



Highlights of 2023



Carnot M.I.N.E.S set a new course during a strategic seminar held on 13 and 14 September (page 7).

IMT Mines Alès celebrate its 180th anniversary.





Laurent Fulcheri, Mines Paris - PSL, was awarded the Carnot Prize for his long-term partnership with the American company Monolith (page 15).

So Ph'Air (Solutions for Pheromones Analysis in Air) joint laboratory,

a partnership between M2i Group and IMT Mines Alès renewed for three more years (page 9).



Mines Paris - PSL celebrate its 240th anniversary.



Mines Paris - PSL launches the Institute for Digital Transformation (ITN), whose aim to put the benefits of digital transformation within society's reach (page 8).

Two new Industrial Research Chairs:





for assessing the impacts of climate change and quantifying the associated risks. https://chaire-geolearning.org/

IMT's **Digital Twins for Industrial Systems Research Chair** (page 14).



Carnot M.I.N.E.S a catalyst for transition

Everything around us seems to compel us to change. Take the climate crisis, the current conflicts in Ukraine and the Middle East, inflation and rising public debt. Most importantly is the explosive emergence of artificial intelligence-based technologies that are as alarming as they are fascinating and which have yet to reveal just where they will lead us.

> Change, yes. But how? We are convinced we should encourage this fullblown transformation of our economic systems, our organisations and our values rather than simply yield to it.

Editorial

This philosophy prompted us to create the Institute for Digital Transformation (ITN), an entity that guides individuals and society through technological transformations. It also spurred MINES Saint-Étienne, IMT Mines Albi and IMT Mines Alès to create the Digital Twinning for Industrial Systems Research Chair with the support of the Fondation Mines-Telecom. Change, and adapting to change, is the overarching principle behind the design of our training programmes, which always combine ethics and innovation in the service of our students. IMT Atlantique has created a new 40-position PhD programme as part of SEED (Societal, Energy, Environmental, Industrial & Digital), a project supported by the European Union.

This vision is also reflected in cutting-edge technological research that holds great promise for environmental transition, such as the IMT Nord Europe's Echohydro hydrogen storage research project. Because if there's one transition that underpins all the others, it's environmental transition. Researchers at our member establishments are tirelessly pursuing their efforts in this field, as illustrated by ELECTRE, the Carnot M.I.N.E.S. 2023 flagship research project. For example, at Mines Paris - PSL, CERNA's research on the macroeconomic and societal effectiveness of building renovation subsidies, or the CGS's research on the law of general average, a principle of maritime law that dates back to ancient Rome.

Is the idea, as Tomasi di Lampedusa's hero predicted in The Leopard, to change everything so that ultimately everything virtually remains the same? Quite the contrary. We should accept this necessary and inescapable transition for what it is: much more than a 'fork in the road', it is a profound and desirable transformation of our models.



Director of Carnot M.I.N.E.S

Governance

Director

Yannick Vimont Operating director Agnès Laboudigue Deputy directors David Delafosse Éric Weiland Administrative and finance manager Anne Piant

The R&D partner of companies

To help companies with their innovation processes, nine of the most prestigious French engineering schools (Mines Paris-PSL, five Écoles des Mines integrated with the IMT, École Polytechnique, ENSTA Paris and Clermont Auvergne INP) have jointed their research laboratories within Carnot M.I.N.E.S, an entity dedicated to partnership research with private-sector companies. These laboratories, including numerous CNRS UMRs (research laboratories), draw on the Armines association to develop their contract-based research studies.



research staff including:

 $430_{\text{research fellows}}$

491 research engineers and technicians

842 PhD students (including 179 in the CIFRE programme)

 96_{postdocs}

One mission of Carnot M.I.N.E.S is to build bridges

Economy, management, society

between business and research

Developing research partnerships means properly showcasing available skills and resources to the right target audience and in the right way. That is why Carnot M.I.N.E.S organises, supports and participates in daylong forums on specific industry issues, webinars, research days , general or sector-specific trade shows and many other events that promote the research activities of its centres to industrial players. Every year, these events bring together our research teams and private-sector companies to discuss industrial, scientific and technical challenges across hundreds of sessions and strengthen current partnerships and build new ones.



Over 320 companies placed their trust in us in 2023

In 8 main sectors of activity:

Energy, resources, environment

• Low-carbon energy • Innovative extraction methods • CO₂ capture, storage and recovery • 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

- Lighter structures Intelligent transportation systems • Logistics • New mobilitie
- Low-carbon mobility

Transformation industries

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

Building, public works

• Recovery and recycling • Novel materials

• Air quality • Energy performance

Health

- Medical textiles Implants 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 and crisis management • Resilience

Luxury industry, consumer goods

• Transmission of know-how • Preservation of intangible cultural heritage • Sensoriality of materials • Connected objects • Flexible electronics • Biosourced materials Over 630

€40 M partnership income with the socio-economic world

€23 M income from direct contracts with the companies

25% of the direct activity with the VSEs/SMEs/intermediate-sized entreprises (ISEs)

529 patents and software programs held in portfolio

12 new priority patent applications and software programs filed in 2022

33 inventions declar

DIOR * PARIS BEDDING TECHNOLOGIES • PFIZER • PLACOPLATRE • PMC • PPG FRANCE • PROCESSIUM • OUALIPAC • RB • RENAULT SAS ROBERT BOSCH GMBH • FRERES • S.F.D.M. • S3D • SALINS DU MIDI ET SANCARE • SANOFI • SALINS DU MIDI ET SANCARE • SANOFI • SALUMA ARLES • SAS • SATYS SURFANCE SAVIMEX • SBM FRANCE SAVIMEX • SBM FRANCE

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LECTRIC • SCIENCES & COMPUTERS CONSULTANTS • SDL P • SECAB • SECHE ENVIRONNEMENT • SET ENTRAPOR • SEQUA • SENSIENT COSMETIC TECHNOLOGIES • SEPRE SERS • SEREME • SFL SOCIÉTÉ FINANCIÈRE DE LATTAC • SOS • SHELL • SICONTIN • SIDEL • SIGVARIS • SISMO • SME SOCIETE METALLURGIQUE DE FONTAINE • SNCZ • SOCIETE DE SERVICES PETROLIERS • SOCIETE GENERALE • SOFRADIM PRODUCTION • SOFRECONOS • SOFTBANK ROBOTICS • SOCIETIES • SOLF • SENSIENT • SOLF • SNCZ • SOLF • SNCZ • SOCIETE DE SERVICES PERROLIERS • SOLVES • SOCIETE GENERALE • SOFRADIM PRODUCTION • SOFTBANK ROBOTICS • STOREWATT • STRATIFORME • SUEZ GROUPE • SYLOB • SYNDICAT DES VINS DES SABLES • SYNVINA SOCIETE METALURGIQUE DE FONTAINE • SPH CONSEIL • SPICE • STADE • STELLA SURGICAL • STIMISHOP • STILLOS • STOREWATT • STRATIFORME • SUEZ GROUPE • SYLOB • SYNDICAT DES VINS DES SABLES • SYNVINA SOCIETE METAWIRELESS • TARKETT FRANCE • TECHNETICS GROUP • TECNIMONT • TEFAL SAS • TEREOS FRANCE • TERRASD • TERREAL • TETRA PAK PROCESSING EQUIPMENT SAS • TEXCELL • THALES • THE WORLD BANK • THUASNE • TIMET SAVOIE SA • TOP INDUSTRIE SAS • TOPPAN 'HOTOMASKS FRANCE S.A.S. • TRACTEBEL ENGINEERING • TRANSVALOR • TRELL • STELLE SOCIETIE SAS • TEREVES PRODUCTS, SERVICES & INNOVATION • TRIPBIKE • TUPPERWARE BELGIUM NV • UBISOFT INTERNATIONALE • TIMET SAVOIE SA • TOP INDUSTRIE SAS • TEREVES PRODUCTS, SERVICES & INNOVATION • TRIPBIKE • TUPPERWARE BELGIUM NV • UBISOFT INTERNATIONALE • TIMET SAVOIE SA • TOP INDUSTRIE SAS • TEREVES PRODUCTS, SERVICES & INNOVATION • TRIPBIKE • TUPPERWARE BELGIUM NV • UBISOFT INTERNATIONALE • UMALIS GROUP • UNITED VISUAL RESEARCHERS IVR • UNIVERSITE CATHOLIQUE DE RIO DE JANEIRO • URBAN COD • URGO RECHERCHE INNOVATION ET DEVELOPPEMENT • USA & INNOVATION • TRIPBIKE • TUPPERWARE BELGIUM NV • UBISOFT INTERNATIONALE • UNALLE • VOLIO • VISUAL RESEARCHERS IVR • UNIVERSITE CATHOLIQUE DE RIO DE JANEIRO • URBAN COD • URGO RECHERCHE INNOVATION ET DEVELOPPEMENT • USA EUCONTIFIC RESEARCH • V. MANE FILS • VALEO • VALLOURE • VARELE • UNALLE • VOLTO • UNTED VISUAL RESEARCHERS

INSTITUT CARNOT M.I.N.E.S - 2023 activity report

Carnot Institutes are public research entities approved by France's Ministry of Higher Education, Research and Innovation. They are strongly committed to spearheading and developing research partnerships that drive innovation in companies of all sizes, from SMEs to large corporations, and amongst socio-economic players.

Carnot — stringent, empowering and attractive

The Carnot name has established itself as a guarantee of scientific excellence and quality. The entities that bear its name are committed to promoting the development of research partnerships, i.e. conducting research led by France's top laboratories and their technology facilities in partnership with socio-economic players, in particular private-sector companies.

Thanks to its strong presence throughout France and its multidisciplinary approach, the Carnot network provides companies in all sectors of industry the R&D resources they need to enhance their competitiveness.

How do we finance what we do?

Through a grant from the French National Agency for Research (ANR) that is proportional to the volume of our bilateral R&D agreements.

This financing is used to:

- Anticipate the future requirements of companies and further develop our skills through financial support for selected projects (past winning projects are presented on pages 10 to 12).
- Strengthen our professionalism in our partnerships.

Key figures | A guarantee of excellence

government-approved Carnot Institutes

of public research staff

55%

of R&D funding from public-private partnerships is allocated to the Carnot network

The H2MINES group at the Hyvolution 2023 trade show.

Working together to meet the needs of industry

The Carnot network's priority is to make a wide range of skills available to companies in any given industry. The entities in Carnot M.I.N.E.S are collectively committed to helping four sectors that are key to France's economy: healthcare, low-carbon energies, fashion and luxury, and the industry of the future. They collaborate closely with the relevant Strategic Sector Committees (CSF) to offer companies comprehensive solutions and a high level of technology readiness.

priority patent applications filed (top applicant holder in France)

La recherche



Ambition and strategy

Placing innovation within reach of all companies

Innovation is a must for all companies regardless of size, location or sector. Not only does innovation keep a company competitive, it also enables it to adapt to both current and future 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 startups to major groups, with the development of their industrial processes or new products and services.

Our means: the art of creating synergies between skills

Whether the focus is on the shift from fossil fuels to electricity, the recyclability of polymers, healthcare or corporate social responsibility, our research centres benefit from the funding dynamics of large-scale Carnot projects. Between 12 and 20 teams from the Institute work together each year to develop new interdisciplinary skills to address the latest challenges. The synergy created by these flagship projects ranks Carnot M.I.N.E.S as one of the leaders in research on these issues with private-sector companies.

Internationally recognised scientific excellence

In line with its objectives, in 2023 Carnot M.I.N.E.S continued to develop its activity internationally, thereby promoting the reputation of French research abroad. The scientific excellence of our researchers extends beyond France's borders. It has enabled them to obtain grants and prizes, coordinate European collaborative projects, publish articles in top international journals and be 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.

Strategic seminar held to set a new course for Carnot M.I.N.E.S

Representatives of the Institute's nine member establishments came together in the southern French city of Aix-en-Provence on 12 and 13 September to map out a common vision for the future.



Research directors, research centre heads, research fellows, and partnership development managers and assistants worked together over these two days to update their establishments' collective goal and define the actions needed to renew Carnot Network certification for the period 2026-2030.

Quality: the core of Armines' strategy



Armines obtained ISO 9001:2015 certification for the first time in late 2023. This certification recognises its quality management system for contractualization activities and administrative and financial follow-up of partnership research contracts.

To read Armines' quality policy, go to

http://cloud.minesparis.psl.eu/index.php/s/JL5ZBJazdJpzpLX/download

Placing innovation within reach of all companies

The etilab research chair published its first report on the carbon footprint of France's intermediatesized entreprises (ISEs)

One year after its creation, the etilab Mines Paris - PSL research and teaching chair published 'Decarbonisation, reindustrialisation and intermediate-sized entreprises (ISEs), its first report on the role middle-market companies can play in decarbonising France's industrial sector. The report's findings, which are based on a detailed study of energy consumption in the nation's industrial sector, show that French intermediate-sized entreprises (ISEs) generate as much greenhouse gas (GHGs) as large companies. The report identifies the 12 subsectors that generate the highest GHGs emissions and proposes a number of actions to help French intermediate-sized entreprises (ISEs) comply with the EU's Corporate Sustainability Reporting Directive (CSRD), which entered into force in 2023.



Click the link below to download the report: etilab-decarboner-les-ETI-30nov23

https://etilab.minesparis.psl.eu



Institute for Digital Transformation (ITN) — making the digital transformation work for society as a whole

With the Institute for Digital Transformation (ITN), Mines Paris -PSL is mobilizing its multi-disciplinary research units and training programmes to accelerate industrial scale-up and technological innovation, as well as promote adoption and future uses. In a world where interactions between humans and machines are growing day by day, Mines Paris - PSL is mobilizing 19 research centres to create leverage, based on solid mathematical foundations and in close collaboration with the business world, to help companies transition from innovative start-up to scale-up to foster a sustainable and socially responsible society.

Training — one method of transferring our research findings to companies

Training is one of the best ways to transfer research findings to companies. In addition to formal training, Carnot M.I.N.E.S provides business leaders, researchers, engineers and technicians with training delivered by its own researchers and based on their most recent innovations. Mines Paris Executive Education offers standard and custom continuing education courses and Mines Paris - PSL has created the Deeptech & Innovation specialized master's degree, which supports and trains candidates in creating innovative companies based on the latest advances in scientific research.

To find out more, click the links below: https://executive-education.minesparis.psl.eu/ https://deeptech.minesparis.psl.eu/

A flagship collaboration – a joint laboratory



IMT Mines Alès and M2i are working together to increase crop protection by fooling insect pests

M2i, Europe's leading producer and distributor of insect pheromones used in crop protection, employs 200 people at four sites in France and has filed a portfolio of 22 patent families since 2012.

Why get rid of insects and other crop pests with pesticides, when you can outwit them instead? That is the idea behind biomimicry and biological pest control, two methods that are rapidly gaining traction in the agricultural sector. Both offer practical solutions for protecting crops, preserving the environment and complying with increasingly stringent European regulations without resorting to the use of pesticides.

"We have long enjoyed a collaborative relationship with IMT Mines Alès. Creating synergies between applied research and scientific and academic knowledge is what drives us and enables us to make faster progress"

Patrick Durand,

Director of M2i's R&D lab in Lacq, France

In 2020, M2i entered into a partnership with the Research on the Interaction of Materials with their Environment (RIME) team at IMT Mines Alès in the south-western French city of Pau (UMR 5254 IPREM) to assess the effectiveness of these methods and propose optimal formulations. The resulting joint laboratory, called 'So ph'air' (Solutions for Pheromones Analysis in Air), looks into the diffusion through the air of molecules that mimic sex pheromones released by female insect pests. The aim is to confuse male insect pests so that they fail to mate, thereby reducing population levels.

The research programme's main objective is to experimentally determine the parameters of airborne pheromone transmission and then model the processes of pheromone emission and dispersion in field conditions so as to estimate the zone of action and persistence over time of the pheromone concentrations needed to maintain the effectiveness of treatment.

The partnership has led to two research theses since its creation. The first looks at pheromone diffusion kinetics as a function of formulations under controlled conditions in order to develop measurement methods that can be applied to crop environments (greenhouses and fields). The second thesis, begun in February 2024, aims to model the dispersion of these active substances and provide new information to validate these biological pest control solutions in real-world conditions.

Thanks to these advances, the agreement behind So ph'air has been renewed for a further three years with



Pheromone-impregnated trellis clip for pest control.

the aim of overcoming other scientific barriers in the field of biological pest control by identifying the best bioactive compounds, the effective doses and the effects on insect behaviours. An electroantennography (EAG) laboratory, where behavioural tests are being developed, has been set up for this purpose. A team of six people (three from IMT and three from M2i) is currently based at M2i Group's R&D lab in Lacq, a few kilometres from Pau.

"Being part of a long-term partnership that drives the growth and development of a French middle-sized hightech company on the national and international markets is very rewarding for our team. The project's strong environmental focus is another reason why we support it."

> Valérie Desauziers, joint laboratory head, IMT Mines Alès

To learn more:

https://www.carnot-mines.eu/biomimetismeprotections-des-cultures-sans-pesticides-so-phair/

Valérie Desauziers,

valerie.desauziers@mines-ales.fr, research fellow, IMT Mines Alès 10

ELECTRE project



Using multidisciplinary research to make a clean break from fossil fuels

Three questions for Philippe Blanc, project coordinator

What role can the electrification of certain activities play in the energy transition?

The International Energy Agency (IEA) has stated ¹ that if the planet is to become carbon neutral by 2050, the portion of electricity in global final energy consumption must increase from today's level of just 20% to 50%. This increase in electricity production, which will have to come from renewable energy sources in particular, will enable many activities, such as transport, heating, air conditioning and certain industrial processes, to shift away from dependence on fossil fuels.

However, the electrification envisaged in a number of forward-looking scenarios, such as RTE's 'Energy Futures 2050¹², faces a wide range of scientific and technical challenges at various scales ranging from materials to national energy systems.

Precisely what challenges does Carnot M.I.N.E.S intend to address?

ELECTRE is a flagship project with four key elements:

- Materials for components such as batteries, electrolyzers and fuel cells, as well as conductors with specific mechanical and thermal properties.
- Energy storage to optimize the integration of renewable energies into power systems by taking account of technological as well as economic aspects.
- Electrification of industrial processes, particularly through hybrid approaches that combine low-carbon electricity with hydrogen combustion.
- The relevance, limits and future difficulties of electrifying activities, such as constraints on mineral and critical resources.

What are the potential impacts on the industrial sectors targeted by the project?

ELECTRE is a multidisciplinary project that brings together the engineering sciences with economics and sociology. Our aim is to develop our teams' novel solutions to a higher level technological readiness so that they are more quickly adopted by various industries. Expected outcomes include new manufacturing processes for low-environmentalimpact components, software solutions for sizing electrical systems incorporating zero-carbon hydrogen, a tool for modelling the partial electrification of industrial processes that require vast amounts of power, and a methodological guide for deploying electrical production infrastructure incorporating a life-cycle assessment (LCA).

¹Net Zero Emissions by 2050 Scenario

² https://assets.rte-france.com/prod/public/2021-12/Futurs-Energetiques-2050principaux-resultats.pdf **6** schools (Paris, Saint-Etienne, Albi, Alès, Atlantique, Nord Europe)





Budget:



Period: 2023-2026 Electrification/Energy transition/Industry/ Transport

Measuring the impact on critical materials

Making a successful shift from fossil fuels to electrification requires giving careful consideration to the constraints on mineral resources and critical materials used in electricity transmission and energy storage technologies, in particular copper, nickel, lithium and certain rare-earth elements.

Led by two postdoctoral fellows from the PERSEE and Géosciences centres at Mines Paris - PSL, this project aims to produce summary reports for industrial and public policymakers, identify the main risks of mineral resource shortages and bottlenecks, and guide the technological choices of grid operators and electricity producers.

Philippe Blanc,

philippe.blanc@ minesparis.psl.eu, project coordinator, professor at the Observation, Impacts, Energy (O.I.E) centre at Mines Paris - PSL.

CARINGS

Engineering at the heart of the healthcare revolution

Using body sensors to improve workstation ergonomics

Musculoskeletal disorders (MSDs) can arise in workers who repeatedly maintain poor posture while performing their tasks. MSDs are responsible for 87% of occupational diseases and occur in a wide range of sectors, from transport and logistics, to industry, agri-food, construction and more.

CERIS at IMT Mines Alès, the Centre de Microélectronique de Provence at MINES Saint-Etienne and the Centre de Robotique at Mines Paris - PSL have joined forces to find ways to address this social, economic and public health issue by reverse engineering workstations to making them as ergonomic as possible.

By combining industrial engineering and operational research, the members of these three complementary teams are working to understand and characterize the whole-body ergonomics score in real time (REBA: Rapid Entire Body Assessment). Their research involves fitting a worker with 17 body sensors and placing 3 separate sensors on tools or other objects typically handled by the worker.

The data captured by the sensors are then integrated into a virtual environment according to a process of optimisation of multiple performance indicators (strain, time,

costs and productivity). The virtual workshop is then recreated in the real world to check the applicability and suitability of this optimal configuration for both the worker and their work environment. Demonstrations are currently being finalised with two industrial partners, Airbus Helicopters and WBI.

The next phase of the project will involve proposing human-centred decision support models that take ergonomic scores into account. In addition, workers will receive recommendations on more ergonomic postures or movements that require less physical effort as well as advice on redesigning their work environments.



REBA score calculation streamed with Unity (REBA score severity: very high in red, medium in yellow).



Marius Huguet et Vincent Augusto - TRACKING project.

TRACKING: using indoor positioning to improve management of accident and emergency departments

Teams from IMT Mines Albi, MINES Saint-Etienne and Mines Paris–PSL are experimenting with using indoor positioning to manage the staff at the A&E department of Le Corbusier hospital in Firminy. It entails the use of a badge-sized sensor that staff wear while on duty.

One significant outcome shows that the proportion of activities directly related to care represents, on average, only a third of doctors' total on-duty time, while activities not directly related to care seem largely attributable to administrative workload and movements. An algorithm that can predict the type of healthcare professional (doctor, referral nurse, etc.) and detect unscheduled changes in activity over the course of a day has also been developed. Building on this work, the researchers are using a digital twin to look at the potential of real-time information accessibility to model patient flows.

To learn more:

https://www.carnot-mines.eu/tracking-

geolocalisation-gestion-des-urgences-hospitalieres/



6 schools (Paris, Alès, Albi, Nord Europe, Saint-Étienne, Clermont Auvergne INP)





Period:

2022-2025

Engineering and health/ Digital technologies/Air pollution

Pierre Slangen, <u>pierre.slangen@mines-ales.fr</u>, professor at IMT Mines Alès

Socially responsible industry

Towards a resilient, sustainable and attractive industry

High added-value technologies and platforms

Using research in chemical kinetics to enable industry to use zero-carbon hydrogen

Combining natural gas with zero-carbon hydrogen and other additives is a very promising way of improving the carbon footprint of industrial plants without adversely impacting their operation and efficiency.

However, a number of technical hurdles still need to be overcome, many parameters and datasets (flame temperatures, auto-ignition times, etc.) need to be clearly determined, and pollutant emissions must be predicted and limited.

The Chemistry and Processes Unit at ENSTA, IP Paris set out to determine how to:

- increase experimental databases to validate/refine detailed kinetic mechanisms based on these data and data from the literature; and
- predict pollutant emissions based on the composition, temperature and pressure of hydrogen-air and methane-air mixtures.

To do this, the fundamental flame speeds of methane/ air mixtures were measured experimentally under various conditions. These experimental data were modelled to differentiate them from kinetic models existing in the literature and improve their predictability. The kinetic models implemented are detailed and bring together all the reactions that actually occur during combustion, thereby paving the way for calculating the dimensions of industrial equipment.

Laurent Catoire, <u>laurent.catoire@ensta-paris.fr</u>, professor at ENSTA Paris

Reconfiguration of production networks

Designing adaptive and robust production systems against a backdrop of crisis and interdependence

The quality of the decisions that production managers have to take is more than ever dependent on the risks and opportunities they are able to address in a very short space of time, even as geographic and time stages and scales multiply. The system needed to manage such situations must have sufficient degrees of adaptation that are known and can be mobilized.

And yet, the COVID-19 crisis demonstrated that some production systems can be reconfigured to meet unforeseen and urgent demands.

The Scientific Management Centre at Mines Paris - PSL and the Industrial Engineering Centre at IMT Mines Albi have collaborated to provide an approach that enables manufacturers to anticipate future crises. Based on the concept of the Physical Internet, which advocates the development of interconnected supply chains in terms of both production and distribution, the teams attempted to determine:

- if it is possible to consider the possibility of adaptation as a normal operating regime for production systems,
- how the reconfiguration and adaptation potential of such systems can be modelled,
- the properties production systems require to allow such adaptations to take place in an organized way.

The teams used ontological models to describe production systems, which are better suited to understanding exceptional situations that are bound to occur or recur. Such a model was built to test the capability of a production system intended to produce a product in an unanticipated way. This research has been extended to a production network, enabling a group of companies to describe its potential for adaptation and optimise the production of the desired product. The findings were validated using two practical cases — a gel and a bicycle frame — with convincing results.

This research has made it possible to design and develop the concepts required for adaptive configuration systems for the production systems of the future, which, in an inherently unstable context, will increase the capacity of production networks to dynamically reconfigure themselves to responsibly and sustainably maintain their performance levels.

Éric Ballot, <u>eric.ballot@minesparis.psl.eu</u>, professor at Mines Paris - PSL **Matthieu Lauras**, matthieu.lauras@mines-albi.fr, professor at IMT Mines Albi 19 research centres

schools (Paris, Albi, Alès, Atlantique, Saint-Étienne, Clermont Auvergne INP, ENSTA)







Period: **2021-2024** Industry / Resilience / Logistics /

Environmental transition

Towards control of recycled PET production parameters

European regulations require that plastic bottles must contain at least 30% recycled PET (rPET) by 2025. However rPET is more difficult to blow mould than virgin PET. This is because the forming range is more restricted, making it difficult to obtain a homogeneous thickness distribution.

As part of a thesis with SIDEL, one of the world's leading suppliers of solutions for liquid food packaging, the teams at CEMEF sought to gain a better understanding of the behavioural variations induced by mechanical recycling. To this end, virgin PET and various mechanically recycled grades were characterized under static and dynamic conditions. For example, the researchers observed a need to blow hotter without thermal crystallisation. The findings of this research will improve understanding of the behaviour of rPET during blow-molding



Figure 1: Free stretch blow molding (without a preform mould) of a recycled PET preform and the transverse deformation field determined by image correlation. and enabling our industrial partner to more effectively adjust forming parameters on the production line.

Christelle Combeaud,

<u>christelle.combeaud@minesparis.psl.eu</u>, senior research fellow at CEMEF, Mines Paris - PSL

Jean-Luc Bouvard,

jean-luc.bouvard@minesparis.psl.eu, professor at CEMEF, Mines Paris - PSL

The latest podcasts and videos from Carnot M.I.N.E.S



Are you curious about how research is helping companies and institutions navigate the challenged posed by environmental transition? Courant Porteur, Carnot M.I.N.E.S' French-language podcast on the major shifts shaping our world, is back with a second season devoted to the recyclability of polymers.

Courant Porteur is available on all listening platforms. Subscribe today!



Latest advances in environmental and social LCA

Paula Perez-Lopez is an expert in the environmental and social life cycle

assessment (LCA) of renewable energy production technologies.

In 2023, she participated in a number of research programs conducted with manufacturers and companies in the energy sector:

- Collaboration with RTE on the Futurs 2050 scenarios, through the LCA study evaluating electrification scenarios,
- Research on wind power, particularly offshore wind power, for environmental and social LCA as part of the LIF-OWI project, with RTE, EDF, Total Energies, Engie and Vallourec,
- LCA modelling of photovoltaic (PV) systems, including end-of-life stages, as part of a CIFRE thesis with Total Energies and IPVF.

Paula Perez-Lopez,

paula.perez-lopez@minesparis.psl.eu, researcher and head of environmental impacts activities at the Observation, Impacts, Energy (O.I.E) centre at Mines Paris - PSL



Leveraging R&D to create value

MINES Saint-Etienne boosts start-up Wallace Technologies

Wallace Technologies is developing an innovative battery based on the Stirling system — an external combustion engine that operates with a heat sink and a heat source — whose efficiency is enhanced by a highly compact heat exchanger.



The company turned to the Centre for Material and Structure Sciences (MSS) at MINES Saint-Etienne to design an exchanger with very thin walls of around 0.2–0.3 mm. To achieve this technical feat, the researchers adapted a laser powder bed fusion (LPBF) process. LPBF involves assembling parts by locally melting successive layers of powder measuring a few microns thick.

They succeeded in producing a new aluminium prototype. Measuring 13 cm high and 8 cm in diameter, it took three whole days to print.

https://www.carnot-mines.eu/fabrication-additive-

comment-lemse-propulse-la-start-up-stephanoise-

The University of Clermont-Auvergne and Michelin: a cutting-edge partnership for modelling tomorrow's materials

The Institut de Chimie de Clermont-Ferrand (ICCF), Michelin, Clermont teaching hospital and CNRS are working together in the SimatLab joint laboratory to determine the properties of polymer materials based on a microscopic view of the interactions between molecules. Powerful simulations, aided by artificial intelligence, can be used to produce models that dispense with the need to handle hazardous or costly materials, or to carry out a large number of experiments. Vehicle tyres contain more than 200 components, hence Michelin's interest in developing predictive systems to select

the materials for tomorrow's tires more quickly.

But the applications don't stop there. For example, in the field of medicine, SimatLab is looking at infusion systems to understand the phenomenon of drug adsorption in infusion systems.



To learn more:

https://www.carnot-mines.eu/modelisation-desmateriaux-polymeres-un-partenariat-de-pointe/

IMT launches the Digital Twinning for Industrial Systems Research Chair



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From optimization of logistics flows, the carbon footprint of a given activity, and reorganization of production, to new operating strategies, maintenance and more, manufacturers have to take many complex and rapid decisions. Digital twinning, whereby a physical object or system is modelled using performance indicators, helps to clarify the decision-making process. The aim of the research chair's experts is to increase the capabilities of digital twining by providing a global view of the systems involved, rather than just component assets. The various models must be able to be assembled together to create a simulation of the whole system and interact with it. Different levels – digital models, digital shadows, digital twins – will be able to be structured and combined.

The findings will be tested and applied by the research chair's industrial partners Siemens Digital Industries Software, Laboratoires Pierre Fabre and Inoprod. This research chair is shared by MINES Saint-Etienne, IMT Mines Albi and IMT Mines Alès, with support from the Fondation Mines-Telecom.

To learn more:

https://www.imt.fr/linstitut-mines-telecom-lancela-chaire-de-recherche-digital-twins-for-industrialsystem/

To learn more:

wallace/

International: contributions and recognition

Steering industrial assets to manage the transformation to Industry 4.0: the case of luxury timepieces

Is industrial scale-up a threat to corporate identity? In the world of luxury goods, such a question is by no means an overstatement. In fact, it is particularly acute. Its players are whipsawed by the pursuit, promoted by digitalisation, of industrial scale-up of craftsmanship and the commercial promise of traditional objects made unique by their handcrafted finish.

The Scientific Management Centre at Mines Paris - PSL (CGS) collaborated with the Swiss luxury timepiece company Audemars Piguet to look into the steering resources available to manufacturers and managers who wish to control Industry 4.0's impact on their company's industrial assets (specific skills and associated object value).

Following on from research on the cognitive role of assets in guiding innovation, the team has shown that assets are impacted by three areas of innovation and demonstrated the dynamics of interactions between players on industrial assets. The research team proposed a system that combines industrial human resources management, responsible governance and industrial innovation strategy to actively manage changes in industrial assets in the event of scale-up.

Sophie Hooge, <u>sophie.hooge@minesparis.psl.eu</u>, professor at Mines Paris - PSL. Scientific Management Centre – i3 UMR CNRS 9217

Laurent Fulcheri received the Carnot Prize for Partnership Research for his long-term collaboration with the American company Monolith

An innovation initiated over 10 years ago to produce turquoise hydrogen by means of high-temperature pyrolysis of natural gas.



To learn more:

https://www.youtube.com/watch?app=desktop&v=qHfIAlad1Zs

Leading ambitious and collaborative industry-intensive projects

Thanks to IMT Atlantique's new SEED PhD programme, supported by the European Union and 10 leading industrial and academic partners, 40 PhD students will benefit from cutting-edge training over the next five years. The programme takes an interdisciplinary, cross-sectoral and international approach to better support major transformations.

To learn more:

https://www.imt-atlantique.fr/fr/actualites/ cofund-seed-formation-doctorale

IMT Nord Europe is coordinating the EcoHydro project with the participation of IMT Mines Alès. The project brings together leading industrial players (Arkema, Airbus, Temsa) to develop a composite material based on Elium[®], a recyclable thermoplastic resin, to build tanks used to store gaseous or liquid hydrogen.

To learn more:

https://imtech.imt.fr/2023/12/05/ecohydrocomposites-recyclables-pour-stockage-hydrogene/





CONTACT

To work with the Carnot M.I.N.E.S

+33 6 8 4 6 4 2 4 9 3

🖄 contact@carnot-mines.eu

✗ @carnotmines

@carnot-mines

🔲 www.carnot-mines.eu



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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Économie, management, société



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