishing priorities. Around twenty were identified as being of major public interest, themselves subdivided into three categories according to the degree of maturity – mature, promising and prospective. For example, technologies that are mature are either already or about to be at the preindustrial demonstrator stage. These include CCUS, sustainable aviation fuels and plastic recycling.

Technologies considered to be promising include the recycling of catalyst materials and batteries, soil qualification and management, digitalization in the mobility sector and the use of hydrogen in transport.

IFPEN is demonstrating its determination to improve how it takes society's expectations into account in its research programs.

Since 1 January 2023, this applied research has been led by four new business units: "Energy systems", "Energy products", "Chemistry for industry" and "Mobility".

Staying with Horizon 2035, I welcome the creation of our new committee of stakeholders, chaired by Michèle Pappalardo following her appointment at the meeting of the board of directors in October 2022. This committee reflects IFPEN's determination to improve how it takes society's expectations into account in its research programs as well as the way it conducts activities, the ultimate aim being to optimize its strategy.

I would also like to highlight the success of the 2022 GHGT conference on the reduction of greenhouse gas emissions, which was held in Lyon. The event, organized by IFPEN's teams and hosted by France for the first time, attracted 1,200 participants from around the world. In the field of CO_2 capture, an industrial pilot was launched at the end of October at ArcelorMittal's Dunkirk site; the aim is to verify the performances of the DMX™ process developed in IFPEN's laboratories over more than ten years.

To illustrate our desire to work collectively, I will mention the signing of a first framework agreement with the CEA (French Alternative Energies and Atomic Energy Commission) as well as our participation in the new French Mineral Resources for Industrial Sectors Observatory (Ofremi) in November.

Concerning fundamental research, IFPEN is copiloting three French priority research programs and facilities initiatives (PEPR) associated with the country's national acceleration strategies, in the fields of the decarbonization of industry with the CNRS, biobased products and sustainable fuels with INRAE, and the digitalization and decarbonization of mobility with Gustave Eiffel University. Roadmaps have been drawn up to support French national research policy in these fields.

At IFPEN, we consider the transfer of research and innovation to industry to be essential, as reflected, in particular, by an active patenting policy. I'm proud that the study published at the start of 2023, which was conducted jointly by the European Patent Office and the International Energy Agency and presents the major trends in the field of hydrogen technologies for the period 2011-2020, places IFPEN second in the global ranking of patent filers among public research organizations in this area.

In this year's activity report, you will find an overview of the research conducted in 2022 by IFPEN's teams aimed at innovating for a low-carbon and sustainable world and equipping young generations of engineers with the expertise to tackle these challenges.

I believe more than ever in our ambition and the future we are building together.

I hope you enjoy reading this report!

CORPORATE **GOVERNANCE**

THE **EXECUTIVE** COMMITTEE*

GENERAL MANAGEMENT

1
Pierre-Franck Chevet
Chairman and CEO

2
Catherine Rivière
Executive Vice-President
Research & Innovation

3
Éric Lafargue
Executive Vice-President Administration
and management of subsidiaries

BUSINESS UNIT DIRECTORS

4
Benjamin Herzhaft
Energy systems

5
Florence Delprat-Jannaud
Energy products

6
Cécile Barrère-Tricca
Chemistry for industry

7
Gaëtan Monnier
Mobility

8
Christine Travers
Education and Training

9
Nathalie Alazard-Toux
Industrial Development

OTHER MEMBERS OF THE EXECUTIVE COMMITTEE

10
Véronique Ruffier-Meray
Human Resources Director

11
Dominique Humeau
Director of Digital Science
and Technology, Digital Office
and Information Systems

** As of 1 February 2023.*

THE BOARD OF **DIRECTORS***

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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 Higher Education and Research

Louis de Franclieu
Assistant Deputy Director, 3rd division, Budget Directorate, representing the Minister of the Economy, Finance and Industrial and Digital Sovereignty

Isabelle Wallard
President of the Regulation and 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 and Innovation, member of the Executive Committee at TotalEnergies

Hervé Le Treut
Member of the Académie des sciences (French Academy of Sciences), Director of Research at the CNRS

Sophie Paturle–Guesnerot
Founding partner of Demeter Partners

Axel Plasse
Research & Development and Marketing Director, Powertrain Driveline Systems Product Group, Valeo

Valérie Quiniou-Ramus
Executive Director Foresight and Research (DEPR), 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 and Industrial and Digital Sovereignty, “Energy” Mission

Philippe Geiger
Government-Commissioner to IFPEN, Energy Assistant Director - DGEC (General Directorate for Energy and Climate) - Ministry for the Ecological Transition

Guillaume Gougeul
Secretary of IFPEN’s Central Works Committee (CSEC)

THE **SCIENTIFIC** BOARD*

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University Professor at the Institute of Applied Sciences in Rouen (CORIA laboratory)

Philippe Cassagnau
University Professor at Lyon 1 University, director of the Lyon research platform: Polymer Science & Engineering, Chairman of the French Rheology Group

Carmen Claver
Professor of Inorganic Chemistry at Rovira i Virgili University, Tarragona (Spain)

Christophe Coperet
Professor of Molecular Chemistry and holder of the surface and interface chemistry chair at the École Polytechnique Fédérale, Zürich (Switzerland)

Marc-Olivier Coppens
Ramsay Memorial Professor and Head of the Chemical Engineering Department at University College London (UK)

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

Sylvie Dequin
Head of the Microbiology and Food Chain Department at INRAE (Jouy-en-Josas)

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

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University Professor at the École centrale de Nantes, Institute of Civil and Mechanical Engineering and member of the French Academy of Sciences

Nicolas Petit
Professor at Mines ParisTech, Director of the Systems and Control Centre (CAS)

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

Marc Schoenauer
Research Director (DR1) at Inria (Saclay), co-director of the TEAM (Artificial Intelligence & Machine Learning) group

Sophie Violette
Professor of Hydrogeology, École normale supérieure de Paris

SOCIAL & 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.

1.530
total full-time equivalent workforce for 2022

including

1.078
researchers and R&I technicians

30
work/study students (FTE)

Nearly **170**
PhD students, post-doctoral researchers and placement students (FTE)

67
national accreditation to supervise research (HDR) holders in the workforce

FINANCIAL DATA

Own resources fell, resulting primarily from declining royalties, partially compensated for by an increase in collaborative services and research activities. Operating expenses fell. Self-funding of "oil and gas" activities was reinforced in 2022. The budget allocation was entirely dedicated to IFPEN's NET activities.

€259.7 MILLION
including €228.8 million for R&I
Operating expenses

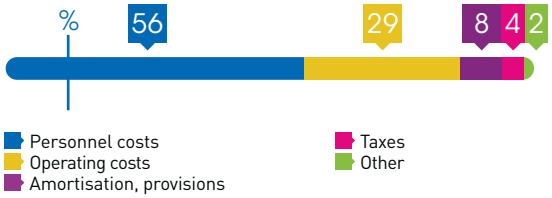
€121.2 MILLION
Budget allocation

€141.5 MILLION
Own resources

Weight of NETs in IFPEN R&I in 2022	%
Total NTE	72
Climate, Environment and Circular Economy	16
Renewable Energies	23
Sustainable mobility	13
Cross-disciplinary fundamental research	20

BREAKDOWN OF OPERATING EXPENSES

Year-end 2022



BREAKDOWN OF OPERATING REVENUES

Year-end 2022

IFPEN NEWS IN 2022: PANORAMA

CARBON NEUTRALITY OBJECTIVE BY 2050: THE INTERNATIONAL CIVIL AVIATION SECTOR ADOPTS THE RESOLUTION

The adoption of the resolution defining carbon neutrality by 2050 as a climate objective for the international civil aviation sector was approved in October 2022 at the 41st assembly of the ICAO. This resolution reflects the commitment – to the process aimed at decarbonizing the aviation sector – of States*, and aviation and energy sector players, including IFPEN, who co-signed the preparatory call via the Toulouse declaration in February 2022. The co-signatories, taking into account society's expectations in the field of the decarbonization of transport, particularly aviation, submitted proposals aimed at achieving carbon neutrality through the improvement of aircraft technologies, the increased use of biofuels, carbon pricing, financial incentives and support for environmental and climate innovation. To this end, Pierre-Franck Chevet gave a presentation underlining IFPEN's determination to contribute to the energy and ecological transition of the aviation sector by providing technological support for the production of advanced biofuels.

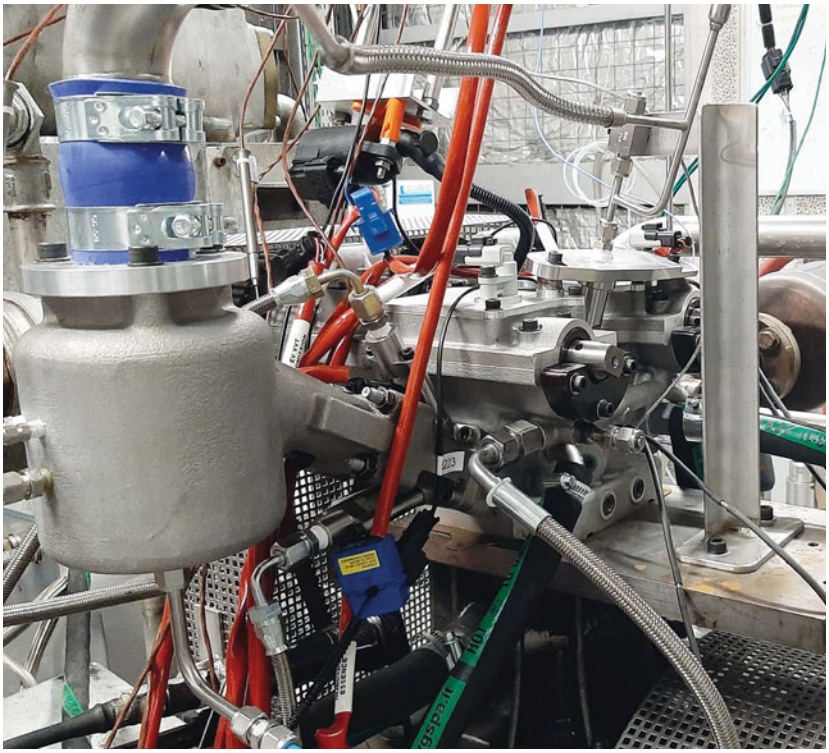
** The 27 States of the EU, 10 States of the European Civil Aviation Conference (Albania, Georgia, Iceland, Moldavia, Monaco, Norway, UK, San Marino, Serbia, Switzerland)*

IFPEN CO-ORGANIZES THE GHGT-16 CONFERENCE ON CO_2 CAPTURE, UTILIZATION AND STORAGE (CCUS)

With more than 20 years' R&I experience in the field of CCUS, IFPEN co-organised the 16th edition of the IEAGHG (International Energy Agency Greenhouse Gas R&D Program) conference on greenhouse gas control technologies, alongside the Club CO_2, ADEME, BRGM and TotalEnergies. At a time when decarbonization objectives call for an acceleration in CO_2 emission reductions, this event was the focal point for international research in CCUS technologies, bringing together more than 1,200 participants to discuss the solutions designed to help meet the objectives set out in the 2015 Paris Climate Agreement.

FOCUS

The ANR's 2022 generic call for projects gave rise to four new projects involving IFPEN. They are aimed at overcoming scientific challenges in fields as varied as underground hydrogen storage, deep geothermal energy with lithium co-production in the Rhine rift valley, the liquid cooling of electric motors and the topological optimization of silicon carbide batteries. IFPEN is also contributing to new projects selected within the framework of the Horizon Europe program.



IFPEN SHARES ITS EXPERTISE WITH THE **HYDROGEN RISK MISSION**

In June, an interministerial delegation made up of members of the French General Council for the Economy (CGE - Ministry for the Economy, Finance and Industrial and Digital Sovereignty) and the French General Council for the Environment and Sustainable Development (CGEDD - Ministry for the Ecological Transition and Territorial Cohesion) was received at IFPEN-Lyon within the context of a mission dedicated to hydrogen risks. The presentation of research and tour of R&I facilities were an opportunity to share IFPEN's expertise on topics relating to the use of hydrogen in the mobility sector, as well as its transport and storage, with a particular focus on the resistance of materials and long-distance transport via LOHCs (liquid organic hydrogen carriers).

IFPEN TAKES PART IN **UNESCO'S FIRST INTERNATIONAL GEODIVERSITY DAY EVENT**

On 6 October, for the first edition of international geodiversity day, proclaimed by Unesco and supported by more than 70 States and 130 organizations, IFPEN's RockNet® mobile app project was presented at the Unesco headquarters in Paris. The app is designed to facilitate access to geological knowledge, thanks to an artificial intelligence model analyzing photos of rocks taken by users. IFPEN took part in this international event in the context of its partnership with Unesco, forged in 2020 in order to study and promote geodiversity.

FOCUS

Benoît Noetinger and his partners are awarded an ERC synergy grant to study karst aquifers

Benoît Noetinger is an IFPEN researcher with a PhD in Physics, specializing in transport in random porous media. Along with Bojan Mohar from the University of Ljubljana (Slovenia), Philippe Renard from the University of Neuchâtel (Switzerland) and Marco Dentz from IDAEA-CSIC (Spain), he secured a prestigious ERC Synergy grant for the KARST fundamental research project. The grant will enable this international, multidisciplinary research team to study the physical laws governing water flow and the transport of pollutants in underground cave systems (karst aquifers). To ensure most of humanity has access to water, understanding the mechanisms of karst formation and studying the impact of climate change on these aquifers is of ultimate importance.

FOSTERING THE EMERGENCE OF INDUSTRIAL CHAMPIONS IN FRANCE: THE INFORMATION-GATHERING MISSION OF THE FRENCH SENATE CONSULTS IFPEN

In February 2022, Pierre-Franck Chevet and Nathalie Alazard-Toux, Director of the Industrial Development Business Unit, were formally consulted as part of the French Senate's information mission: "Excellence de la recherche et de l'innovation, pénurie de champions industriels : cherchez l'erreur française" (Research and innovation excellence, shortage of industrial champions: identifying where France has gone wrong), and underlined the importance of links between research and the industry in order to optimize the transfer of innovation. The mission's objective was to identify the obstacles encountered by France in order to reinforce its applied research and define ways of preserving and cultivating its innovation pool today, with a view to having major European champions tomorrow.

THE TWO IFPEN CARNOT INSTITUTES FOCUS ON THE ROLL-OUT OF ENVIRONMENTALLY-FRIENDLY SOLUTIONS

In October, the IFPEN Transports Energie (TE) and the IFPEN Ressources Energétiques (RE) Carnot Institutes participated in the 2022 Carnot event. The IFPEN TE Carnot Institute promoted its innovative solutions for connected mobility, electrification and environmentally-friendly powertrains, including hydrogen powertrains and fuel cells. There was a particular focus on "the challenges of mobility as a service (MaaS)". Two innovative electric motors developed by IFPEN's teams were also presented at the stand. For its part, at its stand dedicated to renewable energies, the IFPEN RE Carnot Institute presented a model of a wind turbine floater developed in partnership with SBM Offshore. The event also coincided with the launch of its new website. In addition, in December, within the framework of the new inter-Carnot alliance dedicated to low-carbon energies, of which it is one of the founding members, the IFPEN RE Carnot Institute co-organised, alongside PEXE (eco-companies of France and its networks) and ADEME, the 5th Ecotech© Énergie event bringing together players from the energy transition ecosystem.

THE 5 FRENCH RESEARCH ALLIANCES CONTRIBUTE TO THE NEW PRIORITIES FOR RESEARCH AND TRAINING IN EUROPE

In March 2022, within the context of the French presidency of the EU Council, Ancre, currently chaired by Pierre-Franck Chevet, and the Aviesan, Allistene, AllEnvi and Athena alliances organized the "Europe in transition: the challenges for research and training" conference in Strasbourg. The aim of the event: to reinforce trans-European scientific cooperation in order to identify new inter-disciplinary research and training avenues, at the interfaces between the fields of energy, the environment, health, digital technology and human and social sciences. At the end of the conference, a manifesto for new research and training priorities was published.

PATENTS: IFPEN STANDS OUT IN THE FIELD OF H_2 TECHNOLOGIES

The "Hydrogen patents for a clean energy future" study conducted jointly by the European Patent Office (EPO) and the International Energy Agency (IEA) and presenting the major trends in the field of hydrogen technologies for the period 2011-2020, placed IFPEN second in the global ranking of patent filers among public research organisations in the field of H_2 technologies. In addition, for the third year running, IFPEN was third in the ranking of research centres to have filed patents with the French patent office (INPI). IFPEN was also thirteenth in the INPI's general ranking of patent filers in France in 2021, alongside major industrial groups, and was in the top 5 in the field of chemistry.

FOCUS

Following on from a four-year partnership agreement between 2017 and 2020, **the CEA (French Alternative Energies and Atomic Energy Commission) and IFPEN have reinforced their collaboration via the signature of their first framework agreement for research and development collaboration in the field of energy.** The five-year agreement is hinged around four themes of common scientific interest: mobility, the carbon circular economy, digital technology and education. The alliance will foster the emergence of joint research projects (collaborative, bilateral, thesis supervision, etc.), drawing on the scientific and technical expertise of each partner, as well as their complementary know-how.

FOCUS

IFPEN is a partner of L'Esprit Sorcier TV, a science and environment channel proposing creative scientific programmes showcasing the latest research advances. IFPEN researchers will take part in original documentaries throughout the year. The channel also broadcasts the best moments from the last Science Festival, including the documentary entitled "Recycling of Plastics" presenting IFPEN's research in the field.

KEY FIGURES

2 Carnot

ifpen Transports Energie

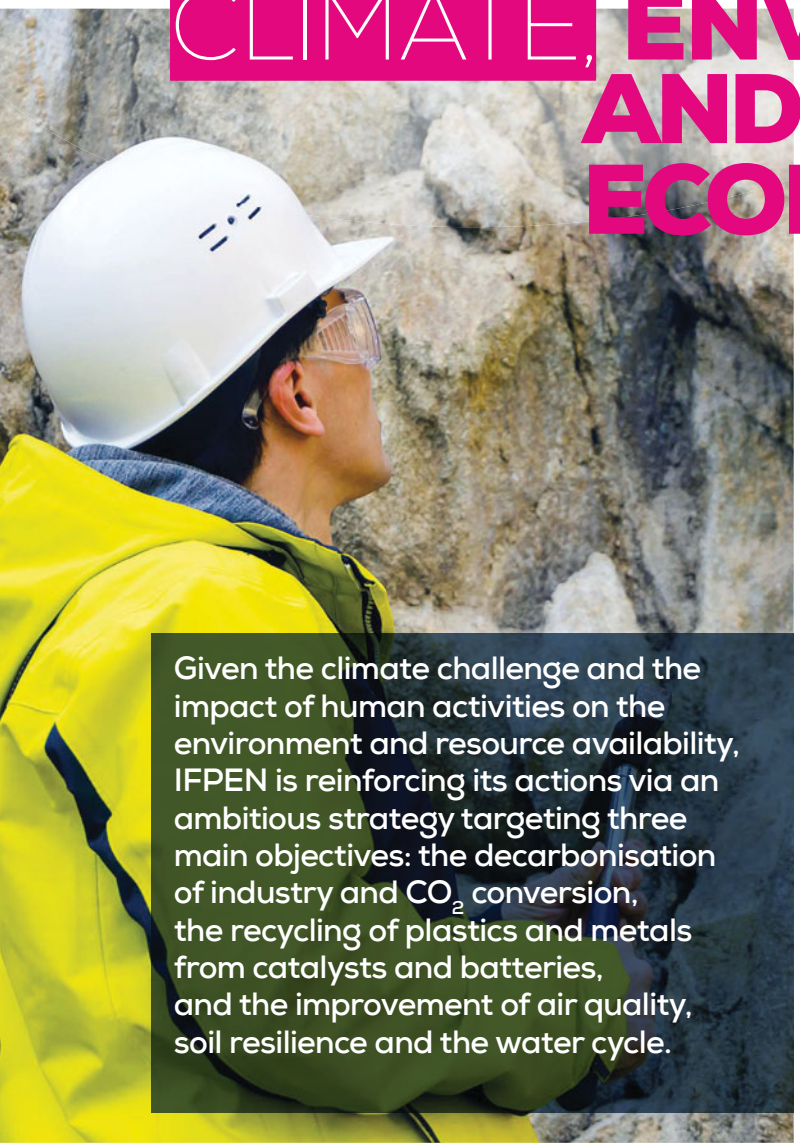
ifpen Ressources Energétiques

AWARDED **ISO 9001** certification for their R&I activities

138 basic patent applications, including **102** in the field of NETs

More than **500** IFP School graduates

CLIMATE, ENVIRONMENT AND THE CIRCULAR ECONOMY



Given the climate challenge and the impact of human activities on the environment and resource availability, IFPEN is reinforcing its actions via an ambitious strategy targeting three main objectives: the decarbonisation of industry and CO_2 conversion, the recycling of plastics and metals from catalysts and batteries, and the improvement of air quality, soil resilience and the water cycle.

CARBON AND PLASTIC POLLUTION IN SOILS: IFPEN TAKES ACTION

Conscious of the climate challenges associated with soils, whether related to pollution or carbon storage, the IFPEN Ressources Energétiques Carnot Institute (RE) forged a number of scientific collaborations in 2022 focusing on these themes. Coordinated by the French national research institute for sustainable development (IRD, Eco&Sols, Montpellier) in partnership with IFPEN, Agriculture & agri-food Canada, the Geographical Institute (Hungary) and Milan University (Italy), the SIC-SOC-DYN (Organic and inorganic carbon dynamics in calcareous soils) project, funded by the ANR, aims at gaining a better understanding of the contribution of calcareous soils – which cover one third of the Earth's surface – to the global carbon footprint. More precisely, the objective is to study SIC (Soil inorganic carbon) and SOC (Soil organic carbon) interactions in calcareous soils from a collection of samples taken in a variety of contexts (usage, management method, etc.), and to analyse them using recent Rock-Eval® technology developments. To address the problem of plastic pollution in soils, IFPEN, via the IFPEN RE Carnot Institute, also launched two new projects: e-DIP, funded by ANR, aims at evaluating the toxicity of microplastics in soil organic matter, once again using Rock-Eval®, and the Plastisol project, funded by ADEME, aims to define indicators for the presence of microplastics in soils.

Interview with Hassan Boukcim, CEO of Valorhiz

It is within the framework of a France Relance project, aimed at maintaining and supporting the employment of active researchers and young graduates, that Valorhiz and IFPEN forged a partnership relating to the development of methods for analyzing sandy soils, characterized by their low carbon content. A better understanding of unstable organic matter in these soils, which have been the focus of few studies compared to carbon-rich soils despite their storage potential, would make it possible to use them as carbon sinks in order to address the challenges of food security and climate control. Valorhiz's measurement methodologies, as well as our know-how in terms of soil rehabilitation, combined with IFPEN's expertise in the field of organic matter and its Rock-Eval® characterization tool, should make it possible to develop a methodology specifically tailored for the purpose. Recruited for a period of 15 months, an engineer specializing in soil organic matter, shared between IFPEN and Valorhiz, will use our database to assemble a panel of different representative samples in order to analyze them and formulate new descriptors. Ultimately, Valorhiz wants to incorporate this new methodology into decision-making tools, vital within the context of mitigation strategies.

FOCUS

In 2022, IFPEN launched a project targeting water management and treatment, including the characterisation of complex aquifers, particularly karst aquifers *(see page 8).*

HIGHLIGHT

An event dedicated to the resources and uses of the underground environment in the energy transition

In September 2022, IFPEN co-organized a conference dedicated to the resources and uses of the underground environment in the energy transition, alongside the CNRS, the Avenia cluster, BRGM and ADEME. The event, bringing together the various stakeholders (local authorities, institutional players, private sector players, researchers, etc.) to examine how the underground environment can play a role in the ecological transition, clarified the legitimacy of the different underground engineering sectors and the conditions for conducting projects on French soil.

HIGHLIGHT

Optimizing the quantification of microplastic pollution in the environment

To address widespread pollution caused by plastics and microplastics, the French National Adaptation Plan for Climate Change (PNACC) made the reinforcement and resilience of ecosystems one of its objectives. It is in within this context that the IFPEN RE Carnot Institute decided to make the issue of plastic waste flows in the environment one of its strategic priorities. Accordingly, in 2022, discussions were held with the Centre for documentation, research and experimentation on accidental water pollution (CEDRE) with a view to develop a rapid experimental method for quantifying microplastics in natural environments.

FOCUS

A study conducted by a multidisciplinary group including David Sebag, one of IFPEN's geological engineers, and coordinated by IRD was published in the Nature journal**.** It clearly establishes the link between global warming and peat decomposition in the Central Congo Basin between 5000 and 2000 BC, causing significant amounts of carbon to be released into the atmosphere. Several analysis tools were used for the study. In particular, the Rock-Eval 6 method was used to accurately quantify the degree of degradation of organic matter. One of the conclusions asserts that if an identical scenario reoccurs in the future, a release of carbon would only further accelerate the climate change already underway.

IFPEN: A LEADER IN THE FIELD OF CO_2 CAPTURE

Against the backdrop of the IPCC report calling for an immediate reduction in greenhouse gas emissions as well as an acceleration in CO_2 capture and storage, IFPEN plays a key role in the development of innovative CO_2 capture technologies. The consortium conducting the Sino-European CHEERS (Horizon 2020) project, whose partners include IFPEN alongside TotalEnergies, Dongfang Boiler Group Co. (DBC) and Tsinghua University, has constructed the world's biggest chemical looping combustion (CLC) demonstration unit. This oxycombustion technology makes it possible to obtain a pure CO_2 flow compatible with low-cost capture, since it minimizes recourse to costly gas-separation processes. This is a major milestone after 13 years of research conducted by IFPEN and TotalEnergies aimed at qualifying the industrial potential of a technology that could play a vital role in helping to decarbonize industry. The test campaign is due to take place in 2023 and will lead to the development of future commercial projects.
In 2022, the Strategy CCUS project involving IFPEN, BRGM and 16 other European partners was completed. The project aimed to provide a strategic framework for the coordinated, large-scale roll-out of the CO_2 capture, transport, storage or use value chain. Via its RE Carnot Institute, IFPEN contributed to the drawing-up and evaluation of scenarios for each of the three regions of southern Europe selected as potential deployment clusters: the Rhône valley, the Ebro Basin in north-east Spain and the Lusitanian Basin on the west-central coast of Portugal. The Strategy CCUS project has already generated another H2020 project: PilotSTRATEGY, launched in May 2021 for a period of five years and aimed at performing the detailed characterization of deep saline aquifers in order to ensure the availability of storage sites. In parallel, within the framework of the European REX-CO_2 project, in 2022 IFPEN teams contributed to the development of a numerical tool designed to help stakeholders make informed decisions about the re-use of end-of-life oil and gas production wells for CO_2 storage.

FOCUS

In October 2022, IFPEN co-organized the 16th edition of the IEAGHG (International Energy Agency Greenhouse Gas R&D Program) conference on greenhouse gas control technologies, alongside the Club CO_2, ADEME, BRGM and TotalEnergies *(see page 7).*

Interview with Laurent Viellard, 3D project operations manager at IFPEN

Developed in IFPEN's laboratories over a period of more than ten years, the DMX™ CO_2 capture process reached an important milestone with the launch of the 3D industrial pilot, within the framework of the Horizon 2020 project conducted alongside Axens, ArcelorMittal and TotalEnergies, at ArcelorMittal's Dunkirk site. Our objective? To demonstrate an innovative process for capturing CO_2 from steel industry flue gases. Following the construction of the pilot unit in the workshop in the form of modules and its assembly, reception and installation test, the last step consisted of pouring the solvent – the innovation at the heart of the technology thanks to its efficiency, competitiveness and durability – into the unit's columns prior to its circulation, once the blast furnace gas to be decarbonized has been injected. To optimize its operation on future industrial units, our teams will also explore the performances of the installation via parametric tests and test the pilot over a longer period of time. Looking further ahead, we are currently preparing for the roll-out of the technology: the construction of a first industrial unit at ArcelorMittal's Dunkirk site, which could be operational by 2025, and the design of the future European Dunkirk-North Sea cluster, which should be capable of capturing, packaging, transporting and storing 10 million metric tons of CO_2 per year and is expected to be commissioned by 2035.

THE ENVIRONMENTAL **ANALYSIS** OF TRANSPORT

To address the challenges of the ecological transition in the field of individual mobility and goods transport, public and industrial players and citizens need to be supported as they make decisions concerning the most appropriate technologies for these new demands. Such is the case, for example, for the introduction of low emission zones (LEZ) in France to address the problems of air quality in major cities (> 150,000 inhabitants). The Carnot IFPEN Transports Energies (TE) addresses these needs by conducting impact studies combining different types of data and simulations as well as life-cycle analyses. These studies will be combined with web services to make them more scalable and accessible to as many people as possible. Following on from the "Je change ma voiture" ("I'm changing my car") online tool and the technical and economic study for the evolution of river transport sector propulsion systems conducted with VNF (the French Waterways Network ; see 2021 IFPEN activity report, page 24), research was carried out in 2022 aimed at feeding into roadmaps for different mobility sectors. For example, as part of the SESAME project, co-financed by ADEME, the Carnot IFPEN TE evaluated the benefits of the onboard measurement of pollutants using IFPEN's REAL-e™ tool, with a view to improving the technical control of vehicles, via tests conducted on an existing fleet. In addition, following a request by ADEME, the E4T 2040 study was conducted, involving a prospective analysis of the technologies to be prioritized in order to reduce the CO_2 emissions of the road transport sector by 2040. Working with la Fabrique de la logistique, the Carnot IFPEN TE also designed the "Verdir ma flotte" ("Green my fleet") tool, which helps logistics sector players seeking to decarbonize their fleets quantify the economic and ecological impact of alternative fuels and hybrid and electric technologies. Lastly, it conducted a large-scale study for Concawe* aimed at evaluating the environmental footprint of plug-in hybrid vehicles (PHEV) in real operating conditions.

Interview with Roland Dauphin, scientific coordinator on fuel quality and emissions at Concawe

Concawe commissioned a study aimed at promoting an approach based on life-cycle analyses (LCA) that is not limited to exhaust emissions. IFPEN has done some remarkable work, extrapolating experimental results via the use of simulations and mathematical models and generating use cases well beyond anything provided by experimental data. This research has resulted in a substantial report, several publications and a web app. The latter has been designed in a simplified form accessible to the public and a more comprehensive form for experts. In particular, it is used to support the arguments of our associations' members seeking to promote the LCA approach. The app provides an insight into the diversity of low-carbon solutions available, including, of course, electrification, as long as the energy mix is not too carbon-intensive and batteries are not too large. These solutions also include plug-in and conventional hybrid vehicles, as long as they use low-carbon fuels and, in the case of plug-in vehicles, batteries are recharged regularly. Buoyed by this success, we plan to continue this research in 2023.*

** Concawe is a division of the European Fuel Manufacturers Association.*

AIR QUALITY: FLAIR BOX™ IS ROLLED OUT AT TERÉGA

Following the roll-out in 2021 of Flair *(see IFPEN 2021 activity report, page 14)* – a sensor and software suite that can be used to explore a given geographic zone in order to detect pollutants of natural and industrial origin – in 2022, IFPEN installed eight Flair Box™ stations (seven fixed and one mobile) at the site of its gas partner Teréga, the aim being to acquire and analyse more data associated with the presence of THT and mercaptan on the site. This is an industrial first for Flair Box™.

HIGHLIGHT

Rewind® PET: the industrialization of the chemical recycling of PET is well underway

Axens and Toray Films Europe are studying the construction of a first PET recycling unit based on the Rewind® PET process developed by IFPEN, Axens and Jeplan. The process involves the optimized glycolytic depolymerization of PET combined with specific purification steps aimed at eliminating all organic and inorganic compounds present in PET waste. The new unit will be integrated at the existing polymerization plant located at Saint-Maurice-de-Beynost (Ain, eastern France). The objective is to recycle 80,000 metric tons/year of complex PET plastic waste and produce up to 100% transparent recycled PET for films, fibers and bottles suitable for food contact.

CHEMICAL RECYCLING OF PLASTICS

IFPEN is present across the various chemical plastics recycling loops via the development of sustainable technological solutions designed to convert plastic waste into high-quality recycled polymer materials. Alongside their partners, IFPEN's researchers develop tried, tested and economically viable technologies that can be used in addition to mechanical recycling in order to be able to process almost all types of plastic and offer industry the solutions required to address society's increasing expectations in terms of reducing plastic waste in line with public circular economy policies. In 2022, Rewind® Mix pyrolysis oil purification technology, developed with Axens and Repsol, was approved for high-quality feeds following R&I work conducted with industrial feedstock that resulted in purity levels in line with the target. Concerning PET recycling, the industrial implementation of chemical recycling has accelerated.

HIGHLIGHT

Rewind® Mix: first licensing agreement signed between Axens and Borealis

Borealis and Axens signed a licensing agreement relating to the supply of the Rewind® Mix process developed by IFPEN, Axens and Repsol. The objective is to treat impurities such as silicon, chlorine compounds, diolefins and metals contained in 50 kilotons/year of pyrolysis oils obtained from plastic waste, at the Borealis petrochemical plant in Stenungsund, Sweden. This purification step will enable the direct 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.

FOCUS

For the 2022 Science Festival dedicated to climate change, two IFPEN researchers took part in a program focusing on plastic recycling. The replay is available on the Esprit Sorcier YouTube channel.

Interview with Magalie Roy-Auberger, Catalyst Metal Recycling Programme manager at IFPEN

In 2022, the proof of concept and economic viability for catalyst metals was demonstrated over the course of a few months, laying the foundations for an acid leaching and direct reincorporation process. These first highly promising results demonstrated the potential of hydrometallurgical solutions (with or without separation), with respect to the explosion in demand for critical metals, paving the way for further work on battery metal recycling. With the increasing role played by electric technology in the mobility sector, battery metal recycling is becoming essential, not only in terms of complying with European regulations but also in order to ensure the independence of the European market. IFPEN, Eurecat and Axens together possess the expertise required – from waste management through to mineral chemistry and battery cell evaluation – to be positioned in this market and make use of the "urban mine" of tomorrow.

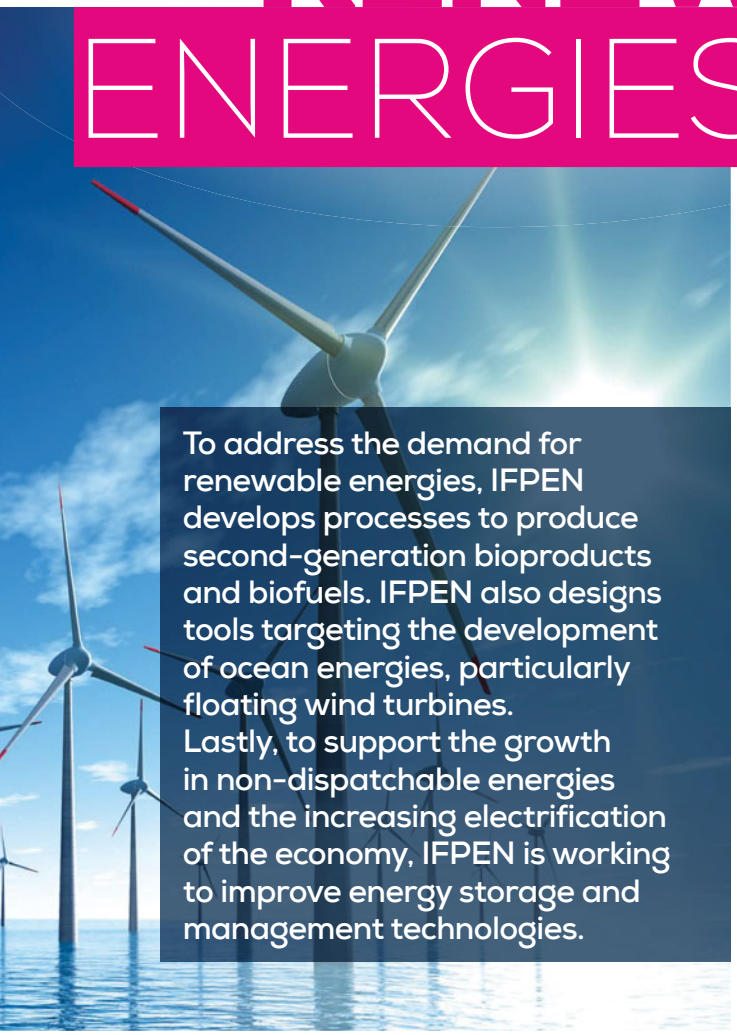
RECYCLING OF CRITICAL MATERIALS

The recycling of critical materials used in the preparation of catalysts and cathode materials for batteries such as cobalt, nickel, lithium and, to a lesser extent, molybdenum is strategically important for the circular economy. Working alongside industrial and academic partners, IFPEN develops processes and solvents for converting materials, the aim being to propose technically and economically efficient solutions. At the start of 2022, Eurecat (a global player in the regeneration and activation of catalysts and the recycling of metal materials), Axens and IFPEN launched a project dedicated to the recycling of catalyst metals and aimed at developing a process for the extraction of metals from hydrotreatment catalysts, in order to re-use them in a closed-loop through the preparation of new catalysts. IFPEN's teams are developing an acid extraction process (from used catalysts provided by Eurecat), enabling the recovery of a solution that can be directly reused by Axens to prepare new catalysts. During 2022, teams also conducted further work on the market for the recycling of cathode active materials (CAM) contained in Li-ion batteries and their re-synthesis.

DECARBONIZATION OF PROCESSES AND CO_2 CONVERSION

Since 2022, IFPEN teams have been reinforcing development of decarbonized processes via the use of decarbonized hydrogen, electricity, biomass, and CO_2 conversion. In order to prepare solutions for the e-fuels market, IFPEN and Axens launched the development of a technology aimed at producing CO from CO_2 and H_2 (Reverse Water Gas Shift reaction). The European Commission's ReFuelEU Aviation initiative, part of the proposed Fit for 55 package set of regulations (14/07/2021), specifies a minimum incorporation level for e-fuels in aviation fuels of 5% by 2035 and 28% by 2050. To meet these targets, it is necessary to have access to reliable, high-capacity processes. Working with Axens and Eni, IFPEN developed the Gasel® commercial technology (based on Fischer-Tropsch synthesis and upgrading). The development of the upstream building block (Reverse Water Gas Shift) and CO_2 capture, for example on industrial emitters via the DMX™ process, will make it possible to supplement this technology, and thus have access to a complete chain, from CO_2 capture through to synthetic fuel production.

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

Scientific day event dedicated to wind energy: a growth sector with the wind in its sails
French wind-energy sector players gathered in October 2022 for the first edition of the "scientific wind day event". Organized by France Energie Éolienne and the IFPEN RE Carnot Institute, the purpose of this conference was to review the latest research developments and to support the sector's growth on the eve of the 12th national wind symposium, at a time when France is set to play an increasingly important role in the field. Academic and industrial players shared their expertise and forged new alliances. At the event, IFPEN presented its turbine wake modelling technology, GP5 Ancre's contribution to the synthesis of R&I needs in the wind sector and its participation in IEA-Wind's OC6 project via a study of the aerodynamics and detection of defects relating to a turbine rotor.

ADDRESSING THE CHALLENGES OF OFFSHORE WIND THROUGH DIGITALIZATION

The IFPEN Ressources Energétiques (RE) Carnot Institute is active in the field of offshore wind turbines, which can benefit from already mature technologies used in the offshore industry. For example, within the framework of its partnership with Vaisala, the IFPEN RE Carnot Institute developed the WiSE-Lidar™ WindField software used for the 3D reconstruction of the wind field from measurements gathered by lidar. The software was launched to market in 2022. Integrated into Vaisala's WindBox solution, the software's high wind detection capacities optimize turbine control by constantly adapting it to wind conditions, thereby improving their performance. Reducing the turbine's mechanical fatigue leads to a reduction in maintenance costs, while increasing its lifespan. Lastly, this improvement in turbine adaptability to the wind makes it possible to optimize their design by increasing the length of the blades or the height of the towers, for example, to reduce investment costs and to maximize energy production. This marks a major technical advance for offshore wind, supported, in particular, by IFPEN's expertise in the field of advanced signal processing.

At a time when wind energy technology is developing rapidly, opening up new opportunities to harness wind resources, the IFPEN RE Carnot Institute has launched the Wind Avatar JIP with a view to more effectively addressing the challenges associated with offshore turbines. How? By applying the digital twin concept that has recently emerged in the field of digitalization. The principle consists of combining data from an operational turbine with physical models and data analysis in order to understand its performance. The objective of this avatar is to improve the identification of potential turbine anomalies, monitor turbine wear and predict the lifespan of their components, detect decreases in electricity production and, ultimately, optimize production and maintenance.

GEOTHERMAL ENERGY: AN ASSET FOR REDUCING THE ENVIRONMENTAL IMPACT OF OIL FIELDS

The IFPEN RE Carnot Institute helps its industrial oil-sector partners shift towards the use of geothermal energy in order to decarbonize their operations. For example, in 2022, alongside its subsidiary Beicip-Franlab, IFPEN conducted a study aimed at reusing oil wells for geothermal energy production via fluid heat recovery.
An evaluation of the heat resources was carried out, as well as a study of the possible conversion to electricity. The analysis also comprised a calculation of the evolution of electricity production potential over the next 20 years.
IFPEN is contributing to two new publicly-funded projects on geothermal energy.

HIGHLIGHT

The IFPEN RE Carnot Institute contributes to two new geothermal energy projects
The HocLoop project, funded by Horizon Europe, was launched at the end of October 2022. Working alongside its partners VITO, Norce and the Universities of Florence, Bari, Darmstadt and Vaasa, the IFPEN RE Carnot Institute is evaluating a new closed-loop technology based on a vertical well extended by a deep horizontal section. The fluid circulates in the annular and then in the central tube separated by an insulator. The system as a whole forms a closed-circuit thermal exchanger exploiting underground heat. The IFPEN teams are studying all phenomena associated with the technology using its expertise and tools in the field of reservoir and well modelling and surface equipment. They will also be working on design optimization as a function of underground properties and thermal recharge potential. In addition, the Gliter project, financed by ANR in partnership with BRGM and Lithium de France, is assessing the potential for the co-production of geothermal energy and lithium in the Upper Rhine Plain. This project was also launched at the end of 2022.

THE DEVELOPMENT OF **ENERGY STORAGE** AND MANAGEMENT SYSTEMS

The intermittent nature of some renewable energies demands a greater degree of flexibility to ensure a balance between production and consumption. In this context, storage and management technologies are essential to ensure the overall and local stability of electricity networks. IFPEN RE Carnot Institute teams are focusing on the development of advanced adiabatic compressed air energy storage technologies (AA-CAES), as well as the consolidation of an energy management system (EMS) solution, in order to facilitate the integration of renewable energies into networks.

Launched in 2021, the TranZAE project continued in 2022. The 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 Cerema (Center for Studies and Expertise on Risks, the Environment, Mobility and Urban Planning) and Enedis, is aimed at developing a methodology on behalf of ADEME 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. IFPEN is using a search engine to process cadastral data provided by IGN (National Geographic Institute) and electricity data provided by Enedis 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.

Interview with Louis Londe, Technical Director, Projects and Innovation at Geostock

In 2022, long-standing partners Geostock and IFPEN worked together closely on an Advanced Adiabatic Compressed Air Energy Storage (AA-CAES) solution, a key development for the ecological transition. Compressed in caverns when electricity is abundant, the air is then discharged to produce electricity via a turbine. This compensates for the intermittent nature of energy generated by wind turbines and solar panels. In order to make the solution more efficient, compression calories are stored in a thermal storage facility and injected into the turbine during electricity production. We have pooled our respective expertise: IFPEN has contributed its know-how in the field of heat compression and storage while Geostock has brought its expertise in the field of underground cavity storage. This partnership was an opportunity for Geostock to develop its technology, with the possibility of promoting it to new prospective customers. The collaboration was a success since it gave rise to a study conducted on behalf of TotalEnergies, a customer we wanted to approach on the subject of CAES. This represents a first significant step for Geostock on the road to developing an industrial pilot.

HYDROGEN AND RISK MANAGEMENT

In the field of hydrogen, alongside research related to mobility (see page 23), the IFPEN RE Carnot Institute is evaluating the impact of hydrogen on materials in order to be able to ensure transport network safety. Research is also being carried out to evaluate the risks and technical feasibility of future operations involving the mass storage of hydrogen underground. For example, the IFPEN RE Carnot Institute is a partner in the HyStorEn project, selected within the framework of the 2022 ANR call for projects and financed as a "collaborative research project with a potential opening to the world of business" (PRCE). The project is aimed at understanding the behaviour of hydrogen in the underground environment.

HIGHLIGHT

A consortium in step with industrial needs
At the start of 2022, in partnership with the Institut de la Corrosion, IFPEN launched a "community". Its purpose is to assemble industrial partners in order to gain a better understanding of the behaviour of materials in the presence of hydrogen in a variety of test conditions (MRC - Membership Research Consortium). The year was particularly productive, with 24 industrial members joining, reflecting the sector's interest in the hydrogen theme. Within this consortium, IFPEN and the Institut de la Corrosion are pooling their expertise and testing resources to provide members with specific analysis capacities. The community has been launched for an initial period of three years.

REDUCING THE CARBON FOOTPRINT OF TRANSPORT

IFPEN develops eco-efficient technologies to produce alternatives to fossil fuels, aiming to broadening the energy mix in the transport sector and limiting the environmental impact. In 2022, IFPEN made a significant contribution to the BioTJet project supported by ADEME to prepare for the installation of France's first industrial BioTfueL® unit for the production of biojet from biomass. An Ethanol-to-jet project was also launched in 2022 with Axens.

HIGHLIGHT

Decarbonization of aviation: the BioTJet project takes off
The BioTJet project dedicated to the production of sustainable aviation fuels, was launched. This project is supported by ADEME within the framework of the sustainable aviation biofuels call for projects. It is led by Elyse Energy and conducted in partnership with Alliance Forêts Bois and Avril and backed by Axens, Bionext and IFP Investissements. The objective is to construct and commission, by 2027, the first French industrial unit for the production of advanced biokerosene from sustainable biomass, primarily made up of local forestry and wood waste. In line with the French road map for the roll-out of sustainable aviation fuels, the national low-carbon strategy and European Fit for 55 regulations, BioTJet will provide an immediate response to the challenges associated with the decarbonization of the aviation sector. The use of advanced biokerosene stemming from BioTJet may reduce greenhouse gas emissions by at least 85% compared with conventional kerosene (on the basis of a life-cycle analysis). An option for the injection of green hydrogen obtained via water electrolysis is also being studied. Based on equivalent quantities of biomass, adding hydrogen to the process could double fuel production.

BIO-BASED **CHEMISTRY**

IFPEN develops new processes, catalysts and biocatalysts aimed at converting lignocellulosic biomass into major bio-based chemical intermediates, which are more environmentally friendly than the same fossil-based products and address the growing need to reduce industrial greenhouse gas emissions while offering a diversification of supply sources. In 2022, cold equipment performance tests were conducted on the BioButterfly demonstrator, designed to produce butadiene using ethanol of plant origin, as a replacement for petrochemical butadiene. Within the framework of a partnership with the subsidiary of a major French group, IFPEN teams also finalized the development of a sugar conversion process. It will make it possible to produce a bio-based molecule used in the manufacture of non-toxic, sustainable resins for bonding wood.

FOCUS

Axens was singled out in two of the sixteen categories of the 6th edition of the Hydrocarbon Processing Awards, handed out by a leading journal in the processing industry. The IFPEN subsidiary received awards in the “Best digitalization technology” category, for the Connect’In® process performance monitoring platform, and in the “Best petrochemical technology” category for the Atol® technology, the fruit of a partnership launched in 2011 between IFPEN, Axens and TotalEnergies and a key technology for the production of biojet using the alcohol-to jet process.

HIGHLIGHT

Plastics industry association: Bio-TCat®™, winner of the innovation prize

The Plastics industry association awarded the 2022 innovation prize in the field of bioplastics to American company Anellotech for its contribution to the development of the first 100% bio-based PET bottle thanks to Bio-TCat®™ technology, developed within the framework of a partnership between IFPEN, Axens and Anellotech for the conversion of lignocellulosic biomass into aromatics (Benzene/Toluene/Xylenes). The TCat-8® pilot unit operated by partners in Silsbee (Texas) produced 100% bio-based p-Xylene in line with specifications for the first PET bottle prototypes, of 100% plant origin, manufactured at the end of 2021 by Suntory.

SUSTAINABLE MOBILITY

The decarbonization of the transport sector requires increased research in order to further reduce the environmental impact of the technologies employed, make use of cleaner energy sources such as hydrogen, biogas or electricity and exploit the optimization potential provided by digitalization. To navigate this energy and ecological transition concerning the sector's players, local authorities and citizens, IFPEN is mobilized in France and Europe via its Carnot IFPEN Transports Energie (TE).

EUROPEAN **DYNAMIC**

2022 yielded some very positive results for European projects involving Carnot IFPEN TE teams. In the field of vehicle electrification, ReFreeDrive, which the Carnot IFPEN TE had participated in since 2017 alongside 12 partners, resulted in the development of two Hybrid Synchronous Motors (HSM) without rare earths and with power electronics with silicon carbide components contributing to the achievement of 99% of the measured efficiency.

Over their life cycle, these motors reduce the energy consumed by 57%, which in turn reduces the CO_2 emitted by 50%. The CEVOLVER (Connected Electric Vehicle Optimized for Life, Value, Efficiency and Range) project, of which the Carnot IFPEN TE was a partner, also came to an end after four years of research. Conclusive results in terms of electric vehicle usage were presented *(see page 26)*.

Concerning advanced batteries, the Modalis2 (Modelling of Advanced Lithium-Ion Storage Systems), a project led by the Carnot IFPEN TE and bringing together 10 partners, models batteries using new materials such as alloys with silicon for negative electrodes or solid electrolytes. Project developments were presented in Brussels at the H2020 RTR conference, organized by the European Commission alongside European bodies ERTRAC, EGVIAfor2Zero and CCAM.

Concerning the improvement of heavy truck powertrains, the annual general meeting of the LongRun (Development of efficient and environmentally friendly LONG distance poweRtrain for heavy dUty trucks aNd coaches) project was held in June at the Rueil-Malmaison site. It brought together more than 70 participants, representing the consortium's 30 partners, to discuss the main advances so far *(see page 23)*.

An increasingly dynamic environment within the framework of Horizon Europe saw the launch in 2022 of the HELENA project on batteries of the future and the continuation of projects launched in 2021 on themes such as low-pollutant-emission and reduced-fuel-consumption hybrid vehicles, Phoenice (PHev towards zerO EmissioNs & ultimate ICE efficiency) and the "greening" of ports and airports (OLGA, MAGPIE).

IMPROVED LOW-CARBON POWERTRAIN PERFORMANCE

Achieving the ambitious objective set for 2030 of reducing the CO_2 emissions of heavy trucks by 30% requires the use of advanced combustion systems powered by low-carbon liquid or gaseous fuels (natural gas, biogas, hythane). Research conducted in 2022 resulted in improvements in the efficiency of powertrains using these fuels. During a presentation of advances made in the LongRun project, aimed at developing a complete set of powertrains for more environmentally-friendly heavy trucks and coaches, the IFPEN Swumble™ combustion system delivered efficiencies between 10% and 15% higher than those of a mass-produced engine. It should be noted that within the framework of this project, the Carnot IFPEN TE teams are contributing their expertise in the design and characterization of combustion systems for low-CO_2 fuels, as well as the development of connected eco-routing and eco-driving services to reduce the amount of fuel consumed. In parallel, the European Phoenice project *(see 2021 IFPEN activity report, page 23)*, aimed at developing a demonstrator for a plug-in hybrid vehicle with reduced fuel consumption and pollutant emissions, continued with the objective of accelerating the transition towards more environmentally-friendly mobility in terms of air quality and the reduction in greenhouse gas emissions. Other research underway concerns air loop management and control, as well as the optimization of specific combustion system measurements, such as the compression ratio.

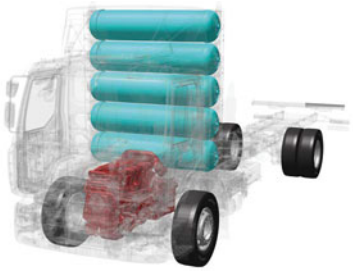
HYDROGEN PROPULSION SERVING LOW-CARBON MOBILITY

The Carnot IFPEN TE is working on solutions for the use of renewable or low-carbon hydrogen to reduce the environmental impact of mobility. For the fuel cell system in the vehicle environment, research is focusing on the dimensioning of the system, its supervision and its control electronics with a view to optimizing use, costs and lifespan, based, in particular, on unique numerical and experimental resources. Teams are also working to optimize direct hydrogen combustion in an IC engine in order to maximize its efficiency and achieve close to zero nitrogen oxide emissions.

HIGHLIGHTS

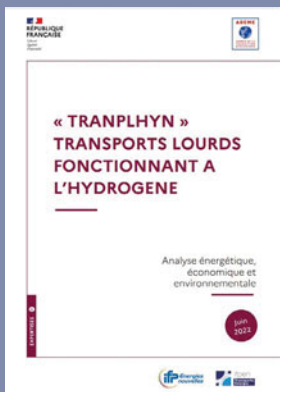
The cost-effective decarbonization of heavy mobility

The PLH2 project, coordinated by Volvo Group - Renault Trucks in partnership with the Carnot IFPEN TE, is one of the projects being driven by the automobile and mobility research steering committee (Coram). It is aimed at equipping heavy-duty vehicles with hydrogen IC engines with a total cost of ownership similar to that of their diesel equivalent. The Carnot IFPEN TE is responsible for calibrating the MD 8 litre 6-cylinder engine. Existing technologies are currently being adapted with the aim of bringing costs under control. This engine could be used in either heavy trucks or buses. Volvo Penta is examining its potential use in shipping. The experimental base enables IFPEN's teams to verify the predictive capacity of 3D combustion calculations (cylinder pressure, combustion speed, wall heat transfer, etc.) and to examine the influence of control (injection phasing, lambda value, etc.) and geometric (hydrogen injector, spark plug, etc.) parameters on this combustion.



TranpLHyn study: evaluating the benefits of hydrogen for heavy mobility

In September 2022, with the support of ADEME, IFPEN published the TranpLHyn (heavy-duty hydrogen trucks) study. The study offers an energy, economic and environmental comparison of the two solutions for the use of hydrogen in a propulsion system: electricity generation in a fuel cell for electric drive and combustion in an IC engine with a conventional architecture. It concerned four types of vehicles and took into account four types of powertrain. The principal conclusions reveal that fuel cells perform better in terms of energy and the environment than hydrogen IC engines, but in both cases the total cost of ownership is between two and three times higher compared to a diesel engine, with an advantage for the hydrogen engine.



HyMot project: a demonstrator for a range of low-carbon commercial vehicles

The HyMot (hydrogen engine) project, coordinated by Bosch and involving seven other industrial and academic players* including the Carnot IFPEN TE, is one of the projects selected by the automobile and mobility research steering committee (Coram) within the framework of the 4th French investments for the future program. It is aimed at demonstrating the feasibility of the decarbonization of a commercial vehicle by converting its engine to hydrogen internal combustion, as an alternative to electrification combined with a hydrogen fuel cell. The objective of the research conducted with the partners is to propose a new range of low-carbon commercial vehicles that will produce close to zero local emissions. Carnot IFPEN TE teams will contribute their expertise in the field of hydrogen IC powertrains to design the combustion system.

* Renault, Alpine Racing, Faurecia, OSE Engineering, TotalEnergies, École centrale de Nantes.

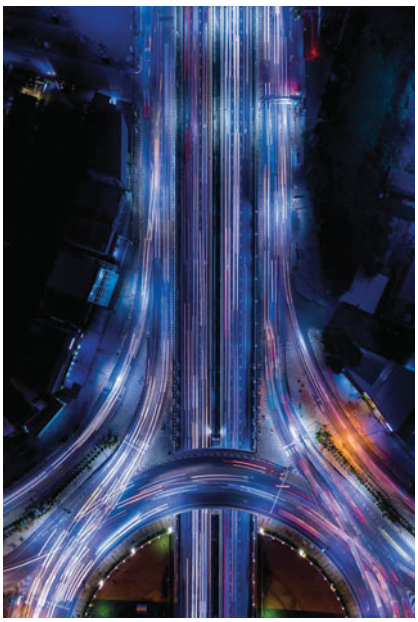
SUPPORTING VEHICLE ELECTRIFICATION

The electrification of private vehicles is the principal objective of the European Union in order to decarbonize the transport sector. All French manufacturers are committed to this transition and the Carnot IFPEN TE is contributing its expertise to improve the performance and energy efficiency of motors as well as electrochemical storage and electricity production systems. Within the framework of its research on electric propulsion, it is developing motors for a broad range of powers.

An integrated low-voltage motor-inverter combination unique in terms of performance (38 kW at 60 V), aimed at small electric vehicles or retrofit applications, has been developed with EREM and Punch Powertrain France. EREM launched the industrialization of the solution in 2022. The HSM technology used for the motor offers excellent performance levels with a small mass of magnets, limiting manufacturing costs. To compensate for the small mass of magnets, appropriate control laws enable highly sophisticated engine torque management. In addition, a more powerful powertrain is being developed by the Carnot IFPEN TE's teams within the framework of the ADEME H2D2 project launched in 2022 as part of the "Démonstrateurs et Territoires d'Innovation de Grande Ambition" (DTIGA, Ambitious Demonstrators and Innovative Territories) initiative. The objective is to design, prototype and test a powertrain powered by a fuel cell for vehicles of more than eight tonnes. Lastly, the Carnot IFPEN TE is designing methodologies to gain a better understanding of electrochemical systems, make them more efficient, develop advanced batteries and improve their recycling. There is a particular focus on battery cell thermal runaway. Experiments, using optical diagnostic techniques in transparent chambers, for example, and modelling are conducted to shed light on the problem within the framework of collaborative projects.

HIGHLIGHT

Melchior project: facilitating motor recycling
In 2022, IFPEN and CEA-Liten Énergies du Futur launched the Melchior (Machines électriques dans une chaîne de valeur orientée vers le recyclage - Motors in a recycling-oriented value chain) project. This project aims to develop a prototype of a motor using magnet technology suitable for recycling. It will focus on specific materials and define architectures to facilitate recycling while maintaining a good level of performance. The Carnot IFPEN TE is responsible for designing this motor, including the evaluation of its environmental impact, while CEA-Liten will develop a new recyclable magnet technology.



DIGITALIZATION, THE CORNERSTONE OF MOBILITY TRANFORMATION

The scheduled end of the sale of new private and commercial IC vehicles by 2035 in the European Union is accelerating the shift towards electrification but raises questions relating to the optimization of technologies and usages as well as the roll-out of associated infrastructures. In this context, the Carnot IFPEN TE is developing energy web services for partner websites in the form of tools to enable the understanding and analysis of the environmental footprint of individual and public transport. These tools are designed in partnership with ADEME, Fabrique de la logistique and the Union des entreprises de transport et logistique de France (Union of French Transport and Logistics Companies). IFPEN also continues to develop software building blocks to help design powertrain systems. For example, in 2022 IFPEN renewed its partnership contract with Siemens for a period of five years and it is also set to open the Amesim system simulation platform to two new themes: fuel cell modelling and the use and integration of real driving emissions (RDE) into simulation. Lastly, 3D CFD modelling is being developed with the CONVERGE code within the framework of a partnership with CSI, which was renewed for a period of five years while encompassing electric mobility (cooling of electric machines, battery management and thermal runaway).

HIGHLIGHT

End of the CEVOLVER project: simplifying the use of electric vehicles

The CEVOLVER project, coordinated by FEV Group and involving nine industrial and academic partners* including IFPEN, ended in 2022. To address charging time, range and accessibility issues, key factors for the large-scale uptake of electric vehicles, CEVOLVER adopted a user-centric approach with a view to proposing solutions for comfortable long-distance journeys with an appropriately dimensioned battery at an affordable price. The idea was firstly to reduce the energy consumption of electric vehicles through new thermal and energy management systems. Connectivity was then exploited to provide the driver with more reliable range predictions and indications of the ideal route for long-distance journeys, with the aim of effectively guiding the driver while taking into account the rapid charging points available and low energy consumption. Carnot IFPEN TE teams developed the route optimisation algorithms and charging point maps used in this second phase of the project.

** FEV Group, FCA-Stellantis, Ford, Bosch, IFPEN, Aachen Un., Vrije Un. Bruxelles, i2M, Uniresearch.*

The CEVOLVER project received funding from the European Union's Horizon 2020 research and innovation program through grant agreement No. 824295.

Interview with Frederik de Smet, research engineer at Ford

The main objective of the CEVOLVER project was to increase user confidence in electric vehicles by improving energy efficiency, reducing long-distance journey times and offering new functionalities. The project adopted a user-centric approach to optimize the exploitation of the thermal system. For the project, the Ford team provided a demonstration vehicle base on an E-Transit commercial vehicle and developed usage scenarios for Europe. The thermal equipment, including heating panels, a low-temperature radiator and a heat exchanger between two circuits, was optimized for these scenarios. In terms of software, CEVOLVER demonstrated that eco-charging, developed by IFPEN, minimizes long-distance journey times by optimizing charge maps. Eco-driving, IFPEN's other tool, reduces energy consumption for short distances. The overall system was demonstrated for a day trip of 700 kilometres. We had regular exchanges with all partners and with IFPEN in particular. Our questions and concerns have always been well handled and the IFPEN team did everything it could to minimize delays. There is no doubt that their extremely reactive approach contributed to the overall success of the Ford demonstrator.

RESPONSIBLE OIL AND GAS

Given the need to increase energy efficiency and reduce CO_2 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 the strictest 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.

BASINS AND RESERVOIRS

The IFPEN Ressources Energétiques Carnot Institute has longstanding experience in the design of software solutions used to model the dynamic evolution of an oil system, on a sedimentary basin scale, and to improve the characterization of complex phenomena in order to better manage production, on an oil and gas reservoir scale. Today, its teams develop quantitative underground environment modelling solutions, risk analysis methodologies and reliable and safe production equipment aimed at limiting drilling operations within the framework of an environmentally-friendly, risk-reduction approach. In 2022, KAPPA Engineering marketed the first version of the Rubis-Puma 3D reservoir simulator, equipped with a dynamic flow simulator developed by the Carnot Institute's teams.

EOR

In a context in which the implementation of the energy transition is gathering pace and the oil market remains strained, the oil industry is faced with the need to reduce costs and reinforce innovation in order to increase production and improve the eco-efficiency of processes. Enhanced oil recovery or EOR helps meet the demand for oil and gas, producing more from existing reservoirs while optimizing the management of produced water and reducing the number of drilling operations. To this end, within the framework of the EOR Alliance, IFPEN, Beicip-Franlab and Solvay are developing technologies and services adapted to different reservoir conditions and all types of EOR – chemical EOR processes, as well as CO_2 EOR with a view to the partial use and storage of CO_2. The range of services covers the entire chain, from the development of EOR formulations in the laboratory through to field implementation. The Dolphin 3 JIP, launched at the end of 2019 with six industrial partners, aiming at studying the impact of additives used in chemical EOR on the management of produced water, was concluded after three years of research.

RISERS AND PRODUCTION LINES

The energy crisis has given a moderate boost to offshore drilling and production activities. In this context and with the aim of supporting industry as it seeks to overcome climate challenges, IFPEN designs equipment and technological solutions aimed at providing access to offshore resources, while ensuring the delivery of safe, cost-effective drilling and production operations. In 2022, significant progress was made on the characterization and detection of deposits on production lines, thereby making it possible to optimize the incorporation of additives and, consequently, reduce the environmental impact of this operation.

PRODUCTION OF PETROCHEMICAL INTERMEDIATES

At a time when the petrochemicals industry is undergoing a radical transformation, IFPEN is developing innovative and eco-efficient petrochemical intermediate production processes to support market demand. Its researchers are also working to improve the performance of existing processes, while increasing product purity. In 2022, considerable progress was made in the creation of a catalyst for propane dehydrogenation and teams also optimized a definition of the xylene separation technology to be developed.

HEAVY CRUDE AND RESIDUE **CONVERSION AND PURIFICATION**

To meet the growing need for liquid fuels in emerging countries, make refining facilities more cost effective while reducing final residues and convert crude oil into a maximum volume of products for the petrochemicals industry, it is still necessary to increase deep conversion capacity. In parallel, these processes need to be adapted to the growing introduction of heavy and ultra-heavy crudes, which are reappearing due to the current geopolitical situation and which will have to be processed in an eco-efficient manner through technological advances. To this end, IFPEN develops solutions to convert and purify these feeds in order to obtain cleaner products meeting ever stricter specifications. Today, conversion processes are very much driven by Oil to Chemicals complexes, designed to convert a large proportion of crude oil into petrochemicals, minimizing fuel production. IFPEN and its partners are committed stakeholders in this transformation of refining facilities. In 2022, IFPEN's research on the Catalytic crude to chemical (CC2C) process developed in partnership with Saudi Aramco, TechnipFMC and Axens was finalized. The CC2C technology developed considerably increases efficiency and chemical product yields, converting around 70% of the crude oil into high-value chemicals for the market, without the need to go through conventional atmospheric or vacuum distillation steps, which are the most energy-intensive refining units. By simplifying the access route to petrochemical bases and drastically reducing fuel production, the CC2C process leads to a much-improved global carbon footprint compared to the refining processes used until now.

GAS **CONVERSION**

The geopolitical context is favourable to the development of efficient treatment technologies to address the growing demand for natural gas. IFPEN has produced a body of technologies ranging from process design through to the development of solvents, via the creation of packings for absorption columns, and is continuing its research in the field of natural gas purification. For example, IFPEN teams are harnessing know-how acquired for the production of blue hydrogen by capturing CO_2 emitted during the methane reforming process. Research is also focusing on the conditionning of energy transition gases: green H2, CO_2 to be stored or used, biomethane, etc. Blue hydrogen research is being conducted in partnership with TotalEnergies and Axens.

CLEAN FUEL **PRODUCTION**

The refining sector is undergoing a historic transformation associated with increasingly efficient engines and the growth of electrification, regulations and public incentives aimed at improving gasoline quality and the need to adapt its offer through the use of converted products by the chemicals sector. In this context, IFPEN develops eco-efficient catalysts and processes for the production of clean fuels, in line with product specifications as well as CO_2 emission reduction objectives, and supports the refining facility transition. In 2022, substantial progress was made with respect to the Prime-G+® gasoline desulfurization process, improving octane index in association with lower energy consumption. In addition, the development of a chlorine-free light naphtha isomerization catalyst was carried out, as well as the consolidation of R&I work targeting a new paraffin aromatization catalyst. Two process and technology books were also delivered in the field of distillates: the first relating to the conversion of LCO (deep hydrogenation) and the second targeting an optimized hydrocracking process with management of a recycling loop on the unconverted feedstock. Significant advances were also made in the field of hydrocracking catalyst regeneration.

Interview with Antoine Fecant, IFPEN research engineer

Prime-G+® is a major process for the purification of fuels and ensuring their compliance with the strictest specifications; one third of global gasoline production is obtained using this process. Within the framework of R&I work conducted at IFPEN and finalized in 2022, significant improvements were proposed to support the transition of refining facilities towards lower energy consumption and a reduced impact in terms of greenhouse gas emissions. Some sulphur-containing compounds such as mercaptans are particularly difficult to remove and make it more challenging to comply with environmental regulations in some areas of the world (particularly China). The improvement developed at IFPEN is aimed at adding an ultra-selective and total mercaptan adsorption step at the end of the process. This final purification means it is possible to make the upstream treatment steps "less stringent", thereby reducing temperatures (and increasing energy efficiency), as well as hydrogen consumption by around 30%, guaranteeing a 10% reduction of the carbon footprint at the process terminals. These gains add up to a higher-quality product since the process improvement ensures compliance with all of the strictest environmental regulations worldwide. In addition, the higher octane gasoline produced is associated with increased engine efficiency, with a higher compression ratio and thus a reduction in CO_2 emissions when operating.

FUNDAMENTAL RESEARCH SERVING INNOVATION

To ensure the scientific excellence of its research activities and to support its innovation ambitions, IFPEN draws on a collaborative fundamental research program, organized around nine scientific challenges. Moreover, in order to anticipate long-term needs and pave the way for the development of new products and processes, IFPEN continually adjusts its scientific questions with a view to acquiring new knowledge and skills.

+ STRUCTURED **FUNDAMENTAL RESEARCH...**

Since 2016, the transversal 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. This organizational structure has been supported over the past few years by a reinforcement of research associated with new energy technologies (NET) and the ecological transition.

IFPEN is also a research center where young researchers from around the world cross paths. In 2022, around ten visiting PhD and post-doctoral students spent time in one of its laboratories to conduct part of their research, almost all of them coming from outside France. These stays took place within different contexts: ITN (Innovative Training Networks), ERC (European Research Council) grants, IFP School CarMa Chair, etc.,or were simply an opportunity for researchers to join forces to work on scientific questions of common interest. Multiple disciplinary fields were concerned: from chemistry through to economics, via IT, thermodynamics and engineering sciences.

At the same time, 14 IFPEN theses were underway within the framework of collaborations with industrial players including EDF, Renault, Siemens, Stellantis and TotalEnergies, the majority in the context of an industrial agreement for training through research (CIFRE). These theses, five of which are being supervised by holders of a national accreditation to supervise research (HDR) from IFPEN, are being hosted in seven research divisions as well as at IFP School, reflecting the diversity of skills sought by the industrial partners working with IFPEN.

+ FOCUS

Luc Vervisch, University Professor at the National Institute of Applied Sciences, Rouen (France), has been appointed chairman of IFPEN's Scientific Board. Luc Vervisch's research relates to numerical simulation and data sciences applied to reactive flow physics, as encountered in combustion. The numerical methods he developed were implemented in software aimed at the production, transport and energy conversion industries.

FOCUS

In addition to the PEPR SNA's (French priority research programs and facilities initiatives associated with national acceleration strategies) in which it is a joint leader (PEPR on the decarbonization of industry with the CNRS, PEPR on bio-based products and sustainable fuels with INRAE and PEPR on the digitalization and decarbonization of mobility with Gustave Eiffel University), IFPEN is actively involved in the PEPR SNAs on Batteries and H_2, as well as in the exploratory PEPRs on Underground common good (CNRS, BRGM), Maths-vives (mathematics for the living world, the environment and society – led by CNRS), FairCarboN (carbon cycle – led by CNRS and INRAE), OneWater (water common good – jointly led by BRGM, CNRS and INRAE), NumPEX (high-performance numerical methods for exascale computing – jointly led by CEA, CNRS and Inria) and Diadem (integrated mechanisms for the acceleration of the roll-out of emerging materials – jointly led by CEA and CNRS).

...AND STRENGTHENED BY ITS PARTNERSHIPS

IFPEN's strategy of openness is reflected by the development of partnerships, such as the framework agreements that were extended and reinforced in 2022. Following on from a partnership agreement signed in 2017, in 2022 the CEA (French Alternative Energies and Atomic Energy Commission) and IFPEN signed their first framework agreement for research and development collaboration in the field of energy. The five-year agreement is hinged around four themes: mobility, the carbon circular economy, digital technology and education. Similarly, after twenty years of partnership, in 2022, IFPEN and Andra extended their existing framework collaboration agreement (signed in 2018) for a further two years. The objectives are to improve the modelling of the underground environment, geological storage site surveillance and gas transfer monitoring, numerical fluid flow simulation and management of steel corrosion risks.
Numerous collaborative agreements with universities cover a broad variety of topics. In the field of the synthesis of materials and structured reactors, IFPEN has partnered up with Politecnico di Milano, while in the field of chemical engineering and fluidization IFPEN is working with Naples University. In the field of AI applied to imaging, Laval University's CERVO research center in Quebec hosted IFPEN researcher Maxime Moreaud for a year to work on numerical holography. In the field of the thermodynamics of complex fluids and electrolytes, 2022 saw the launch of the EleTher 2 collaborative project, involving seven industrial partners. To treat hydrogen, from its subsurface genesis to the study of its underground migration when it interacts with the environment, the HydroGEMM research group was launched in November 2022. IFPEN is contributing to its organization, as well as activities dedicated to the microbiology and numerical simulation of reactive flows. Finally, to better elucidate and assess the risks specific to complex systems (renewable energies, low-carbon aviation, etc.), the collaboration with Safran Tech continues and enriches the Lagun open source web tool dedicated to data exploration and optimization.

HIGHLIGHT

Twinn2SET: the twinning of research laboratories throughout the European Union to accelerate research on sustainable energies

In October 2022, the European Twinn2SET* (Twinning to sustainable energy transition) project was launched by IFPEN, IFP School, Stavanger University (Norway) and the Greek Geoenergy Institute (FORTH/IG), project leader, with a view to helping the institute increase its research and training capacities on sustainable energy themes: carbon capture and storage, deep geothermal energy and underground hydrogen storage. Two exploratory studies will also be conducted in the fields of hydrogen storage in geological formations and geothermal energy.

** Twinn2SET, submitted within the framework of the Twinning coordination and support initiative (twinning with research laboratories of various levels of maturity), received funding from the European Union's Horizon Europe programme through grant agreement No.101079246.*

HIGHLIGHT

Carmen Joint Research Laboratory: a very productive year

The CARMEN Joint Research Laboratory was launched in 2019 for a period of five years to study porous solids, focusing on three classes of materials: zeolites, aluminas and clays, all of great interest for the energy transition. Although the laboratory faced some early challenges associated with the Covid pandemic, its teams had made significant progress by the half-way point in its mission. This research was related, in particular, to numerous methodological developments and to the acquisition of new data that enhances our understanding of porous media, with an accent on their transport properties. The CARMEN Joint Research Laboratory also represents a spirit of scientific sharing and influence within a community. For example, the laboratory was the driving force behind the CARMEN.EVOLUTION workshop, held on 21-22 June 2022. The objective? To jointly define the scientific and social challenges involved in the development of new materials for energy, and to determine the strategies required to meet these challenges.
To find out more, go to www.ifpenergiesnouvelles.fr

HIGHLIGHT

IFPEN takes part in the SIG on uncertainty quantification

In October 2022, Paris-Saclay University launched the scientific interest group (SIG) LARTISSTE (Laboratoire de recherche en traitement des incertitudes par apprentissage statistique pour la sûreté, la conception et la transition énergétique, or research laboratory on uncertainty treatment through statistical learning for safety, design and the energy transition). Devoted to the quantification of uncertainties in numerical simulations, this SIG brings together numerous researchers from academia, national research institutions and industry*. Uncertainty quantification concerns the modeling of physical, chemical, climatology and biological, phenomena, etc. Within this context, IFPEN will host two theses, one with CentraleSupélec on uncertainty quantification for wind energy and the other with ONERA on the optimization of multiphysical coupled systems.

** IFPEN, EDF, CEA, Framatome, CentraleSupélec, AgroParisTech, CNRS, INRAE, Inria, Paris-Saclay University, ENS Paris-Saclay, Évry University, Versailles Saint-Quentin-en-Yvelines University, ONERA, Safran, Airbus, Phimeca, Cerfacs, Clermont Augnergne INP and IRT SystemX.*

HIGHLIGHT

IFPEN joins the MaTerRE DIM

IFPEN joined the new Major Research and Innovation Area (DIM: Domaine d'intérêt majeur) baptized MaTerRE (MaTériaux avancés écoREsponsables, or Advanced Ecoresponsible Materials), selected by Île-de-France region in 2022 and led by ESPCI Paris-PSL. DIMs bring together research laboratories and companies to work on emerging themes with significant innovation potential. The MaTerRE DIM focuses on four priority areas: the production, use and management of strategic gases (CO_2, H_2) as part of a circular economy objective, efficient and eco-friendly energy storage and recovery processes, the design of environmentally-friendly construction materials and, lastly, the exploitation of urban mines, recycling and eco-design.

Interview with Anne Sinquin, IFPEN research engineer

The annual Gas Hydrate research group days event, held at IFPEN in 2022, brought together 70 experts to discuss hydrates and their multiple properties. This research group was established in 2018 and its mission was extended at the end of 2022 in the form of a CNRS themed network. It is made up of around one hundred members. The next step will be to raise its profile on a European level. Hydrates have been the focus of numerous research studies. In the past, oil companies were concerned about the risk of blockage of the pipes by hydrates, and research was conducted to avoid their formation. Current research concerns the hydrate risk during CO_2 injection in depleted reservoirs, the risk of methane release in the seabed or permafrost, processes harnessing hydrates to purify or desalinate water, separate gases, produce cold, transport it or store hydrogen.

AWARD WINNERS IN 2022...

Interview with Martina Torelli, winner of the 2022 Yves-Chauvin prize

"My thesis related to biogenic methane generated naturally by microorganisms in shallow sediments. This gas is an energy source but it is also a climate agent if it is emitted into the atmosphere or the ocean. The evaluation of biogenic gas genesis processes requires an understanding of biological activity on a microscopic scale and of the evolution of the degradation of organic matter over time, combined with an understanding of geological evolution on a sedimentary basin scale. This research demonstrated that basin modelling is useful to quantify seabed gas emissions over the past several million years. In the zones studied – the Aquitaine passive margin and those of Mozambique and Madagascar around the Mozambique canal – methane is emitted into the ocean, but the same approach is applied to biogenic gas from terrestrial sediments."

FOCUS

In October 2022, to reinforce research in the field of karst aquifers, the ERC (European Research Council) awarded a Synergy grant to four researchers from European research institutes including IFPEN's Benoît Noetinger *(see page 8).*

Hélène Olivier-Bourbigou is awarded the Codron-Fautz prize

Hélène Olivier-Bourbigou, IFPEN's fundamental research coordinator, was presented with the first Codron-Fautz Award by the Institut de France. Created in 2021, this annual award recognizes a researcher who has carried out remarkable work in the field of science applied to technology, as proposed by the French Academy of Sciences. In this case, it recognizes firstly a scientific approach ensuring that there is a continuum between fundamental research in the field of homogeneous catalysis and industrial applications and, secondly, the results of research into the design and implementation of more efficient catalysts. These make for more sustainable and economically-competitive chemistry.

Bertrand Guichard, an IFPEN research engineer, won the 2022 French Chemistry Society Catalysis Division (DivCat) **Innovation Award** for the development of highly efficient catalysts in the field of refining for the study of the behaviour during catalysis of innovative formulations used in the production of fuels and biofuels via co-processing.

Elsy El Hayek, an IFPEN PhD student from 2017 to 2020, was awarded the 2022 Denise Barthomeuf Thesis Prize for her work on new acid zeolites obtained from silicogermanates.

Bassel Othman, an IFPEN PhD student from 2018 to 2021, received the Sanef Abertis France Chair Award, in the Transport Infrastructure Management category, for his thesis entitled "Limitations de vitesse variables et contrôle d'accès dans un réseau routier urbain pour une meilleure durabilité environnementale". ("Variable speed limits and access control in an urban road network for better environmental sustainability").

Several IFPEN PhD students also received conference and competition awards in various fields. For example, **Thomas Pigeon** won the prize for the best poster at the ICTAC (International Conference on Theoretical Aspects of Catalysis), and **Wassim Ammar** won the best presentation award at the 11th edition of the AFA (Association Française de l'Adsorption, French Adsorption Association) conference. **Beatriz Pereira Barata** won a CCDC (Cambridge Crystallographic Data Centre) prize at the 33rd European Crystallographic Meeting, and **Loïc Dumortier** won first prize in the ParAMS ReaxFF parametrization challenge, organized by the SCM (Software for chemistry and materials) society. Finally, at the 24th conference on power electronics and its applications (EPE 2022 ECCE Europe), **Alexandre Battiston,** an engineer in the Mobility and Systems Division, received an award for the development of high-power, high-voltage silicon carbide inverters.

ENCOURAGING AND SUPPORTING INNOVATION

IFPEN contributes to the development of green industrial and sustainable mobility sectors, 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.

SUPPORTING ITS EMPLOYEES TO REINVENT ITSELF

IFPEN is diversifying in the field of new energy technologies, firstly by encouraging the creativity and entrepreneurial spirit of its own employees. In 2022, the company continued to support the development of winning projects from the latest internal challenge. These projects deal with the phenomenon of clay shrinkage or swelling, which causes significant damage to buildings, make it possible to produce a chitin polymer for agrifood or medical applications via the use of enzymes, or provide a solution to filter microplastic fibers discharged by washing-machines, for example. All these projects are the result of an innovation culture enabling IFPEN to reinvent itself in order to address the challenges of the ecological transition. Via its spin-off policy, IFPEN also helps employees seeking to set up their own companies. In 2022, with the support of IFPEN, an employee set up So Sponge, a company proposing an energy-free humidity control solution for agricultural greenhouses.

IFPEN, A MEMBER OF THE BPI DEEPTANK NETWORK

Launched in 2019 by BPI France, the Deeptech plan is aimed at making France a major international disruptive innovation player. The plan was allocated a budget of €3 billion to support the creation of 500 deeptech start-ups by 2025 and drive the growth of the industrial leaders of the future. The objective is to create 10 unicorn companies by 2025 and have 100 industrial sites by 2030. In addition, the French State announced its determination to create a €100 million fund to provide equity support to start-ups for their development. Within this context, in 2021, IFPEN and its subsidiary IFP Investissements signed a partnership agreement with BPI France. IFPEN is thus contributing to the design and creation of tools to facilitate the development of innovative start-ups (associate research platform, memorandum of collaboration to foster links between start-ups and major groups, etc.).

Interview with
Olivier Pernot, CEO of Soclema

Soclema contacted IFPEN through the Axelera competitiveness cluster to develop a previously non-existent solution, in line with its focus on renewable gases: ultra-low flow gas odorization. As well as the technical resources to validate the technology, IFPEN contributed its knowledge of fluids, meeting the specifications via test bench trials in line with demand. The deliverable was particularly useful for us to demonstrate the feasibility of the solution to our gas partners. IFPEN also made sure the semi-industrial system was perfectly operational and provided support for the patent filing process. GRTgaz, GRDF and Teréga accepted the prototype: the trials conducted in real conditions in their laboratories, and then out in the field, were conclusive and resulted in the solution being taken to market.

Interview with
Michel Thomas and Hélène Biguerd, IFPEN engineers

IFPEN helped Agua de Sol develop a new type of solar panel dedicated to drinking water production: fixed via adsorption overnight, atmospheric water vapour is desorbed during the day, then condensed and recovered for consumption. Solar radiation provides the energy (heat and electricity) for sterilization purposes. We joined the project in 2021 to help the SME optimize the choice of solid used as an adsorbent. We selected several alumina- and zeolite-type solids and tested them for their water adsorption capacities and characteristic desorption temperatures in order to compare them with the silica-based solution used by Agua de Sol during the development phase of the technology. The adsorbent recommended as an alternative to silica gel, at the end of the series of trials, will be tested in real conditions in the solar panel by the partner.

SUPPORT FOR INNOVATIVE START-UPS AND SMES: THE NETWORK EXPANDS

IFPEN has been actively supporting SMEs and startups spearheading innovation projects for more than 35 years. These projects are in line with the triple ecological, energy and digital transition. To identify collaborative opportunities, IFPEN can draw on an extensive network of partners: target incubators, innovation support networks and the Carnot Institute network. Support for innovation also takes the form of financial participation in investment funds specializing in eco-industries, eco-energies and sustainable mobility, which invest in young start-up companies. In 2022, IFPEN contributed to FAIM, a seed and venture capital environmental and social impact fund sponsored by the cities of Lyon and Saint-Etienne. Also this year, YLEC Consultants turned to IFPEN for help to obtain International Maritime Organization (IMO) certification for its ship hold oil/water separator.

FROM RESEARCH TO INDUSTRY: IFPEN SUPPORTS THE RISK ASSOCIATED WITH INNOVATIVE COMPANIES

IFPEN, a new technology initiator, takes these innovations through to the industrial stage by seeking industrial and financial partners and project leaders. For example, 2022 saw the culmination of a collective adventure that started more than ten years ago: the industrialization of the BioTfueL® process. IFPEN, Avril and BioNext joined forces with Elyse Energy to create the BioTJet® project company, which will operate France's first industrial unit dedicated to the production of advanced biokerosene from sustainable biomass (see page 20). IFP Investissements and Axens acquired stakes in the company alongside Elyse Energy, Avril and BioNext to support the study and construction of this new plant.

FOCUS

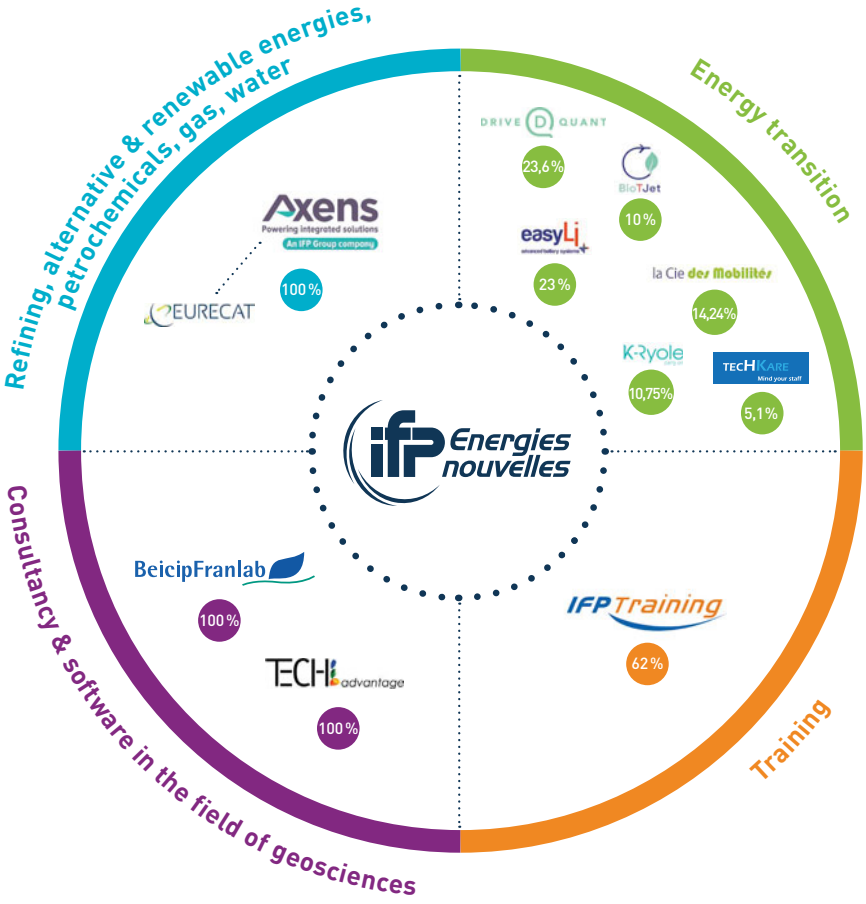
In 2022, IFPEN met with nearly 300 companies.

THE GROUP PURSUES ITS TRANSITION

In 2022, turnover and the order book maintained their upward momentum, although the level of activity of IFPEN Group's main subsidiaries – Axens, Beicip-Franlab and IFP Training – was down compared to pre-health crisis levels. The companies have continued their diversification associated with the energy and environmental transition. Axens Group launched the industrialization of the Rewind® Mix process in the field of plastics recycling, signed licensing agreements in the field of aviation biofuels and acquired HydroThane, a company proposing technologies in the field of water treatment and biogas co-production. The year also saw subsidiaries focusing on the development of their respective five-year development plans, including reflection on future growth drivers in line with the energy, environmental and digital transition.

PORTFOLIO OF INDUSTRIAL STAKEHOLDINGS*

*As at 31 December 2022



IFPEN GROUP CONSOLIDATED ACCOUNTS IN 2022

€968.3 million
Turnover

€43.5 million
EBIT

€30.3 million
Net profit Group share

TRAINING TALENTED YOUNG PEOPLE FOR THE ENERGY TRANSITION

IFP School, an applied graduate school and apprentice training center (CFA), prepares its students to be active players in the energy transition. The school has a dual objective: to address industry's needs and society's aspirations by providing outstanding training programs in the fields of energy and sustainable mobility, based on innovative teaching methods. It is also supported by an ecosystem of academic and industrial partners in France and around the world, research activities and a committed socially responsible approach.

GRADUATE PROGRAMS **ADAPTED** TO INDUSTRIAL AND SOCIETAL NEEDS

IFP School prepares new generations of talented young people to drive development in the energy and mobility sector in order to build a low-carbon world. Consequently, the ten specialized engineering degree programs are continuously adapted and the share of teaching hours dedicated to new energy technologies is constantly increasing. For example, a module dedicated to the hydrogen value chain is now incorporated into the programs of the four fields covered: Powertrains and sustainable mobility, Energy economics and management, Processes for energy and chemistry, and Georesources and energy. In 2022, recognition of the quality of course programs and their relevance to companies' needs was reflected in the renewal of the Specialized Master's® label for the Powertrain program and the signing of a partnership agreement with Strasbourg University for the imminent launch of a master's program in the field of georesources. In addition, graduate and PhD students were also singled out for awards: a PhD student from the ECAV chair was elected best young author at the 10th International Federation of Automatic Control Conference; teams from the Powertrain Engineering program won first and second prize for the best student poster at the Powertrain & Energy conference of the French Automotive Engineers Society (SIA); a student from the Energy Technology Economics and Management program was one of eight young graduates elected Energy Leaders for Tomorrow; a team was second in the final of the Laurie Dake Challenge organised by the European Association of Geoscientists and Engineers (EAGE); a team won the final of the Minus CO_2 challenge also organized by the EAGE.

The School also values the associative, social and professional commitment of students taking into account skills and know-how acquired in the program validation process. It promotes in-house initiatives too, such as the Initiatives for a sustainable campus club.

Reflecting society's diversity, the School is committed to increasing the number of women enrolled on its programs (31% of the 2022 intake) and facilitating the integration of people with a disability with, for example, its active contribution to Duoday. In parallel, initiatives are implemented on campus to limit its environmental impact and encourage eco-responsible behaviour, as well as within the French sustainable development graduate school (RESDD) network to pool best practices in training programs associated with sustainable development.

FOCUS

IFP School, which aims to be exemplary when it comes to incorporating current societal, economic and environmental concerns, is fourth in the HappyIndex®AtSchool rankings of engineering schools in terms of their commitment to the challenges of social responsibility (CSR category).

TRAINING TALENTED YOUNG PEOPLE
FOR THE ENERGY TRANSITION

Interview with

Sidney Lambert-Lalitte, manager of the Energy technology economics and management programme and coordinator of the Initiatives for a sustainable campus club

Of course, when it comes to its CSR approach, the School is supported by the expertise of an officer responsible for its implementation in line with IFPEN's policy. It also draws on initiatives driven by IFP School personnel and by its students, who belong to a generation concerned by sustainable development issues on a daily basis. Through the Initiatives for a sustainable campus group, which was created in 2018 and which I coordinate, we're working together to implement concrete actions aimed at making sustainable development a reality on campus. Successful initiatives include: an awareness-raising campaign concerning eco-practices, the publication of a sustainable development guide proposing local solutions that can be applied on an everyday basis, the distribution of re-usable water bottles to reduce plastic use on the School site. I support students in their initiatives as well as for organizational and budgetary aspects. I also ensure the continuity of initiatives among subsequent student intakes. To reinforce this link, students wanted to create a section dedicated to sustainable development within the Student Association. A clothing collection initiative launched by its members resulted in 60 kg of clothes being donated to the Emmaüs homelessness charity. The initiatives for a sustainable campus group also supports a variety of small local, concrete and useful initiatives. And longer term initiatives are not overlooked! They are presented to the School management for their potential permanent implementation. I'm thinking here, for example, about proposals concerning the reduction of the transport carbon footprint of lecturers as well as students travelling to their placement sites. Sustainable development is genuinely at the heart of everyday life at IFP School.

AN EDUCATIONAL APPROACH THAT IS CONSTANTLY BEING REINVENTED

IFP School proposes course programs based on innovative and agile teaching methods that prioritize experimentation for better knowledge acquisition. Real cases, serious games, virtual reality, the use of industrial software, etc.: innovative training methods can also provide an alternative to overcome issues relating to safety and access authorization to components and facilities. While students take part in numerous field placements, digital tools and digitalization of course programs make it possible for students to go further in the discovery of professional environments or their learning of professional practices. The School draws on developments emerging from LAB e·NOV™, its digital culture laboratory. In 2022, the team supported the development of a module on hydrogen and mobility and designed a MOOC in the form of an online series on the energy transition. Permanently at the cutting edge of innovative education, LAB e·NOV™ acquired a 3D printing studio.

HIGHLIGHT

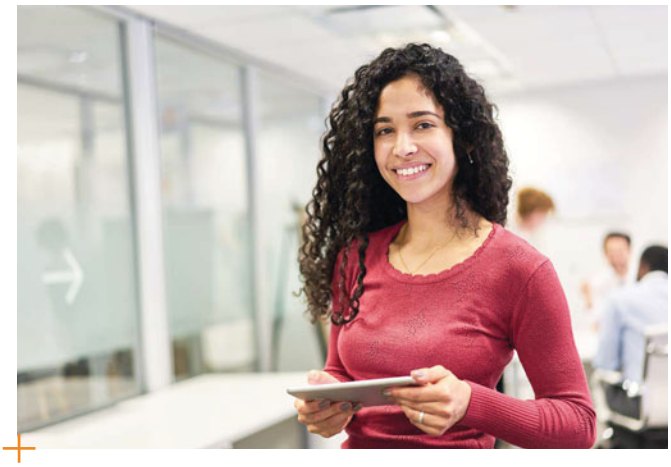
IFP School awarded the 4Digital excellence label

The Conférence des grandes écoles (CGE, the French Association of Grandes Ecoles) awarded the 4Digital label to the School in recognition of its expertise in the use of digital technology to support remote learning and teaching. In recent years, the digitalization process at IFP School has accelerated thanks to the commitment of teaching staff, LAB e·NOV™ and SMILE (the School's multimedia IT and logistics department) teams and the equipment investments made. This label will enable the School to deliver some of its Specialized Master's® programs remotely and develop new ones in this hybrid format.

HIGHLIGHT

Delving into the heart of the energy transition and innovations for a low-carbon future

At the start of 2022, IFP School launched two online training modules designed with the support of LAB e·NOV™ by teaching staff in collaboration with IFPEN researchers. The first, Energy Transition, derived from the Energy transition for a low-carbon future MOOC, contained a selection of video clips and games. The second module, Hydrogen for Mobility, gave students the chance to discover hydrogen technologies applied to heavy mobility through three sequences of video clips: H2 production methods, hydrogen IC engines and fuel cell vehicles. These modules, which brought together more than 5,000 participants, were followed by webinars giving those taking part the opportunity to go into the concepts in greater depth and interact with designated teams.



A SUCCESSFUL **DEVELOPMENT STRATEGY**

In 2022, off-site operations led by IFP School in partnership with IFP Training continued apace and several programs were renewed: The 20th edition of the Petroleum engineering and project development master's in Nigeria; the third intake of the Petroleum Upstream Techniques & Economics and Petroleum Downstream Techniques & Economics master's programs in Côte d'Ivoire; the second session of the specialized master's in oil and gas engineering in Senegal. In addition, the School's development strategy led to the forging of new partnerships with companies positioned in the energy transition markets. Research activities conducted at IFP School also contribute to its influence via the publication of scientific articles and conference papers. These relate to research conducted within the School's four teaching chairs: Electricity and Digital Transition (EDT); Electric, Connected and Autonomous Vehicles for Smart Mobility (ECAV); Electrolyte Thermodynamics (EleTher) and Carbon Management and Negative CO_2 Emissions Technologies Towards a Low-Carbon Future (CarMa). By way of illustration, mention can be made here of the participation of the CarMa team at the 16th Greenhouse gas control technologies conference *(see page 7)*. Three agreements were also signed within the framework of this chair. One, with the Massachusetts Institute of Technology (MIT), concerns a subsidized research contract for a post-doctoral researcher and the other two, with the CNRS and INRAE-AgroParisTech, relate to PhD theses. A first thesis, since the chair's launch in 2019, was also defended at the end of 2022. A dense alumni network contributes to IFP School's influence. Among other things, its members take part in IFP School Voices, monthly webinars that have recently tackled the role of biofuels in transport decarbonization, the competitiveness of green hydrogen, new challenges for electric systems, digital twins and sustainable aviation fuels; themes that reflect the School's determination to contribute to the development of solutions aimed at addressing the major energy, environmental, societal and economic challenges of the 21st century.

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MEETING TOMORROW'S CHALLENGE TODAY

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 directions: climate, environment and circular economy – renewable energies – sustainable mobility – responsible oil and gas.

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