total.com

Supplying affordable energy to a growing population, addressing climate change and meeting new customer expectations are the three main challenges Total must meet as an energy major.

That is what guides what we do. With operations in more than 130 countries, we are a top-tier international oil and gas company. We are also a world-class natural gas operator and a global solar leader through our affiliate SunPower. Our activities span oil and gas production, refining, petrochemicals and marketing. Demonstrating their commitment to better energy, our 100,000 employees help supply our customers worldwide with safer, cleaner, more efficient and more innovative products that are accessible to as many people as possible. Our ambition is to become the responsible energy major.

TOTAL S.A.
Share capital: 6,133,930,082.50 euros
542 051 180 RCS Nanterre
Exploration & Production – Paris
Phone: +33 (0)1 47 44 45 46
2, place Jean Millier – La Défense 6
92078 Paris La Défense Cedex – France
Exploration & Production – Pau
Phone: +33 (0)5 59 83 40 00
Avenue Larribau – 64018 Pau Cedex – France
www.total.com

TERRE DE SIENNE – March 2017 – Photo credits: SORDOILLET Patrick, BIP Info, PASCAL Laurent, LABELLE Michel, Texas A&M University at Qatar, Total SA. Translated by: Audrey FRANK.

RESEARCH & DEVELOPMENT,

AN INTERNATIONAL NETWORK

TOTAL RESEARCH CENTER - QATAR

R&D, THE WORLD IS OUR LABORATORY

Our research organization spans the globe. By basing our specialized research centers and teams strategically near the regional hubs of the oil & gas industry, we gain access to these regions and project our image of R&D excellence around the world.

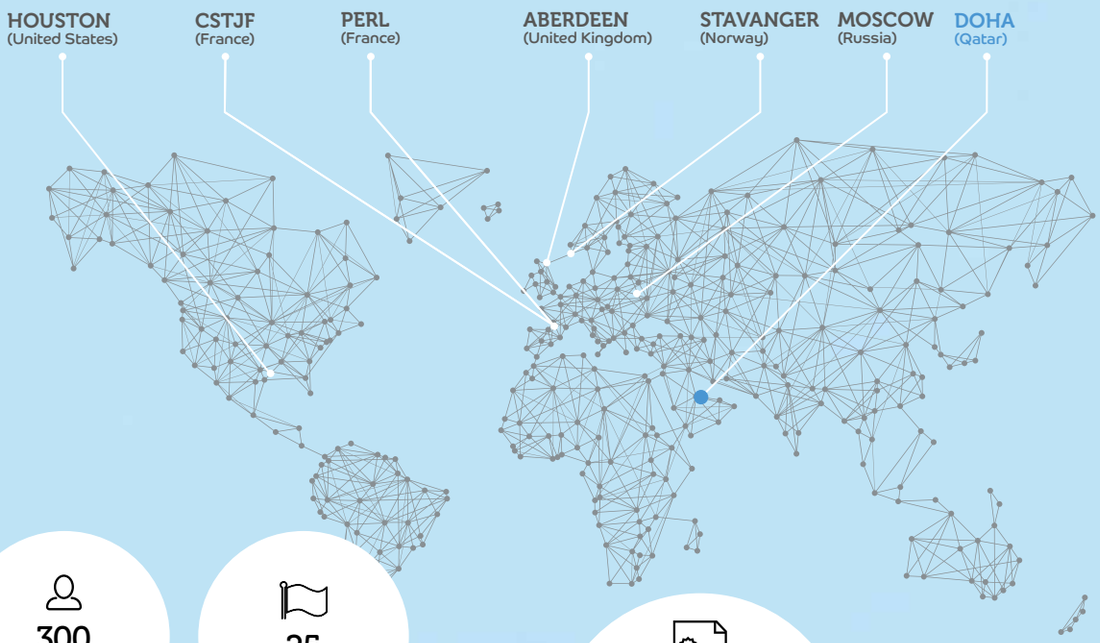
Working in full synergy with the key R&D center of Total E&P at the *Centre Scientifique et Technique Jean-Féger* (CSTJF) in southwest France, researchers are part of network teams and focus on research programs and themes that are crucial for Total's competitiveness.

Our international network and the close ties we have forged with leading-edge public and private research bodies enable us to tap into the academic and industrial expertise available in each region. This open innovation strategy helps us access the most promising scientific and technological advances. We can leverage them to deliver tomorrow's breakthrough technologies.

The Total Research Center - Qatar (TRC-Q), a cornerstone of this international network, focuses its expertise and advanced R&D resources on topics key to optimizing oil and gas production in the Middle East.

DANIEL **PLATHEY**
Vice President of R&D, E&P

R&D IN FIGURES



300
RESEARCHERS

25
NATIONALITIES

NEARLY **340**
PATENT FAMILIES COVERING SOME
1,580
PATENTS FILED ALL AROUND THE WORLD*

9,000 m²
OF LABORATORY SPACE

10
DISRUPTIVE TECHNOLOGIES FIELD-TESTED EACH YEAR

8
PROGRAMS ON STRATEGIC THEMES

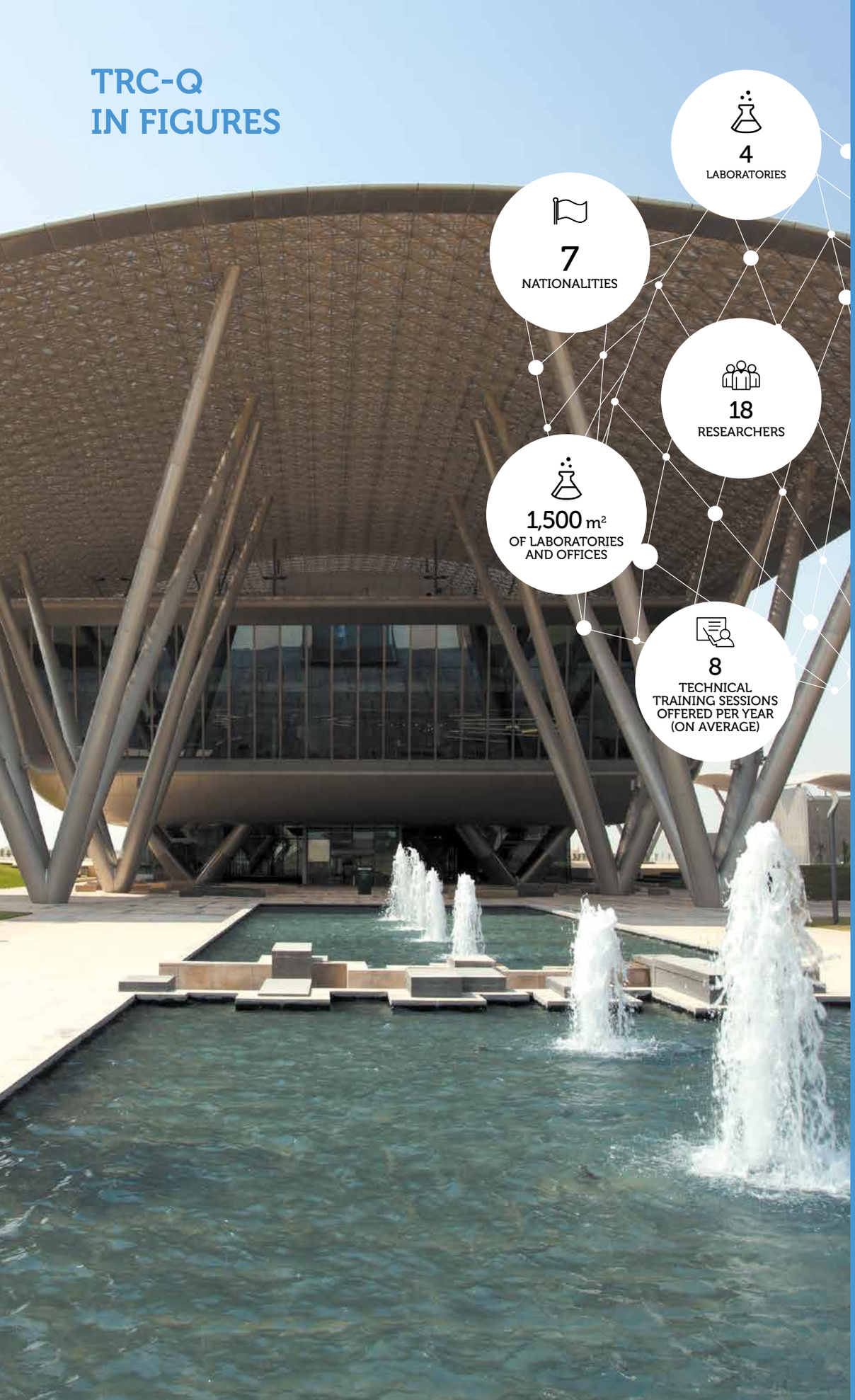
- Frontier Exploration
- Earth Imaging
- Field Reservoir
- Sustainable Development
- Wells
- Deep Offshore
- Unconventionals
- Gas Solutions

4
PROSPECTIVE LABS DEVOTED TO PERIPHERAL TOPICS THAT HAVE STRONG POTENTIAL FOR THE OIL & GAS INDUSTRY

- Nanotechnologies
- Robotics
- Biotechnologies
- Image processing

*With greater selectivity since 2015 in the choice of technologies to patent and the geographical areas of patent protection.

TRC-Q IN FIGURES



TOTAL RESEARCH CENTER - QATAR

The Total Research Center - Qatar (TRC-Q) opened its doors in 2009 to spearhead Total's R&D activities in the Middle East. It is located in Doha, in the Qatar Science and Technology Park (QSTP). The R&D activities conducted here are applicable to Total's Exploration & Production and Refining & Chemicals branches, focusing on four areas of interest to Qatar and the rest of the Middle East:
Geochemistry, Acid Stimulation of Carbonate Reservoirs, Produced Water Management and the CO_2 value chain for the Petrochemicals sector.

Moreover, thanks to its proximity to Total teams working on projects in Qatar on which Total is operator or partner, TRC-Q is ideally positioned to facilitate the transfer of innovations developed at Total's head office.

TRC-Q pursues its in-house R&D activities in partnership with local scientific and industrial players, including Qatar Petroleum, Qatar University, Qatar Environment and Energy Research Institute, and Texas A&M University at Qatar.

TRC-Q provides state-of-the-art contract research services on behalf of the local oil and gas industry – notably Qatar Petroleum, Qatargas and Dolphin Energy – as well as for Total in connection with the Group's operations on the Al Khalij field. The Center also offers training programs for the technical staff of these companies and runs a lecture series for students at Qatari universities.

YOUSEF M. **AL-JABER**

Deputy Director Total Research Center at Qatar

PIERRE **MONTAUD**

Director Total Research Center at Qatar

GEOCHEMISTRY

DEVELOPING INNOVATIVE TECHNIQUES FOR ANALYZING PETROLEUM FLUIDS TO YIELD KEY DATA AT LOWER COST AND THEREBY OPTIMIZE PRODUCTION AND WELL INTEGRITY MANAGEMENT.

Geochemistry laboratory, TRC-Q.

Laser impacts on a core of carbonate source rock to map organic matter distribution using LIPS (Laser Induced Pyrolysis System).

LIPS is an instrument for quantifying and mapping the organic content of a sample.

High-resolution 3D image of organic matter measured by LIPS, geomodeled using SISMAGE.

LIPS, AN INSTRUMENT THAT MAPS ORGANIC MATTER

The Laser Induced Pyrolysis System (LIPS) quantifies and automatically maps the distribution of organic matter within a core sample. This fruit of Total's R&D efforts is the only tool of its kind in the world. It uses laser technology to provide high-resolution measurements of organics content over the entire length of the core.

The LIPS can operate continuously 24/7 to analyze up to 150 meters of core samples per week. It is portable, designed for *in situ* use, and has become a vital tool on Total's unconventional exploration plays since its introduction in 2009.

Since becoming available at the TRC-Q in 2014, the LIPS has been successfully used to map the distribution of tar-mat zones as well as to pinpoint organic matter in carbonate source rocks in the Middle East.

EXPERTISE

OPERATIONAL RESERVOIR GEOCHEMISTRY

Development of new-generation tools suitable for field deployment (in terms of size, weight and ATEX-compliance) to reduce costs, avoid transport of samples and facilitate production allocation.

Testing of the PACS prototype (Production Allocation & Compartmentalization Solution) on fields in which Total is a partner in the Middle East. Developed by R&D teams at Total's head office in France, the tool is designed to automatically prepare samples before characterization.

ORGANIC GEOCHEMISTRY IN ROCKS

Development of tools and methodologies with a view to providing contract services leading to a greater understanding of organic carbon distribution in rocks. This research focuses on two main objectives:

- mapping of tar-mat zones – i.e., accumulations of tar that constitute fluid flow barriers in reservoirs – which are found in a number of carbonate reservoirs in the Middle East;
- development of methodologies to predict the spatial distribution of organic matter in carbonate source rocks in unconventional plays.

GEOCHEMISTRY OF FLUIDS

Geochemical analysis of fluids (source type, age, maturity, migration, alteration, etc.), provided as contract services.

EXPERIMENTAL RESOURCES

AN UNPRECEDENTED GEOCHEMISTRY LABORATORY IN QATAR

The TRC-Q in Qatar is equipped with a fully operational organic geochemistry laboratory. Its state-of-the-art facilities include capabilities for advanced fluids characterization (gases and liquids): high-resolution gas-phase chromatography coupled with numerous detection instruments such as a Flame-Ionization Detector (FID); a Thermal Conductivity Detector (TCD); a Flame Photometric Detector (FPD) and NanoElectroMechanical Systems (NEMS) as well as a Gas Chromatograph-Mass Spectrometer (GC-MS) and a Gas Chromatography/ Combustion/ Isotope Ratio Mass Spectrometry (GC C IRMS) system.

PROPRIETARY TOOLS UNMATCHED IN THE INDUSTRY

The LIPS (Laser Induced Pyrolysis System) quantifies and automatically maps the organic carbon present in a core sample. The PACS (Production Allocation & Compartmentalization Solution) automatically separates the water, oil and gas in a sample in accordance with specifications, before characterization, right at the production site.

MAJOR PARTNERSHIPS

PRODUCTION GEOCHEMISTRY

To develop its tools, the TRC-Q collaborates with numerous partners based in France including the LATMOS (Atmospheres, Environments and Spatial Observations Laboratory), Bmax, APIX Analytics and Sanchez Advance Technologies (SAT-ICF).

ACID STIMULATION IN CARBONATE RESERVOIRS

DEEPENING OUR UNDERSTANDING OF THE MECHANISMS INVOLVED IN ACID STIMULATION, A TECHNIQUE CRUCIAL TO WELL PRODUCTIVITY IN CARBONATE RESERVOIRS, TO ENHANCE ITS EFFECTIVENESS AND BETTER CONTROL THE COST OF OPERATIONS.

Acid stimulation of wells is the most widely used solution to the problem of low matrix permeability in carbonate reservoirs. Stimulation laboratory, TRC-Q.

A test of wormholing in a core sample.

DEVELOPING A PROPRIETARY MODEL

An in-house acid stimulation model for carbonates is currently under development. The overriding aim is to give Total a predictive borehole scale tool to optimize the design of acidizing treatments (in terms of cost and performance) and analyze the effect of stimulation on the wells. The same model could also serve at the core scale to limit the number of core flood tests and calculate the key parameters needed to design acidizing treatments.

This finite-volume 3D code solves equations concerning reagent transport through porous media (through a coupling of Darcy's law, the advection-diffusion-reaction equation and a law of conservation of mass). It is calibrated to laboratory data collected from core flood tests and will be built in several steps:

- initially, a core scale model will be validated for various acid formulations and rock types;
- subsequently, after being scaled up to the borehole scale, the tool will allow modeling of different injection parameters.

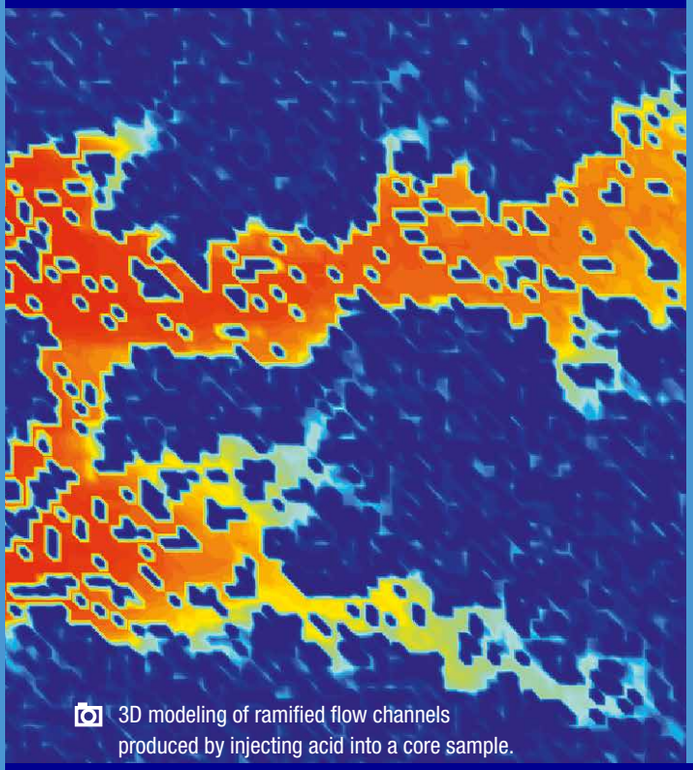
The tool will be utilized to define operational recommendations (optimization) as well as to simulate innovative acid stimulation strategies that offer new prospects for improving the performance/productivity of Total's wells.

X-ray microtomography image of a core section (Texas A&M University at Qatar).

SYNERGY WITH R&D HEADQUARTERS IN FRANCE

The TRC-Q experimental program aimed at improving our understanding and control of acid stimulation processes in carbonate reservoirs is being conducted in synergy with the CSTJF *(Centre Scientifique et Technologique Jean-Féger),* the R&D hub for Total's E&P in France. The latter is equipped with the full range of apparatus needed for core characterization both before and after core flood tests performed on the TRC-Q bench:

- CT scanner to characterize porous media at the core scale;
- X-ray microtomography unit for pore-network scale characterization of small samples, duplicating the unit at Texas A&M University at Qatar, the TRC-Q partner for this aspect of carbonate characterization;
- Instruments for mineralogical characterization (e.g., X-ray fluorescence, X-ray diffraction), porosity measurement (helium pycnometry), permeability measurement (steady state test with nitrogen) and pore throat determination (by mercury injection capillary pressure method).



3D modeling of ramified flow channels produced by injecting acid into a core sample.

EXPERTISE

IMPROVED CONTROL OF ACID STIMULATION MECHANISMS

Bench studies aim to improve our understanding and control of the physical-chemical processes that occur during acid stimulation (or acidizing) of wells in carbonate reservoirs. The experimental program looks at different types of rocks (calcite, dolomite) and different acid formulations (hydrochloric acid and diesel emulsified acid). It includes:

- carbonate characterization by CT scanning and X-ray microtomography (mineralogy, porosity, permeability and pore throat);
- core flood bench tests on quarry samples at temperature/pressure levels representative of reservoir conditions (80 - 95 °C, 250 bar);
- development of a proprietary acid stimulation model calibrated to data collected through the core flood tests.

Research efforts are focusing on two main areas key to the success of acid stimulation treatments:

- wormholing: this specific dissolution phenomenon extends the reach of acid penetration in the near-borehole area using a minimal volume of acid and is affected by a number of parameters: injection rate, temperature, pressure, rock type, petrophysical characteristics (permeability, porosity and pore structure);
- diversion: this work aims to characterize the behavior of the injection fluid in the event of heterogeneities or differences in matrix permeability and/or mineralogy in conditions representative of the reservoir.

Future studies will explore the behavior of complex non-Newtonian stimulation fluids (such as acids with added surfactants or polymers that create viscoelastic effects).

EXPERIMENTAL RESOURCES

DUAL CORE BENCH

In 2017, TRC-Q converted the single core bench used for the core flood tests of the wormholing study into a dual core bench. The upgraded installation can now run simultaneous tests on two cores exhibiting different mineralogy and/or permeability characteristics. It will also serve in experiments on diversion. To date, such studies had been carried out on the dual core bench at the CSTJF in France (the R&D hub for Total's Exploration & Production branch).

CORE CHARACTERIZATION TOOLS

X-ray microtomography (Texas A&M University at Qatar), for pore-network scale characterization of small samples.

MAJOR PARTNERSHIPS

CARBONATE CHARACTERIZATION

Texas A&M University at Qatar
Texas A&M University, USA (JIP: Acid Stimulation Research Program)

WATER MANAGEMENT

INNOVATING TO REDUCE THE IMPACT OF OUR INDUSTRIAL ACTIVITIES ON WATER QUALITY AND MAXIMIZE THE VALUE OF A VITAL RESOURCE BY MAKING PRODUCED WATER AVAILABLE FOR REUSE BY OUR STAKEHOLDERS.

A cell fitted with electrodes to detect the presence of corrosion inhibitors.

An experiment to test detection of corrosion inhibitors in produced water from Al Khalij oil field.

Experiments with beneficial reuse of Al Khalij oil field produced water, Qatar University.

Analysis of produced water using liquid chromatography, Qatar University.

PRODUCED WATER, A POTENTIAL NEW RESOURCE

On average, the global oil industry produces about three times as much water as it does crude oil, with water production rising as oil fields mature. When it is not reinjected into the reservoir to sustain oil production, produced water is typically viewed as "waste" that must be disposed of – by discharge into the sea or injection into disposal wells – following treatment in strict compliance with applicable standards.

Recovering produced water and using it to irrigate non-food crops tolerant to saline waters containing residual traces of chemicals and hydrocarbons has both environmental and societal benefits, particularly in water-stressed regions such as the Middle East. At stake is a solution that can provide stakeholders with a vital resource in a context of increasing tension between limited supply and rising demand (due to population growth and increasing water requirements for agriculture and industry).

EXPERTISE

BENEFICIAL WATER REUSE

Identifying opportunities to maximize the value of produced water recovered from our assets in Qatar through beneficial reuse by civil society for crop irrigation, especially biomass. The experimental design entails:

- a detailed characterization of produced waters from the Total-operated Al Khalij field and other Qatari assets in which we are partners;
- screening of reuse scenarios appropriate for produced water (high salinity), notably including the selection of plants and soils through laboratory trials.

DETECTION OF CORROSION INHIBITORS

Pilot testing on Al Khalij produced water of an innovative technique developed by Total's R&D for detecting corrosion inhibitors. This electrochemical assay method uses voltammetry to determine the concentration of corrosion inhibitors in water, and will help us limit our impact on water quality by:

- avoiding the use of the environmentally-harmful chemicals (such as chloroform) required under conventional detection methods;
- improving detection sensitivity so inhibitor dosage can be adjusted as closely as possible to requirements, thereby limiting chemical use.

EXPERIMENTAL RESOURCES

GEOCHEMISTRY LABORATORY

The instruments of the TRC-Q Geochemistry lab are used to test the innovative corrosion-inhibitor detection method developed by Total's R&D.

MAJOR PARTNERSHIPS

BENEFICIAL WATER REUSE

Qatar University (Department of Biological and Environmental Sciences): screening of local plants and soils for compatibility with reuse of Al Khalij produced water

Qatar Environment and Energy Research Institute (QEERI): characterization of Al Khalij produced water

CO_2 UTILIZATION

WORKING TO DEVELOP NEW ROUTES FOR USING CO_2 AS FEEDSTOCK IN THE SYNTHESIS OF VALUE-ADDED COMPOUNDS FOR THE CHEMICALS INDUSTRY TO ACHIEVE CONVERGENCE OF BUSINESS OPPORTUNITY AND EMISSIONS-REDUCTION OBJECTIVES.

In an inert atmosphere, analysis of compounds yielded by the conversion of CO_2 in the Petrochemicals laboratory at TRC-Q.

VALUE-ADDED UTILIZATION OF CO_2 TO REDUCE EMISSIONS

Total has fully embraced the climate challenge as a pillar of our strategic vision, with the aim of keeping global warming below 2 °C by 2100. Reducing the carbon intensity of the fossil energy mix is a key means of meeting our environmental commitments. One way to achieve that goal is to accelerate the development of Carbon Capture, Utilization and Storage technologies (CCUS). Total has decided to allocate one-tenth of its R&D budget to this crucial topic.

The concept of capturing CO_2 at our industrial facilities for utilization in the synthesis of value-added chemicals holds great promise. It is believed that doing so would permit a significant reduction in CO_2 emissions. At the same time, it would create value in the form of useful chemical compounds, jobs and income, which would offset some of the costs of CO_2 capture.

Identifying new pathways for converting CO_2 into value-added compounds.

EXPERTISE

METHANOL SYNTHESIS FROM CO_2 AND METHANE

The aim is to synthesize robust, stable new catalysts to boost the rate of the chemical reactions involved in synthesizing methanol from CO_2 and methane. The challenge is to avoid the rapid deactivation of the nickel- and zinc-based catalysts conventionally used in these reactions.
One of the innovative techniques under scrutiny is Atomic Layer Deposition, which entails applying a thin (nanometer-scale) layer of aluminum oxide on the surface of a catalyst to prevent fouling due to coke formation (carbon species deposited on the catalyst). Coke formation is exacerbated by the very high temperature (800 °C) at which the reactions take place.

CO_2 CONVERSION TO INTERMEDIATE MOLECULES FOR PETROCHEMICALS

These activities aim to develop new pathways for the synthesis of CO_2-derived chemical and polymer building blocks. Efforts are notably directed at identifying a route for synthesizing acrylic acid from CO_2 and ethylene. Objectives of the current research are:

- to gain a clear understanding of the chemical synthesis route of acrylates from CO_2 and ethylene;
- to develop a bench-scale process (50-100 ml) for acrylate synthesis in which regenerated catalyst can be used.

Looking ahead: the launch of research to identify other pathways for converting CO_2 to value-added products (formic acid, carbon monoxide, methanol, ethylene, methane) by photo-electroreduction of CO_2 mediated by catalysts containing semiconducting composites.

MAJOR PARTNERSHIPS

METHANE REFORMING WITH CO_2

Texas A&M University at Qatar, Northwestern University (USA) and Qatar University, under the research program entitled "Design of Novel Catalysts and Processes for CO_2 Conversion from Micro to Macro Scale" funded by the Qatar National Research Fund (QNRF)

CO_2 CONVERSION TO INTERMEDIATE MOLECULES FOR PETROCHEMICALS

Freie Universität Berlin
Qatar University