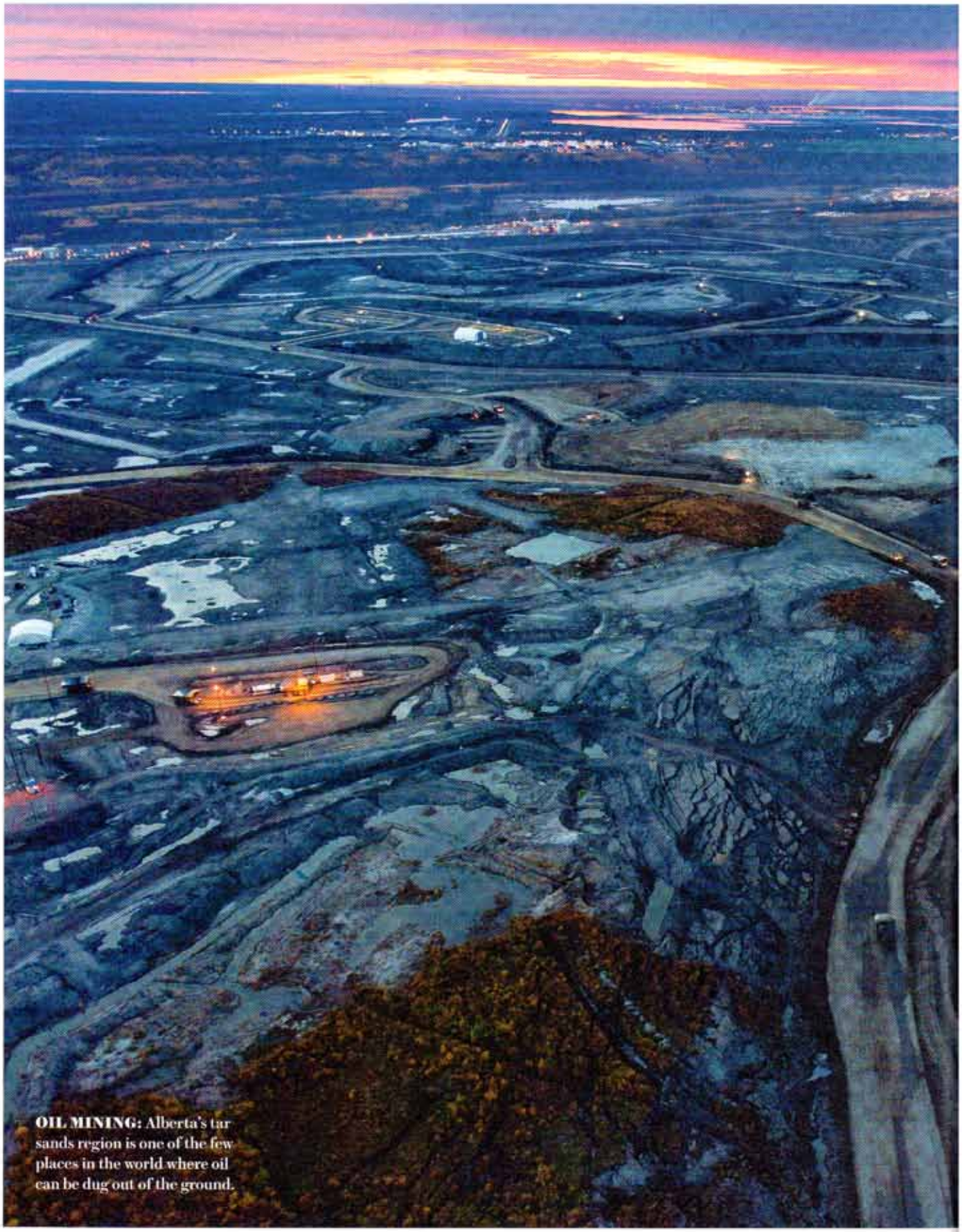


OIL MINING: Alberta's tar sands region is one of the few places in the world where oil can be dug out of the ground.

ENVIRONMENT

greenhouse goo

The fate of the Alberta's tar sands mines—and the climate—may come down to the Keystone XL pipeline

By David Biello

Red lights are flashing, but Ben Johnson pays them no mind. The long, lean, weathered engineer rests against a counter lined with computer monitors, describing life in the tar sands mines of Alberta, Canada. His task is to take a mud made of ore and water and "liberate the bitumen," a tarlike oil that can be refined into conventional crude oil. He and two colleagues man a monitoring station that sits near the base of a cone-shaped structure the size of a three-story building. Mud and hot water flow into the middle of the inverted funnel. Bitumen rises to the top and spills over onto surrounding grates.

One time in 2012 bitumen bubbled up so fast that it cascaded down the sides of the cone and flooded the building shin high. To keep this kind of thing from happening again, sensors track temperatures, pressures and other parameters, and if something is amiss, a warning goes off. This happens so often—"1,000 alarms a day," Johnson says—that the engineers have taken to keeping the sound turned off. "It's not going 'bing, bing, bing,'" he says, "because that would drive us crazy."

Suncor Energy's North Steepbank mine, where Johnson operates one of many "separator cells," is a tiny portion of the current output of Alberta's tar sands, which underlie an area the size of Florida. High oil prices over the past decade have made such tar sands mines profitable, and Canada has rapidly expanded production. In 2012 alone Alberta exported more than $55 billion worth of oil, mostly to the U.S., so it is no wonder that Johnson's crew does not pause for alarms.

The rush to exploit the Alberta tar sands is triggering alarms of another kind, however—from climate scientists. Carbon dioxide emissions from burning fossil fuels are driving the world quickly toward a greenhouse gas threshold—an atmospheric concentration of 450 parts per million, which corresponds to two degrees Celsius or more of warming—beyond which some scientists fear that climate change could prove catastrophic. Coal constitutes a bigger source of fossilized carbon, but the Alberta sands require more energy to mine and refine than conventional oil, adding an extra overhead in greenhouse gas emissions. And the tar sands operations are growing far more quickly than most other sources of oil. Releasing the carbon now trapped in the tar sands would most likely dash any hope of avoiding the two degree C threshold.

The fate of Alberta's tar sands—and the climate, for that matter—now seems to be converging on the proposed Keystone XL pipeline. Keystone XL, which would run from Alberta to refineries in Texas along the Gulf of Mexico, would serve as a primary conduit for tar sands crude. For a decade or more advocates of Alberta's operations have argued that the tar sands constitute a much needed source of oil for the U.S. that is not subject to turmoil in the Middle East and abroad. All that was needed was a way to transport the tar sands oil from Canada to where it would be used—to the U.S. and beyond to Europe and Asia. And if a pipeline like Keystone XL could not be built, then other pipelines or rail could do as well. But independent experts suggest that Keystone XL is critical to the continued growth of Alberta's tar sands industry.

None of this had come to light when President Barack Obama postponed a decision on whether to build the Keystone XL pipeline during his reelection campaign. When the issue comes up again, a great deal more will be riding on his decision.

THE TRILLIONTH TONNE

EXPOSED TO THE BITTER CHILL of a northern Alberta winter at an overlook above Suncor's mine, I can't help but think that a little global warming might be nice. The mine is located in an industrial expanse of boreal forest some 30 kilometers north of Fort McMurray, a boom town where rents run as high as Manhattan's and truck drivers make $100,000 a year. Down below, along a gravel road, I can see a parade of Caterpillar 797Fs, the world's largest trucks, each carrying a 400-metric-ton load of clumped tar sands. (Women drivers are highly sought because they are easier on the equipment, but they are hard to come by because men outnumber women three to one in town.) The trucks shuttle back and forth between massive electric-powered shovels and Johnson's separation facility, a 40-minute round-trip.

The trucks dump the ore into an industrial grinder the size of a compact car, which feeds an oversized conveyor belt that brings the tar sands to the separation cell that Johnson helps to oversee. A chunk of ore can go from truck to liberated bitumen in a mere 30 minutes. This black and sticky but free bitumen froths from the top of the separator, is collected and then flows down a pipeline to a mini refinery, where it is cooked at high heat to remove carbon and create a hydrocarbon stew similar to crude oil. Alternatively, the bitumen is mixed with lighter hydrocarbons in squat, huge storage tanks; the resulting mixture, known as dilbit (for diluted bitumen), is liquid enough to flow on its own through long-distance pipelines like Keystone XL, bound for refineries in the U.S.

Suncor's North Steepbank is only a small fraction of the world's first tar sands mine—and just one of the company's complex of mines, which together produce more than 300,000 barrels of oil a day. Suncor's holdings make up about 30 percent of the total production from mining of the Alberta tar sands, which currently comes to nearly two million barrels a day—equal to the output of more than 80,000 oil wells and one twentieth of U.S. demand. The mines, with their vast lakes of toxic water residue and blocks of bright yellow elemental sulfur, are already big enough to see from space—an industrial patch steadily spreading in the boreal forest.

The invisible environmental impact of the mines may prove the most challenging, however. Avoiding the two degree C warming threshold means that humanity faces what some scientists have called a carbon budget: an estimated one-trillion-metric-ton limit on cumulative carbon emissions.

The carbon budget is the brainchild of physicist Myles Allen of the University of Oxford and six other scientists. In 2009 the team assembled observations of rising temperatures and plugged them into computer models of future climate change, which accounted for, among other things, the fact that CO_2 persists in the atmosphere, continuing to trap heat, for centuries. Their one-trillion-metric-ton budget encompasses all the carbon that human activity can safely generate between now and the year 2050, if we are to stay below the warming threshold. It doesn't matter how quickly we reach that limit. What matters is not exceeding it. "Tons of carbon is fundamental," argues now retired NASA climatologist James E. Hansen, who has been testifying about climate change since 1988 and has recently been arrested at protests against the Keystone XL pipeline. "It does not matter much how fast you burn it."

The source of that carbon does not matter, either. The world can burn through only a set amount of carbon-based fuels, whether tar sands, coal, natural gas, wood or any other source of greenhouse gases. "From the perspective of the climate system, a CO_2 molecule is a CO_2 molecule, and it doesn't matter if it came from coal versus natural gas," notes climate modeler Ken Caldeira of the Carnegie Institution for Science's department of global ecology at Stanford University.

To date, burning fossil fuels, clearing forests and other activities have put nearly 570 billion metric tons of carbon into the atmosphere—and more than 250 billion metric tons of CO_2 just since the year 2000, according to Allen. Currently human activi-

IN BRIEF

Turning tar sands into oil and burning it as fuel produce enormous amounts of carbon dioxide.
To prevent an average global temperature increase of more than two degrees Celsius, triggering potentially catastrophic climate change, cumulative carbon emissions must be kept below one trillion metric tons.
The earth's atmosphere is already more than halfway to the trillion-metric-ton target; expanding production of even more tar sands would accelerate emissions.
If built, the Keystone XL pipeline will be a spigot that speeds tar sands production, pushing the planet toward its emissions limit.

PRECEDING PAGES: GARTH LENZ

ties emit about 35 billion metric tons of CO_2 (9.5 billion metric tons of carbon) a year, a figure that is steadily climbing, along with the global economy. By Allen's calculations, at present rates society will emit the trillionth metric ton of carbon sometime during the summer of 2041. To stay on budget, on the other hand, emissions must drop by 2.5 percent a year, starting now.

UNDERGROUND TREASURE

ALBERTA'S TAR SANDS represent a lot of buried carbon, the remains of countless algae and other microscopic life that lived hundreds of millions of years ago in a warm inland sea, pulling CO_2 out of the atmosphere via photosynthesis. With today's technology, about 170 billion barrels of oil could be recovered from Alberta's tar sands, which would add roughly 25 billion metric tons of carbon to the atmosphere if burned. An additional 1.63 trillion barrels of oil—which would add 250 billion metric tons of carbon—waits underground if engineers could figure out a way to separate every last bit of bitumen from the sand. "If we burn all the tar sands oil, the temperature rise just from burning those tar sands will be half of what we've already seen," or roughly 0.4 degree C of global warming, notes mechanical engineer John P. Abraham of the University of St. Thomas–Minnesota.

Surface mining can reach deposits as deep as 80 meters, but that accounts for only 20 percent of the tar sands. In many places, the tar sands lie hundreds of meters underground, and energy firms have developed a method—known as in situ production—to melt out the bitumen in place.

In 2012 Cenovus Energy melted more than 64,000 barrels of underground bitumen every day at Christina Lake, a facility in Alberta named after nearby waters. The operation is one of the frontier camps of this latest tar sands boom. Clouds of steam rise from the nine industrial boilers on-site, burning natural gas to heat treated water into 350 degree C steam. Cenovus employees in a control room even bigger than Suncor's inject the steam deep below the surface to melt the bitumen, which is then sucked back to the surface through a well and piped off for further processing. Greg Fagnan, Christina Lake's director of operations, likens the complex to a giant water-processing facility "that happens to produce oil as well." Every once in a while, a blowout shoots steam and partially melted tar sands into the sky, like one Devon Energy caused in the summer of 2010 by using too much pressure.

At Christina Lake, engineers inject roughly two barrels of steam to pump back out one barrel of bitumen. All that steam—and the natural gas burned to heat it—means melting bitumen results in two and a half times more greenhouse gas pollution than surface mining, itself among the highest emitters for any kind of oil production. Greater production by this melting method has caused greenhouse gas emissions from Alberta's tar sands to rise by 16 percent since just 2009, according to the Canadian Association of Petroleum Producers. In 2012, for the first time, underground production of tar sands in Alberta equaled that of surface mining, and thanks to efforts such as Christina Lake, it will soon become the primary mode of production.

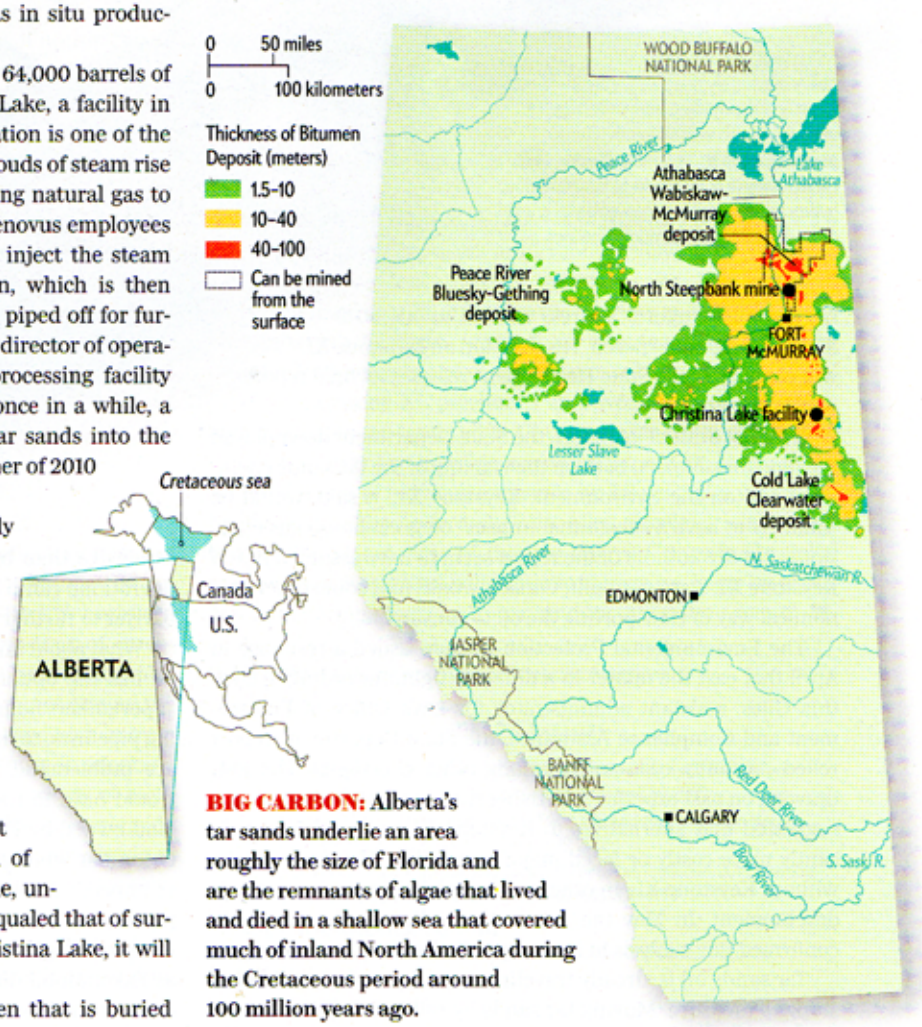
In situ production works only for bitumen that is buried below 200 meters, however. That leaves a gap of 120 meters or so that is too deep for surface mining but too shallow for in situ. So far engineers have not figured out how to tap the gap, which means burning all the fuel contained in the tar sands deposits is an unlikely prospect at present.

Yet burning a significant portion of tar sands will go a long way toward blowing the planet's carbon budget. The only way to do so and stay on budget would be to stop burning coal or other fossil fuels—or to find a way to drastically reduce tar sands' greenhouse gas emissions. Neither prospect seems likely. Tar sands "emissions have doubled since 1990 and will double again by 2020," argues Jennifer Grant, director of oil sands research at the Pembina Institute, a Canadian environmental group.

KEYSTONE CONNECTION

THIS CARBON BUDGET explains why Abraham, Caldeira and Hansen joined 15 other scientists to sign a letter to President Obama urging him to reject the proposed 2,700-kilometer-long Keystone XL pipeline. Building the pipeline—and thus enabling even more tar sands production—is "counter to both national and planetary interests," the scientists wrote.

Obama, who postponed approval of the pipeline just before the 2012 presidential election, struck a climate-friendly note in



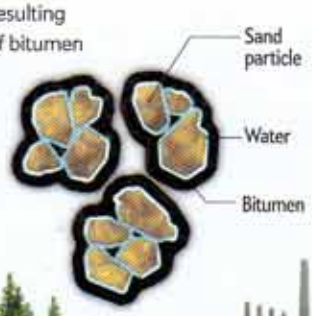
BIG CARBON: Alberta's tar sands underlie an area roughly the size of Florida and are the remnants of algae that lived and died in a shallow sea that covered much of inland North America during the Cretaceous period around 100 million years ago.

SOURCE: ALBERTA GEOLOGICAL SURVEY AND ENERGY RESOURCES CONSERVATION BOARD

Map by Michael Newhouse

How Tar Sands Oil Is Made

Alberta's oil sands have been cooked by the earth's heat, resulting in a thick, tarry form of petroleum, or bitumen. Each blob of bitumen coats sharp-grained sands and water, both of which must be released before the bitumen can be processed. A typical ore might be 73 percent sand, 12 percent bitumen, 10 percent clay and 5 percent water. Separating the sticky elements results in lakes' worth of toxic residue.



Melting So-called in situ production involves piping superhot steam more than 200 meters underground where it melts the bitumen in place, which is then sucked to the surface for processing via production wells. The resulting bitumen can either be refined or diluted to flow in a long-distance pipeline. The method requires more energy than mining, emitting more greenhouse gases.

Mining To mine Alberta's bitumen, heavy machinery first scrapes away the boreal forest and the muskeg peat underneath it, uncovering seams of tar sands. Electric-powered scoop shovels mine the ore, which is carted away in giant trucks to be refined into hydrocarbons similar to conventional crude oil or diluted to flow through pipelines.

his second inaugural address as well as his 2013 State of the Union speech. His decision on Keystone XL will come after the State Department releases its final report on the pipeline.

In a first draft of its report, the State Department downplayed the pipeline's impact, both on the viability of the tar sands operations and on the environment. Keystone XL, it said, would be "unlikely to have a substantial impact" on greenhouse gas emissions. But the authors of the report seem to have assumed that if Keystone XL were not built, Canada would find some other economical way of transporting the oil to consumers.

The Environmental Protection Agency issued a response in April that cast the matter in a different light. According to Cynthia Giles, assistant administrator for EPA's Office of Enforcement and Compliance Assurance, the State Department report relied on faulty economics, among other oversights. The EPA, drawing on past experience with big environmental assessments, suggested that alternatives to Keystone XL were either significantly more costly or faced major opposition. Having to get by without Keystone XL, in other words, might constrain tar sands development. In May the International Energy Agency (IEA) confirmed this analysis in its own prediction for the tar sands.

Tar sands oil is already traveling south by train, but this is a stopgap measure. Moving tar sands by rail is three times more expensive than by pipeline at current rates. As the tar sands operations ramp up, rail alone could prove a prohibitive cost barrier to further development.

What about another pipeline, should Keystone XL fail? Canada has the option of going west to the Pacific Coast to reach supertankers bound for China. Or it could go east, through existing pipelines, to the Midwest or the Atlantic Coast. These options are problematic. A Pacific pipeline—the least viable choice—would have to traverse the Rocky Mountains, passing through land owned by First Nations and other native groups in British Columbia, who have opposed a pipeline for fear of spills and other impacts. An Atlantic pipeline could be cobbled together from pipelines that now link Alberta to the eastern coast of North America. Engineers would have to reverse the flow of oil, much as ExxonMobil did for the Pegasus pipeline, which now carries crude from Illinois to Texas. But older pipelines that have been

Illustration by Emily Cooper

reversed may be more prone to leaks. Pegasus, for instance, sprung a tar sands oil leak in Arkansas this past April. And retrofitting existing pipelines is likely to elicit strong protest from environmentalists and others.

Given these obstacles, the tar sands industry needs Keystone XL to further expand, according to the EPA and IEA reports. At present, Alberta's tar sands produce 1.8 million barrels of oil a day. Keystone XL would ship another 830,000 barrels daily.

Mindful of the environmental opposition, Alberta and energy firms have tried to minimize greenhouse gas pollution in the tar sands operations. Royal Dutch Shell is trying an expensive alternative to breaking down bitumen into oil that involves adding hydrogen, rather than cooking off carbon into pet coke, to reduce CO_2 emissions. The international oil giant has also begun developing plans for adding carbon capture and storage equipment to one of its mini refineries, a project dubbed Quest. When completed in 2015, Quest will attempt to annually store deep underground one million metric tons of CO_2, or roughly one third of the facility's pollution. Another similar project plans to capture CO_2 for use to flush more conventional oil out of the ground.

Alberta is also one of the only oil-producing regions in the world to have a tax on carbon. Currently capped at $15 per metric ton, discussions continue to potentially raise that price. The province has invested the more than $300 million collected to date in technology development, primarily to reduce CO_2 emissions from the tar sands. The tax "gives us some ammunition when people attack us for our carbon footprint, if nothing else," Ron Liepert, then Alberta's minister of energy, told me in 2011.

Efforts to reduce the carbon footprint of the tar sands add further to the cost of extracting the oil and have not had a big impact on the carbon footprint. The 1.8 million barrels of tar sands oil a day produced in 2011 resulted in more than 47 million metric tons of greenhouse gas emissions in 2011, according to the Canadian Association of Petroleum Producers.

The IEA, in a 2010 analysis of ways to stay below the two degree C threshold, suggested that tar sands production in Alberta cannot exceed 3.3 million barrels a day by 2035. Yet mining already approved or under construction in Alberta could raise production to five million barrels a day by 2030. It's hard to imagine how to mine the tar sands without blowing the carbon budget.

BREAKING THE CARBON BUDGET

IS IT UNFAIR TO SINGLE OUT THE TAR SANDS? After all, other forms of fossil fuel add more to the world's carbon budget, yet they do not draw as much ire. Perhaps they should. In 2011 U.S. coal-fired power plants emitted nearly two billion metric tons of greenhouse gases—roughly eight times the amount produced by mining, refining and burning tar sands. Many coal mines around the world create just as visible a scar on the landscape and an even bigger climate change legacy. Yet mines like those in Montana and Wyoming's Powder River Basin are not the targets of high-profile protests such as those facing Keystone XL; protesters do not tie themselves to the tracks to block the kilometers-long trains that carry coal from the basin day after day. The U.S. Geological Survey suggests that basin alone holds 150 billion metric tons of coal that could be recovered with existing technology. Burning it all would send the world flying beyond any trillion-metric-ton carbon budget.

Australia's plan to expand coal exports to Asia could add 1.2 billion metric tons of CO_2 to the atmosphere each year when that coal is burned. That amount dwarfs emissions from even the most optimistic tar sands expansion. The U.S. and countries such as Indonesia are also planning coal expansions. Shutting down or even curtailing the U.S. coal industry would more than compensate for any tar sands development as a result of Keystone XL, although the two fossil fuels are used for different purposes—coal for electricity, oil for transportation.

Canada also offers a target of some convenience, given that it is a friendly democracy susceptible to environmental pressure. Producers of "heavy oil"—similar in pollution to tar sands bitumen—in Mexico, Nigeria or Venezuela do not find themselves under as much scrutiny despite high rates of CO_2 pollution. In fact, scouring such heavy oil from an old field in California is the single worst CO_2 polluter among all oil-extraction efforts in the world, including the melted tar sands. "If you think that using other petroleum sources [than tar sands] is much better, then you're delusional," says chemical engineer Murray Gray, scientific director of the Center for Oil Sands Innovation at the University of Alberta. "Increasing coal use worldwide gives me a lot more pause."

These other sources of petroleum are not growing anywhere near as fast as Alberta's oil sands, where in the past decade production increased by more than a million barrels a day. To keep to the atmospheric carbon budget, the world must produce less than half of the known and economically recoverable oil, gas and coal reserves. That means much of the fossil fuel—especially the dirtiest forms of petroleum, such as that produced from the tar sands—will have to stay buried.

Economic forces may come to the aid of the global environment. Fracking for oil in North Dakota's portion of the Bakken Shale has begun to depress U.S. demand for Canada's dirty oil; in response, new infrastructure projects in Alberta's tar sands, such as the $12-billion Voyageur mini refinery, have been dropped. New mandatory fuel-efficiency standards for U.S. cars will reduce demand as well, at least in the short term. Regardless, the tar sands will be there, waiting, an ever tempting target for future extraction once the easier oil runs out.

If the Keystone XL pipeline is approved or other means are built to get the tar sands oil to China, exports could continue to rise, accelerating the invisible accumulation of CO_2 in the atmosphere. Instead of reducing emissions by 2.5 percent a year, starting now—the effort Oxford physicist Allen calculates is necessary to keep the planet clear of the two degree C threshold—global greenhouse gas pollution will continue to increase. Every bit of carbon from burning fossil fuels—tar sands or otherwise—counts. ■

David Biello is an associate editor at Scientific American.

MORE TO EXPLORE

Warming Caused by Cumulative Carbon Emissions towards the Trillionth Tonne. Myles R. Allen et al. in *Nature*, Vol. 458, pages 1163–1166; April 30, 2009.

The Alberta Oil Sands and Climate. Neil C. Swart and Andrew J. Weaver in *Nature Climate Change*, Vol. 2, pages 134–136; February 19, 2012.

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SCIENTIFIC AMERICAN ONLINE

For a more in-depth look at tar sands production, visit ScientificAmerican.com/jul2013/tar-sands