GROWTH SECTORS

EXTRA-HEAVY OILS & OIL SANDS

THE CHALLENGES OF DEVELOPMENT
At the current rate of production, conventional oil reserves are expected to last for fifty years. Heavy oils can supply an additional twenty years’ worth of production. However, these oils are difficult to recover, and there are a number of technical and environmental issues that must be addressed in order to develop them responsibly.

Heavy oils are an essential component of the world’s future energy mix. The volume of oil-in-place is estimated to be between 4,000 and 5,000 billion barrels (Gb), translating to resources of up to 600 Gb. These figures reflect the enormous potential of heavy oils: they are equivalent to 60% of global reserves of conventional crude oil and account for 20 to 25% of the world’s petroleum resources.

THE AMERICAS, FROM NORTH TO SOUTH

Some 80% of all heavy oils are extra-heavy. These include oil sands, which are highly complicated as well as costly to develop. Although found in all parts of the world (e.g., Russia, USA, Middle East, Africa, Cuba, Mexico, China, Brazil, Madagascar, Europe and Indonesia), the largest accumulations are located in Venezuela (the Orinoco Belt) and Canada (Province of Alberta). Combined, these two regions represent nearly 3,000 billion barrels of oil-in-place. They also account for 95% of global production of heavy oils (2.2 million barrels per day in 2008, two-thirds of which are in Canada and one-third in Venezuela). Although less than 1% of these resources are produced or under active development today, output should nearly quadruple, reaching at least 7 or 8 Mbd by 2030.

LIMITING ENVIRONMENTAL IMPACTS

The processes involved in extracting and upgrading these oils require huge quantities of energy and water. For this reason, developing them sustainably on a large scale poses major economic, environmental and technological challenges. Improvements focus on driving down technical costs; enhancing recovery factors and energy efficiency; curbing CO₂ emissions and limiting water consumption and the footprint of these huge developments.

There is no question that the complexity of these challenges is of another order of magnitude compared to conventional oil developments. Total, backed by its engineering and Research & Development teams, possesses the skills and innovative capacities needed to develop these promising resources responsibly.

Heavy oil is petroleum that has become extremely viscous as a result of biodegradation: bacteria active at the low temperatures associated with shallow deposits consume the lighter hydrocarbons, leaving behind the more complex compounds such as resins and asphaltenes.

At viscosity values up to 10,000 centipoise (cP), the oil is highly viscous but remains mobile in reservoir conditions. This is termed “extra-heavy” oil, and can be recovered using cold production methods. Petroleum with viscosity above 10,000 cP is called bitumen, and is so viscous that it is immobile at reservoir conditions. Mining methods are feasible to extract the bitumen to a depth of up to 100 meters. For deeper deposits, thermal recovery methods are required to mobilize the oil by heating it.
Total, a world-class player

The size and diversity of Total’s project portfolio reflects the Group’s goal to rank among the leaders in extra-heavy oils and bitumen. With expertise in both cold and thermal recovery methods, mining techniques and in upgrading, we have the capabilities to deploy the full range of development solutions.

**SITES IN ACTIVE DEVELOPMENT OR UNDER STUDY AROUND THE WORLD**

**H**eavy oils are a pillar of the Total Group strategy and a strong presence has been built up in the world’s two most prolific regions: the Orinoco Belt (Venezuela) and the Athabasca region (Canada).

**PIONEERING COLD RECOVERY**
Total has been demonstrating its capacity to produce Venezuela’s colossal reserves of extra-heavy oil since the late 1990s. The Sincor venture, which became Petrocedeño in 2008, stands out as one of the most ambitious projects in the Orinoco Belt to date. It sets a global benchmark for cold recovery of extra-heavy crude and illustrates the Group’s expertise as both an oil producer and a refiner. Petrocedeño integrates the entire chain of technology from the extraction of extra-heavy oil through to its conversion into a light synthetic crude.

**SPEARHEADING THERMAL RECOVERY**
Involved in steam injection since the late 1970s (in the Upper Lacq basin, southwest France), Total brings a long history of expertise to thermal recovery methods. Since 1999, the Group has been a partner in Surmont in Canada, one of the world’s largest permits being produced by Steam Assisted Gravity Drainage (SAGD).

**TOMORROW, MINING FOR BITUMEN**
In Canada, Total is also gearing up to meet the challenges of open-pit mining. The Group, as operator, will begin to extract bitumen from the Joslyn Project in 2017-18 with a target plateau production of 200,000 b/d, to be reached in two phases. The first phase, the Joslyn North Mine, will produce 100,000 b/d. Total is also operator of the Northern Lights Project, where mining is scheduled to start sometime after 2020.

Since early 2011, Total has also held a 39.2% interest in the Fort Hills permit. According to the Group’s estimates, that mine should come on stream in 2016.

**UPGRADING EXPERTISE**
As in Venezuela, the Group will deploy an integrated development strategy in Canada with the acquisition of a 49% stake in the Voyageur Upgrader Project. The unit, located near Fort McMurray, is operated by Suncor Energy Inc. with a processing capacity of around 250,000 b/d of bitumen, including Total’s production from the Fort Hills and Joslyn mines.
Producing and upgrading all types of heavy oil

By introducing numerous innovative technologies and successfully applying them on Petrocedeño, Total has made this bold project a global benchmark for cold recovery.

The Group is also actively contributing to the large-scale deployment and optimization of SAGD – currently the most innovative of the thermal recovery techniques – on the Surmont permit in Canada.

Backed by ten years of experience with in situ production of heavy oils, Total is also gearing up to meet the challenges of mining oil sands. The Joslyn North Mine in Canada will be the Group’s first oil sands mining project as operator and will showcase technologies designed to combine economic, technical and environmental performance from the outset.

By involving ourselves in this wide range of recovery techniques, we are securing our position among the leading developers of unconventional oil.
Mastering **cold recovery**

The scale, bold technologies and level of performance achieved on the Petrocedeño project in Venezuela’s Orinoco basin make this a global benchmark for cold recovery of extra-heavy oils.

Of the four projects that emerged in the Orinoco Belt in the late 1990s, Petrocedeño is by far the most ambitious. This single 504-square-kilometer (km²) lease has a cumulative production potential estimated to exceed 2 billion barrels over 35 years.

**A FULLY-INTEGRATED PROCESS**

Harnessing the Group’s know-how in crude oil production and refining, Petrocedeño is the only project in the region to implement an end-to-end process from extraction of extra-heavy oil through to upgrading into a high-quality light synthetic crude oil. This option allows Venezuela to export a commercial-grade product and is a source of added value for Petrocedeño.

**FROM PRODUCTION...**

Extra-heavy oil averaging 8.3° API gravity is produced on the Zuata field. Adding naphtha into the well yields a blend of 17° API gravity, which is transported by multiphase pumps over a few kilometers to the main processing complex at San Diego de Cabrutica. Here, it is separated from the gas and water it contains.

**... TO UPGRADING**

It is then piped to the Jose upgrader. The desalting, distillation, delayed coking, hydrocracking and hydrotreating units of this vast upgrading complex deliver the very low-sulfur Zuata Sweet, a syncrude of 32° API gravity ready for processing in any refinery.

**PETROCEDEÑO: FROM EXTRA-HEAVY OIL TO LIGHT SYNCRUDE**

Crude oil of an average 8.3° API gravity is diluted with naphtha. After separation, it is then transported to the upgrader, which yields a commercial-grade light synthetic crude of 32° API gravity.

**PETROCEDEÑO > MILESTONES**

- **1997**: establishment of Sincor C.A, the operating entity of the Sincor project (Total 47%, PDVSA 38%, Statoil 15%).
- **1998**: launch of Sincor development.
- **2000**: start of production of Zuata extra-heavy crude (plateau production: 200,000 b/d).
- **2002**: start-up of the upgrader and production of 32° API syncrude, called Zuata Sweet (180,000 b/d).
- **2007**: migration of Sincor C.A into a mixed company. Control of operations is transferred to PDVSA (PDVSA 60%, Total 30.323%, Statoil 9.677%).
- **2008**: Sincor becomes Petrocedeño.
- **2010**: more than 600 wells drilled to date. Ultimately, the project will comprise more than 2,000 wells.

**LEADING TECHNOLOGY TO IMPROVE PERFORMANCE**

In addition to its high viscosity (2,500 to 3,000 centipoise), oil produced at Petrocedeño is contained in low-pressure reservoirs. Production from these reservoirs would be impossible without advanced know-how in several areas:

- **sophisticated seismic** processing to understand the complex geology of these thinly layed sandstone reservoirs;
- **drilling horizontal drains** 1,400 meters long using (for the first time in Venezuela) real-time optimization of borehole trajectories by satellite links between the drilling rigs and the offices in Caracas;
- **industrialized drilling operations** allowing a record of 5.1 days for drilling and well completion — and ultimately simultaneous management of up to 2,000 horizontal wells;
- **installation of Progressive Cavity Pumps (PCPs)** in the wells, a technique formerly reserved for bitumen recovery in Canada;
- **state-of-the-art monitoring**: detectors to measure pressure drop along the drains and fiber optics developed to monitor water ingress.
As a partner in the Surmont permit, one of the largest Canadian projects being developed using Steam Assisted Gravity Drainage (SAGD), Total is heavily invested in the optimization of this innovative technique, strategic for the future of bitumen recovery.

Steam Assisted Gravity Drainage is a recently developed thermal recovery technique. It was invented in the 1980s as a solution for producing Alberta’s oil sands. SAGD is especially effective for in situ production of thick, homogeneous reservoir layers, where recovery factors of better than 50% can be achieved. The technology is based on two horizontal wells drilled one above the other. A continuous injection of steam into the upper well creates a steam chamber. The steam makes the bitumen fluid enough to flow by gravity into the production well (mixed with the condensed vapor), where it is pumped to the surface.

A HIGHLY PROMISING TECHNOLOGY
Total is a partner in the Surmont project where it is working with its partner to optimize bitumen production using the SAGD process. At the end of 2010, SAGD was providing nearly half of Alberta’s in situ production versus 20% in 2006. Surmont was one of the first fields to launch an SAGD pilot followed by industrial-scale production. It is also one of the largest leases in the Athabasca which will be completely developed using this process.

THE SECRETS OF THE STEAM CHAMBER
Understanding the characteristics of the steam chamber has important implications for SAGD process control and efficiency. How does the chamber develop spatially? How is it affected by subsurface heterogeneities? Total is using an extensive and innovative monitoring system to help find answers to these key questions. To optimize the SAGD process and promote large-scale deployment, technologies such as 4D seismic; observation boreholes instrumented with pressure and temperature gauges for continuous monitoring; and fiber optic sensors to measure temperature in the production wells, have been successfully tested.
Basic engineering studies under way for the Joslyn North Mine, Total’s first oil sands mine in Canada, are focused on maximizing recovery while minimizing the environmental footprint.

From the extraction of the ore by shovels and trucks to the recovery of a barrel of bitumen, the mining process generally takes place in four phases. After crushing, the ore is mixed with hot water to form a slurry. A primary separation of bitumen and sand occurs during the transport of this slurry. Secondary separation of the water-bitumen-sand mixture is achieved using hydrocyclones and flotation units. The froth (60% bitumen, 30% water, 10% solids) yielded by this initial processing phase is treated by the addition of a hot solvent. The bitumen is then separated from the solvent. It is washed and mixed with a diluent for transport to an upgrader or refinery. Residues (sand, clay, water) are stockpiled in tailings ponds. After the particles settle, eighty percent of the process water they contained is recycled.

**PRESERVATION OF WATER AND SOIL**

The Joslyn North Mine is being designed to optimize each of these phases, with a particular focus on limiting both water consumption and the surface footprint of the mine. The project’s water consumption will be less than current average industry performance and the segregated tailings management process will allow for a water recycle rate of up to 85%. This will reduce the number and size of tailings ponds and a 90-day fresh-water storage facility will help reduce water withdrawals from the Athabasca River during low flow periods in winter.

Finally, the land will be reclaimed section by section, using gradual reclamation techniques over the lifetime of project.

**THE OIL SANDS MINING PROCESS**

In **Venezuela**, the Jose upgrader transforms a heavy crude (8 °API) into a light desulfurized synthetic crude (32 °API), a commercial-grade product.

In **Canada**, the Group acquired a 49% stake in the Voyager Upgrader Project in early 2011. The unit, located near Fort McMurray, is operated by Suncor Energy with a processing capacity of around 250,000 b/d of bitumen, including Total’s production share from the Fort Hills and Joslyn mines. The construction of this upgrader unit is expected to resume after fine-tuning the engineering design to reflect additional production volumes, with a start-up date scheduled for 2017.

**UPGRADING**

Joslyn lease has 217 km². Over thirty years, cumulative production is forecast to reach two billion barrels.

- **2005**: Total acquires Deer Creek Energy Ltd. and secures operatorship (75%) of the project.
- **2011**: Suncor joins the project. Total is operator (38.25%).
- **2011-2013**: completion of the regulatory approval and sanctioning processes.
- **2017-2018**: start of the first phase of production (100,000 b/d) on 70 km².

**4 to 5 years later**: possible phase 2 production.
Finding solutions to ensure the sustainable recovery of extra-heavy oils and bitumen is without a doubt one of the greatest challenges facing the oil industry today. In this context more than any other, economic, technological and environmental performance must go hand in hand.

Total is focusing on boosting recovery factors, reducing water and energy consumption, curbing CO₂ emissions and limiting the footprint of its mining projects.

These goals are mobilizing our research teams both in France and in Canada, as well as universities and industry. An extensive network of innovation is at work to forge technological solutions – the first of which are already in the pilot phase – to meet tomorrow’s challenges.
Improving recovery

Boosting recovery factors is a priority for all in situ production processes. For thermal recovery, this challenge is coupled with an active focus on minimizing the energy consumption of the processes.

Improving the recovery factors associated with in situ methods is the key to enhancing the profitability of heavy oil developments. At the same time, better recovery will contribute to increasing the reserve volume of this unconventional oil. In view of the immense quantities in place, every additional percentage point of recovery will have significant implications for future oil supply. The challenge is to find ways to produce the residual oil bypassed using current in situ methods. This can be achieved by tailoring the production strategy to the mobility of heavy oil.

TWO PILOTS TO TEST COLD RECOVERY

Existing developments in the Orinoco Belt (Venezuela) are based on cold recovery. These represent the most “conventional” projects in the heavy oils segment. Their energy balance is more favorable than that of thermal recovery projects and their environmental impact is less significant. On the downside, cold production has typically lower recovery factors: of the order of 8 to 10%. Determined to significantly improve on this performance, Total is investigating two Enhanced Oil Recovery (EOR) techniques, one based on chemical recovery, the other on thermal recovery.

IMPROVING THE “PISTON” EFFECT OF INJECTION WATER

Chemical EOR will be the first technological option to be tested on Petrocedeño. In this pilot, the viscosity of the injection water is modified through the addition of polymer to accelerate recovery by enhancing the “piston” effect. The test aims to assess process efficiency in the thinnest reservoir layers for which thermal EOR techniques are not suitable. The pilot will include the deployment of a complete monitoring system consisting of vertical and horizontal observation wells, logging, sampling, and fiber optic sensors installed to allow continuous monitoring of production wells. At stake is a potential doubling of recovery factors.

THERMAL RECOVERY PREVIEW

Thermal EOR is the other avenue that Total is investigating as a means to improve the recovery of mobile extra-heavy oils. The approach here is to enhance the mobility of the crude by injecting steam into the thickest reservoir layers, where the process can be the most efficient.

Total would be the first to test the performance of thermal EOR in the Orinoco Belt, comparing the results of a pilot that will deploy three different recovery mechanisms on Petrocedeño:
- Steam Drive (SD), consisting of steam injections via vertical wells and production via horizontal wells,
- Steam Assisted Gravity Drainage (SAGD), untested to date on mobile oils,
- Horizontal Alternate Steam Drive (HASD), a concept developed by Total and tested in a world first, in which alternating injection and production are carried out via a pair of horizontal wells.

OPMIZING ENERGY CONSUMPTION

Boosting the recovery factors associated with thermal recovery methods must go hand in hand with improvements in process energy efficiency. The key to this dual objective is to lower the Steam-Oil Ratio (SOR), or the amount of steam (which is highly energy-intensive to produce) needed to recover each barrel of bitumen by SAGD. To improve this process, it is essential to have the best possible control of the steam chamber to ensure maximum efficiency. This is achieved both by monitoring and using innovative mechanical diversion technologies to ensure that steam injected is evenly distributed.

Total is also striving to improve the process itself. The Group is a partner in a pilot on Surmont to test the Enhanced-Solvent-SAGD process, which involves adding a solvent to the injected steam to better liquefy the bitumen. It is hoped that this process improvement will enhance recovery and lower the SOR overall.

Improving the energy efficiency of thermal recovery is also the focus of numerous other studies. These include: the conditioning of boiler water for use in innovative steam generators; switching to fuels other than natural gas that are by-products of the production process, or resorting to other energy sources (electricity, geothermal or solar energy).

Solar power holds promise as a supplemental energy source to limit the CO₂ emissions associated with thermal recovery.
Bitumen recovery raises a dual challenge: curbing CO₂ emissions, which are higher during SAGD than in conventional oil production, and reducing water requirements, which are especially great during mining.

The CO₂ emissions associated with conventional oil production average 25 kg per barrel. This compares with 45 kg for bitumen mining, and 70 kg per barrel of bitumen recovered by SAGD, due to the huge quantities of steam generated in natural gas-fired boilers. It is easy to see why emissions abatement is a focal challenge in developing thermal recovery methods, and a priority for Total’s R&D.

IN THE VANGUARD OF CO₂ CAPTURE AND STORAGE
Improving the energy efficiency of SAGD will be the primary source of emissions reduction. In the short term, this will be achieved by process improvements that will decrease the amount of steam required for production (see previous page). Other options are also being studied to cut emissions even further, specifically by developing alternatives to steam injection, such as VAPEX (injection of solventalone), in situ combustion and electric heating. Looking farther ahead, the option of capturing and storing the CO₂ will become available. Total is in the vanguard in this field and has deployed Europe’s largest pilot facility to test an end-to-end process – from oxyfuel combustion and capture of the CO₂ through to injection into a depleted reservoir for storage – on an industrial scale. Simultaneous investigations are under way to adapt boilers to the special requirements of the capture phase and develop cost-effective solutions for treating flue gases, particularly for upgraders.

PRESERVING A VITAL RESOURCE
Limiting water consumption is a prerequisite for the sustainability of oil sands mining. In Canada, the primary challenge is to avoid having too great an impact on the seasonal discharge of the Athabasca River, which flows near the Joslyn site. Indeed, huge quantities of water are necessary to process the ore, which entails separating the bitumen from the sand and fine particles (clay and minerals).

Today, mining projects withdraw 2 to 3 barrels of makeup water per barrel of bitumen recovered. Counting on innovative separation process, the Joslyn North Mine project will cover up to 80% of its needs with recycled water. The aim is to limit water consumption to 1.6 barrels per barrel of bitumen recovered – which would be among the lowest ratios ever achieved by the industry. Moreover, a freshwater storage facility established on site will reduce the need for withdrawals from the Athabasca River during the winter months.

REDUCING STEAM CONSUMPTION
Although less of a problem in the context of thermal recovery, the water consumption associated with the SAGD method is also in the crosshairs of Total’s R&D teams. Studies are under way aimed at limiting the amount of steam needed for production and optimizing water treatment. This work should pave the way to lowering water consumption to 0.3 barrel per barrel of bitumen recovered for phase 2 of the Surmont project. That performance would be nearly two times better than the industry average, now 0.5 barrel of water per barrel of bitumen.
The challenge is on par with the scale of mining projects, which occupy more extensive areas of land than conventional developments. For Total, the issue of site reclamation must be planned from the outset to allow the best possible restoration of soil and ecosystems.

Canada’s bitumen is buried in the muskegs and peat bogs of the boreal forest. This huge forest extends over 3.2 million square kilometers (the size of India). The oil sands accessible by surface mining occupy 4,300 km², of which 650 km² is now in production. The mining process calls for clearing and excavating significant tracts of land and creating a variety of structures, disposal areas and tailings areas. Although the tracts being mined actually account for only a very limited portion of the boreal forest, the wealth of the biodiversity there nonetheless warrants the fullest protection and is of the highest priority.

ACCELERATING RECLAMATION

Limiting the mine’s impact on the landscape, the quality of the soil and the biodiversity is a key effort at Total. Given the pioneering nature of oil sands development, the industry has worked hard to take major strides in improving performance and will continue to progress. Currently, 65 km² of mined areas have been certified reclaimed. The complexity of dealing with tailings cannot be under-estimated, particularly with respect to the ability of mature fines tailings to settle over time. The consequence has been significant: tailings ponds occupy a huge land area and the remediation process has been slow.

PROGRESSIVELY RECLAIMING THE SITE

For Total, reclamation will begin well before operations actually start. On the 70 km² area directly impacted on the Joslyn North Mine site, the overburden removed to gain access to the ore will be put back in place as the mining progresses, and will be revegetated. The Group has pledged to have over 60% of the land reclaimed by the end of mining operations. The future of the tailings ponds remains a key issue and has inspired Total to invest heavily in finding innovative solutions that will not only limit the size of the ponds, but accelerate the settling process.

SMALLER TAILING PONDS

Thanks to the innovative layout developed by Total’s teams, the tailings ponds of the Joslyn North Mine project are expected to have a significantly smaller footprint than conventional ponds. The separation of the various residue streams (called tailings segregation) is more efficient, allowing faster treatment, minimizing the quantity of liquid flow and maximizing water recycling. The aim of the design is to ensure complete settling within about ten years. Tailings ponds also contain toxic by-products of the bitumen itself or from the processing line. To keep these substances from seeping into the groundwater, Total plans to build dykes and dams to world-class standards, while devoting R&D efforts to the water tightness of the ponds, bio-attenuation of naphthenic acids and to accelerating the sedimentation process.