Highlights 2021

Nadia Maïzi is lead author of the 6th IPCC report

DIWII: a full-scale demonstrator of the industry of the future at Mines Saint-Étienne

Two new shared laboratories on the inspection and control of complex mechanical parts or structures (Inspection 4.0 with IMT Mines Albi and the company Diota) and on the study and development of innovating methods and processes (LabCIS with IMT Atlantique and the company Segula)

New full-scale experimental device in controlled environment to optimise the drilling process, especially for geothermal energy (Mines Paris-PSL)

SciDoSol, a chair dedicated to solar energy data science: Mines Paris-PSL and RTE

CARATS meetings: the fashion and luxury industry meet with innovation at La Caserne

Clermont Auvergne INP inaugurates its bioceramic additive manufacturing centre for the production of bone substitutes: a disruptive approach to customise tailor-made implants.
Adapt

While 2020, struck by the health crisis, was a year of innovations and faster transformations of all types, 2021 was a year which saw the consolidation and confirmation, if this was still necessary, of the central role played by our institutes to regain the independence of our country's industrial tool and, encouraged by the Recovery plan, its modernisation. A role which, apart from our traditional missions aimed at supporting companies through partnership research programs, extends more and more frequently to supporting the public decision in an increasing number of sectors led by the energy and automotive industry. In 2021 for example, by taking part in numerous studies such as the definition of the purpose-driven companies or the IPCC reports, the Carnot M.I.N.E.S Institute demonstrated its ability to enlighten the public decision.

However, the most striking event of this year, and clearly of the years to come, is undeniably the historical turning point being taken by our society, and the consequences of this turning point on the meaning and very purpose of the research programs conducted with the companies. In a world in which transformation is amplified by climatic events highlighting the urgency of an ecological transition, which caused unprecedented changes in the behaviour and relation of the French population with respect to consumption and generating new expectations in our students and PhD students, innovation must now be sustainable, responsible and meaningful. Charles Darwin claimed that “It is not the strongest of the species that survives, nor the most intelligent; it is the one most adaptable to change”.

Our mission is now to help companies and communities to adapt by adapting ourselves to the societal, economic and environmental changes of our world.
The R&D partner of companies

To help companies with their innovation processes, 9 of the most prestigious French engineering schools (Mines Paris-PSL, 5 Écoles des Mines integrated with the IMT, École Polytechnique, ENSTA Paris and Clermont Auvergne INP) federated their research laboratories within Carnot M.I.N.E.S, a structure dedicated to partnership research with companies. These laboratories, including numerous CNRS (National Centre for Scientific Research) Joint Research Units, rely on the ARMINES association to develop their contract-based research studies.

Our 5 fields of expertise

- Earth and environmental sciences
- Materials sciences and engineering
- Energy and process engineering
- Applied mathematics, computer science, automation
- Economy, management, society

Employment: the Recovery Plan relies on research

A key measure of the National Recovery Plan launched at the start of 2021, the R&D job preservation Plan is intended to support the competitiveness of companies through innovation, by encouraging partnership research through employing or providing R&D personnel in projects between public research laboratories and companies.

Together with their industrial partners, Carnot M.I.N.E.S research centres have therefore contributed to creating or safeguarding 50 R&D jobs. For example, the SME M2i and the RIME team of IMT Mines Alès reinforced their partnership around their shared laboratory Soph'air (Solutions for Pheromones Analysis in Air), by hiring an engineer and a post-PhD student.

2021 activity report - Carnot M.I.N.E.S Institute
In 2021, over 400 companies placed their trust in us:

**Energy, resources, environment**
- Low-carbon energy
- Innovative extraction methods
- Carbon Capture, Utilisation and Storage (CCUS)
- Power to X
- Smart electrical networks
- Energy efficiency
- Hydrogen technologies
- Energy market economics
- Depollution
- Environmental impact
- Eco-design

**Transportation, sustainable mobility**
- New materials and their transformation processes
- Light structures
- Intelligent transportation systems
- Logistics
- New mobilities
- Low-carbon mobility

**Technology industries**
- Systems control
- Additive manufacturing
- Innovative design
- Digital business transformation
- Digital twinning
- Virtual reality
- Augmented reality
- Digital modelling and simulation

**Building, public works**
- Revalorisation and recycling
- New materials
- Air quality
- Energy performance

**Health**
- Medical textiles
- Biosensors
- Innovative galenic technologies
- Statistical learning algorithms
- Image analysis
- Hospital management support tools

**Telecom, Digital**
- Supervision
- Cybersecurity
- Quantum technologies
- Data mining
- Databases
- Media use

**Services**
- Corporate forms and governance
- Managerial practices
- Innovation management
- Future of industry and labour
- Risk practices
- Innovation management
- Corporate forms and governance
- Managerial practices
- Innovation management

**Luxury industry, consumer goods**
- Transmission of know-how
- Preservation of intangible heritage
- Sensitivity of materials
- Connected objects
- Flexible electronics
- Biosourced materials

**Who are we?**

Over 740 contracts per year

- €45M partnership income with the socio-economic world
- €25M income from direct contracts with the companies

32% of research contracts with the VSEs/SMEs/intermediate-sized enterprises (ISEs)

354 patents and software programs held in portfolio

17 new priority patents and software programs filed in 2021

51 inventions declared

Carnot M.I.N.E.S Institute - 2021 activity report
What are our commitments?

- Scientific excellence and cutting-edge technical resources
- Professionalism of the partnership relation
- Optimisation of knowledge transfers
- Guarantee of confidentiality
- Balanced intellectual property
- Attentiveness and reactivity
- The strength and momentum of a multi-disciplinary network

How do we finance our actions?

By receiving a grant from the French National Agency for Research (ANR) proportional to the volume of our our bilateral R&D contracts.

This financing is used to:

- Anticipate the future requirements of companies and further our skills through financial support for selected projects
- Strengthen our professionalism in the partnership relation.

What support for the economic sectors?

By fostering the structuring of the offer provided by the Carnot institutes around major economic sectors, the Future Investment Program (PIA) 2015-2021 enabled numerous SMEs to benefit from partnership research specific to their activities. Boosted by the success of this strategy which led to an 85% increase in the activity with the SMEs across all the Carnot institutes, they continue their collective commitment through alliances with each economic sector. Carnot M.I.N.E.S is involved in four alliances: Fashion and Luxury, Low-carbon impact energies, Mobilities and Industry of the future.
Our ambition: place innovation within the reach of all companies

Whatever their size, geographic situation or activity, companies need to innovate, not only to remain competitive in a globalised economy, but also to adapt to the energy, ecological and digital transitions. Through its multidisciplinary nature and the professionalism of its partnership relation, Carnot M.I.N.E.S can support companies of every type, at every stage in their growth, from the startup to the major group, with the development of their industrial processes or new products and services.

Our means: the art of creating synergies between skills

Whether additive manufacturing, the hydrogen sector, the responsible industry or the recycling of polymers, our research centres benefit from the financing boost of large scale Carnot projects. Every year therefore, between twelve and twenty teams from the Institute join together to develop new interdisciplinary skills to take up an energy, digital or environmental transition challenge. The synergy created by these flagship projects ranks Carnot M.I.N.E.S as one of the leaders conducting research on these subjects with the companies.

Internationally recognised scientific excellence

In line with its objectives, in 2021 Carnot M.I.N.E.S continued to develop its activity internationally, thereby promoting the reputation of French research abroad. Highlights: increased participation in major community projects in the fields of the energy and environmental transition and a major contribution to the IPCC studies. The scientific excellence of our researchers was recognised by grants awarded by the European Research Council (ERC) and prizes, as well as by the coordination of European collaborative projects, publications in the best international journals and by our researchers being invited to prestigious conferences. At the same time, the skills and means of the institute have received significant publicity at the major international trade fairs.
Responsible industry

From the industry of the future to a resilient, sustainable and attractive industry

3 questions to Éric Ballot, in charge of the Responsible Industry federating project

Today, what are the main challenges for French industry?
French industry is at a turning point in its history. The models which drove down production costs and led to delocalisations proved to be ineffective and even counter-productive. Now subject to strong pressure to become more resilient and responsible, French industry suffers from a poor image making it unattractive to young graduates. Regaining its reputation will clearly involve more than improving its image and will require a significant scientific investment worthy of this new challenge.

To address these challenges, Carnot M.I.N.E.S is promoting a “responsible industry”. What does this mean?
Over the last ten years, the prevailing vision of the future of the industry is the German “Industry 4.0” model, based mainly on robotisation of the production tool. Our approach is to study the integration of new tools and above all its impact on the organisations. Carnot M.I.N.E.S therefore promotes a “responsible” industry organised around two pillars: the digital platforms and reconfiguration of the networks.

What do companies and Carnot M.I.N.E.S researchers expect from this project?
The mission of Carnot M.I.N.E.S is to help industrial companies with their transition. For us, this project is a good opportunity to set up true dialogue with the industrial companies in order to provide a joint response to the challenges to be taken up to move towards a responsible industry. Discussion days will be organised to promote the search for solutions and the emergence of original collaborations based on multi-disciplinary inputs combining engineering sciences and human and social sciences.

Interconnected production systems: the new challenges of the supply chains
The quality of the decisions made by the production managers depends more than ever on the risks and opportunities that they are capable of handling. To provide the production systems with sufficient degrees of adaptation, the Mines Paris-PSL Scientific Management Centre and the IMT Mines Albi Industrial Engineering Centre suggest using the paradigms of the Physical Internet, which recommends in particular developing the interconnection of supply chains, both in production and distribution.

Through a PhD thesis shared between the two teams, the aim is to design and develop the concepts required by the adaptive configuration systems of the future production systems. In a context which has now become deeply unstable, these concepts will allow the right decisions to be taken, to increase the ability to dynamically reconfigure to maintain the performance levels of the systems responsibly and sustainably.

Éric Ballot, eric.ballot@minesparis.psl.eu
Professor of production and logistics system at the Mines Paris-PSL Scientific Management Centre. Holder of the Physical Internet research chair

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OUR FLAGSHIP PROJECTS

2021 activity report - Carnot M.I.N.E.S Institute
Polymers

Accelerate the transition towards the circular economy by improving the recyclability of plastics

A pillar of the circular economy, recycling of plastic materials involves extensive research studies to make recovered polymers an efficient "secondary raw material". The objectives of the “Polymer recyclability” project are to use recycled PET in bottles, recover textile wastes and design new biosourced composites. This project also aims to assess the economic, social and societal performance of a production system based on incorporating recycled material in new products, in line with an industrial policy based on recycling.

New high-added-value biomaterials based on old textiles

Several tens of millions of tons of textiles are marketed every year, generating the same amount of waste of which only a very small proportion is recycled. Recycling is highly complex, since most of this textile waste consists of several components. In this context, the project team developed a technology to extract and transform cellulose-based bio-aerogels from old textiles, such as rayon, viscose and cotton, in order to use them for cosmetic, pharmaceutical or agribusiness applications.

Internal structure of cellulose aerogel beads produced by prilling from 100% viscose textile waste.

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Jean-Luc Bouvard, jean-luc.bouvard@minesparis.psl.eu coordinator of the polymer recyclability project, in charge of the Physical mechanics of Industrial Polymers group, CEMEF, Mines Paris-PSL

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Stretchability of recycled PET: Application to the stretch blow moulding process

The "Single-Use Plastics" directive, approved by the European Parliament in March 2019, set the objective of incorporating 30% of recycled plastic in all PET beverage bottles from 2030. The team built a digital model to predict the temperature changes of PET preforms due to the recycling rate. It also studied the effect of contaminants on the formability of PET and defined the relation between the microstructural properties and the crystallisation process of recycled PET compared with virgin PET.

Monitoring of the deformations during a PET blow moulding process at 120 °C.

Tatiana Budtova, tatiana.budtova@minesparis.psl.eu

Internal structure of cellulose aerogel beads produced by prilling from 100% viscose textile waste.

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Jean-Luc Bouvard, jean-luc.bouvard@minesparis.psl.eu coordinator of the polymer recyclability project, in charge of the Physical mechanics of Industrial Polymers group, CEMEF, Mines Paris-PSL
Covering the entire value chain of the hydrogen sector, the HyTrend project studies several production pathways, by high and low temperature electrolysis or methanation of hydrogen, as well as its massive storage in salt caverns. The project also studies the consequences and associated environmental risks as well as societal acceptability. Boosted by its successes, the HyTrend project will continue its development as part of the activities of the H2MINES group, which federates all the R&D expertise of Carnot M.I.N.E.S for the hydrogen sector.

Hydrogen: operational solutions at the service of a true industrial sector

Efficient and sustainable hydrogen production
Single-atom catalysts have been developed to produce hydrogen from biogas. More efficient than industrial catalysts, they reduce the energy consumed by the process by optimising its operating conditions. Other applications are being investigated, such as the production of sustainable synthetic fuels with perspectives of industrial cooperation with companies, for example Altens, the alternative fuel supplier.

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associate professor, deputy director of the RAPSODEE centre - IMT Mines Albi.

What is the opinion of the general public concerning hydrogen?
Despite what many people think, a study conducted with the general public regarding the acceptability of hydrogen energy demonstrates that the safety issues, whether risks of inflammation or explosion, do not represent a major concern. In contrast, it revealed numerous interrogations and criticisms concerning the sustainable nature of hydrogen-based energy systems “clean” production, scale of the deployment to cope with the transition challenges, its place alongside gas and nuclear energies.

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Christian Beauger, christian.beauger@minesparis.psl.eu
H2MINES coordinator and manager of the Materials and processes for energy group, PERSEE Centre, Mines Paris-PSL
MINDS (Mines Initiative for Numeric and Data Science) focuses on the challenge that the convergence between "intensive computing" and "data science", as well as the use of predictive science, represents for the digital business transformation. By creating an R&D platform implementing this convergence, MINDS now forms an outstanding tool assisting with the development of high-level expertise in digital science.

Model the dispersion of particles in the wind

A thesis between Mines Paris-PSL and IMT Mines Alès led to the development of new neural network architectures, not only to create a model replacing the Navier-Stokes equations used to predict laminar or turbulent flows, but also to detect anomalies and quantify the uncertainty in the prediction of speed and pressure fields, thereby drastically increasing the accuracy of the model. The direct application resulting from these studies will be to model the dispersion of the particles transported by a predicted wind field around a complex obstacle on an industrial site.

Elie Hachem, elie.hachem@minesparis.psl.eu
professor and head of the Computing & Fluids research group, CEMEF, Mines Paris-PSL

Representative steady-state temperature distributions at the solid/flow interface.
R&D to create value

Co-development: capitalise on “waste heat”

The RAPSODEE laboratory of IMT Mines Albi is helping Eco-Tech Ceram, a fast growing SME, to develop systems for the recovery and storage of heat emitted during industrial processes. Set up 7 years ago, this partnership was reinforced with the creation of a new LabCom in 2021 and contributed to the success of a major fund-raising operation in October 2021. The laboratory also benefits from positive fallout related to the collection of top quality data and the access to the company’s industrial test equipment.

Assaad Zoughaib, assaad.zoughaib@minesparis.psl.eu (founder), Mines Paris-PSL Centre for Energy Efficiency of Systems.

Spin-off: highly energy-efficient air dehumidification and water distillation

Based on the research results of the Carnot AVENE-PME program and winner of the Mines Paris Spin-off 2021 competition, STEM (Société Technologique d’Échangeurs Membranaires) proposes a technology which reduces the mechanical (electrical) energy consumption from 50 to 75% in air dehumidification and water desalination processes.

Didier Perrin, didier.perrin@mines-ales.fr C2MA, IMT Mines Alès.
Carnot M.I.N.E.S abroad

E-SHAPE (EuroGEOSS Showcases: Applications Powered by Europe), an H2020 project to provide innovating services based on observation of the earth

Combining data science, co-design methods and the use of cloud resources, E-Shape develops unique services for the players involved in agriculture, health, renewable energies, ecosystems, water, disasters and the climate. Relying on Carnot M.I.N.E.S expertise in creating and monitoring European projects and coordinated by Thierry Ranchin from the Mines Paris-PSL O.I.E. centre, the E-Shape projects federates 69 international partners.

For more information: https://www.e-shape.eu

Monolith: an emblematic collaboration for the production of green hydrogen

In 2021, the research centres of Carnot M.I.N.E.S conducted bilateral research projects with 48 international partners, for a total contract volume of almost €7 M. The collaboration between the American startup Monolith and the PERSEE centre of Mines Paris-PSL has led to three new bilateral contracts, making a total of ten contracts signed with this company since its creation in 2013, for an amount of over €2.3 M. Further to a scientific breakthrough achieved by the PERSEE centre, the company developed its clean hydrogen production technology which consists in cracking a molecule of methane (CH4) at very high temperature to produce not only hydrogen but also carbon black, a material of high-added value for numerous industrial applications. The company, which employs 150 persons, currently operates a commercial unit and is making its first sales.

Laurent Fulcheri, laurent.fulcheri@minesparis.psl.eu

Silvère Bonnabel, associate researcher at the robotics centre and professor at Mines Paris since 2009, wins the 2021 European control award

Silvère Bonnabel and Axel Barrau, in partnership with Safran Electronics & Defense, developed a new version of the Kalman filter for inertial navigation.

Alexandre Dolgui, one of the most cited researchers in the world in 2021

Professor Alexandre Dolgui, head of the Department of Automation, Production and Computer Sciences at IMT Atlantique is on the Clarivate list of Highly Cited Researchers which identifies the world’s scientists most cited by their peers.
Simplify access to R&D

Place research within the reach of all companies

Initially, a company which has never conducted any R&D needs help to build its innovation strategy. This is the role of the Armines innovation support managers, who cooperate directly with our scientists. They propose a step-by-step action plan for the company, with milestones adapted to its leadtimes, means and constraints. Assistance to find additional funding is also proposed. The partnership relation is therefore set up in a climate of trust and co-construction.

Training: the way to R&D

Composed of engineering schools, Carnot M.I.N.E.S proposes engineering student courses to its company partners, which often lead to R&D. The institute’s technological platforms also open the way to partnership research. Lastly, the alumni are efficient relays and promoters of Carnot research within their own companies. Once the first collaboration has been set up, it can be continued according to the usual partnership research procedures, from the simplest to the most binding: bilateral contract, post-PhD research, CIFRE or CFR thesis, teaching and research chair.

Technology maturing process: the example of fashion and luxury

To enable SMEs to use our results more easily and reduce the risk inherent to their transfer, Carnot M.I.N.E.S produces proofs of concept and demonstrators of its technologies. Supported by the Future Investment Program and the ANR, we have been able in particular to create/propose new solutions to address the needs of the fashion and luxury industries. Each one comes with a laboratory logbook for companies to imagine future possible applications.

For more information: http://www.carats-innovation.com

Carnot M.I.N.E.S teaching webinars

In 2021, Carnot M.I.N.E.S proposed a cycle of webinars on the vocation and benefits of partnership research for companies.

Find these webinars on our YouTube channel: https://www.youtube.com/user/CarnotMINES

Titane Vivant: the new titanium colour ranges
Jenny Faucheux, Mines Saint-Etienne.
Exemplary collaboration

Nanomaterials for sustainable lithium extraction

GEOLITH in brief
GEOLITH is a startup providing an innovative and sustainable technology for the extraction of lithium, a rare metal used more and more frequently in modern technologies. The company which employs 16 persons, including several doctors and R&D engineers, has achieved its first sales of pilot installations in the United Kingdom and Chile.

What was the company situation in 2018, when the first contacts were made with Carnot M.I.N.E.S?
Our ambition was to develop an innovating process to extract the large quantities of lithium contained in geothermal water, but which had remained unused. However, after exploring several avenues, no satisfactory solution had emerged. It therefore became urgent, for the survival of the company, to quickly demonstrate the feasibility of our idea. We then met Jean-François Hochepied, who suggested using nanomaterials whose properties could meet our need.

You have cooperated several times with the Mines Paris-PSL Centre of Materials. What can you tell us about your experience?
We first hired an intern for six months, who was welcomed and co-supervised by the laboratory. This internship enabled us to validate a proof of concept of the nanomaterial for our application. A real racing start to trigger a first fund-raising operation for the company. In 2019, we launched a CIFRE thesis to optimise the manufacturing recipe for these nanomaterials, which enabled us to build a pilot at industrial scale and open the way to two orders for installations used to produce several metric tons of lithium per year. Recently the Centre of Materials hired a research engineer, under the Recovery Plan, to continue improving the performance of our solution.

Apart from the scientific input, what can you tell us about the support proposed by Carnot M.I.N.E.S?
It is not easy for companies to find the expert capable of addressing their issues. The Carnot M.I.N.E.S innovation support managers helped me find the right person. By initiating collaboration through a research internship, we were able to explore a new pathway within very short delays with a limited financial risk. Lastly, I especially appreciated the quality of the exchanges and the positive attitude during the negotiation and contractualisation steps which marked and simplified the implementation of our partnership.

The expert’s point of view: Jean-François Hochepied, Centre of Materials, Mines Paris-PSL
"The collaboration with GEOLITH is the perfect partnership! It allows me to develop materials that I know well for a new application framework, which is always a stimulating challenge. It also combines knowledge breakthroughs and more applied research. Lastly, it is very rewarding to see, almost in real time, the impact of our research on the company development."

Carnot M.I.N.E.S Institute - 2021 activity report
The research structures of Carnot M.I.N.E.S rely on the ARMINES association to develop their contract-based research studies.

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