RESEARCH & INNOVATION

TRANSMISSION AND STORAGE
2019 REPORT & OUTLOOK

TERĒGA
GAS, ACCELERATING THE FUTURE

WHY THIS REPORT?

This document is Teréga's fourth report on its Research and Innovation (R&I) activities. It provides an overview of the strategic programmes our teams are currently working on in accordance with the IMPACTS 2025 corporate plan.
In addition to transmission, this report is the first to include the work undertaken on the now-regulated activity of gas storage, all of which is supported by the French Energy Regulatory Commission (CRE).

TRANSITION ACCELERATOR

The current situation poses twin challenges with global repercussions: the energy transition and digital transformation. Against this background, innovation is clearly a major priority for Teréga.

To successfully deliver the IMPACTS 2025 plan, the innovation effort is focused primarily on the long-term future of the company as a gas infrastructure operator that leads by example. Innovation also reinforces its ability to assert itself as a powerful accelerator of the energy transition.

The Teréga innovation policy is designed to motivate and stimulate its people so that everyone is an acknowledged contributor to delivery of its corporate plan.

Teréga is also committed to inviting its wider ecosystem to play a full part in developing the company's strategic priorities. This was the rationale behind the Innovation Tour organised and coordinated in all its operating regions by Teréga and some of its R&I partners in 2019.

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EDITORIAL

Cécile Boesinger

Head of R&I in the Teréga Strategy & Innovation Unit

"**The energy industry faces unprecedented challenges in meeting its energy transition goals.** In practical terms, the energy system must evolve towards a low-carbon, renewable, diversified and decentralised energy mix, and move away from being a vertically structured system dominated by fossil fuels. Gas in general, and the infrastructures operated by Teréga in particular, are central to this process of change, and innovation is an essential factor in the successful delivery of this transformation.

Its IMPACTS 2025 corporate plan sets out Teréga's commitment to being a key facilitator of this energy transition. Research & Innovation is integral to this framework at two levels:

- adapting infrastructures to accommodate the arrival of new gases (also known as green gases) by focusing work on their quality, the definition of acceptance thresholds, the management of new flows, etc.

- developing Smart Multi-Energy Grid projects that promote synergies between energy carriers (electricity, methane, heat, hydrogen, etc.) and their infrastructures.

The flexibility and adaptability of gas transmission and storage infrastructures make this resource a central link in tomorrow's energy system.

Naturally, continuous improvement initiatives remain key priorities for assured service continuity, security of supply and enhanced corporate responsibility.

This mission allows R&I to research and explore any new technology, technique or method with the potential to improve the integrity of engineered structures, installation performance, process digitalisation, personal safety, energy efficiency or environmental protection."

IMPACTS 2025 AND R&I... IMPROVING, SECURING AND ACCELERATING

The Teréga IMPACTS 2025 corporate plan is designed to enable the company to achieve its ambitions in tomorrow's energy landscape. It is structured around five key strategic priorities:

- **Guiding the consumer and the market**
- **Improving efficiency and accountability**
- **Raising the profile of the company**
- **Securing and accelerating**
- **Reinventing Teréga DNA**

Two structural initiatives flow from the corporate plan: BE POSITIVE (the Positive Environmental Performance initiative that aims to achieve a neutral environmental balance in 2020, and generate environmental value thereafter) and PARI 2025 (the Accidents and Industrial Risk Prevention initiative).
R&I plays a central role in this dynamic impetus through its IMPACTS 2025 Innovation Plan, which brings together seven innovative programmes for the regulated activity of gas transmission and storage.

THE 7 INNOVATION PLAN PROGRAMMES

IMPACTS 2025


INFRASTRUCTURE INTEGRITY


OPERATIONAL PERFORMANCE AND SAFETY


GREENHOUSE GAS EMISSIONS CONTROLS AND ENERGY EFFICIENCY


LOCAL INTEGRATION & ENVIRONMENTAL FOOTPRINT


NEW GASES

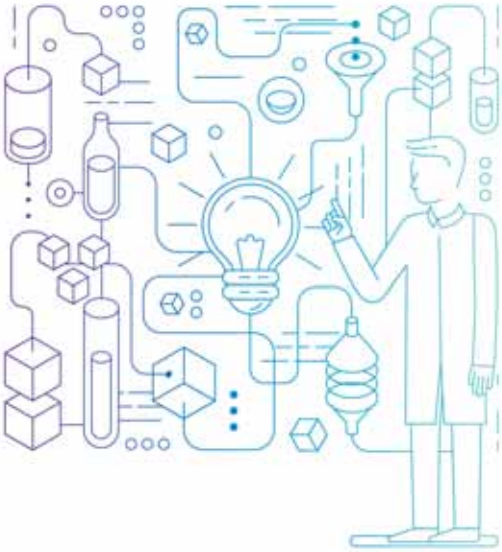

NETWORK AND SMART GRID INTEGRATION


UNDERGROUND STORAGE PERFORMANCE AND INTEGRITY

"Innovation focuses mainly on the two main issues of energy transition and digital transformation, but the priority mission of R&I remains that of boosting company performance."

Cécile Boesinger

Head of R&I in the Teréga Strategy & Innovation Unit



WHAT DEFINES AN R&I PROJECT?

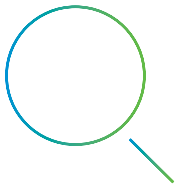
In essence, an R&I project contributes to achieving the ambitions and targets set out in the IMPACTS 2025 Innovation Plan programmes. To meet its operational needs, Teréga develops solutions that have a direct practical application for its infrastructures and the services offered to its customers. The sphere of activity covered by R&I is therefore broad to cover three main aspects:

- Improving and developing the knowledge and practices of Teréga
- Testing and building prototypes to qualify technologies and new methodologies wherever feasibility is uncertain
- Responding to integration issues within its operational environment

As an enthusiastic promoter of applied research, R&I conducts projects that can be directly deployed in Teréga's industrial facilities on completion of a development process of approximately three years. Once feasibility is established, the project moves into the industrial-scaling and roll-out phases. At this point, the project is no longer within R&I scope, and is passed along to the dedicated business teams for full deployment.

60+
employees

EVERY TERÉGA DEPARTMENT IS INVOLVED IN THE INNOVATION PROCESS, WHICH EQUATES TO AROUND 10% OF THE COMPANY'S WORKFORCE.



€5 million

THAT'S THE AVERAGE ANNUAL BUDGET ALLOCATED TO TERÉGA R&I.

40+ projects

FOCUSED ON TRANSMISSION, AND OVER 10 ON STORAGE ARE INCLUDED IN THE IMPACTS 2025 INNOVATION PLAN.

3 patents

FILED TO COVER ENERGY EFFICIENCY, GAS QUALITY AND DIGITAL INNOVATIONS.

40+
partners

WITH COMPLEMENTARY SKILLS.

Throughout 2019, the R&I team hosted Innovation events in all its operating regions as part of its plan to bring the department's culture of innovation to all employees.

TENEXI enhances an already proactive partnership strategy

For many years, Teréga R&I has implemented and pursued a diverse partnership strategy that has three major goals:

1. **To secure, intensify and develop the knowledge and skills of internal teams** in key technical disciplines by working alongside public and private research organisations, such as the University of Pau and Pays de l'Adour (UPPA) and the National Institute of Applied Sciences in Toulouse (INSA).
2. **To pool efforts over the long term** with other companies from the energy industry to address similar issues, as is the case with GRTgaz, Storengy and SNAM (launching shared projects, exchanging progress in terms of results, etc.).
3. **To support the development of innovative technologies or methods** with the potential to create value for Teréga. In the majority of cases, these are addressed through partnerships with engineering consultancies, SMEs and startups. They facilitate the development of solutions to problems faced by Teréga, help to identify new applications, and support industrial-scale development.

Teréga is also a committed and established contributor to many Open Innovation initiatives, including CITEPH, Avenia GeoEnergy Days of the Pole Avenia, BigUp for Start Up, etc.). The company is also strengthening its partnership strategy and promoting collective intelligence with the launch of its own participative innovation initiative called TENEXI (Tous ENsemble EXplorons l'Innovation - Let's All Explore Innovation Together). The initial call for projects in May 2020 focused on the PARI 2025 goal of identifying innovative solutions for preventing construction worksite accidents involving personnel and machinery, and invited submissions from the external ecosystem to support the development of innovative companies.

But TENEXI is about more than Open Innovation. Teréga also intends to encourage and implement appropriate solutions put forward by its own employees in response to problems within the company.

So a number of topic-specific ideation challenges were launched in June 2020. As well as supporting more home-grown innovation, this approach is also about encouraging and rewarding collaborative working and gives everyone the opportunity to make their contribution to company development.

Teréga, a responsible, involved and high-profile stakeholder

The projects and programmes run by R&I promote Teréga through its scientific publications and participation in high-profile international research conferences and congresses.
Examples include:

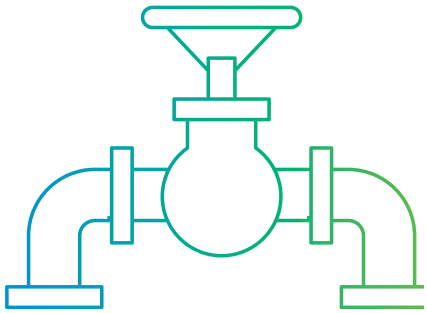
The International Gas Research Conference (IGRC) in Muscat (Oman)
At this event, the R&I teams showcased the RINGS project to illustrate its research on the impact of new gases in underground storage facilities, and the BEST greenhouse gas emissions reduction project.

The European Gas Technology Conference (EGATEC) in Groningen (Netherlands)
The MARS and RINGS research projects and the thesis on biomethane compound research came 1st, 2nd and 4th respectively in the 9th Young Research Awards.

The Énergie & Territoires symposium and student competition in Pau (France)
Hosted jointly by Teréga, Compagnie d'Aménagement des Coteaux de Gascogne (CACG) and Crédit Agricole Pyrénées Gascogne, this symposium gave R&I the opportunity to present its roadmap enabling regions and communities to enjoy the benefits of tomorrow's energy sources. An initial competition for university-level students was also launched at the event on the theme of 'Innovation to deliver the energy transition for rural regions'. The award will be presented at the end of 2020.

INFRASTRUCTURE INTEGRITY

Protecting and inspecting pipelines effectively using the best technologies and methods currently available



Teréga's status as a **leading stakeholder in the European gas landscape** imposes a **responsibility** to maintain **safety, reliability** and **availability** of its installations, at the same time as optimising network costs and performance. With more than 5,100-km of pipelines, the integrity of its infrastructures is an **essential issue** and major challenge for Teréga, highly supported by the PARI 2025 Accidents and Industrial Risk Prevention initiative.
In this respect, the R&I programme sets out to **develop and implement innovative technologies that facilitate the inspection of inaccessible structures** that are encased or underground, without the need to excavate. It also requires the company to be at the cutting edge of the latest developments in both **passive protection** techniques and methods for structures (pipeline coatings) and **active protection** solutions (cathodic protection).

"R&I's role is to improve pipeline protection and inspection techniques, since these structures present significant technical challenges, such as accessibility, operating conditions, environmental variability, etc."

Rémi Lancien

Inspection Department Manager
and R&I Infrastructure Integrity Programme Manager

R&I projects to improve pipeline inspection and protection

1 – Detecting defects and optimising cathodic protection

THE AIM

R&I has twin ambitions for this project: to develop an inspection technology that avoids the need to excavate unpiggable pipelines, and to gain a better understanding of corrosion to make cathodic protection (CP) more effective.

The approach

- A new non-destructive pipe inspection technology (the magnetic tomography method) is currently being developed and tested in conjunction with Skipper.
  The resulting data are being compared with those from other inspection methods already in use.
  These advances are being achieved in partnership with GRTgaz.
- CP efficiency criteria are being studied in conjunction with the French Corrosion Institute on the basis of various pipeline environmental parameters.
  The work also includes the ageing of coatings and their effects on CP performance.

Customer benefits

- Inspection cost optimisation.
- Improved integrity of gas infrastructures and their extended working life.

Progress to date

- Improved performance from the magnetic tomography technology since incorporating the results of tests carried out jointly with GRTgaz.
- Finalisation of initial research into the parameters that influence CP and commencement of new work on new parameters.

Future developments

- Formalising performance indicators to improve the process of analysing inspection results and challenge the technology.
- Enhancing the data processing algorithm by incorporating correlation with the results gathered by excavation.
- Updating Teréga standards and improving corrosion risk analysis tools.

Magnetic tomography inspection of pipelines in conjunction with specialist contractor Skipper.

WHAT RESOURCES ARE AVAILABLE FOR PIPELINE PROTECTION AND INSPECTION?

In addition to special external coatings, underground pipelines are protected against corrosion using cathodic protection devices. This technique involves applying an electrical voltage to the metal outer surface of the pipe to significantly reduce its potential for corrosion.
Regular inspections are also necessary to characterise pipeline conditions as accurately as possible.
These operations are an essential part of ensuring network integrity.

For this purpose, Teréga uses a number of complementary techniques:

- **Inspection by measuring electrical parameters to detect defects in external coatings**
- **Surface magnetic inspection to detect losses of metal and/or pipe distortion**
- **Inspection using an instrumented piston to precisely map structural indications in the metal**
- **Visual inspection by excavation**

2 - Innovation in duct inspection

THE AIM

The R&I ambition for this project is to inspect the 10,000 ducts used in the 5,100-km Teréga network as effectively as possible. Duct defect detection is a major priority for ensuring end-to-end network safety. For this reason, Teréga is initially developing a high-performance methodology for prioritising inspections, and continuing its search to identify new non-destructive technologies.

The approach

- Development of a duct analysis and sampling model. This model has so far identified 224 ducts to be inspected as a priority, out of the 5,000 unpiggable ducts in the Teréga network.
- Design of a 10-year plan to inspect these ducts by excavation to enhance the model and the relevance of future inspections.
- The work of national and European working groups is monitored to identify other innovative and non-destructive duct inspection methods.

Customer benefits

- Improved efficiency and optimised costs as a result of adapting inspection frequency.
- Improved control of engineered structure integrity.

Progress to date

- Restructured sampling plan.
- Analysis to establish the completeness and quality of current data (at the end of 2020, 40% of ducts had been inspected under the 10-year plan).
- Ongoing incorporation of inspection results to improve the model.

Future developments

- Verifying the impact of the excavation results on the initial model and revising the 10-year plan if necessary by incorporating potential new forms of inspection for those families of ducts identified as being at risk.
- Testing of a new duct inspection technology, followed by its roll-out if the results are conclusive.

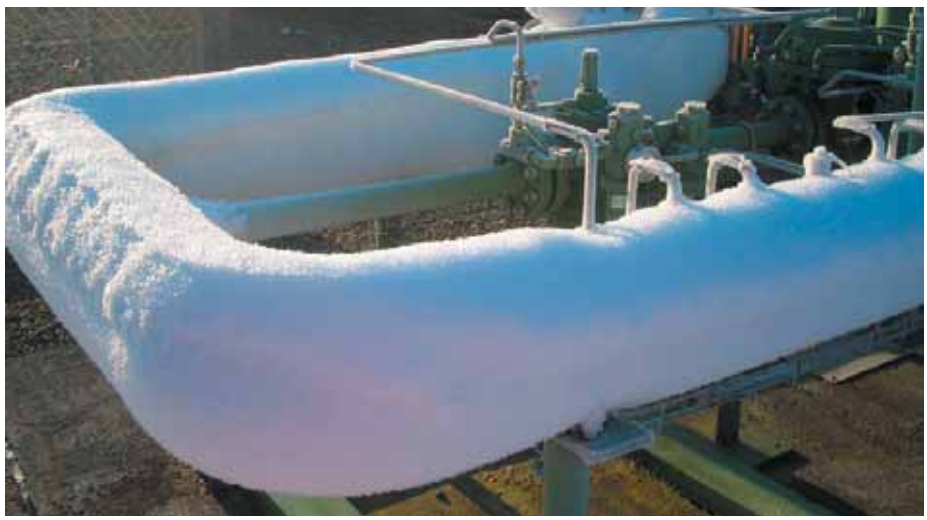
WHAT IS A DUCT?

This term refers to the steel or concrete casing used to protect underground pipelines against external mechanical stresses imposed by rail tracks, motorways or rivers. Although ducts play a role in keeping structures safe and protected, inspecting them is a very labour-intensive task due to their difficult access and the high cost of excavation (road closures, river crossings, etc.).

PIPELINE ICING IS ANOTHER ISSUE ADDRESSED BY R&I

Depressurisation downstream of delivery points causes an abrupt and substantial fall in gas temperature. Under some circumstances, this can result in undesirable icing of the pipe, which can potentially impose mechanical stresses on pipes, distort civil engineering structures and interfere with correct valve operation. R&I is therefore evaluating a number of alternative solutions to address this operational issue. A new and innovative coating is currently being laboratory tested at CANOE, a specialist in composite and other advanced materials R&D.

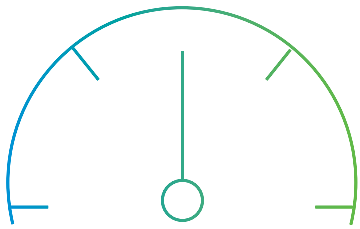
Pipeline running into a duct.



Icing of a gas pipeline.

OPERATIONAL PERFORMANCE AND SAFETY

Improving network monitoring and maintenance means exploiting the capabilities of digital technology



As a high-profile gas industry stakeholder and infrastructure manager, Teréga has a clear responsibility **to deliver operational excellence in complete safety.** This essential and non-negotiable priority is central to the PARI 2025 Zero Accident, Zero Snagging initiative. Its goal is clearly stated: to apply a constant process of innovation to guarantee continuity of supply through greater **agility, reliability** and **anticipation**.
R&I therefore plays an integral role in the commitment to deploy automated real-time monitoring of the network. The programme also aims to introduce **new digital** predictive maintenance and augmented reality systems to improve the operational efficiency of field staff. For this purpose, R&I is eager to exploit the new opportunities presented by **big data architectures** and the broad range of applications for artificial intelligence. The applications of technology are expanding all the time: for example, data storage and processing capacity have exploded with the advent of cloud computing, while progress in telecoms and connected objects now allows the status of individual assets to be viewed in real time. Advances on this scale are clearly beneficial to business and customers alike.

"Operational performance and safety are essential drivers of improvement for a company like ours, which must ensure the availability and reliability of its installations regardless of circumstances."

Natacha Merlet

EI2A (Electricity, Instrumentation, Automation and Analysis) Manager and R&I 'Operational Performance and Safety' Programme Manager

R&I projects that harness the power of digital for the benefit of the network

1 - Applying artificial intelligence to aerial monitoring

THE AIM

This R&I project continues the strategy of improving and automating aerial monitoring of the network, which is currently carried out by fixed-wing aircraft or helicopter. The wider ambition of this project is to avoid the risks associated with unregistered third-party work, urban development or land movement.

The approach

- Artificial intelligence data processing tools are being developed for use in conjunction with those monitoring methods already in use (automated processing of vertical photography acquired from a fixed-wing aircraft or helicopter).
- New aerial monitoring techniques are also at the experimentation stage (drone overflight and the use of satellite imagery) with the aim of superseding conventional methods in certain situations.

Customer benefits

- Optimised monitoring safety and reliability.
- Traceability of anomalies (using an auditable system).
- Increased monitoring frequency.

Progress to date

- Finalisation of the automatic threat detection system: the current model is effective, but its reliability will be boosted by upgrading its georeferencing and image quality performance.
- Finalisation of the technical and economic study to assess the feasibility of implementing a monitoring solution based on satellite imagery analysis: cost too high.

Future developments

- Upgrading the quality of vertical photographic images and georeferencing (new aerial monitoring RFQ).
- Developing an automatic threat detection system based on free satellite imagery and using bought-in images to refine analytical detail for specific areas. - Launching a new project to replace aircraft with drone overflights for certain areas.

PERFORMANCE IS ALSO ABOUT THE SAFETY OF PEOPLE

In addition to ensuring and monitoring the integrity of network structures, R&I focuses on the everyday priority of Teréga to ensure the safety of its operations staff, partners and local residents. R&I is fully committed to providing innovative solutions to achieve the ambition set for the PARI 2025 'Zero Accidents, Zero Snagging, Zero Surprises' initiative. The R&I 'People Safety' programme is designed in the first instance to deploy technologies that ensure safe man/machinery interactions on worksites. For this purpose, an initial external call for projects has been launched via the TENEXI platform.

Laying a pipeline on a worksite.

2 - Detection of leaks, unregistered work or land movement using new-generation fibre optic technology

THE AIM

This R&I project confirms the Teréga commitment to developing more powerful technologies that align more accurately with its monitoring needs and infrastructure specifications. It follows on from an initial R&I assessment of the capabilities offered by optical fibres for real-time transmission of data reporting the condition of gas pipelines and their immediate surroundings.

The approach

- A new optical fibre technology to measure temperature, stress and vibration simultaneously is being developed and tested as part of a collaborative project involving TOTAL, SAIPEM and startup Febus Optics.
- Systems to detect pipeline external attacks or even potential leaks are also being evaluated on a specially built test rig.

Customer benefits

- Development of a technology that provides improved remote real-time detection of network activity
- Faster response times for a higher level of service continuity.

Progress to date

- Final report on the preliminary tests conducted on the Gascogne Midi Reinforcement (RGM) project site: encouraging results
- Construction of the test rig and commencement of tests designed to build an extensive database of signals recorded in response to different types of aggression.

Future developments

- Test data processing and analysis.
- If the results obtained are persuasive, an initial operational system will then be tested in an area of known risk, so that the accuracy of the resulting alarms can be evaluated.
- Modifying optical fibre installation standards and defining the rollout strategy.

The Febus Optics test rig.

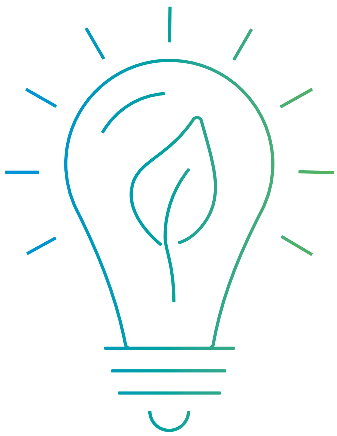
MONITORING FOR DELIVERY POINTS TOO

The Laluque delivery point.

Network monitoring is not confined solely to underground pipelines. Delivery points are key elements of the gas transmission system, because they are the interface between Teréga and its clients. There are 450 of these sensitive installations that require significant levels of monitoring to ensure continual safe operation and continuity of service.
R&I is therefore working to develop a remotely operated hybrid solution that will detect gas leaks (triggering an on-site response where necessary), at the same time as increasing expansion valve reliability using predictive maintenance. Field tests including failure trials are being conducted over a period of several months. Depending on the results obtained, Teréga may begin work on developing an all-in-one sensor specifically for this environment and to address the needs identified.

GREENHOUSE GAS EMISSIONS CONTROLS AND ENERGY EFFICIENCY

Positive environmental performance means avoiding, reducing, offsetting and innovating



As a responsible company, Teréga pays special attention to containing its environmental footprint. It is also committed to successfully meeting the challenges set out in the French Energy Transition for Green Growth Act (LTECV), which aims to reduce greenhouse gas (GHG) emissions to 40% lower than 1990's levels by 2030. For this purpose, R&I is focusing particularly on three priorities while maintaining the same level of service:

- The first is to develop a system to optimise compressor fleet operation and achieve the optimum balance between lower emissions and reduced energy consumption
- The second is to bring forward innovative solutions for reducing overall Teréga GHG emissions
- The third involves the recovery of waste energy for re-use.

"As a company that has been ISO 50001 certified since 2014, Teréga has made energy efficiency one of its main concerns. As an integral part of the BE POSITIVE initiative, this R&I programme consolidates and intensifies that commitment."

Éric Bouley

Processes Department Manager
and R&I 'Controlling our Greenhouse Gas Emissions and Energy Efficiency' Programme Manager

R&I projects to improve energy efficiency at Teréga

1 - Introducing solutions to reduce methane emissions

THE AIM

This R&I project is testing a range of different technologies to limit and recover the methane emissions that result directly from network operation.
The main source of Teréga GHG emissions relates to discharges of gas when reducing pressure in the system following compressor shutdowns, or in lengths of pipeline for installation and maintenance work. Other emissions originate in leaks from the seals used for rotating compressor components, which allow small volumes of gas to escape as part of their normal operation. So the ultimate ambition of R&I is to help Teréga contain its environmental footprint over the long term by introducing solutions that will recover these losses for re-use.

The approach

- Potential solutions are studied and compared in order to select the most effective for particular application scenarios, which then undergo more specific tests and/or development in preparation for potential deployment.
- Decision-making support tools are being developed to identify the most appropriate method.

Customer benefits

- The guarantee of a contractual relationship with a responsible operator committed to shrinking its environmental footprint by meeting and exceeding its legal commitments.

Mobile Comp, the Teréga recompression truck, at work in Urgosse.

Progress to date

- Delivery of the mobile recompression truck (Mobile Comp), personnel training and the first operational use of the truck for decompressing transmission pipelines: results show that the opportunity for reducing emissions is much higher than originally believed (> 10,000 CO_2 eq. per year).
- Selection of the best solution for recovering gas leaking from seals via a dedicated pilot project, and the launch of detailed design work prior to network interventions.

Future developments

- Delivering the compressor seal gas leak recovery system in 2021, and defining the rollout strategy for other compressors.
- Launching design studies for a small-scale mobile recompression system for smaller operations (an easily mobilised technology delivering short recompression times as an alternative technique to flaring and venting).

DIFFUSE LOSSES: A FUTURE DEVELOPMENT PATH

Diffuse losses are fugitive emissions from equipment during normal operation (e.g. compressor seals, valves or flanges). The highly disparate nature of these leaks makes them difficult to measure and recover. A number of solutions - especially the seal gas leak recovery system - are already in development to address these issues, following on from changes to Teréga operating procedures introduced more than two years ago. Further complementary developments are still required, and will undoubtedly be the focus of future R&I projects.

2 - Optimising compressor stations operation

THE AIM

The aim of this R&I project is to develop and offer a simulator that identifies the most advantageous usage scenarios for the Teréga compressor fleet and its Transmission and Storage machinery. The ultimate goal is to optimise compressor station operations by rationalising the many financial overheads and reducing the CO_2 emissions that account for around 30% of all Teréga's GHG emissions. Because each Teréga compressor currently has its own specific technical characteristics, there is no off-the-shelf solution that fulfils this function.

The approach

- The Optimus simulator has been developed and integrated with the Teréga information system.
- The optimum compressor fleet configurations are defined on the basis of the required gas flow scenarios. For example, Optimus helps select the optimum compromise between GHG emissions and energy costs from ten startup configurations.

Customer benefits

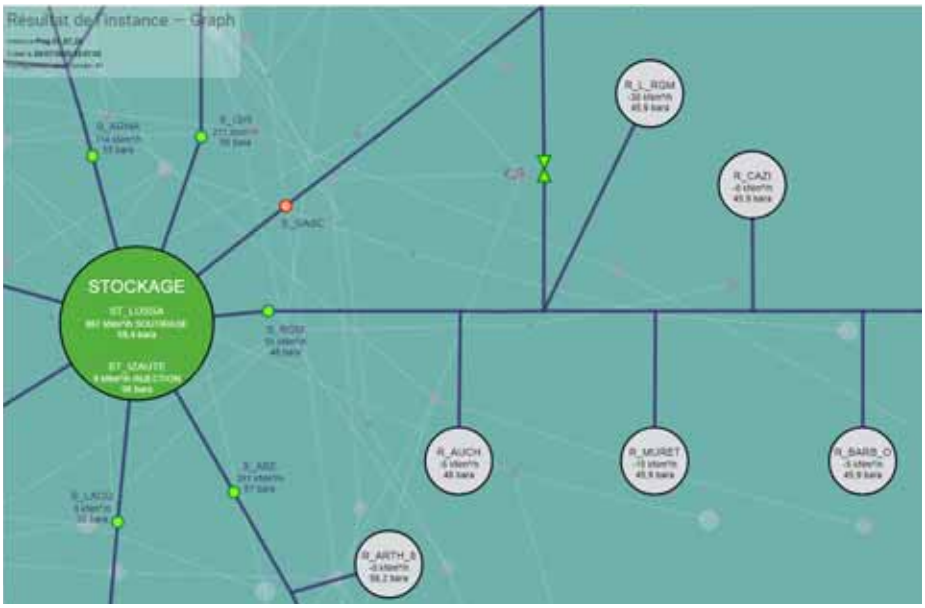
- Rationalised operation of the compressor fleet for optimised energy usage and reduced operating expenses.

Progress to date

- Resolution of interfacing and system rollout issues.
- Satisfactory operational startup and feedback.

Future developments

- Ongoing development to create a smarter solution based on machine learning.



Optimus system screen capture.

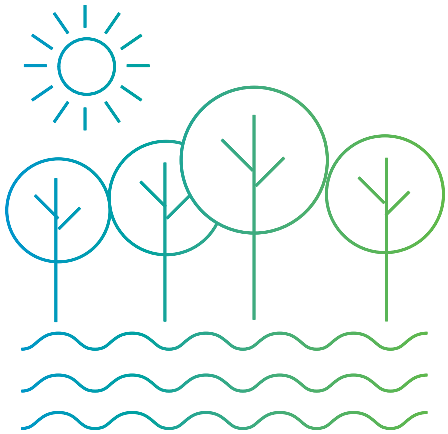
AVOID-REDUCE-OFFSET

Teréga's environmental policy is guided by three principles: Avoid-Reduce-Offset. Convergence around a joint approach that combines the R&I energy efficiency and environmental footprint programmes is uniting Teréga teams as they work towards achieving the ambitious goal of BE POSITIVE: to achieve environmental neutrality for Teréga in 2020, and deliver positive environmental performance by 2025! Building on previous initiatives, Teréga continues to take a proactive approach to AVOIDING greenhouse gas emissions, REDUCING its carbon footprint through energy optimisation, and OFFSETTING its residual impacts on the environment and biodiversity.

Handling: transport, unloading and alignment of pipeline sections before they are laid underground.

LOCAL INTEGRATION & ENVIRONMENTAL FOOTPRINT

Leading by example means protecting biodiversity, water quality and the landscape



Teréga is keen to demonstrate its **environmental commitment** at every level in its organisational structure, so the purpose of this R&I programme is **to integrate the activities of the company more effectively at local level,** promote their social acceptability and limit their environmental impacts. It has set four major ambitions for this programme:

- Developing measures that reduce impacts during the construction and/or operational phases
- Establishing Teréga **as the benchmark for environmental impact controls**
- Considering and envisioning easements as potential **reservoirs of biodiversity**
- Putting in place effective and innovative resources that facilitate **public acceptance** of Teréga, its operations and its projects.

"R&I has set itself the twin targets of improving the local integration of infrastructures and limiting their environmental impact. The programme therefore incorporates several projects directly related to BE POSITIVE."

Laëtitia Mahenc

Head of the Environment & CSR Department,
R&I Local Integration and Environmental Footprint Programme Manager, and BE POSITIF Manager

R&I projects to improve local integration

1 - Protecting biodiversity through appropriate offsets and a clearer understanding of the contribution made by linear infrastructures

THE AIM

This R&I project reflects the willingness of Teréga to optimise its operations to avoid compromising biodiversity and, wherever possible, to promote it. Teréga has made its industrial resources available for this project and since 2014, has been co-funding the ITTECOP programme initiated with impetus from the French Ministry for Ecological and Solidarity Transition and ADEME (the French Environment and Energy Management Agency). Teréga intends to use the results obtained by this programme to improve its practices by including landscapes and ecosystems in its considerations.

The approach

- The linear infrastructure offset strategy and the potential of easements to improve biodiversity are subjects addressed by theses developed in the context of this programme.
- The ecological losses caused by a development project and the gains delivered by offset areas are identified objectively using the MERCIe methodology.
- The results gained by implementing certain impact reduction practices on worksites (e.g. ecological engineering and/or plant engineering techniques) can also be evaluated more effectively.

Customer benefits

- The opportunity to exercise responsibility in purchasing by choosing Teréga as a gas transport operator committed to protecting biodiversity.
- The development of more responsible - and therefore more 'acceptable' - projects.

Progress to date

- Presentation of the MERCIe thesis and promoting the systematic use of this methodology in reference to the methodologies traditionally used by environmental consultants.
- Launch of the new 2020-2023 call for projects and promotion of applications related to linear gas infrastructures.

The *Hoplia coerulea* blue beetle.

Future developments

- Applying the MERCIe methodology to new Teréga projects.
- Monitoring new gas infrastructure-related ITTECOP projects/theses.

THE MERCIe METHOD IN GREATER DETAIL

Ensuring maximum compliance with Teréga's ecological commitments means developing an objective method for evaluating the offsets implemented after on-site project completion. For this purpose, R&I has worked with the University of Montpellier to co-develop the MERCIe (Rapid Assessment Method for Ecological Impact Offsetting) methodology. Known as ITTECOP (Land Transport Infrastructures, Ecosystems and the Landscape), this more operational approach compares the ecological losses resulting from an infrastructure project with the gains delivered by the offsets implemented. It then assesses the status of an area across its 'entire ecosystem', rather than focusing its analysis solely on certain species or categories (protected species, for example). A total offset area is then calculated to complete the process. This methodology provides a more standardised overview of offsetting, and is applicable to business activities other than those of Teréga.

ITTECOP
Infrastructures de transports terrestres écosystèmes et paysages

2 - Adapting and implementing impact reduction measures during the on-site and/or operational phases

THE AIM

The aim of this R&I project is to respond effectively to a very real challenge by working on a series of application scenarios to improve Teréga's operational issues.
There are two project priorities: conserving the environment and biodiversity, and reducing adverse environment effects and waste generation.

The approach

- Environmental protection solutions are first researched and then tested (filtration of worksite water, alternatives to sandblasting for paint stripping, and remediation following the use of weedkillers at delivery points).
- If the tests prove convincing, the selected solutions are then deployed on a wider scale.
- Other solutions are constantly being sought to solve new application scenarios.

Customer benefits

- The guarantee of entering into a contract with a responsible operator committed to reducing its environmental footprint.
- Guaranteed continuity of service as a direct result of reliability gains that meet regulatory controls.

Progress to date

- Testing of a new Geotube membrane solution for filtering worksite water, and the design of an improved flocculant to precipitate suspended solids.
- Consultation on possible solutions offering alternatives to the use of weedkillers: initial testing of biological controls and the introduction of preventive solutions for block-valve and delivery points.

Future developments

- Measuring the performance of the new water filtration system and the measures introduced as alternatives to the use of weedkillers.
- Adding to the body of feedback received and sharing it with other environmental protection stakeholders.

Easement above a pipeline, following the upgrade project carried out by the Rion-des-Landes branch.

R&I AS A VECTOR OF SOCIETAL INTEGRATION

As operator of two aquifer storage facilities, Teréga is working to improve the societal acceptability of this as part of its service, which often faces public opposition. The initial ambition of R&I is to develop and promote the use of innovative ways of improving the societal acceptability of underground resource operators.
This initiative is embodied by the GÉFISS (Extended Governance for Underground Engineering Operators) project, which also plans to act ahead of new gases being introduced into underground storage facilities and work effectively on their public acceptability.
Teréga also contributes to research into the practical hydrogeological aspects of the deep aquifers used for its storage facilities.
The GAIA (Aquitaine South Basin Aquifer Geology) project is one of these research programmes. Its work spans a broad range of earth sciences disciplines. The results of the project will be made available to other aquifer operators as the basis for coordinated and harmonised management of these natural geological structures.

NEW GASES

Facilitating their integration is all about anticipating change and working today on the energy mix of tomorrow

Teréga firmly believes that **gas is an energy for the future** with a key role to play in energy transition. This is why the company continues to drive initiatives that promote and facilitate the integration of new gases. Indeed the energy transition will inevitably result in more of these gases being injected into existing gas supply networks through techniques such as **methanisation, Power-to-Gas, pyro-gasification and methanation.** For example, R&I is studying the composition of biomethanes, methane syngas and the acceptable level of hydrogen content when blended with natural gas to assess their **compatibility with installations** prior to promoting their injection into the supply system. There are plenty of future challenges: anticipating the issues surrounding gas safety and quality, flow management and continuity of supply. Teréga R&I teams are also actively contributing to **collaborative projects to evaluate a range of different methanation processes** to ensure high gas quality, and position itself as an accelerator for growth in this channel.

"We want to be proactive in adapting our infrastructures to the new technologies associated with the renewable gas sectors. This is one of our priority commitments, not only in terms of innovation, but also in terms of our corporate plan."

Guilhem Caumette

Environment Engineer, Energy Research and R&I New Gases Programme Manager

R&I projects to facilitate the integration of renewable gases

1 - Researching the impacts of biomethane injection on existing installations

THE AIM

Teréga is continuing its R&I efforts to promote the injection of biomethane into gas infrastructures. The number of injection points is increasing, but there is still work to do on analysing the long-term impacts and managing these new flows.

Corrosion indicators at a biomethane injection site.

The approach

- Measurement campaigns are being conducted at new biomethane injection sites in France to gain a better understanding of the composition and concentration of trace elements.
- Sampling methods and special analytical techniques for bio methane compounds are also under development.
- The impact of biomethane on pipeline integrity is measured on site and by laboratory testing using corrosion indicators installed at injection points.

Customer benefits

- Improved integration of bulk biomethane by anticipating the potential operational constraints imposed by their injection into the infrastructure.

Progress to date

- Consolidation of the gas quality database for biomethanes produced in France.
- Removal of the first series of corrosion indicators a year after their installation: no impact of biomethane-related corrosion.
- Design and delivery of a high-pressure sampling test rig and patenting of the adsorption cartridge specific to biomethane trace compounds.

Future developments

- Continuing existing projects to identify possible injection constraints: this work is being carried out in conjunction with other European gas operators to provide a shared overview and make an active contribution to the standardisation of practices and gas quality.

2 - Researching the impacts of hydrogen injection on existing installations

THE AIM

This R&I project aims to characterise the potential impacts of injecting H_2 into Teréga transmission infrastructures in order to identify the optimum blending rate with natural gas and develop appropriate remediation techniques.

Hydrogen pressure chamber with test piece intention.

The approach

- Laboratory tests on steel embrittlement are conducted using different levels of hydrogen.
- There is a high level of contact and interaction with other French and European gas operators (regulatory and technological monitoring, definition of common acceptability criteria, feedback sharing, etc.).

Customer benefits

- Anticipation of potential operational constraints.
- Preparation for injection/transmission of H_2 through Teréga pipelines.

Progress to date

- Laboratory testing of welds in the presence of hydrogen (resistance, crack propagation, fatigue, etc.) using the same test protocols as GRTgaz (tests on pipe bodies) so that outcomes can be shared.

Future developments

- Launching new laboratory tests in conjunction with GRTgaz to investigate the permeation of H_2 through different grades of steel and different pipe surface finishes.
- Finalising the various tests, publishing recommendations and defining acceptable H_2 concentrations for a range of situations.

3 - Accelerating development of the methanation sector by ensuring its compatibility with injection into the grid

THE AIM

R&I asserts the commitment of Teréga to promoting the appeal of the renewable gases channel by studying a range of methanation processes in conjunction with startups, public-sector R&D laboratories, universities and other industry stakeholders. Methanation enables the practical use of CO_2 from other processes (e.g. methanisation) by converting it into methane with the addition of H_2 from renewable sources. This process can double the energy production efficiency of a methanisation plant.

The approach

- A range of innovative methanation projects involving Teréga are now emerging out of a process to evaluate the technological, economic and regulatory issues around this technology building block.
- The quality of gases produced by methanation is controlled by Teréga as a result of sharing its expertise and upskilling its own in-house teams.

Customer benefits

- Promoting the network injection of new gases and developing expertise in their quality control and qualification.
- Optimising biomethane production by developing solutions for recovering energy from CO_2 by methanation.

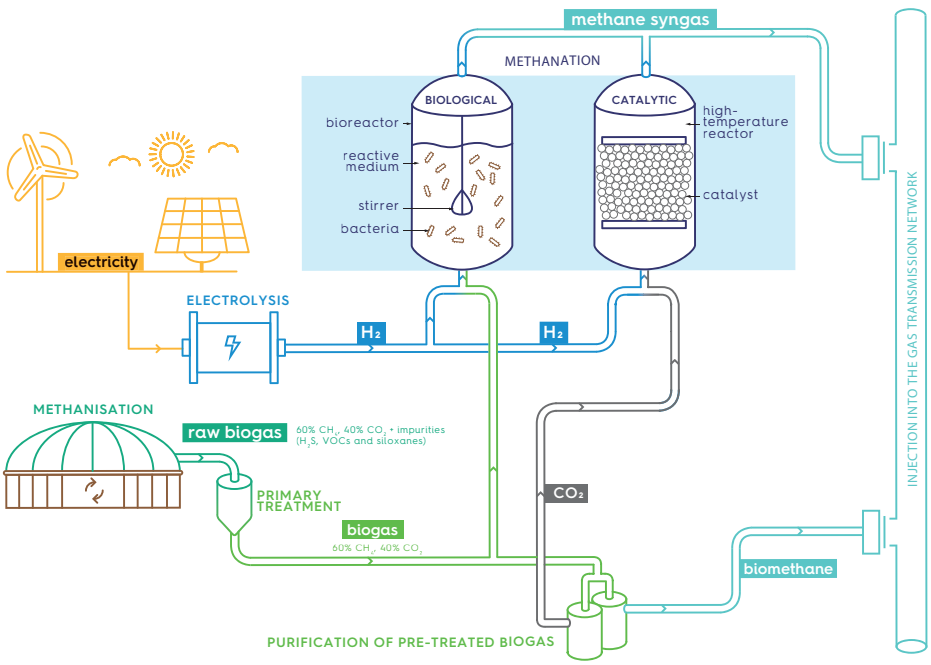
Progress to date

- The SOLARVI electrolytic hydrogenation project: evaluating process performance and producing the first H_2: results so far are encouraging ahead of synthetic methane production.
- The DEMETHA biological methanation project: grants provided by the region of Occitanie and signature of a partnership agreement.
- The MARS solar renewable methanation project: launch of the initial operations and optimisation of the related reactions.
- The METHAMAG catalytic methanation project: A partnership agreement is now being drafted.

Future developments

- Building the SOLIDIA platform (see inset), designing the semi-industrial pilots and starting testing (for the DEMETHA and METHAMAG projects).
- Continuation of ongoing projects and the technical/economic qualification of the processes involved.
- Consultation on the construction of larger-scale demonstrators if the initial tests prove persuasive (for the MARS and SOLARVI projects).

BIOMETHANE AND METHANE SYNGAS

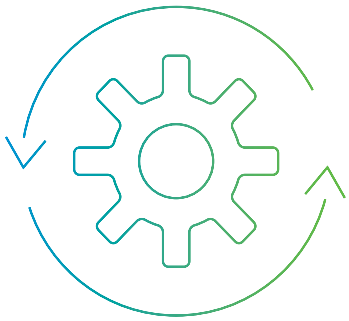


THE SOLIDIA PILOT PROJECT PLATFORM

Located at the heart of the Teréga region in Bélesta-en-Lauragais, the SOLIDIA platform is designed to host semi-industrial research pilot projects using purification or methanation to enrich raw biogas (particularly in the context of the DEMETHA and METHAMAG projects). Its proximity to the Cler Verts facility that produces biogas from agricultural waste connects SOLIDIA directly to a source of raw biogas (60% methane, 40% CO_2). The platform will be run jointly with INSA in Toulouse, which will have access to Teréga's gas infrastructures construction and operation expertise, which is essential to the success of a project on this scale. Teréga is also raising its profile as a proactive stakeholder in the energy transition and renewable gas sector development.

NETWORK AND SMART GRID INTEGRATION

Accelerating the energy transition means preparing for the future... today



Teréga is demonstrating its commitment **to accelerating the energy transition** by pursuing its initiatives to secure and promote the role of gas in tomorrow's energy mix.
So it is only logical that R&I takes a close interest **in network and Smart Grid integration,** since both are cross-functional issues central to the energy transition. In practical terms, this should result in a higher level of complementarity between energy sources. Gas networks are at the heart of this new paradigm, and will play a central role in **balancing energy demand**. So R&I is continuing to expand its knowledge in areas consistent with achieving the strategic ambitions of the IMPACTS 2025 corporate plan. In 2019, Teréga launched t**he first phase of IMPULSE 2025,** its large-scale smart **multi-energy systems** project.

"Energy sources can no longer be considered in silos. Energy systems must be considered in their entirety if we are to recover and reuse losses and optimise end-user consumption. The gas network has a key role to play in these systems."

William Rahain

Business Opportunities Research Manager
and R&I 'Network and Smart Grids Integration'
Programme Manager

R&I projects that prepare the way for the future of gas

1 - Making an active contribution to JUPITER 1000, France's first Power-to-Gas Demonstrator

THE AIM

This project underlines the commitment of Teréga and several of its partners, including GRTgaz, to demonstrate the ability of gas infrastructures to balance and underpin the electricity grids by leveraging Power-to-Gas technology. The JUPITER 1000 project is designed to study the conversion of surplus renewable electricity first into green hydrogen (by electrolysis of water) and then into methane syngas (methanation reaction) by combining it with CO_2 captured from industrial flue gases. In this way, R&I is anticipating future developments around the network injection of new gases and contributing to the 'decarbonation' of natural gas.

The approach

- The acquisition of skills across the full range of technical and operational issues related to Power-to-Gas.
- Determining conditions that will favour the injection of hydrogen and methane syngas.
- Studying the viability of the Power-to-Gas financial model, its regulatory context and smart management of the entire system.

Customer benefits

- Maximised integration of renewable energies and recovery of surplus electricity for re-use.
- Guaranteed security, quality and continuity of supply of new energies.
- Early-stage readiness for requests from future clients.

Progress to date

- Production and injection of the first m^3 of hydrogen and the operational introduction of smart operations management.

Future developments

- Completion of construction and delivery in early 2021, including commissioning of the CO_2 and methanation technology building blocks.
- Tests, trials, analyses and publication of results.
- Finalisation of the study and demonstration of the technical and financial viability of the Power-to-Gas solution.

Jupiter 1000

Electrolyser.

Aerial view of the demonstrator site.

Project supported by:

The project partners:

2 - Launching an ambitious smart multi-energy system project: IMPULSE 2025 (Innovating and Mobilising to Unify Energy Systems)

THE AIM

Today's electricity, natural gas, heating, cooling and water utilities networks are designed and operated separately and are not optimised. Teréga's intention for this project is to deploy a smart multi-energy system that interconnects all these networks to encourage pooling and to make optimum use of their synergies with the ultimate aim of making them more energy efficient.

The approach

- A technology building-block optimisation and modelling system is being developed to define the optimum configurations of given multi-energy systems (Phase 1).
- The operational feasibility of such a system will be tested at a demonstration site to confirm the estimated gains (Phase 2).
- In parallel, a digital solution will be developed to provide real-time multi-energy system optimisation and control.

Customer benefits

- Promoting the development of multi-energy systems.
- Upgrading gas infrastructures for energy transition stakeholders, and ensuring the long-term presence of gas in the future energy mix.

Progress to date

- Signature of the Phase 1 cooperation contract with UPPA and EPFL (see inset).
- Grants awarded by the Nouvelle Aquitaine Region and certification by the Avénia and S2E2 competitiveness clusters.
- The first modelling studies are underway.

Future developments

- Finalising Phase 1 (mid-2022) and applying the results to the industrial facility selected for Phase 2 (the demonstrator).
- Continuing meetings with industrial and equipment manufacturers to define the Phase 2 partnership and funding conditions.
- Construction of the demonstrator for the end of 2024.

IMPULSE 2025

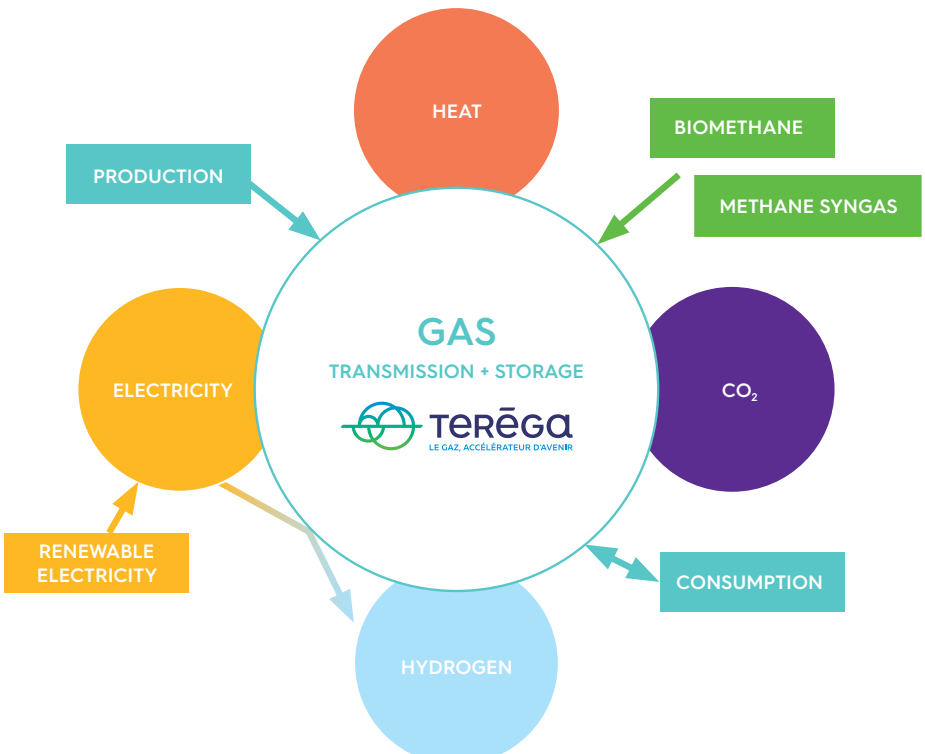
INNOVATING ALONGSIDE THE BEST PARTNERS

Teréga wanted to join forces with highly specific and recognised areas of expertise for the development of the IMPULSE 2025 Phase 1 optimisation and modelling system:

EPFL - the École Polytechnique Fédérale de Lausanne (the Swiss Federal Institute of Technology in Lausanne), which is an international leader in multi-target optimisation.

UPPA - the University of Pau and Pays de l'Adour, which has advanced skills in thermal and dynamic process simulation.

TERÉGA INFRASTRUCTURES AT THE HEART OF ENERGY NETWORKS



Project supported by:

Project accredited by these competitiveness clusters:

Project integrated into the following contract:

UNDERGROUND STORAGE PERFORMANCE AND INTEGRITY

Ensuring meticulously controlled management of natural storage infrastructures

Teréga delivers **a public service mission**, so operating underground gas storage facilities correctly and improving their performance are essential parts of its expertise. Delivering that mission demands the ability **to guarantee meticulously controlled management** of these sub-surface infrastructures.
The ambitions of Teréga are primarily focused on developing the technologies required for the precise and regular monitoring of storage facilities, contributing to their **optimum operation in complete safety,** and ensuring that storage reservoirs are completely sealed. More than 15 years of research has already been conducted into demonstrating the safety of natural gas storage in the context of aquifer chemistry. The energy transition goals mean that this research is now directed towards **the injection of new gases** and identifying their potential impact on underground storage facilities.

"The gas storage facilities operated by Teréga account for 24% of the total French storage capacity. It is our responsibility to operate them safely and anticipate the arrival of new gases, while maintaining the same demanding standards of operation."

Pierre Chiquet

Head of the Geosciences Department and Leader of the R&I 'Underground Storage Performance and Integrity' programme

R&I projects to ensure the long-term future of gas storage

1 - Developing innovative storage monitoring techniques

THE AIM

This R&I project involves the development of innovative, efficient and reliable monitoring solutions to assess the seasonal effects of gas injection/extraction more accurately, monitor the water/gas interface from the surface, and ensure the complete integrity of the geological structure above the storage aquifer and its boreholes.

The approach

- A range of monitoring techniques are being explored before deployment in an operational environment (research into soil movement, tracing of gases in soils and the annular spaces of boreholes, acoustic monitoring of geological formations, piezometric radar monitoring of aquifers above storage facilities, etc.).

Customer benefits

- Higher integrity levels for Teréga underground storage facilities.
- Ensuring greater acceptability of Teréga storage activities among local residents, environmental protection bodies, local government and funding providers.

Progress to date

- Development of a system to monitor ground movements by applying radar interferometry to satellite images: the deformations observed since 2014 show very little amplitude (a few millimetres) and relate to elastic deformations of the soil.
- Development of the GasMap system in collaboration with IFPEN to monitor gases emitted by soils in and around storage facilities using a vehicle-mounted sampler/analyser.
- Development of special analytical techniques to identify the origin of gases: thermogenic if they originate from the storage facility (potential leakage) or biogenic if they originate from the natural breakdown of organic matter.

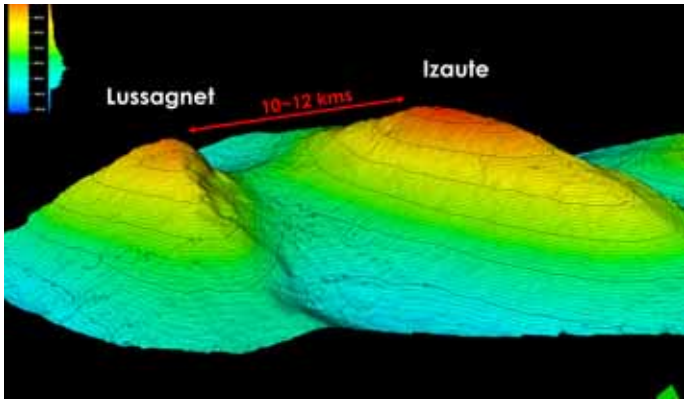
Future developments

- Introducing a permanent soil gas analysis system, because if leakage is detected, it is vital that the best means of remediation is identified as quickly as possible.
- Launching a collaborative project to implement a new solution to provide 4D imaging of sub-surface structures and 'passive' seismic monitoring using ambient noise.

UNDERGROUND STORAGE: A STRATEGIC LINK IN THE GAS ENERGY CHAIN

Underground gas storage is used to meet seasonal variations in demand for natural gas. They provide an efficient and economical technical solution for responding to fluctuations during peak consumption periods. Each of the two underground storage facilities operated by Teréga at Lussagnet and Izaute consists of a porous geological layer at depths of approximately 500 to 700 metres. This 'reservoir' rock formation is covered by an impermeable 'cover' rock formation consisting mainly of clay.

One of the main challenges posed by this type of storage is to reconcile the technical performance it offers gas suppliers with the need to analyse the potential piezometric impacts on facilities operated by other water table stakeholders, including thermal and geothermal companies, and suppliers of drinking water and water for irrigation. The crucial element of these infrastructures is monitoring. In addition to dedicated monitoring boreholes, a full range of precautions is in place to provide an appropriate monitoring network and measure the potential impact of gas storage on the environment and groundwater.



Map showing the isobaths of Teréga storage sites.

2 - Preparing for the injection of new gases into storage facilities, and ensuring the safety of the process

THE AIM

Conducted in collaboration with UPPA and Storengy, this R&I project is studying the effect of adding hydrogen and biomethane to the gas streams injected into storage facilities. In this way, Teréga is anticipating the potential interactions of these new gases with aqueous, mineral and microbiological subsoil components. The potential impacts on steels and borehole cements are also being researched.

The approach

- The RINGS (Research into the Injection of New Gases into Storage) project has developed a three-phase (gas, water, underground rock) reactor in the laboratory to reproduce a pressurised mini-storage facility in which microorganisms sampled directly from storage aquifers will be grown in culture. Alternative biomethane and/or hydrogen injection scenarios will be tested at different concentrations to assess their impacts.
- As part of the $CorrO_2$ project, additional research is underway to discover more about the corrosion of borehole steels in the presence of oxygen (the main corrosion factor present in biomethane).

Customer benefits

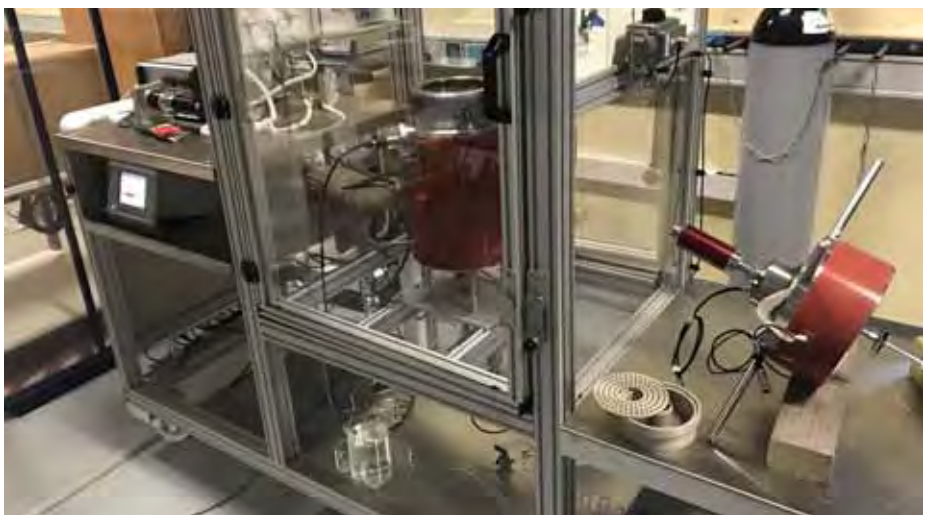
- Improved integration of renewable gases into underground storage facilities by anticipating potential operational constraints.
- Anticipating requests from future gas suppliers by setting acceptable limits for new gas injection.

Progress to date

- The RINGS project: construction of the pilot plant and commencement of experimentation on water and rock samples from the Izaute storage facility in the presence of 1% oxygen, and preparation for the next experiment in the presence of hydrogen. Inclusion of SNAM (Italy) and ENAGAS (Spain) as members of the project granted privileged access to its results.
- $CorrO_2$ project: construction of the autoclaves has begun.

Future developments

- Finalising current experiments (September 2021 for RINGS and May 2021 for $CorrO_2$) and launching additional experiments, if necessary.
- Publishing the results and identifying the acceptable concentrations of hydrogen and biomethane in natural gas prior to injection.



The reactor developed as part of the RINGS project.

WHY ARE 'NATURAL' STORAGE FACILITY BACTERIA IMPORTANT?

The natural gas injected into storage facilities is composed mainly of methane (more than 90%). It also contains a small proportion of other gaseous compounds, including ethane, propane, butane, nitrogen and carbon dioxide, as well as trace elements such as BTEX (Benzene, Toluene, Ethylbenzene and Xylenes). These are aromatic compounds present in the gas at levels of concentration in the order of a few parts per billion. But even at such low concentrations, their solubility in groundwater may pose a risk to humans. This is why Teréga regularly monitors the quality of the water around its storage facilities. Added to which, the results of several studies conducted since 1998 have shown that some bacteria naturally present in the underground geological layers have the ability to biodegrade these BTEX. It is therefore essential to protect them, which is why Teréga is studying any parameter with the potential to modify these natural attenuation agents.

GLOSSARY

Delivery point
An installation whose purpose is to deliver gas to clients. Its other main functions are pressure regulation and gas volume measurement.

Electrolysis
The process used to convert electrical energy into chemical energy. Electrolysis of water is used to produce hydrogen.

Isobath
A depth curve on a map connecting all points sharing the same depth below the surface of the earth or the surface of water.

Machine learning
A technology based on artificial intelligence that enables computers to learn automatically and make statistical predictions from a given set of data.

Magnetic tomography
A contactless pipeline inspection technology that can detect wall and weld defects, corrosion, cracks, physical characteristics, alignment and below-ground depth.

Methanation
A biological or catalytic industrial process in which carbon dioxide or carbon monoxide reacts with hydrogen to produce water and methane. This type of methane is referred to as methane syngas.

Microorganisms
Microscopic organisms, such as bacteria, microalgae and many fungi, such as yeasts. Some are naturally present in the underground layers of Teréga gas storage facilities.

Non-piggable pipeline
An underground pipeline through which it is not possible to send cleaning or inspection devices.

Piezometric level
Depth of the upper surface of the underground water table. It is expressed in metres relative to the ground surface.

Power-to-Gas
An industrial process in which surplus electricity generated from renewable energy sources is converted into hydrogen gas by electrolysis. This hydrogen can either be injected directly into the natural gas network at a controlled rate or converted by methanation into methane syngas by combining it with carbon dioxide captured elsewhere.

Predictive maintenance
Predictive maintenance is based on the forecasting of breakdowns and failures to predict the condition of a device or item of equipment before it fails.

Trace compounds
Compounds that are present in gas in very low concentrations, but which nevertheless pose potential risks to Teréga operations.

Venting
The atmospheric release or expansion of gas from a pressurised structure in order to make it available for remedial work or maintenance.

TERÉGA would like to thank CRE for its support on R&I activities, which is enabling the company to prepare effectively for the future of gas transport and storage networks.

Design & Production: MAKHEIA

Text: TERÉGA

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July 2020

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