
BUCYRUS
495HF
CATERPILLAR
797B
CAT
108

Extracting Oil from Sand & Rock

Alternative technologies provide a critical bridge to renewable fuels and energy sources

By Virginia Hughes

Spread across the mountainous region where Wyoming meets Utah and Colorado, the 48-million-year-old Green River Formation holds tens of thousands of deer, millions of fish and dinosaur fossils and 213 billion tons of oil shale—the fine-grained sedimentary rock that, when properly cooked, turns into oil.

Energy experts estimate that the Green River Formation's oil shale reserve holds at least 800 billion barrels of recoverable liquid oil. About half lies in a 35-by-45-mile plot of the Piceance Basin, on U.S. federal land in northwestern Colorado.

"It's a very, very compact area," says James Bartis, a senior policy researcher at RAND Corp., a nonprofit U.S. research organization. "And in that area alone, we've got more oil than all of Saudi Arabia."

Meanwhile, 1,500 miles north, underneath the Boreal Forest in Alberta, Canada, rests the world's largest reservoir of crude bitumen. This "heavy oil" is trapped inside a sticky, dense mixture of sand and water known as "oil sands." The Canadian oil sands are processed by just a few factories, the largest of which, Syncrude, produced 77 million barrels of its refined product in 2006—accounting for 14 percent of all Canadian oil sales.

If and when these alternative oil technologies advance, they will potentially help free North America from its dependence on foreign oil. "Because of that, they also provide a national security premium because that means less money goes to fairly unstable governments," Bartis says.

These industries have a long way to go—in both ensuring environmental protections and increasing output efficiencies—before they can be scaled up for worldwide use. Still, alternative oil technology advocates say it is going to be hugely important in the transition to a renewable energy system.

"This is a bridge," says Jerry Boak, director of the Center for Oil Shale Technology and Research at the Colorado School of Mines. "In the long run, we'll all use renewable fuels and energy sources. But that long run may be quite long."

Oil From Shale

About 48 million years ago, the Green River Formation consisted of two massive lakes, each full of robust blooms of blue-green algae. Over time, the algae accumulated in the sedimentary basins at the bottom of the lakes and, thanks to rapid climate swings, was periodically covered by mud and sand. Sheltered from the oxygen in the air, the algae decomposed very slowly, and was joined by layers of more algae and more sand. As still more time passed, the basin sank under the accumulated organic matter, and increasing temperatures and pressures compressed the layers into carbon-based rocks, called oil shale.

The highest concentrations of oil shale are found in the United States, China and Russia.

Had the rocks been buried deeper, and left for another 250 million years, they may have formed coal, the black rock that's made of mostly carbon. But oil shale contains a premature form of carbon, called kerogen, which, when heated, turns into crude oil.

Most of the world's oil shale deposits are small, thin, and thus insufficient for commercial production. But in regions with large deposits—such as the Baltic Basin of Estonia and São Mateus do Sul, Brazil—oil shale is a viable commercial industry. (See By the Numbers, pg. 15.)

In these regions, miners obtain oil shale using one of two methods, depending on the depth of the deposit. For deep deposits, they use underground mining with a 'room-and-pillar' method, in which many 30-foot-square columns are cut vertically into the shale beds. These spaces (the 'rooms') are cut out in a parallel grid, leaving undisturbed 100-foot-wide 'pillars' of earth in between them. The pillars support the top weight of the mine while miners can dig out the shale in the rooms.

The second mining method, called surface mining, is simply removing the rock and plant material that's covering oil shale deposits close to the surface.

After mining, the oil shale is transported to a facility for retorting, a heating process that extracts the oil from the rock. The shale is crushed into small (half-inch to 3-inch) particles, then quickly heated and reheated in an approximately 100-foot-tall, steel vessel, called a retort, at 650 to 700 degrees Fahrenheit until the kerogen becomes liquid oil. After retorting, the oil goes through further chemical processing and is eventually shipped to a refinery. The oil-less rock leftovers, called spent shale, are usually dumped in landfills or put back into the mined area.

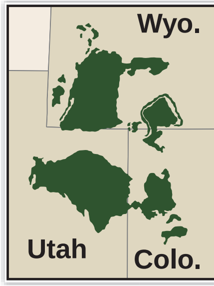
In November 2006, for the first time in 30 years, the U.S. federal government issued six, 160-acre "research, development and demonstration" (RD&D) leases for exploratory oil shale production on federal land in the Green River Formation.

"Our national and economic security depend on our developing domestic energy resources like the oil shale found in western Colorado," said C. Stephen Allred, assistant secretary of the interior for land and minerals management, in a public statement.

The U.S. government first looked into oil shale during World War I, and the Middle East oil crises of 1973 and

Oil shale resources

The U.S. holds more than half of the world's oil shale resources, but extracting the oil requires huge amounts of energy.

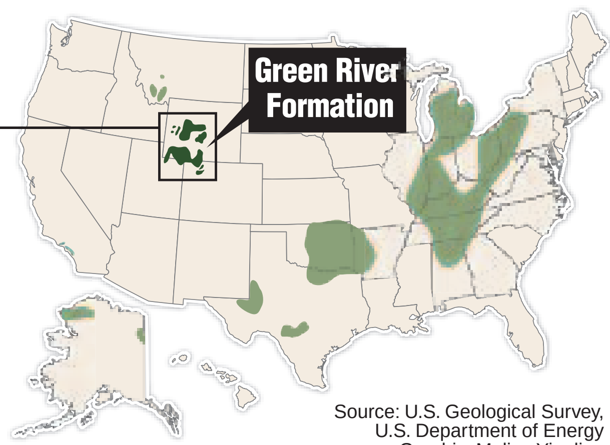


Green River Formation

- 16,000 sq. mi. (41,400 sq. km)
- Largest known deposits of oil shale
- Estimated to contain 1.2-1.8 trillion barrels of oil

Major U.S. oil shale deposits

- Richest, most concentrated
- Less concentrated



Source: U.S. Geological Survey, U.S. Department of Energy
Graphic: Melina Yingling

1979 caused a boom in the American oil shale industry. But by the early 1980s, when Middle East oil supplies were restored and prices plummeted, all but one American company abandoned oil shale development.

Slow-cooking Underground

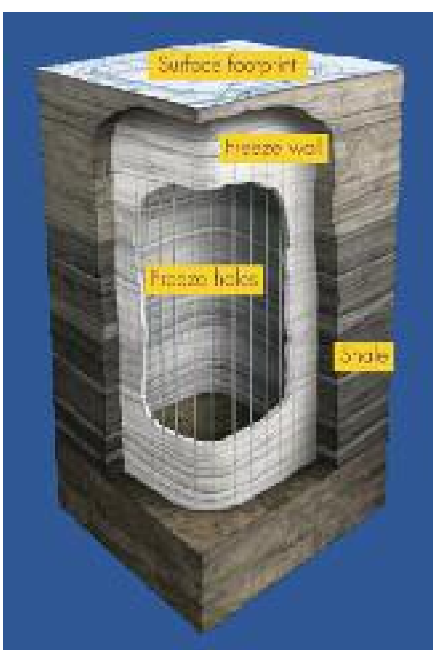
Shell Oil Co. didn't give up. In 1982, on privately owned land in Rio Blanco County, Colo., Shell began testing a new, more efficient oil shale technology: heating the shale underground and then pumping it out as liquid.

This "in-situ" technology works by first lowering electric heaters into heating wells, spaced about 40 feet apart, that reach the shale deposits 2,000 feet below ground. The heaters, which reach between 650 and 750 degrees Fahrenheit, slow-cook the shale for about four years. In that time, the kerogen slowly changes into oil and gas, which are then pumped through separate recovery wells to the surface for further refining.

Keeping this liquid oil out of the groundwater is one of the biggest challenges facing the technique. To solve this problem, in early 2007, Shell scientists began testing a "freeze wall" technology on the same private land in Colorado. The technology works by pumping boiling ammonia through pipes surrounding the shale deposits. Because ammonia's boiling point is 27 degrees Fahrenheit below zero, this freezes the water surrounding the shale, and thus forms an impermeable barrier between the shale and the groundwater.

Shell representatives say they won't know the full effectiveness of the freeze wall until 2012. "I think they're cautious, but optimistic" about the feasibility of oil shale development, says

Shale oil heated to liquid form underground must be kept out of groundwater. Shell Oil Co. is using freeze wall technology to contain the liquid oil, below left. Steam-assisted gravity drainage technology injects steam into underground wells near oil sands deposits and collects the bitumen released by the heat, below right.



One of the world's largest resources of oil sands is located in Alberta, Canada. The sands are moved out to processing plants—at the rate of 500,000 tons per day—by the world's largest Caterpillar trucks.

Boak, director at the Colorado School of Mines.

Despite the excitement over the new federal oil shale leases, the leasers are still in the initial research and development stages, notes Glenn Vawter, executive director of the National Oil Shale Association, who has been an engineer in the Colorado oil shale industry for half a century. "The first thing they have to do is demonstrate the technology is going to be economically feasible and environmentally acceptable," he says.

On the environmental front, one of the biggest obstacles may be water supply. Last fall, the Colorado Department of Natural Resources published a study that questioned whether the Colorado rivers could provide enough water for extensive oil shale production, which would consume 123 billion gallons of water a year.

Vawter says that oil shale developers are all looking at ways to reduce water consumption, such as using the region's wastewater. "Many developers believe their technologies will use much less water than stated in the study," he says. Still, he admits that "we're certainly into the next decade before there would be any commercial projects."

Oil Sands Technology

If you think of oil shale as a kind of undercooked oil, then oil sands are more like overcooked oil: a sticky tar in which an extremely heavy oil, called bitumen, is embedded in sand, clay and water.

Scientists debate how oil sands formed, but the prevailing theory is that over millions of years, water and bacteria turned naturally occurring petroleum into bitumen.

The world's largest oil sands—which cover 54,000 square miles—are the Athabasca oil sands in northeastern Alberta. For centuries, Canadian Indians have used this tar to waterproof their canoes. In the early 18th century, European fur traders wrote home about it.

In 1883, Canadian geologist G.C. Hoffman discovered how to separate the bitumen from the rest of the tar. "When you put that heavy molasses in water, and heat it gently, it separates very nicely," explains Eddy Isaacs, executive director of the Alberta Energy Research Institute. That's because within the tar, water surrounds each grain of sand, separating it from the oil. By adding hot water, "you get all of the oil going to the top, and the sand settling on the bottom," he says. "That's how the industry got started."

Nineteenth-century Canadian explorers and geologists thought that the oily sand was a hint of black gold far below. In 1888, the director of the Geological Survey of Canada said that Athabasca was likely to become "the most extensive petroleum field in America, if not the world." Between 1906 and 1917, 24 oil wells were drilled in the region. But all came up dry.

Half a century passed before the oil sands industry rose to commercial success. In 1978, a company called Syncrude shipped its first barrel of light crude product, called "Syncrude Sweet Blend," which can be used just like regular crude oil. Today, it makes 350,000 barrels every day.

More than 70 countries benefit from a modest oil sand industry, but only Canada, Venezuela and the United States have robust production. Experts estimate a worldwide production of

1.25 million barrels of oil per day from oil sands. "That is a remarkable achievement, considering that you're talking about an industry that's quite young," Isaacs says.

To mine the surface oil sands in Alberta, Syncrude and the handful of other Canadian oil sands companies start by cutting down spruce and fir trees from the Boreal Forest. Once cleared, they must dig out up to 150 feet of soil, rock and plant and animal habitat (called overburden) to finally uncover the oil sands. The sands are moved out—via the world's largest Caterpillar trucks, with payloads of 380 tons—to processing plants where the tar is mixed with hot water, the bitumen separated and hydrocarbons added to make the synthetic liquid crude.

This surface mining—which is used for about 20 percent of oil sands reserves in Alberta—comes with significant environmental consequences. Huge sections of forest land must be destroyed; 160 square miles of forest was cleared in Canada in 2007 alone. And Canadian oil sands processing plants draw large amounts—up to 92,000 gallons per year, according to Greenpeace—of water from the Athabasca River. That water is recycled many times in the plant, eventually emerging as a black liquid full of toxic waste. It's then funneled to nearby 'tailing ponds,' where it sits dammed and uncapped.

The other 80 percent of the oil sands reserves, resting beneath at least 250 feet of overburden, must be acquired using in-situ methods. Usually, this is done by injecting steam into horizontal wells near the base of the oil sand deposit. The steam thins out the tar, which can then be pumped to the surface for further processing.

Efficiency Concerns

The growth of these unconventional oil industries will depend mostly on the supply of conventional oil.

"The truth is, the world is running out of the cheap and readily available oil that we've had for the past century," Isaacs says. He predicts that within the next decade, as demand for oil grows and supply drops, "you will see higher oil prices on average, and that will [mean] a lot of unconventional resources will be developed."

One caveat to that idea is that both oil shale and oil sands depend on conventional oil. "Everything they use to mine it—the trucks and tires and steam shovels—comes from the main economy that's driven by oil and gas," says Charles Hall, a professor at the State University of New York College of Environmental Science and Forestry. "So when the price of oil and gas goes up, so does the cost of producing the alternatives."

Even if economic and political pressures favored the production of oil shale and oil sands, Hall says that these technologies are not efficient enough

Extraction separation cells separate large masses of raw bitumen from the oil sand using the most advanced technologies in the industry.

One of the largest oil sands production plants is located north of Fort McMurray, Alberta. Officials there hope to more than double oil sands production to over a half-million barrels per day in the next decade.

to take the place of conventional oil.

When making efficiency calculations, he says, the most vital figure is the energy return on investment (EROI), the net energy gained from a technology after subtracting the amount of energy it takes to produce it. In the large oil wells of the Middle East, for example, you get 14 units of energy back for every one unit that you spend on pumping it out. The EROI for Canadian oil sands is about 3-to-1, and the EROI of oil shale is lower still.

"Three-to-one is great for companies, [because] you can make money on it. But our calculations show that the minimum required … today is something around 5-to-1," Hall says. "So the question for [unconventional oil] is, can you scale it up to make any sense of it all?"

Yes, say its advocates, and the sooner the investment is made, the better. "It's slow and capital intensive," says Boak. "There's a lot of work that's done before you get product out of it."

The speed is all the more important, they say, because unconventional oils are only a short-term bridge to more sustainable forms of renewable energy, such as nuclear or wind power.

"We're seeing the peaking of petroleum supplies in the world. In the next 10, 20, 30 years, it's essential that we have some domestic supply that's going to bridge the need," says Vawter. "Nobody looks to unconventional oil as 'the answer.' It's only one of a number of answers to get us to the ultimate energy solution."

Coal-to-Liquids Technology

While some American engineers and geologists are trying to figure out how to profitably turn the country's huge oil shale reserves into liquid oil, others are looking to do the same conversion from a long-proven source: coal.

"We have about 270 billion tons of coal, more coal than any other country in the world. We use about a billion tons a year, which means we have over 200 years of coal," explains James Bartis, a senior policy researcher at RAND Corp. "If we took 15 percent of that coal and used it to make liquid fuels, we would be able to make something like 3 million barrels a day for almost 100 years," he says.

These numbers are compelling, and "coal to liquids" (CTL) fuel technology was worked out a long time ago. First, coal is mixed with very hot water at very high temperatures. This results in a gas, called syngas, which is a mixture of hydrogen and carbon monoxide. The syngas, when exposed to a chemical catalyst, condenses into liquid fuel, which can then be further refined into specific types of oil, including petroleum, diesel, synthetic waxes and methanol.

The major obstacle facing CTL development is not the technology itself, but carbon emissions. Producing oil from coal releases twice as much carbon into the air as drilling crude oil. "And that's unacceptable these days," says Bartis.

CTL would quickly take off, however, if scientists developed a successful carbon capture technology, says Bartis, who testified before Congress in 2007 with recommendations for CTL development. "We think there are approaches to using coal for making liquid fuels in which you can have greenhouse gas emissions at a significantly lower level than conventional petroleum," he says. "On the other hand, not all of the technology for that has been proven, especially carbon sequestration."

By the Numbers:
Top countries in oil shale/bitumen reserves

Estimated Oil Shale Resources (million barrels)*

Country	
United States	2,085,228
China	328,000**
Russia	247,883
Democratic Republic of the Congo	100,000
Brazil	82,000
Italy	73,000
Morocco	53,381
Jordan	34,172
Australia	31,729
Estonia	16,286

*Source: 2007 Survey of Energy Resources, by the World Energy Council
**Source: Adjusted estimate by Jerry Boak, based on Jilin University study

Estimated Reserves of Extra-Heavy Oil and Bitumen
(Primarily in Oil Sands) (million barrels)*

Country	
Canada	173,605
Venezuela	58,555
Kazakhstan	42,009
Russia	28,373
China	750
Nigeria	574
Angola	465
Indonesia	422
Italy	300
Madagascar	221

*Source: 2007 Survey of Energy Resources, by the World Energy Council