Barrels for the future

Canada's oil sands are the world's largest single hydrocarbon resource. The huge volumes of thick, sticky crude oil – bitumen – are now being exploited at an increased pace. Thanks to thriving oil prices and improved technology, production is bound to double and reach two million barrels per day in only a few years time.

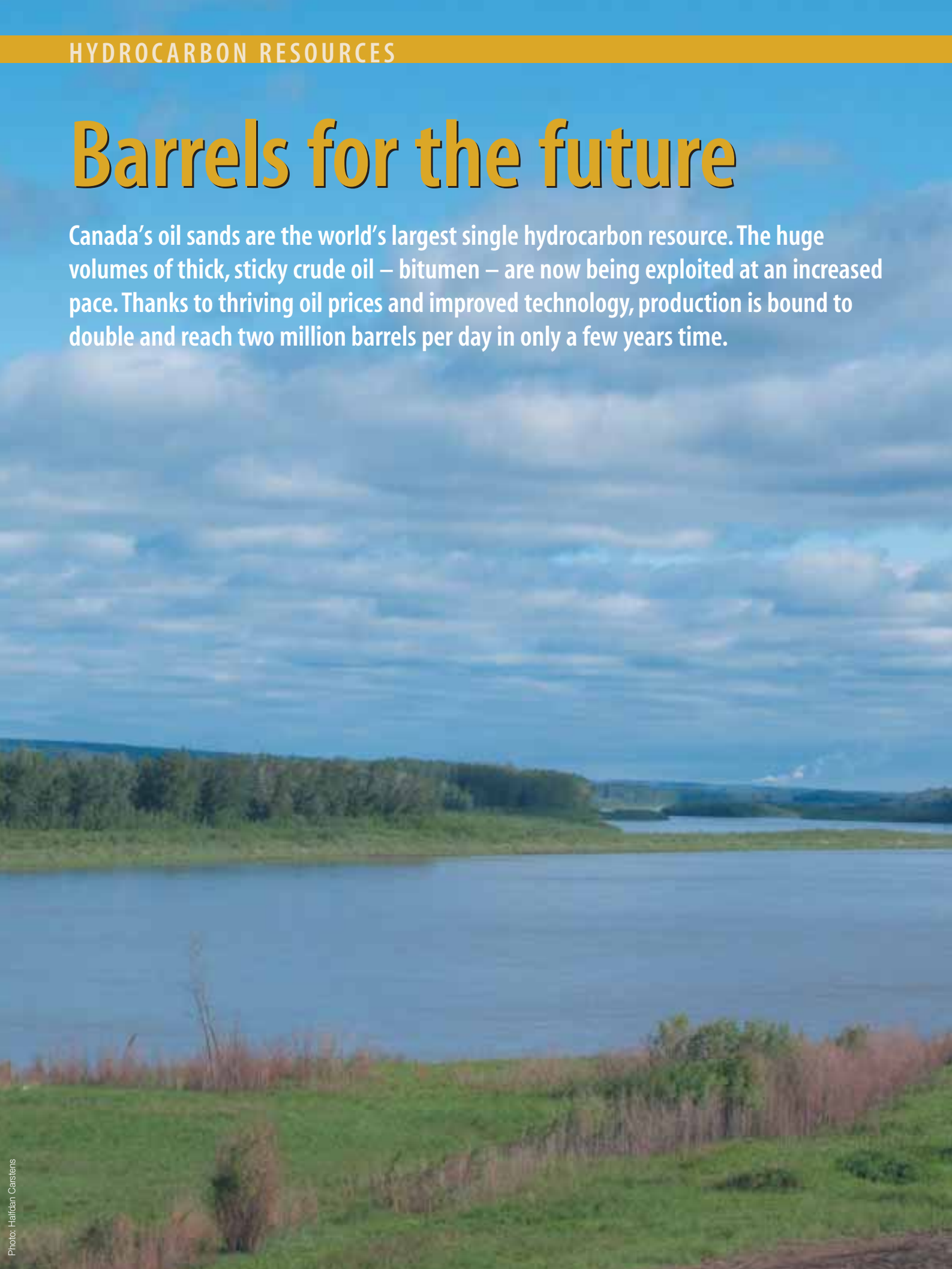

Photo: Halfdan Carstens

The Athabasca oil sands surrounding Fort McMurray in the Canadian outback, some 400 km north of Edmonton, is the largest (40,000 km^2) and most accessible resource. It also contains the most bitumen, and perhaps as much as 20% can be strip-mined while *in situ* techniques are needed for the deep deposits. Additional deposits are found in the Cold Lake and the Peace River oil sands. The Cold Lake area (22,000 km^2) has Alberta's second largest resources of bitumen. Presently, some of these deposits are recovered using *in situ* technology. The Peace River area (8,000 km^2) is the smallest of the oil sands areas. Deep deposits are also here being recovered with *in situ* methods. Several oil sands leases produce significant quantities of coal, coal bed methane and natural gas.

Photographed on a late summer evening, the Athabasca River flows leisurely northwards and later joins the Mackenzie River and ends up in the Mackenzie Delta in the Arctic. Here, on the north side of the booming Fort McMurray, it cuts through the oil sands that are mined in several places further north by a number of oil companies. Water vapour emitted from extraction plants and "upgraders" in the Suncor operations along Highway 63 can be seen in the distance.

World Resources

Oil sands also occur in countries other than Canada, including the Former Soviet Union (FSU), the United States and Nigeria. Outside Canada, significant resources are only found in the FSU.

Halfdan Carstens

"Take the Abasand Drive, pass the school and park on the opposite side. Then follow the gravel road all the way down to the river. Here you can have a first-hand look at the oil sands." The instructions are given by one of the interpreters at the Oil Sands Discovery Centre in Fort McMurray. I am on my way to my first encounter with the famous oil sands. Huge deposits of sandstones filled with ultraheavy oil – bitumen – have been mined and produced for almost 40 years. The deposits are now gaining increased interest from all over the world, including U.S. policymakers eager for a source of oil in a politically stable part of the world.

Five hours drive north of Edmonton through endless stretches of cattle country, first; then desolate forests, rests Fort McMurray on a huge reservoir of bitumen. It is now generally accepted that the small boomtown of 50,000 inhabitants is in the centre of an area that has the largest resources of petroleum on Earth.

I do as I'm told. The road is muddy and quite slippery after the early morning rain, but with good shoes it is nonetheless an easy walk. The walls of the narrow valley are steep, as the moving water in the river down below has had an easy task of eroding these loosely consolidated sedimentary rocks. Small landslides are common. Much to my surprise, the road appears to be paved as I approach the river. Closer inspection, however, reveals that oil from the sandstones has flowed onto the road and made a natural paving during warm, sunny days.

The walk is definitely worth the effort. This is a unique chance to look right into the reservoir without seismic, without electric logs and not having to deal with drill cuttings and slim cores. Best of all, the rocks smell oil.

Photo: Halfdan Carstens

Oil sands – sandstones filled with bitumen – in a road-cut just above the Athabasca River. This is also the location of the now extinct Abasands Oils plant that was first opened in 1936. It operated on a regular basis by 1941 producing 2000 barrels a day. They drilled holed in the sandstones, inserted blasting powder and set it off. The loos sand was loaded onto trucks and hauled to the separation plant. A fire in 1945 completely destroyed the plant, and in 1946 the federal government abandoned the site. It took another 20 years before Great Canadian Oil Sands (now Suncor) launched a project to produce synthetic oil from oil sands.

The first attempts

The oil sands were known to the native people long before the White Man ventured west and northwards on their way towards the cold Arctic. They knew that if they mixed the bitumen with spruce gum they could use it to caulk the seams of their birchbark canoes. They may also have used bitumen for other purposes such as dressing wounds and waterproofing garments.

The first written account of the oil sands dates back to 1719 when a fur trader described a sample "that flowed out of the banks of the river," and by the late 18th century several European explorers were reporting of bitumen seeps along the Athabasca River. They didn't know it at that time, but they had in fact discovered what would much later turn out to be the world's largest petroleum resource.

Commercial interest in the bitumen deposits was triggered by scientists from the Geological Survey of Canada at the end of the 19th century. Their insights resulted in investigations funded by the Government, and in 1894 a well was drilled to see if the bitumen was seeping from a conventional reservoir below the sand. The conclusion was negative, and since then huge efforts have concentrated on mapping the extent of the oil sands and how to exploit the resource economically.

The first real attempt to recover oil from the sandstones was made in 1915 when an engineer wanted to use it for a road-paving experiment. Several paved roads in cities like Ottawa and Jasper resulted.

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Only 20% of the oil sands can be strip-mined, the rest is lying too deep for this technology to work. Nevertheless, recoverable reserves amount to 65 billion barrels of oil, six times the recoverable volumes of Prudhoe Bay. If this had been conventional oil, the shallow deposits of the Athabasca oil sands would have ranked as the world's 3rd largest oil field.

Transportation of huge volumes of rocks turned out to be a costly affair, and hot water came into use as a means of separating bitumen from the mined sand. In 1925, a scientist with the Alberta Research Council successfully demonstrated a separation method using hot water and caustic soda. The same fundamental principle is still being used today in a process the industry calls "upgrading". Upgrading is the process that converts bitumen and heavy oil into a product with a density and viscosity similar to conventional light crude oil.

Gasoline, fuel oil and asphalt were first produced by Abasand Oils Ltd. in 1936. Again, hot water and solvents were used to extract the bitumen from the rocks. The plant burned down just as it was going to operate efficiently, but along with a similar mining-refining project elsewhere it was now proven that the technology could work. More than 200 years after the oil sands were first discovered, a technology had been invented that could extract bitumen from the sandstones.

The discovery of significant reserves of light crude in the late 1940s due south of Edmonton (GEO ExPro No. 2-3, 2005), however, halted further developments of any oil sands project for at least a decade. Instead, everybody wanted to invest in a resource that was much cheaper to produce and which did not require en elaborate process of "upgrading" before being sent to the refinery.

Towards a prospering industry

The modern era of extracting bitumen from oil sands began in 1967, almost 40 years ago, at a time when Fort McMurray was just a fur trading post and river port of 1,300 people far away from civilisation.

First on the scene was Great Canadian Oil Sands (GCOS), the forerunner of today's Suncor Energy Inc. Later, the Syncrude project, a consortium of oil companies, launched their project just as the oil crisis of the early 1970's shook the world. Syncrude nevertheless began producing upgraded crude oil in 1978.

Both operations were mining oil sands from deposits sitting close to the surface. Deposits below more than 75 metres of overburden require a different technology to get the bitumen out of the rock. This is called the in-situ method.

The story of in-situ bitumen development also began in the 1960's. Imperial Oil built a test plant to extract bitumen from the deeply buried Cold Lake deposits south of Fort McMurray. The technology involved injecting steam under high pressure into the oil sand formation, and pumping the bitumen to the surface as it became more inclined to flow. During the 1970's Shell developed a similar technology for producing bitumen from the Peace River oil sands deposit to the west of Fort McMurray.

Today, a licence map of the area around Fort McMurray shows a whole range of operators witnessing an industry eager to exploit the vast resources. Some 20 projects are either producing, from a few thousand barrels to more than 250,000 barrels a day, or are under way and plan to be producing in only a few years time. These are all mining extraction projects using huge shovels that load sand into equally big trucks.

Bitumen and oil sands

Bitumen is a thick, sticky form of crude oil with a specific gravity greater than 0,96 g/cm^3 and is a general name for solid and semisolid hydrocarbons. At 11°C it has the consistency of a hockey puck, at room temperature it is a tar-like substance that pours extremely slowly, and in order to flow into a well or through a pipeline it must be heated or diluted.

Bitumen stored in the Canadian Oil Sands started out as conventional, crude oil more than 1000 metres below the surface. Some fifty million years ago, however, huge volumes of conventional oil migrated upward until they reached and saturated large areas covered by sandstones close to the surface. Bacteria then feasted on the light hydrocarbons components and slowly turned the oil into bitumen. Bacteria always eat the simplest hydrocarbon first and convert them into carbon dioxide and water. The larger hydrocarbon molecules, as well as sulphur and metals, are left behind. As a result, there are more heavy hydrocarbons, sulphur and metals in bitumen than in conventional oil.

Upgrading is the process that changes bitumen into synthetic crude oil.

Heavy oil is a thick crude oil with a specific gravity greater than 0,90 g/cm^3. The term includes some oil that will flow, albeit slowly, but most heavy oil also requires heat or dilution to flow to a well or through a pipeline.

Oil sands are naturally occurring mixtures of bitumen, water, sand and clay. On the average a sample of oil sand will contain 12% bitumen by weight, but the bitumen content varies from 1% to 18%. More than 12% is considered rich, while less than 6% is poor. On average, it takes 2 tonnes of mined oil sand to produce one barrel of synthetic crude oil. The upgraded product is called "synthetic" because it is altered from its naturally occurring state by a chemical process. Synthetic crude oil is very similar to conventional oil. The synthetic oil leaves Fort McMurray by pipeline travelling 5 km/hr, and it takes 3 days to reach refineries in Edmonton.

Oil sands are water wet. Each grain of sand is covered by film of water, which is then surrounded by a slick of bitumen. The sands are bonded firmly together by grain-to-grain contact. The sand is composed primarily of quartz grains.

Oil sands are often referred to as "tar sand" because the bitumen resembles black, sticky tar. However, the term "tar sand" is incorrect as tar is a man-made substance formed through distillation of organic material.

Samples of the oil sands represent the ultimate experience for petroleum geologists as you can see both the reservoir and the oil it contains. In addition, you can smell the oil!

How much?

The amount of bitumen reservoired in mostly Cretaceous sandstones of the Western Canada Sedimentary Basin is colossal. Nowhere else on earth is the concentration of petroleum per square kilometre higher, and the Canadians themselves claim this is the world's largest petroleum resource.

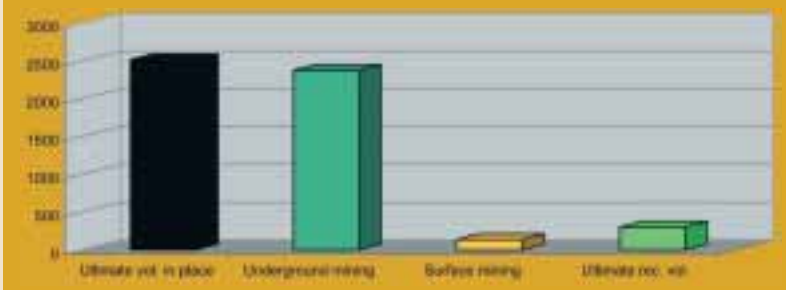
Canada's bitumen resources are situated almost entirely within the province of Alberta. Three deposits have been defined: the Peace River, Athabasca and Cold Lake Oil Sands Areas (compare map on page 47). These deposits collectively cover an area – 80,000 sq. km – comparable in size to Ireland or Scotland.

According to the Alberta Energy and Utilities Board (AEUB), the initial volume of bitumen in place is now reckoned to be 1.6 trillion (10^{12} barrels) barrels. The ultimate volume of bitumen in place, the volume expected to be found when all exploratory and development activity has ceased, is 2.5 trillion barrels. It is hard to grasp this number. It may help to know that you get this volume by multiplying the reserves of Prudhoe Bay (10 billion barrels recoverable) 250 times.

The larger part of the resources can only be accessed through underground mining because they are deeply buried. Only a small part is available for strip mining (compare diagram).

Of the ultimate in place volume of bitumen, approximately 315 billion barrels is estimated to be recoverable. Initial established reserves are 180 billion barrels. In comparison, the original reserves of Ghawar in Saudi Arabia, the world's largest oil field, was 80 billion barrels and the remaining reserves of Saudi Arabia is 263 billion barrels (BP Statistical Review of World Energy 2005).

Future estimates of reserves (recoverable bitumen) may increase, as the current numbers are based on a recovery factor of only 12 percent. There is a considerable potential for this percentage to increase as advances are made in recovery technology of deposits that are buried too deeply to be mined.



The upper diagram visualises how much oil that may be present in the Canadian oil sands altogether (black), how much of this that can be produced in situ (dark green), how much that can be mined (yellow), and how much oil that can be recovered (12 percent) taking into account current technology and economic conditions. The Alberta Energy and Utilities Board (AEUB) has estimated that some 315 billion barrels is ultimately recoverable. The lower diagram compares the potential oil sands reserves with numbers published this year by BP concerning remaining oil reserves (BP Statistical Review of World Energy).

Only about 10-15%, perhaps as much as 20%, of the Canadian oil sands can be mined. At more than 75 metres below the surface, a large part of the Athabasca resource is buried too deep for this technology. Instead, the in-situ method must be used. The same applies to the Cold Lake deposits that sit below 300-600 metres of overburden and the Peace River oil sands that are found 150-760 metres below the surface.

2 tonnes = 1 barrel

While conventional oil flows naturally or is pumped from the ground, bitumen from oil sands must be mined if close to the surface or recovered in-situ when buried more than about 70-80 metres.

The mining operation has gained worldwide fame because of the large-scale machinery being used. Through documentaries we have witnessed colossal shovels dig into the oil sand deposits and load their cargo into huge trucks that then transport it to crushers. Hot water is here added causing the fluids to dissolve from the rock fragments, and the slurry is then transported to the extraction plant through pipelines. At the extraction plant the bitumen is released from the slurry through the use of separators.

The sand is sent back to the mine site to fill in mined-out areas. Water from the extraction process containing sand and clay goes into settling ponds. The water is recycled back to the extraction plant for use in the separation process.

On the average, about two tonnes of oil sand have to be removed and processed to make one barrel of crude oil. Oil sand mining is thus very efficient with respect to the amount of bitumen recovered. The recovery rate is in general higher than 90 percent. In comparison, recovery rates in conventional reservoirs average 30 percent and very seldom exceed 50 percent.

Bitumen, behaving like a solid rather than a fluid, cannot be produced from wells unless it is heated or diluted. Injected steam is used for this purpose in most commercial in-situ operations. The heat softens, while the water vapour helps to

"GO BIG, OR GO HOME". In the late 1800's and early 1900's, when people first began mining oil sand, the operation was completely manual. Now, mining oil requires extremely large machines. To prepare for surface mining, the overburden, consisting of muskeg and glacial deposits, is first removed and saved to use in land reclamation. Suncor, Syncrude and Albian Sands are today using the same mining technology: Truck and shovel. The shovels move easily to select the richest oil sand and ignore low-grade ore. Open pit mining is done in benches or steps, as is evident in this photo. The benches are each approximately 12-15 metres high. Giant shovels dig the oil sand and place it into heavy hauler trucks that range in size from 240 ton to the largest with a 400-ton capacity. The latter can thus transport 400 tons of rock, equivalent to 200 barrels of oil when crushed and upgraded. The trucks dump the oil sand into crushers, which break up the big chunks of oil sand. From the crushers, warm water is added, and the slurry is then separated into bitumen, sand and water. The sand and water is pumped to holding ponds, while the bitumen is further awashed with a hydrocarbon solvent to prepare it for transport into the upgrading plant. Breaking the heavy bitumen into smaller molecules by adding hydrogen, heat and pressure and removing nitrogen and sulphur create synthetic crude oils. The main product of upgrading is thus synthesized crude oil that can later be refined like conventional oil into a range of consumer products.

Photo: Halfdan Carstens

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Syncrude's massive oil production facility, the Mildred Lake operation just off Highway 63, is the largest single source of crude oil in Canada. In the background we see the main plant facilities for bitumen extraction and upgrading that is in the final stages of an $8 billion expansion. The strip-mining process scars vast acres of land that must be reclaimed and restored to what is called "equivalent land capabilities." In front, what appears to be a massive tidal flat with wet, light-brown sand, is an area that is currently being reclaimed, i.e. disturbed land is restored so that it is as productive as it was before it was mined. It will take 12 to 15 years to turn the site into rolling, grass-covered hills. Just south of Syncrude's plant (not seen is this photo) is the company's first mining site. It is now reclaimed and rolling hills of grass and trees support a herd of buffalo. The site includes also a pond used for mine tailings.

dilute and separate the bitumen from the sand grains. The pressure forced on the formations also forms cracks through which the bitumen can flow to the wells. The operation takes place in three stages: Stage 1 involves steam injection; Stage 2 means soaking the reservoir for several weeks, and in Stage 3 bitumen is flowing or being pumped through the same wells as the steam was injected. When the production rate declines after weeks or months, the cycle is repeated.

The production technology is continuously improving, steam-assisted gravity drainage (SAGD) being the latest development. Pairs of horizontal wells, one above the other, are drilled into a formation. Steam is injected into the upper well; the bitumen softens and drains into the lower well.

During in-situ operations between 25 and 75 percent of the bitumen in the reservoir can be recovered.

Ice that burns

The paved road out of Fort McMurray continues for about 65 km. On our way we pass a number of "oil fields", notably Syncrude's operations which can be overlooked from a viewing point, and with a SUV it is possible go on for another 40 km or so during summer. After that it is wilderness. All the way to the Arctic. Continuing on foot is no option. A five-hour flight north out of Edmonton will, however, take us to the next adventure. The Mackenzie Delta where enormous amounts of gas is stored in sandstones at several thousand metres depth.

In addition, the Arctic may contain vast amounts of gas in the form of gas hydrates (GEO ExPro No. 1, 2004, www.geoexpro.com). That gas is also, like bitumen in oil sands, stored in a solid state. Also similar to the oil sands, the hydrocarbons are found at shallow depth.

Unlike the oil sands, however, it may take decades before this resource can be produced economically.

Photo: Tim Collett, USGS

Canada's hydrocarbon resources are plentiful. While the Alberta oil sands are now tapped at an increased rate, gas hydrates may be a huge resource in the future.