RESEARCH & DEVELOPMENT,
EXPLORING NEW DIRECTIONS
A WORD FROM
THE SENIOR
VICE PRESIDENT
STRATEGY, BUSINESS
DEVELOPMENT
AND RESEARCH &
DEVELOPMENT, E&P

MARTIN DEFFONTAINES

Today’s hydrocarbon resources are more diverse than in the past. They are also more complex to produce and increasingly located in frontier provinces beyond the reach of conventional development methods. Extracting their value sustainably and profitably demands boldness and breakthrough technologies.

This makes innovation not an option, but rather the very purpose of Research & Development in Total’s Upstream segment. Many world firsts have punctuated our industrial career and propelled us into the top tier of the global oil and gas sector. Reflecting the pioneering spirit and inventiveness of our researchers, such trailblazing achievements will continue to be the hallmark of our major oil and gas projects. Faced with increasing competition and the overriding need to control the costs of developing and producing our future assets, our R&D organization is mobilized to spearhead the delivery of disruptive innovations: technologies that will make the difference and permit economically viable production of resources to fuel the global economy. At the same time, they must ensure responsible exploitation, preserve the environment and meet the expectations of civil society.

Our R&D programs are geared to topics strategic for our competitiveness. They are organized to identify game-changing technologies at a very early stage. To coax out new ideas and turn them into technological assets, program teams collaborate with prominent players in academia, science and industry to gain access to state-of-the-art knowledge obtained through experimental technologies; new, molecular-scale understanding of complex phenomena; and simulations of multiple physical phenomena on multiple scales. As sequels to these R&D programs, technological innovation projects are developed in order to carry innovations to industrial maturity via large-scale pilot trials. This process ensures that innovation can quickly be delivered to our projects and operations.

Sharpening our competitive edge, keeping one step ahead of our rivals, and finding better, less costly solutions applicable to our target growth sectors, all pose huge challenges – as huge as our determination to overcome them.
**The 3 Drivers of Excellence**

**Selectivity**

The future sets high standards. Only the best will be able to meet its challenges and achieve the necessary technological breakthroughs. Based on our vision of the way forward, we have identified the areas in which excellence is a prerequisite for competitiveness. These are the areas on which we are focusing our efforts – on strategic themes for which we have the determination and the wherewithal to rise above the crowd.

Our selective approach dictates the scope and roadmap of our R&D. It revolves around eight thematic R&D programs, each having its own objectives and schedules, but all aimed at inventing and developing disruptive technologies that will push back the limits of oil and gas exploration and production. At the same time, we are running Prospective Labs devoted to more exploratory research on emerging scientific and technological topics that lie outside of our traditional scope. Their purpose is to “capture” advances in other fields that have the potential to affect our own operations.

**Teams**

The main priority of the teams assigned to our R&D programs is to advance their research. This model limits pressures and urgent operational demands on their work. It gives them the assurance of continuity in their efforts and their relations with partners outside the company. Driven by their will to succeed, these teams spawn new ideas. They bring together a community of world-class researchers, doctoral candidates and experts with complementary backgrounds and know-how, united in their efforts to attain common goals. Teams often work together from several different locations, such as in our worldwide research centers. This network model enables them to tap into our regional hubs of excellence.

Researchers are selected from a shortlist of top candidates; they are given the time they need to bring their ideas to fruition and are guaranteed access to the necessary resources for the duration. They constitute the lifeblood of a value chain of expertise which, like our operational organization, offers recognition and rewarding career opportunities.

**Openness**

Today more than ever, we must be open to scientific and technological advances taking place outside our organization so we can detect the most promising innovations at the earliest possible stage, tailor them to our own sector and deliver them to our operations as quickly as possible. The aim here is to track down outstanding skills and cutting-edge knowledge through strategic alliances with the world’s leading academic and industrial research entities. Naturally, Total is not the only company seeking to team up with the most brilliant minds and the most celebrated research teams, because such partnerships translate to an absolutely decisive competitive edge. This is why our priority targets are win-win partnerships that offer an international dimension, an extended duration and significant added value. This policy is reflected in our exclusive and far-reaching collaborations with Stanford University, ONERA, Ifremer and the Massachusetts Institute of Technology (M.I.T.). In addition, we maintain a network of high-caliber regional partnerships located near our main R&D center in southwest France. This network features agreements with Université de Pau et des Pays de l’Adour and the University of Bordeaux.

**Comments from Daniel Plathey, Vice President, R&D**

**Selectivity**

The future sets high standards. Only the best will be able to meet its challenges and achieve the necessary technological breakthroughs. Based on our vision of the way forward, we have identified the areas in which excellence is a prerequisite for competitiveness. These are the areas on which we are focusing our efforts – on strategic themes for which we have the determination and the wherewithal to rise above the crowd.

Our selective approach dictates the scope and roadmap of our R&D. It revolves around eight thematic R&D programs, each having its own objectives and schedules, but all aimed at inventing and developing disruptive technologies that will push back the limits of oil and gas exploration and production. At the same time, we are running Prospective Labs devoted to more exploratory research on emerging scientific and technological topics that lie outside of our traditional scope. Their purpose is to “capture” advances in other fields that have the potential to affect our own operations.

**Teams**

The main priority of the teams assigned to our R&D programs is to advance their research. This model limits pressures and urgent operational demands on their work. It gives them the assurance of continuity in their efforts and their relations with partners outside the company. Driven by their will to succeed, these teams spawn new ideas. They bring together a community of world-class researchers, doctoral candidates and experts with complementary backgrounds and know-how, united in their efforts to attain common goals. Teams often work together from several different locations, such as in our worldwide research centers. This network model enables them to tap into our regional hubs of excellence.

Researchers are selected from a shortlist of top candidates; they are given the time they need to bring their ideas to fruition and are guaranteed access to the necessary resources for the duration. They constitute the lifeblood of a value chain of expertise which, like our operational organization, offers recognition and rewarding career opportunities.

**Openness**

Today more than ever, we must be open to scientific and technological advances taking place outside our organization so we can detect the most promising innovations at the earliest possible stage, tailor them to our own sector and deliver them to our operations as quickly as possible. The aim here is to track down outstanding skills and cutting-edge knowledge through strategic alliances with the world’s leading academic and industrial research entities. Naturally, Total is not the only company seeking to team up with the most brilliant minds and the most celebrated research teams, because such partnerships translate to an absolutely decisive competitive edge. This is why our priority targets are win-win partnerships that offer an international dimension, an extended duration and significant added value. This policy is reflected in our exclusive and far-reaching collaborations with Stanford University, ONERA, Ifremer and the Massachusetts Institute of Technology (M.I.T.). In addition, we maintain a network of high-caliber regional partnerships located near our main R&D center in southwest France. This network features agreements with Université de Pau et des Pays de l’Adour and the University of Bordeaux.
INTERNATIONAL PRESENCE

Our R&D organization achieves global reach through a number of world-class research centers located near hubs of Oil & Gas industry know-how in key regions of the globe.

The CSTJF (Centre Scientifique et Technique Jean Feger) in Pau (southwest France) is the nerve center of R&D for Total’s Exploration & Production (E&P) branch. This world-class facility is a hub of technological excellence, staffed by some 2,500 employees of some 35 different nationalities. It is home to a large share of the E&P branch’s scientific expertise and research facilities.

A few kilometers away is the PERL (Platform for Experimental Research at Lacq), one of the focal research centers of our multi-site R&D network. Not only has the PERL earned a global reputation for expertise in acid gas processing, it also excels in the field of physical chemistry. Its achievements include formulating the first polymer used in offshore enhanced recovery applications. On the strength of this expertise, the PERL recently established a joint laboratory devoted to the physical chemistry of complex interfaces with École Supérieure de Physique et de Chimie Industrielles de la Ville de Paris (ESPCI-Paris Tech).

Thanks to our worldwide locations, we can take advantage of leading-edge academic and industrial know-how wherever it may be, either through dedicated R&D centers or through more streamlined entities that maintain close ties with top-flight public or private research bodies. Today stretching from the United States to Russia and from Britain to the Middle East, our network is destined to further extend its reach to other countries, such as Brazil.

ABERDEEN (United Kingdom)

20 RESEARCHERS

MAIN R&D THEMES
- Seismic techniques
- Advanced geocellular modeling
- Digital rock physics
- Technologies for petroleum development

MAIN PARTNERSHIPS
- Imperial College London (pore-scale modeling)
- Heriot-Watt University (4D seismic)

STAVANGER (Norway)

10 RESEARCHERS

MAIN R&D THEMES
- Environmental technology for the marine environment
- Flow performance
- Subsea technology
- Future well and drilling technologies

MAIN PARTNERSHIPS
- SINTEF (Flow performance)
- Norwegian University of Science and Technology (hydrates and paraffin characterization)
- University of Tromsø (remote sensing)
- University of Stavanger and IRIS (environmental technologies for the marine environment)
- Center for Integrated Petroleum Research (reservoir characterization)
- Aker (subsea processing)
- ABB (subsea electrification)

DOHA (Qatar)

15 RESEARCHERS

MAIN R&D THEMES
- Fluids and organic geochemistry
- Acid stimulation of wells in carbonate formations
- Rock chemistry (conversion of CO2)

MAIN PARTNERSHIPS
- Qatar Petroleum (mattix acidizing)
- Qatar Petroleum and Q Analytica (geochemical production allocation)
- LATMOS (Atmospheres, Environments and Spatial Observations Laboratory)
- Autonomous gas-phase chromatography
- Qatar University (produced water management and CO2 treatment)
- Texas A&M University (matrix acidizing – CO2 conversion)

PERL (France)

80 RESEARCHERS

MAIN R&D THEMES
- Seismic acquisition, Seismic imaging, Microseismic and HPC (High Performance Computing)
- Deep offshore (subsea development)
- Flow assurance (modeling) and Drilling
- GEO2R (Chemical Enhanced Oil Recovery) and Reservoir simulation
- Environmental and stakeholder issues

MAIN PARTNERSHIPS
- University of Texas at Austin
- Houston University
- Rice University
- Purdue University – M.I.T.
- Stanford University – Member of the RPSEA and DEEPSTAR consortiums (deep offshore)

CSTJF (France)

60 RESEARCHERS

THE MAIN R&D HUB OF THE EXPLORATION & PRODUCTION DIVISION:

140 RESEARCHERS

8 STRATEGIC R&D PROGRAMS

11 TECHNOLOGICAL INNOVATION PROJECTS

5 PROSPECTIVE LABS

MAIN R&D THEMES
- Environmental technology for the marine environment
- Extreme cold
- Mathematical modeling

MAIN PARTNERSHIPS
- Moscow State University
- Kurchatov Institute
- Murmansk Marine Biological Institute
- Baikir State University
- Zubov Oceanographic Institute

HOUSTON (United States)

30 RESEARCHERS

MAIN R&D THEMES
- Seismic acquisition, Seismic imaging, Microseismic and HPC (High Performance Computing)
- Deep offshore (subsea development)
- Flow assurance (modeling) and Drilling
- GEO2R (Chemical Enhanced Oil Recovery) and Reservoir simulation
- Environmental and stakeholder issues

MAIN PARTNERSHIPS
- University of Texas at Austin
- Houston University
- Rice University
- Purdue University – M.I.T.
- Stanford University – Member of the RPSEA and DEEPSTAR consortiums (deep offshore)

MOSCOW (Russia) – in progress

4 RESEARCHERS

MAIN R&D THEMES
- Environment
- Gas separation and treatment
- Physical chemistry of interfaces

MAIN PARTNERSHIPS
- École Supérieure de Physique et de Chimie Industrielles de la Ville de Paris (ESPCI-Paris Tech)
- University of Texas at Austin and Rice University (chemical EOR)
- Ugelstad Laboratory
- NTNU Trondheim (physical chemistry and liquid/liquid separation)
- University of Bordeaux (biomonitoring)
- University of Toulouse (modeling of biological and membrane processes)
THE MEANS TO MAKE THE DIFFERENCE

Being a frontrunner takes more than good ideas: you also need the means to test them and bring them from the laboratory to the field. At Total, our resources are on par with our ambitions and with the complexity of our challenges. For example, we have one of the world’s most powerful supercalculators, which we use for reservoir imaging and modeling. We also have a full gamut of experimental facilities to test our innovations from bench scale to field pilot.

The computing power installed at the CSTJF, the scientific and technical center serving Total’s Upstream segment, ranks us among the world leaders in terms of scientific computing power. We are steadily expanding our High Performance Computing (HPC) capacity, which will soon be increased to 6.7 petaflops (6.7 million billion operations/second) and is set to reach the threshold of one exaflops (one billion billion operations/second) by 2020. Expanding our HPC resources enables more efficient scientific calculations, more realistic physical models and more reliable subsurface simulations. Our R&D teams are taking a number of steps to secure our leadership in this strategic area: designing HPC architectures for tomorrow, evaluating languages and programming models and developing algorithms to optimize intensive computing.

BILLIONS OF BITS

Our HPC resources enable us to exploit increasingly huge volumes of data in our imaging and simulation tools. Depth imaging, a technique formerly reserved for only the most complex geological contexts, is becoming the rule: the processing times are now acceptable to yield increasingly detailed subsurface images. In the future, we will be able to exploit all the seismic data recorded by our sensors – elastic as well as acoustic – to see the subsurface as it has never been seen before.

The promise of HPC also extends to our reservoir simulations, which will boast enhanced resolution and pertinence. As co-owners of the new-generation INTERSECT code, we are developing new equations to simulate increasingly complex and varied physical phenomena. And we already have the capacity for a giga-cell (one billion cells) reservoir simulation.

CAPTIONS: 1. The Centre Scientifique et Technique in Pau boasts one of the world’s most powerful supercomputers, Pangea, with a computing capacity of 2.3 million billion operations per second. The aim of this investment is to achieve gains in the processing time and resolution of subsurface models and simulations of reservoir behavior. 2. Simulation of a field in the Middle East using the INTERSECT code. 3. High Performance Computing in the global top ten.
EXPERIMENTATION FROM BENCH TO FIELD PILOT

We are one of the few global oil and gas majors to be equipped in-house with a series of latest-generation laboratories able to perform drill core analyses and studies in fields such as fluids and organic geochemistry, petrophysics, recovery mechanisms, rock mechanics, drilling muds and cements and corrosion. These labs are fitted out with a full range of scientific and technical apparatus to test our ideas and conduct the experiments vital to achieving more reliable modeling of reservoirs, fluids, and their dynamic behavior.

Beyond the laboratories, we use our company facilities to test and validate new solutions and concepts on an industrial scale. Thanks to this end-to-end experimental infrastructure, we are able to meet the crucial challenge of scaling up our solutions from the laboratory to the field.

CUTTING-EDGE EQUIPMENT

We make a point of procuring the latest equipment technologies for our labs. But we also draw on our own inventiveness to develop in-house research systems to build our understanding of oil and gas fields.

> To enhance our simulation tools with new physics equations that are more representative of reality, we can now visualize fluid flows in porous media at any scale. At the pore scale, our studies are supported by X-ray microtomography or by new-generation micromodels in which throat size has been reduced to about ten microns. For core-scale studies, we developed the CX Box, a novel test bench equipped with a built-in X-ray system to monitor the advance of the saturation front inside a fluid-swept core.

> Our researchers use their ingenuity to make our characterizations of unconventional resources more reliable and efficient. A mobile laboratory tool called LIPS (Laser Induced Pyrolysis System) automatically quantifies and maps the organic matter contained in a core. It can also be used in the field. Step Decay is a proprietary method for measuring permeability and porosity in highly compact reservoirs. By coupling an innovative laboratory bench with a numerical tool for interpreting the results, it delivers reliable, high-quality measurement data in just a few hours.

> PILOT RIVERS: This outdoor laboratory is the only one of its kind in the world. It consists of 16 man-made watercourses diverted from the Gave de Pau river. These are used to study the impacts of industrial effluents on water, assess impacts using biological indicators and evaluate the risks associated with certain substances.

> INTEGRATED EOR TEST PLATFORM: This installation replicates the complete topsides configuration involved in producing hydrocarbons with the help of chemical EOR. It is used to qualify effluent separation and treatment processes for produced water, in a quest for efficacy and management of environmental impacts.

> A TEST SITE SPREAD OVER NEARLY 6 HECTARES: This extensive area has been allocated to pilot facilities, and will likely be the site of the future 800-meter-long COOTRAINS test loop designed to validate thermodynamic models of dense-phase CO2 transport in the presence of impurities. These models are the fruit of our laboratory research.

LARGE PILOT INSTALLATIONS

Facilities at the PERL (Platform for Experimental Research at Lacq) comply with the requirements of Europe’s Seveso 2 Directive on sites containing environmental hazards. These extensive installations accommodate large-scale testing.

> PILOT RIVERS: This outdoor laboratory is the only one of its kind in the world. It consists of 16 man-made watercourses diverted from the Gave de Pau river. These are used to study the impacts of industrial effluents on water, assess impacts using biological indicators and evaluate the risks associated with certain substances.

> INTEGRATED EOR TEST PLATFORM: This installation replicates the complete topsides configuration involved in producing hydrocarbons with the help of chemical EOR. It is used to qualify effluent separation and treatment processes for produced water, in a quest for efficacy and management of environmental impacts.

> A TEST SITE SPREAD OVER NEARLY 6 HECTARES: This extensive area has been allocated to pilot facilities, and will likely be the site of the future 800-meter-long COOTRAINS test loop designed to validate thermodynamic models of dense-phase CO2 transport in the presence of impurities. These models are the fruit of our laboratory research.

CAPTIONS: 1. With its staff of 2,500, the Centre Scientifique et Technique in Pau is one of the most prominent centers of technological excellence in the oil and gas industry. 2. Step Decay is used to appraise reserves and more generally to estimate production profiles in highly compact, very low-permeability reservoirs. 3. The aim of X-ray microtomography is to provide a visualization of phenomena – such as oil and water flows and the formation of gas phases – at pore scale. 4. Visualization of the pore space of sandstone (local zoom, resolution < 700 nm). 5. The PERL’s network of 16 pilot rivers is dedicated to curbing the environmental impacts and energy consumption of oil and gas facilities. 6. The research findings of the Physical Chemistry of Interfaces department of the PERL contribute to the formulation of innovative surfactants, polymers and additives to improve oil recovery. 7. The PERL’s integrated test platform devoted to EOR effluent treatment includes a loop for preparing polymer solutions, another for generating synthetic produced waters and an oil/water separation pilot.
INNOVATION ON THE MARCH

The challenge of renewing our hydrocarbon reserves sustainably and cost-effectively demands the best: the best knowledge, the best know-how and the best technologies. In partnership with some of the world’s leading-edge scientific research bodies, our R&D teams are defining the contours of that energy future within the framework of our R&D Programs and Prospective Labs. Dedicated to discovering and exploiting resources from new provinces identified as strategic to our growth, their studies have in common the goals of excellence and controlled costs – the keys to Total’s competitiveness. The latest outcomes of this research, in fields where our experience and know-how rank us among the top performers in the global industry, are evidence of our ability to change the game through innovation.
RETHINKING OUR GEOLOGICAL CONCEPTS

Petroleum exploration still has a bright future, as the major discoveries of the past decade clearly illustrate. The fact that several of these finds have been located in little-explored areas has prompted us to revisit our geological concepts and extend our exploration scope to include frontier basins whose potential has yet to be revealed.

To guide our exploration efforts efficiently to these potentially promising areas, our geologists are starting over from scratch and updating their structural, sedimentary and fluid hypotheses. They need to start with a comprehensive understanding of geodynamics – the processes involved in the formation of sedimentary basins – based on which they will reconsider the conditions conducive to forming petroleum systems, with their reservoirs and traps.

To shape these innovative concepts and predict new “hunting grounds” and the types of petroleum traps they may contain, keeping abreast of advances in academic research is paramount: this is how we will stay poised to detect, quickly take up and grasp the oil and gas implications of new scientific ideas. It is the key to managing our risks effectively as we explore new plays.

THREE HIGH-POTENTIAL PROVINCES

In line with Total’s exploration strategy, our R&D teams are focusing on three priority provinces that show high potential: transition zones (known as margins) between the continent and the ocean floor, foothills, and carbonates. Under-explored, highly complex or a combination of the two, mastering each of these provinces will require identifying critical events and processes that have had a decisive influence on the development of a petroleum system, and on the characteristics of that system.
We are investigating continental margins through the PAMELA research program (for PAssive Margins Exploration Laboratories), which we are running jointly with French oceanographic research institute Ifremer and a network of academic partners. Extensive in scope, this multidisciplinary study will examine the continental margins from the river basins which are the source of the sediments to the deepwater regions where the sediments are deposited. It will pave the way to important scientific advances by acquiring new types of data from areas key to deepening our understanding of margin zones. Data from exploratory surveys carried out in 2014 in the Mozambique Channel is being used to develop our innovative source-to-sink approach in the context of abrupt margins. We anticipate that characterizing and quantifying sedimentary sources over time will enable us to make robust predictions of reservoir location and quality. As we revisit what we know about compression areas, we must develop a more comprehensive understanding of mountain ranges able to incorporate recent (and future) scientific advances. Updating and broadening our paradigm will improve our ability to predict the potential of foothills formed by folded sedimentary layers. Our new understanding of these deformations will be decisive. It will guide our prospecting in environments that are poorly illuminated by seismic due to difficult access and structural complexity. “Carbonate Factories through Time and Space” is an ambitious and innovative project aimed at developing concepts and models that will guide our lease acquisition strategy for frontier exploration in carbonate rocks. The project involves reconstructing the paleogeology of “carbonate factories” at strategic ages. It is the first approach that aims for a characterization that couples extrinsic (geodynamics, climatology, oceanography) and intrinsic (biology, sedimentary dynamics, diagenesis) parameters. These parameters control both the spatial and temporal evolution of carbonates.

This major investment in the development of innovative geomodeling tools benefits from advances in numerical capabilities: today’s models are able to integrate multiple processes (e.g., chemical, mechanical, hydrological, climatological, diagenetic, and biological). But it is also by working on multiple scales, from the global lithosphere to basin model to reservoir model, that we will be able to make our simulations more realistic and more meaningful.

This research is backed by collaboration with academic and scientific partners in the vanguard of this field such as IFPEN for basin modeling and Bergen University for models of lithospheric dynamics. It will give us access to tools for testing our hypotheses and generate new ones.

**CAPTIONS:**
1. Paleoclimatological study of carbonate sediments of the Borealian, Lower Cretaceous (140 million years).
2. Tectonics and fluids circulation — toward a coupled large-scale hydro-mechanical simulation of fluid circulation in a basin of complex faulted structure —

**PAMELA, DISCOVERING THE SECRETS OF PASSIVE MARGINS**

Launched in 2013 for a six-year period, PAMELA gives us an opportunity to develop innovative material on topics crucial to our understanding of continental margins: their geodynamics and structure, the related sedimentary systems, the fluids and weak signals of a petroleum system, geohazards and seabed instabilities, as well as the ecosystems of these zones. Data acquisition (seismic, sonar, sediment samples, cores, etc.) is targeting four separate areas. They were selected as being representative of the various morphological forms of the margins: the Mozambique Channel, the Gulf of Aden, the Bay of Biscay and eastern Corsica. The first three acquisition programs, which took place in 2013, concentrated on eastern Corsica and the Bay of Biscay.

In 2014, PAMELA shifted its focus to the Mozambique Channel, an area of tremendous geological interest that constitutes the main study focus. Acquired in nearly 300 days at sea, the highly innovative data obtained by the expedition will yield vital secrets that will facilitate our understanding of the geology and the petroleum traps found in these environments.
EARTH IMAGING

In the field of 3D imaging, Total is in the vanguard. Today, we are focusing on disruptive innovations to deliver reliable 3D models of the subsurface and near-surface. To achieve our goal of excellence, we are directing our efforts to innovate at each step of the imaging chain from data acquisition to processing. Our aim is to invent new integrated systems that will “fast-track” our acquisitions of multiphysics data, which we will then process and interpret at various scales and resolutions. The point here is to quickly obtain information of a quality that will give us a crucial competitive edge in understanding the geology of complex, hard-to-access oil and gas provinces – which have not yet been fully explored.

Researchers in France, the United States and working in close collaboration with our research partners are striving under this program to turn geophysical data into a true competitive asset for Total’s E&P. Ten years from now, their goal is to generate high-value surface and subsurface models in less time and for a lower cost, in zones that are complex or difficult to access.

REMOTE SENSING, SCOUTING NEW EXPLORATION OPPORTUNITIES

Natural hydrocarbon seeps at sea or at the Earth’s surface are clues to the possible presence of petroleum systems. Detecting and identifying these shows using innovative remote sensing techniques will be decisive in guiding our exploration effort toward new discoveries. We are addressing this challenge jointly with ONERA, a European leader in remote sensing, under a broad research and innovation partnership agreement signed in 2014 for a renewable five-year term. The research is focused on hyperspectral imaging, radar and lidar (laser) techniques, with the dual objective of developing workflows for acquiring and processing multiphysics data geared to the needs of our oil and gas operations, and determining the best satellite and/or airborne (i.e., airplane, dirigible or drone) technologies for obtaining that data.

Sismage®, our geoscience interpretation platform, underpins our R&D effort to understand natural hydrocarbon seeps. Now that we have implemented the new Remote Sensing module, we are able to map occurrences of seeps based on a time series of repeat radar images of a given offshore zone. This mapping highlights areas where the presence of seeps is highly probable and which therefore may constitute promising exploration targets. The mapping can provide valuable insight into the associated petroleum system.
Our ambition is to change the game through research and innovation. For onshore acreage, we intend to develop new integrated solutions for multiphysics acquisitions that optimize technological, economic and environmental performance. The enablers of these technological step changes include deploying a carefully defined number of “lightweight” seismic sources that can be used simultaneously; multicomponent and multiphysics wireless sensors that combine not only active and passive seismic data but also gravimetric and electromagnetic information; and revolutionary operating procedures that significantly diminish both the survey turnaround time and the HSE risk exposure associated with our operations.

For offshore and transition zones in water depths of less than five meters, we will capitalize on the marine vibrator and the benefits it offers. This new-generation marine seismic source developed under the MARVIB Joint Industry Project (JIP) will pave the way to more economical marine seismic acquisitions thanks to the productivity gains that result from the use of simultaneous sources. Moreover, the marine vibrator is less aggressive for marine mammals than airguns.

The first prototype will be tested in operational conditions in the course of 2015.

CHALLENGING THE LIMITS OF SEISMIC IMAGING

Total has a reputation for technical excellence in seismic depth imaging, which we routinely apply for both exploration and development targets. We invented and industrialized several major advances in depth imaging for highly complex structures and objects masked by salt overhangs or other seismic barriers. Our in-house algorithm for calculating Surface-offset Common Image Gathers (CIG), which improves the quality of our Reverse Time Migration (RTM) images, is unique in the industry, and our Full Waveform Inversion was one of the earliest implementations of this technology for high-resolution velocity model-building. They are the fruit of our leading-edge R&D expertise.

We are pursuing our research and innovation effort to develop tools and workflows that will enable us to take full advantage of the improvements in our seismic acquisitions. Indeed, by improving the fidelity of our simulations, we aim to generate quantitative images of subsurface petrophysical properties and thereby maximize the value that we extract from our data.

Seismic wave propagation through the subsurface is actually much more complex than what we have been able to simulate so far, which has been based on various acoustic approximations to the wave equation. With the growth in available computing power, coupled with our algorithmic expertise, we are now moving to minimize the limitations of that simplification. Accurate estimation of the full range of parameters relevant to P-wave propagation (density, anisotropy, attenuation) by means of innovative joint inversion algorithms will push our mastery of the acoustic domain to the very limits of feasibility, while pursuing our ambition of getting a head start on the elastic domain as well. To achieve this leap forward, we will exploit multicomponent seismic acquisition. This will open the door to interpreting the elastic signals of the wave field, currently considered as “noise.”

Our imaging capabilities already integrate multiple parameters. To derive the full benefit from all the field data we acquire, we must develop our multiphysics capability as well. The main challenge here is to compensate for the limitations of seismic, particularly with respect to near-surface characterization, by generating multiphysics 3D models based on joint inversions of seismic and non-seismic data (i.e., gravimetric, electromagnetic and remote sensing data).

CHALLENGING THE LIMITS OF SEISMIC IMAGING

Total has a reputation for technical excellence in seismic depth imaging, which we routinely apply for both exploration and development targets. We invented and industrialized several major advances in depth imaging for highly complex structures and objects masked by salt overhangs or other seismic barriers. Our in-house algorithm for calculating Surface-offset Common Image Gathers (CIG), which improves the quality of our Reverse Time Migration (RTM) images, is unique in the industry, and our Full Waveform Inversion was one of the earliest implementations of this technology for high-resolution velocity model-building. They are the fruit of our leading-edge R&D expertise.

We are pursuing our research and innovation effort to develop tools and workflows that will enable us to take full advantage of the improvements in our seismic acquisitions. Indeed, by improving the fidelity of our simulations, we aim to generate quantitative images of subsurface petrophysical properties and thereby maximize the value that we extract from our data.

Seismic wave propagation through the subsurface is actually much more complex than what we have been able to simulate so far, which has been based on various acoustic approximations to the wave equation. With the growth in available computing power, coupled with our algorithmic expertise, we are now moving to minimize the limitations of that simplification. Accurate estimation of the full range of parameters relevant to P-wave propagation (density, anisotropy, attenuation) by means of innovative joint inversion algorithms will push our mastery of the acoustic domain to the very limits of feasibility, while pursuing our ambition of getting a head start on the elastic domain as well. To achieve this leap forward, we will exploit multicomponent seismic acquisition. This will open the door to interpreting the elastic signals of the wave field, currently considered as “noise.”

Our imaging capabilities already integrate multiple parameters. To derive the full benefit from all the field data we acquire, we must develop our multiphysics capability as well. The main challenge here is to compensate for the limitations of seismic, particularly with respect to near-surface characterization, by generating multiphysics 3D models based on joint inversions of seismic and non-seismic data (i.e., gravimetric, electromagnetic and remote sensing data).
To unlock economically-viable access to reserves of increasing complexity, a better understanding of our reservoirs and the physics of their hydrocarbon flows is indispensable – from the tiniest to the largest scale. Thanks to state-of-the-art experimental technologies and a high degree of integration among the various sub-disciplines of geoscience expertise, our laboratories are poised to take our knowledge to the next level. Only by doing so can we hope to enhance the fidelity of our geological and reservoir models and generate more realistic simulations of our production. When coupled with the development of more economical enhanced recovery technologies suited to our asset portfolio, this finer knowledge of our reservoirs holds promise for optimized development architectures and profitable, sustainable production of reserves.

1 BILLION GRID-BLOCKS – THE INTERSECT

RESERVOIR SIMULATOR PLACED TOTAL IN THE VANGUARD OF SIMULATION BY ACHIEVING THE MILESTONE OF GIGA-CELL SIMULATION IN 2013.

IT TOOK ONLY TWO HOURS TO SIMULATE A FOUR-YEAR PRODUCTION HISTORY USING 576 PROCESSORS IN PARALLEL.

IN 2012, THE SAME EXERCISE PERFORMED WITH THE ECLIPSE SIMULATOR REQUIRED 1,000 PROCESSORS AND TOOK SEVERAL DAYS.

NEW-GENERATION MODELING

Our R&D teams are addressing the crucial challenge of developing a new generation of reservoir modeling tools able to portray geological targets of complex structure and sedimentary heterogeneity, implemented on the T-StoRM® platform (Total Seismic to Reservoir Modeling) common to all the disciplines involved in the reservoir modeling process, such proprietary tools can be leveraged to significantly reduce uncertainty and improve the fidelity of our models, the key to optimal development architectures.

One of our priorities here is to develop gridding tools designed to embrace a new era of unstructured grids, freed from the limits of conventional uniform-geometry models. In unstructured grids, the “blocks” of conventional models are replaced by variably-sized cells that give us the flexibility to coarsen or refine specific zones of the model. Thus, we can “zoom in” on sectors or periods that exhibit faster or more complex changes.

Integrating the geomechanical component into our modeling workflow is another priority. The point is to understand, foresee and manage the changes that will occur in the reservoir and its geologic environment over the entire life of the field. This will enable us to manage the impacts of depletion and injections over the production period, and thereby optimize the safety and economics of our development projects.

LEADING THE WAY IN RESERVOIR SIMULATION

Improving our characterization of the porous medium and fluid mechanics of the reservoir is a crucial factor in extracting more hydrocarbons at lower cost. We are tackling this challenge by gaining leading-edge knowledge and know-how that span all aspects from defining innovative experimental methods to building new models of fluid physics in porous media. These advances will enhance the value of our reservoir simulations.

T-STORM®, AN INTEGRATED MODELING PLATFORM

T-StoRM® is part of our Integrated Geosciences Suite, which is regularly enriched by implementing the latest modules developed by our R&D teams. Today, T-StoRM® integrates our full range of tools relating to the 2G workflow (Geophysics and Geology) of a reservoir study from seismic interpretation to construction of the static reservoir model. The multidisciplinary T-StoRM® platform optimizes and accelerates this workflow; it will be expanded to include reservoir simulation in 2015. The major benefit here will be more efficient updating of the reservoir models of producing fields, which are calibrated using the field production histories.
In 2012, we demonstrated experimentally that the presence of polymers alters the relative permeability curves that affect multiphase flows (oil, gas and water). The model representing this new correlation between the relative permeabilities of oil and water in the presence of polymers was implemented in our prototyping platform and validated on actual cases. At the same time, we developed a new algorithm to model the case of a polymer/surfactant sweep. This functionality is not currently available in any off-the-shelf simulation package. It enables us to simulate the generation of the microemulsion phase triggered in the reservoir by the injection of the chemical mixture. Implementing this improved physical representation into our computing codes is a major step toward more reliable predictions of additional reserves in connection with chemical EOR.

**MORE RELIABLE COMPUTING CODES**

IMPROVING THE ECONOMICS OF EOR

EOR will be a strategic factor in maximizing our reserves, but curtailing its costs is essential for the technology to gain operational momentum. This is thus the main thrust of our R&D efforts in EOR. It will entail optimization at every step of the enhanced recovery process, from subsurface to surface.

Chemical injection (with polymer and/or surfactant) and miscible gas injection techniques offer the best potential for the assets currently in our portfolio; they are the focus of numerous studies. Our investment in furthering our fundamental understanding of the physical mechanisms involved in enhanced recovery will help us improve process efficiency and thereby lead to low-cost EOR projects by limiting the quantity of chemicals required. Already, the PERL’s world-class expertise in physical chemistry and the lessons learned from our field trials of chemical EOR have given us a competitive edge. Total was the first company to tackle the challenge of polymer flooding in the offshore context in pilot tests carried out from 2008 to 2012 on the Dalia field (Angola). We then marked another first by running a pilot test of polymer transport at the surface. This trial took place in 2013 at a test facility owned by the United States Department of Energy to characterize and model the rheology of polymer-viscosified water during transport. Such pilot experiences advance our fundamental knowledge of polymer degradation, a crucial factor in the efficacy of the technology. They also drive progress in specific aspects of EOR architecture. Based on pilot results, we can optimize the sizing of polymer injection projects now being designed.

Cost reduction will also be achieved by developing compact, modular EOR systems that can easily be transported from site to site for chemical injection and treatment processes. These advances will contribute to the development of integrated, economical solutions designed to address the specific needs of our affiliates. The ground-breaking development of a portable injection skid designed to handle any kind of chemical solution will considerably shorten the time it takes to prepare our pilot trials and evaluate the potential benefits of chemical EOR in exploration wells.

**BETTER ESTIMATES OF ADDITIONAL RESERVES**

Single Well Tracer Tests (SWTT) carried out in 2014 to measure the residual oil saturation in the vicinity of a well before and after pilot injections of surfactants on the ABK field (Abu Dhabi) yielded excellent results. The findings were especially remarkable given that for the first time in the world, they had been obtained on a carbonate reservoir that was not only hot (83°C) but highly saline (240 g/l). The accuracy and precision of these measurements – far superior to those obtained by conventional well logging thanks to the broader scope of investigation – can be attributed to our complete mastery of the test design, including the development of customized partitioning tracers. This innovative technology is a major step toward more reliable determinations of the additional recovery that can be expected from use of a given EOR technique. It will provide important decision support in the highly competitive segment of carbonate reservoirs in the Middle East.
SUSTAINABLE DEVELOPMENT

As concerns about the environment come increasingly and justifiably to the fore, our projects will not become reality unless they secure full stakeholder acceptance. Our R&D teams have a role to play in managing the risks of our operations and coming up with technological solutions tailored to today’s more stringent regulations. But we must do even more: we need to earn the trust of our stakeholders. This will entail understanding their fears and expectations and developing innovative approaches to information-sharing designed to alleviate their concerns and underscore the benefits of our future projects.

FRONTIER EXPLORATION
EARTK IMAGING
FIELD RESERVOIR
SUSTAINABLE DEVELOPMENT
WELLS
DEEP OFFSHORE
UNCONVENTIONALS
GAS SOLUTIONS
PROSPECTIVE LADS

CLEANER WATER, MORE AFFORDABLY
Membrane filtration technologies can considerably improve the performance of water treatment installations. As early as 2011, our leading-edge research in this field led to the first deployment of a large-scale seawater microfiltration unit on the Pazflor deepwater development (offshore Angola). That same year, we achieved a world first by pilot-testing ceramic membranes for produced water treatment in Gabon, where performance was 500 times superior to that of conventional technologies. In view of that successful result, we proceeded to qualify the technology for an industrial project.

Today, we are preparing a new milestone with pilot tests on FLEX, an innovative concept that allows simultaneous filtration of produced water and seawater. Validating this technology would pave the way to a single compound filtration process. This would deliver substantial cost savings compared to the current configuration in which the two types of water require separate treatment. Ultrafiltration (coupled with preliminary oxidation of the feedwater) is the backbone of the new process that our R&D teams are developing to address the specific challenge of treating produced water that contains polymer. This disruptive innovation has already been validated at laboratory scale.

PRODUCED WATER REUSE

As our oilfields mature, they generate increasingly large volumes of produced water. Making this water a resource available to local communities, especially for non-food applications like irrigation in regions characterized by water stress, would constitute a valuable benefit of our operations for stakeholders. To validate this innovative option for produced water beneficial reuse, we are working on the design of a pilot system due to be ready by 2016. Based on a multicriteria analysis (effluent quality, water stress, soil characteristics, agricultural activities), we determined which affiliates would have the best potential sites for the pilot trial. At the same time, in cooperation with partners specializing in agronomy, laboratory experiments are under way to identify the optimal combinations of plants, water and soil. We are also testing new seed varieties that are more resistant and produce large quantities of biomass.
It is the first technology suitable for application to waters of higher than 1.5-centipoise viscosity. Industrial-scale testing is planned in 2015 in partnership with Austrian oil company OMV, on a field pilot designed by our teams. If results are conclusive, the new technology would remove one of the current obstacles to chemical EOR by allowing produced water containing polymer to be reinjected into the reservoir. This would provide a major boost and spur responsible, cost-effective development of chemical enhanced oil recovery.

REDUCING MAJOR INCIDENT RISKS

Managing the risk of major incidents and their potential consequences for personnel, site neighbors and the environment demands excellence. Spill Watch, the fruit of four years of R&D, is an operational suite for tracking and predicting oil spill drift. It marks a major step forward – one that consolidates our capabilities to combat marine pollution. Today, one of our goals is to develop disruptive technologies that will shorten our response time in the event of a gas release and thus further limit its consequences. Driven by our conviction that remote sensing holds enormous potential for enhancing the safety of our operations, we have teamed up with ONERA, a world leader in remote sensing technologies. Our collaboration focuses on developing hyperspectral cameras and laser technologies tailored to our requirements, namely: rapid detection and identification of the gas, as well as quantification of its concentration and leakage flow rate, and prediction of zones that will be exposed as the gas cloud disperses.

INFORMATION, ENGAGEMENT AND TRANSPARENCY

Citizens are increasingly distrustful of the risks of technological and industrial innovation, and stakeholder perceptions of our projects take on paramount importance in this context. Naturally, managing the impacts and risks of our operations is essential, but it is no longer enough. We must also be in a position to answer people’s questions and address the concerns our projects can raise; we must be able to establish our credibility by sharing our information through transparent disclosures. The integrated CO₂ capture and geological storage pilot facility installed in the Lacq basin (southwestern France) was in operation from 2010 to 2013, setting a European precedent for the technology. It was accompanied by an innovative and proactive approach to securing project acceptability among local residents. Engagement with site neighbors was initiated in 2007, three years before start-up, to give residents an opportunity to voice their opinions about the project’s goals, characteristics and the monitoring system that would be put in place. In addition, a local information and monitoring commission (CLIS) kept all parties up to date on project status through a series of thirteen meetings. Total E&P France published and sent personally to each local resident a quarterly newsletter devoted to the pilot project from the start of CO₂ injections in 2010 through to the end of operations. This approach was hailed by the French Environment and Energy Management Agency (ADEME) as “a key organizational innovation through which Total has managed to involve local residents, elected representatives and citizens’ groups to make them active stakeholders in the project rather than feel it is being forced upon them.”

SPILL WATCH: RELIABILITY AND ACCURACY

Spill Watch is a crisis management tool that brings a chain of innovations into play. This operational suite dramatically improves the reliability and accuracy of our predictions of oil spill drift. It incorporates oceanographic and meteorological monitoring systems, marine current and wind models, and a drift model coupled with satellite observation of the actual spill. These capabilities make it a highly effective aid for defining our offshore oil spill response strategies.

- Generation of the metocean model
- Integration of satellite images of the affected area
- Integration into the oil spill drift model
- Repositioning of the model

Spill Watch allows virtually real-time integration of metocean data, satellite images and oil spill drift models to deliver reliable five-day predictions of oil spill drift.
Total has always played a key role in advancing drilling and well construction technologies; we have spawned technological breakthroughs—such as horizontal drilling and Measurement While Drilling (MWD)—that marked turning points for the industry and have now become standard practice. Our innovative momentum has led us to develop new solutions decisive for our competitiveness, with the consistent priorities of optimizing the economics and maximizing the safety of drilling operations and wells. These factors will be increasingly crucial as wells become more complex and the drilling conditions to reach our targets become steadily more challenging.

**NEARLY 50 RIGS ARE MOBILIZED EACH DAY FOR OUR EXPLORATION AND DEVELOPMENT OPERATIONS, MORE THAN A THIRD OF WHICH INVOLVE COMPLEX WELLS (i.e., HIGH-PRESSURE/HIGH-TEMPERATURE, FOOTHILLS, VERY LONG OFFSETS, ETC.).**

**CAPTIONS:** Drilling in the tight gas context:
1 Las Caeceles field near the Aguada Pichana field, Argentina
2 Well intervention, Aguada Pichana field
3 Installation of a Blow-Out Preventer (BOP) on the Laggan-Tormore field, British North Sea.

**BETTER MANAGEMENT OF MAJOR ACCIDENT RISKS**

During intensive drilling programs, well construction contributes significantly to the major risk scenarios associated with exploration and production activities. The risk reflects not only the probability of an accident, but also its potential consequences for people, facilities and the environment. Risk management is therefore a top priority from the standpoint of the safety of our drilling operations in increasingly challenging environments (e.g., deeply-buried reservoirs, deep offshore, unconventional acreage). Given these extremely high stakes, we must find more effective means of preventing the most critical accident scenarios, namely blowouts and accidental collisions with an adjacent well during drilling. To address both of these risks, we are focusing on sharpening our risk-prediction capabilities through the use of bottomhole detection systems to avert kicks. Our solutions will include real-time imaging tools ahead of the drill bit and expert systems for decision support in complex drilling contexts. In parallel, to prevent the risk of collision with an existing well, we are developing a real-time well detection system to ensure we maintain a safety perimeter within a certain radius of the drill bit. Moreover, the concern for safety must prevail over the entire life of the well. Cementing quality is crucial for its long-term integrity. Our world-class expertise has made us frontrunners in this area. For example, we are the only operator whose cementing laboratories are equipped with an in situ system to measure the mechanical properties of cement under the actual pressure and temperature conditions of the well. The reliability of this apparatus, known as the Slurry To Cement Analyzer (STCA), is such that we can make a rigorous selection of the right cement—the one that will withstand the stresses to which it will be subjected over its lifetime. We thus eliminate the need for empirical safety coefficients, which are conventionally
applied to offset the approximate nature of available measurements. In parallel, our T-Desk software suite now has been enhanced with models of the various phenomena at play during the cementing process. The bottom line here is substantial cost savings that do not jeopardize safety in the slightest.

**OPTIMIZING PROJECT ECONOMICS**

Accelerating the Rate Of Penetration (ROP) of the drill bit is one of the main parameters that can be leveraged to rein in the cost of well construction. Our R&D teams worked in partnership with Tercel to develop the concept for an innovative technology known as the MicroCoring Bit. This tool was originally designed to allow continuous production of micro-cores, but it also translates to a 10 to 35% increase in ROP when drilling in the hardest rock formations. Tested in more than 80 runs, the MicroCoring Bit attained or even exceeded that target in more than 70% of the trials. It achieved its record performance on a well in Brazil’s deep offshore, exceeding the target ROP by more than 60%.

Pursuing additional avenues of innovation to optimize drilling efficiency, we are also investigating hammer drilling. In this technique, which is expected to be pilot-tested by one of our affiliates, the diamond bit rate of penetration is accelerated by combination with a percussion hammer. A further determinant of a well’s profitability is its productivity. Here too, our R&D initiatives (e.g., sand consolidation, stimulation of carbonate formations, artificial lift) have given rise to solid know-how and yielded a few major innovations. One of these is the metal-to-metal downhole pump for “hot” wells involved in steam injection processes for the extraction of oil sands. Another is Full Control of Wells® (FCW), a tool that optimizes the automatic management of pumped wells or those stimulated by gas lift on the scale of a platform or a field. Based on the highly conclusive results of FCW, we are expanding its scope of application, and recently delivered a new release designed for oil sands production by Steam Assisted Gravity Drainage (SAGD). This new version optimizes the steam distribution among different wells according to their productivity. It is currently being pilot-tested on a well on Canada’s Surmont field, and promises to live up to expectations.

**FEDERATING KNOW-HOW WITH T-DESK**

As much a competitive asset as it is a guarantor of our complete independence from drilling contractors, the proprietary engineering software platform T-Desk, for well design and drilling operations, is now deployed and used by more than 600 Total drilling engineers worldwide.

Thanks to ongoing enhancement, this tool now federates our know-how in drilling simulation, computation of wellbore trajectories, well control, cementing and architecture. Tomorrow, new functionalities will further enrich the performance of a tool unmatched by any other industry major.

This will be achieved by implementing new modules dedicated to cement integrity, high-pressure/high-temperature drilling and real-time optimization of drilling and well architecture parameters based on logging data acquired during operations.
DEEP OFFSHORE

By 2017, Total will be producing about 15% of the world’s deepwater crude via 500 subsea wells and 10 floating production vessels. Our deep offshore assets, initially concentrated in West Africa, now cover a much more extensive area that includes South Africa as well as East Africa, Asia and South America. Backed by our bold and highly inventive R&D organization, our deepwater expertise has propelled us into the vanguard of this field. Today, the knowledge we have acquired and lessons we have learned on our numerous projects enable us to look ahead with confidence. Indeed, we have everything it takes to tackle the next two major challenges in a segment strategic for the future of energy: the increasing distance from shore and the greater water depths of hydrocarbon reservoirs.

HUNDREDS OF KILOMETERS FROM SHORE

Many reservoirs located far from shore are too small to warrant the deployment of a floating production vessel. DEPTH® (Deep Export Production Treatment Hub), a new concept shaped by our leading-edge expertise in subsea processing, will be the secret to their profitable development. This self-sufficient and integrated processing plant installed on the sea floor will perform all the processing operations that usually take place topside. The resulting export-ready and refinery-ready products will be transferred to shore via tie-backs stretching over hundreds of kilometers. SPRINGS® (Subsea PRocessing and INjection Gear for Seawater), a subsea seawater sulfate removal and injection unit, will be one of the building blocks of this breakthrough concept. Designed to filter seawater through organic nanofiltration membranes with a cutoff of a hundredth of a micron (being used in the deep offshore for the first time), this innovative technology already proved its effectiveness in a pilot test conducted in 2014.

As subsea processing gains momentum and development operations move farther and farther away from shore, the shift from hydraulic to electric control is becoming imperative. We have already taken a major step in that direction.
on the KSF gas field in the North Sea (Dutch sector). This project is the first in the world to deploy electrically-controlled production wellheads. In 2016, we will achieve a new world first there when we bring an all-electric well (wellhead, downhole safety valve, subsea control module) on stream for the first time on an industrial scale. In parallel, as part of JIP Electrification ABB, a joint industry project undertaken along with Statoil and Chevron in 2012, we have significant involvement in subsea power transmission and distribution. Goals here are to find ways to extend the range of alternating current transmission, currently limited to 150 or 200 kilometers, and to develop pressure-compensated subsea electric power distribution equipment designed for subsea use in water depths of 3,000 meters.

**WATER DEPTHS OF 3,000 TO 4,000 METERS**

Our R&D team has set its sights on a new frontier: the ultra-deep offshore, an emerging theme for which we are already working to define suitable architectures to produce reserves lying in 3,000 to 4,000 meters of water. Risers, as the link between the seabed and the surface, are the most critical aspect of the chain of technology developments needed to conquer the ultra-deep offshore. Steel pipes of the length required in this scenario could not bear their own weight. To find a solution, we are actively involved in an effort to qualify flexible pipes made of lighter-weight composites. We are working closely with several suppliers on this topic.

1982 First experimental horizontal well drilled in 1,714 meters of water in the Mediterranean Sea.

1996 First discovery on the “Golden Block” of Angola’s deep offshore (Block 17), the first in a series of fifteen discoveries.

2001 Start-up of the Girassol field (Angola), the largest development in 1,400 m of water, producing at a rate of 200,000 b/d.

2006 The IPB (Integrated Production Bundle) riser of the Dalia field (Angola) is the fruit of many innovations, including being the first riser equipped with built-in gas lift and heating on demand.

207 The tie-back of Rosa to the FPSO Girassol (Angola), 20 km long in 1,400 m of water, was a first for a field this size in such deep water.

2008 First tests of electrically-controlled production wellheads on KSF, Netherlands.

2011 Subsea gas/liquids separation in 800 m of water, a world first achieved on Pazflor, Angola.

2014 Start-up of CLOV (Angola), the 4th production hub of Block 17 and the first to deploy subsea multiphase pumping.

**SPRINGS® test results**

In 2014, the nanofiltration membranes of SPRINGS® were tested for filtration and cleaning system performance in an initial deepwater pilot phase carried out in the Congo. Tests confirmed that treated water had a residual sulfate concentration well below 40 ppm.

**INTEGRITY OF FACILITIES IS A PRIORITY**

More remote or at greater depths than is currently the norm, tomorrow’s deep offshore fields will demand improved solutions for subsea inspection and repair. We are devoting major efforts to this issue, which has key repercussions on the integrity and operability of our assets. We will be conducting pilot tests in 2015 on an initial AUV (Autonomous Underwater Vehicle) dedicated to acoustic and visual pipeline inspections. This new subsea robot is being designed jointly with Chevron and will be made available to our affiliates in 2016. The robot’s self-sufficiency means that no support vessel is required during inspection operations, translating to sharp cost reductions. The AUV also completes its tasks four times faster than a conventional ROV (Remotely Operated Vehicle). We will be pursuing this strategy with the goal of deploying a “resident” AUV by 2017 to one of our deep offshore fields in the Gulf of Guinea, and by 2020, a multifunction “resident” AUV able to intervene on our subsea facilities.

**MASTERING MULTIPHASE FLOWS**

Designing multiphase pipelines for increasing lengths or deeper waters calls for precise and reliable flow models that can integrate transient states of sometimes complex fluids. To meet this need, we developed LedaFlow®, a dynamic simulation code for multiphase transport, commercially available since 2011. Offering performance superior to that of the competing OLGA simulator, the physics equations of the LedaFlow® code deliver higher precision and reliability. LedaFlow® is optimized and enhanced with new functionalities from year to year. For example, it is the first code to introduce simulations of pipes in motion, such as risers subject to vertical oscillation due to marine currents. One of the next advances now being developed is a Quasi-3D module. This is an optimized 2D simulation that will yield much more detailed results than a 1D simulation, but much more quickly than a 3D simulation.
UNCONVENTIONALS

Yet-to-find quantities of unconventional resources trapped in source rock amount to thousands of billions of barrels of oil-equivalent. Tapping this enormous potential will require substantial advances in our fundamental knowledge of source rock mechanisms. Within the framework of strategic scientific cooperation projects with world-renowned academic partners, we are developing new modeling and simulation tools that will guide our exploration effort to the sweet spots. We are committed both to improving the economics and to minimizing the environmental impact of shale oil and shale gas projects. In addition, we are spearheading the development of new thermal production techniques. We will apply these to exploit vast – to date unproducible – oil shale and viscous crude resources in various parts of the world.

DEEPENING OUR UNDERSTANDING OF SOURCE ROCKS

Which of Planet Earth’s mature source rocks containing gas or oil can be exploited most profitably? Which thermal processes will be the most efficient for producing synthetic crude from the hydrocarbon precursor kerogen – the organic material contained in immature source rock? These questions are crucial for our energy future. Our ability to answer them depends on enhancing our fundamental understanding of these rocks. To meet the challenge, we are conducting an ambitious project aimed at deciphering the mechanisms that are involved when source rock generates, expels or retains liquid or gaseous hydrocarbons, either in natural conditions (i.e., shale oil and shale gas) or as a result of being subjected to pyrolysis (oil shales).

This research includes an extensive experimental program to characterize the different types of source rock in detail and study the processes taking place at scales ranging from pore to basin. Based on the research findings, new methods for studying petroleum systems as well as new simulation tools will be developed. The latter will be able to replicate all the phenomena at play from hydrocarbon generation through to oil and gas production using dedicated technologies. Total is currently the only company tackling the challenge of developing this end-to-end simulation chain. The exceptional difficulty of the task stems from the numerous phenomena involved (e.g., mechanical, chemical, thermomechanical and kinetic) and from the complex interactions between them.

The Energy Resources Engineering Laboratory of Stanford University is the international benchmark in the area of reservoir simulation and thermal production simulation. This prestigious partner has agreed to address this challenge with us under an exclusive six-year agreement. Research will be carried out by a dedicated team of Total engineers and university researchers, based at Stanford. This game-changing simulation capability will give us a decisive competitive edge and secure our leadership in the area of exploration and production of unconventional resources.

AHEAD OF THE GAME IN SIMULATION

We have successfully developed the first simulation “brick” destined to be incorporated into our future end-to-end simulator of the industrial-scale oil shale pyrolysis process. This is the first tool in the world with the capability to predict the composition of a synthetic crude oil yielded by in situ pyrolysis, based on the operating parameters of the process (gradient of temperature rise, duration of heating plateau, pressure, etc.). The gradual transformation of kerogen into petroleum as a result of the pyrolysis reaction was modeled using data acquired in an experimental program run jointly with Schlumberger Doll on oil shales from the Green River formation. Calibrating the tool on other plays will give us access to a potentially predictive simulation applicable to all oil shales.
PULLING HYDRAULIC FRACTURE MONITORING ON THE
Aguada Pichana field, Argentina.

2008
Pilot for microseismic fracture monitoring on the
Aguada Pichana field, Argentina.

2009
Total enters the U.S. shale gas production sector through a joint
venture with Chesapeake covering all Chesapeake leases in the Barnett
Shale, Texas.

2009
Acquisition of 50% ownership of American
Shale Oil LLC (AMSO) to develop an in situ
pyrolysis pilot for oil shale development in Colorado.

2011
Total invests in shale oil exploration and
production in the United States via
the joint venture with Chesapeake in the
Utica Shale, and increases the number
and analysis of the acoustic response. It is a
multiscale and multiphysics scientific approach
that involves an intertwining of experimental
data acquisition and simulation.

TESTING TWO DIFFERENT OIL SHALE PYROLYSIS PROCESSES
The core challenge of tapping the value
of oil shale is to develop thermal production
processes that are both acceptable and
economically viable. In these immature source
rocks, organic matter is present in the form of
kerogen – it has not yet been subjected to
heat diffusion from the well to the rock by
convection and condensation of hydrocarbon
vapors. In parallel, we have another

2010
Acquisition of 50% ownership of American
Shale Oil LLC (AMSO) to develop an ex situ
pyrolysis process.

2012
Acquisition of mining assets in the Piceance
(Colorado) and Uinta (Utah) basins in readiness
for launching industrial development as soon as
the relevant technologies have been proven on
a commercial scale.

2012
Partnership with Red Leaf Resources, Inc. to develop
ECOSHALE® In-Capsule, an ex situ oil shale
pyrolysis process.

2012
Partnership with Red Leaf Resources, Inc.,
under which we are developing an ex situ
pyrolysis process, ECOSHALE® In-Capsule.
In this case, the oil shale ore is extracted from
an open-pit mine and heated by pyrolysis
inside a sealed capsule. An Early Production
System involving an industrial-scale capsule
and analysis of the acoustic response. It is a
multiscale and multiphysics scientific approach
that involves an intertwining of experimental
data acquisition and simulation.

The decision to proceed with commercial
development of the process is expected by
2017, with the output of synthetic crude
due to ramp up to 40,000 barrels per day.

Partnership with Red Leaf Resources, Inc.,
under which we are developing an ex situ
pyrolysis process, ECOSHALE® In-Capsule.
In this case, the oil shale ore is extracted from
an open-pit mine and heated by pyrolysis
inside a sealed capsule. An Early Production
System involving an industrial-scale capsule
will be brought on stream in Utah in late 2015.

2013
Pilot-scale production on the order of
1,000 barrels is planned in 2016. The pilot
phase will serve to qualify the so-called
Conductive Convective Reflux™ process in
which heat diffuses from the well to the rock by
convection and condensation of hydrocarbon
vapors. In parallel, we have another

2012
Agreement with Sinopec covering
shale gas exploration and production in China.

2013
Agreement with Sinopec covering
shale gas exploration and production in China.

2014
Total becomes the first
major to invest in shale gas
exploration and production in
the United Kingdom.

2014
Total becomes the first
major to invest in shale gas
exploration and production in
the United Kingdom.

SEISMIC DETECTION OF SWEET SPOTS
Multicomponent 3D seismic allows the
acquisition of multi-azimuthal data. This
technique could become an essential tool for
locating sweet spots within
a field. Based on encouraging initial results
of the processing of a multicomponent 2D
acquisition from the Utica
Shale (North America) in
2013, we expect to be able
to pursue in this vein.
A new and suitably-
designed 3D acquisition
is planned in 2014 via
our joint venture with
Chesapeake.
GAS SOLUTIONS

Our expertise in acid gas treatment and liquefied natural gas (LNG) is internationally renowned. Since setting a global precedent 60 years ago with our bold decision to exploit reserves of highly acid gas, we have not stopped innovating: today, we offer a portfolio of proprietary sweetening processes that constitute a benchmark for the global industry. We also hold interests in 16 liquefaction plants around the world and rank among the major players in LNG, a strategic option for gas monetization.

To ensure the continuing growth of natural gas’s share of the energy mix, we need new solutions. Solutions that will reduce costs and curb greenhouse gas emissions. This is the challenge we are addressing today as we concentrate on two main areas: treatment processes for slightly- to moderately-acid gases, and targeted value-chains for the monetization of natural gas and CO₂.

2,000 TPD OF SLIGHTLY- TO MODERATELY-ACID GAS REMAIN TO BE TAPPED TO DATE – EQUIVALENT TO NEARLY HALF OF TOTAL’S 2013 ESTIMATE OF NATURAL GAS RESERVES. OUR PORTFOLIO OF EVER-MORE EFFICIENT TECHNOLOGIES WILL SUPPORT VITAL GROWTH IN GAS DEVELOPMENT.

EFFICIENT AND ECONOMICAL

Our R&D activities in the area of acid gas treatment are guided by the goals of producing new gas reservoirs, meeting more stringent quality specifications for the gas we produce, and curbing our greenhouse gas emissions. While pursuing our efforts to optimize conventional solvent-based processes for extracting CO₂ and H₂S from slightly- to moderately-acid gases (up to 15% CO₂ and 10% H₂S), we are also seeking to expand our portfolio with innovative solutions for extracting additional compounds such as mercaptans (RHS) and carbonyl sulfide (COS). HySWEET® DEA, a new process technology in which a hybrid solvent simultaneously removes CO₂, H₂S, RHS and COS, was our first step in that direction.

Our R&D teams made use of our acid gas pilot rig, which proved instrumental to perfecting this new development. The rig’s modular design will enable us to test the most promising technologies (membrane contactors, dynamic systems, etc.) and deliver tomorrow’s cost-effective treatment solutions. These must feature a compact layout and the flexibility necessary for our future operating environments (i.e., deep offshore, shale gas).

HYSWEET®: PERFORMANCE AT A LOWER COST

The fruit of six years of R&D, HySWEET® technology is an efficient and economical solution designed to meet the increasingly stringent limits on permissible concentrations of sulfur-compounds in treated gas. HySWEET® DEA eliminates some of the steps of conventional sulfur-compound removal processes and also limits losses of treated gas to the process. Finally, it is more energy-efficient than a conventional amine-based process. The first commercial HySWEET® DEA unit came on stream in 2013. Development of another version of the process, HySWEET® MDEA, was completed in 2014. The latter achieves complete removal of H₂S and sulfur compounds along with controlled extraction of CO₂. We will be expanding our commercial offering with a version called HySWEET® Energized MDEA that will feature better separation efficiency than MDEA along with even higher energy efficiency than the DEA version.
Our recent acquisition of a hexapod system, a new pilot rig that can simulate the effects of ocean swell, will be an additional resource as we strive to adapt our technologies to the offshore context.

NEW OPPORTUNITIES FOR NATURAL GAS MONETIZATION

The Floating LNG (FLNG) vessel is a floating liquefaction plant that offers new monetization opportunities to producing countries. Indeed, it allows cost-effective monetization when gas deposits are of modest size or located too far from shore to warrant conventional infrastructure. Our FLNG concept is both innovative and mature, benefitting from our dual expertise in LNG and deep offshore development while also incorporating highly innovative features to meet our standards of safety, simplicity and operability. In addition to being equipped with an electric-only drive system suited to many different production conditions for maximum operational flexibility, it is currently the safest concept on the market.

SAFETY, THE ABSOLUTE PRIORITY OF FLNG

Liquefaction at sea is synonymous with large inventories of flammable gas and the associated risks of a major incident. The technical options selected for our concept are decisive in managing these risks: • a liquefaction cycle based on an inert gas, which is much safer than alternatives that involve large volumes of hydrocarbon refrigerants; • an unprecedented and innovative tandem offloading design that sharply limits the risk of colliding with an LNG tanker as compared to the conventional side-by-side offloading configuration.

1957
First gas from the Lacq reservoir (France), containing 10% CO2 and 15% H2S, an extraordinary proving ground that total exploited until 2013.

1960
Start-up of the first acid-gas sweetening unit based on DEA (an amine), with the capacity to treat one million cubic meters of gas per day.

1977
Development of MDEA, a technological step change that paved the way to amine-based selective deacidification.

1987
Addition of activated MDEA technology to our portfolio of à la carte deacidification solutions, for full or controlled removal of CO2.

2006
Launch at the Lacq complex of a pilot trial of SPREX® to test cryogenic separation of H2S from natural gas containing high concentrations of H2S, and commencement of work to adapt this breakthrough technology for CO2 removal by cryogenic separation.

2007
Successful test of HYSWEET® DEA, a technological first in which the solvent removes CO2, H2S, RHS and O2 simultaneously, in one of the Lacq gas treating units.

2010
Start-up of the first commercial HYSWEET® DEA unit.

2012
Start-up of the first commercial HYSWEET® DEA unit.

2013
Finalization of our Floating LNG concept.
Prospective Labs

The future of our industry is also being shaped by scientific and technological developments unfolding outside our usual scope, in emerging disciplines that represent potential game-changers for our own operations. For example, the ceramic membranes currently revolutionizing our water treatment techniques were initially developed for the food processing industry. Graphics cards, which can be leveraged to accelerate high-performance computing, are the brainchild of video game developers. Staying a step ahead of competitors in ferreting out the nascent breakthroughs that could yield decisive benefits for the E&P sector requires openness coupled with an acute sense of anticipation. These qualities are the very essence of our Prospective Labs, the reconnaissance teams of our R&D organization.

Scouting for Tomorrow’s Breakthrough Technologies

We created the Prospective Labs as an “early warning system” to detect and acquire concepts born outside our core business and featuring low technological maturity but strong potential. Each Prospective Lab targets a strategically selected discipline. It is set up for a limited period – two to three years – compatible with transferring its outcomes quickly to our R&D Programs or Technological Innovation Projects. These exploratory research teams give us a jump on the capture of promising innovations. Our Prospective Labs on Nanotechnologies and Robotics have already achieved some encouraging inroads that confirm the value of building bridges between our R&D organization and scientific and technological disciplines adjacent to, but not strictly a part of, the Exploration & Production sector.

Economical High-Performance Nanosensors

Monitoring for environmental or safety purposes is one area in which nanotechnologies can be leveraged to significantly optimize our performance. We are tackling this challenge in partnership with the APIX company and Total’s Scientific Development Division. Our goal is to develop economical, ultra-sensitive nanosensors designed to detect gas leaks or provide continuous air quality monitoring in the vicinity of our facilities.

Micro and Nanotechnologies to Increase Reserves

Total became a member of the AEC (Advanced Energy Consortium) in 2008. This is the largest research consortium devoted to nanotechnology-based applications for petroleum reservoirs. Its mission is to develop intelligent nano-objects (tracers, contrast agents, capsules, sensors, etc.) that can be injected into reservoirs to contribute to better subsurface characterization and monitoring, in order to increase recovery from our existing fields and future developments. A number of strategic applications have been identified for future development. We are directing our priority efforts at the following:

- contrast agents for water flood and hydraulic fracture mapping;
- nano-enhanced hydrocarbon recovery based on functionalized nanoparticles able to optimize surfactant performance;
- subsurface autonomous nano-devices for downhole, cement integrity and hydraulic fracture monitoring.

Captions:
2. A self-contained microsystem packaged in a 1-mm² housing for downhole monitoring and hydraulic frac monitoring.
3. Autonomous chemical microsensors for downhole monitoring.

Following pages:
4. The five teams competing in the ARGOS Challenge (AIR-K - Japan, ARGONAUTS - Austria/Germany, FOXIRIS - Spain/Portugal, LIO - Switzerland, VIKINGS - France).
5. The “arena” for the ARGOS Challenge, representative of an oil and gas environment, is a former gas dehydrating plant at the Lacq complex.
6. The ARGOS teams visiting the site of the competition, in Lacq.
The initial prototypes from our research will be pilot-tested at the Lacq site in 2015 to qualify their detection performance with respect to volatile organic compounds and BTEX (Benzenes, Toluenes, Ethylbenzenes, Xylenes). The backbone of this innovative device is a nanoelectromechanical system or NEMS etched on a chip and featuring an oscillating horizontal strip about 1 micron long and 1 nanometer thick. Molecules of the target gas settle on this strip. Besides the NEMS, the complete “lab-on-a-chip” device includes micro gas chromatography columns. These are about 2 meters long, but are inserted onto a chip measuring only 2 cm². The columns separate the gas chemical species present in ambient air. In addition to the environmental function, this nanosensor serves safety purposes by monitoring concentrations of combustible and toxic gases, and appears to have game-changing potential for production allocation applications as well.

**PAVING THE WAY TO A NEW GENERATION OF ROBOTS**

None of the land-based robots available today is designed to operate in a potentially explosive atmosphere or move autonomously within and around our facilities to inspect, maintain or repair them in the place of humans. Filling this gap will allow us to reduce worker exposure, which is especially desirable in extreme environments (harsh climates, remote/isolated locations) and emergency scenarios. To this end, we decided in late 2013 to create the research momentum needed to spawn the first generation of robots tailored to oil and gas facilities – in under three years. This proactive open innovation strategy takes the form of an international competition called the ARGOS Challenge (for Autonomous Robot for Gas & Oil Sites). The contest was devised and funded by Total and implemented in partnership with the French National Research Agency (ANR). A screening of more than 30 candidate projects led to the selection of five international teams composed of actors from the robotics industry and academic research.

The teams will compare the performance of their prototypes in a series of three contests scheduled from June 2015 to December 2016. The contests will take place at Lacq (southwestern France), on a site representative of our facilities and operating conditions. The test drills will become increasingly difficult with each successive round: avoiding obstacles, climbing stairs, taking measurements, operating in degraded conditions on surfaces wet and slippery from hydrocarbon spills, fault detection, etc.

**VERSATILE ROBOTS FOR MANY APPLICATIONS**

In the future, the robots to be deployed on our onshore and offshore facilities will be robust enough to operate in potentially explosive environments; they will be designed with the range and capacities needed to inspect equipment and carry out targeted reporting assignments in remote or hard-to-access locations. In emergencies, these robots will be able to detect anomalies and hydrocarbon leaks, alert personnel and transmit images and data in real time. In the most critical scenarios, when human presence is impossible, these robots will be invaluable as reporting and intervention resources.

By spearheading technological innovation in an area so critical to enhancing the safety of our personnel and our operations, our ambition is to become the first oil and gas operator to pilot-test an autonomous robot on one of our sites, in 2018/2019. More importantly, our initiative will have spurred the development of a new generation of robots which, in addition to meeting our needs, will address those of many other industrial complexes around the world, with favorable repercussions for emergency management.
FOR A MORE LASTING EXPERIENCE

Access the flipbook of this brochure on your laptop, tablet or smartphone. Enjoy interactive content as you discover the many facets of our R&D.

Flash this code or go to:
Total is a global integrated energy producer and provider, a leading international oil and gas company, and the world’s second-ranked solar energy operator.

We are committed to better energy that is safer, cleaner, more efficient, more innovative and accessible to as many people as possible, and our 100,000 employees play an active role in helping us achieve this mission. As a responsible corporate citizen, we focus on ensuring that our operations in more than 130 countries worldwide consistently deliver economic, social and environmental benefits.