A lakeful of trouble

Africa's Lake Kivu contains vast quantities of gas, which makes it both dangerous and valuable. **Anjali Nayar** asks whether it is possible to tap the gas without causing a disaster.

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In late 2001, Mount Nyiragongo in the Democratic Republic of the Congo (DRC) was growing restless. Plumes of smoke issued from the central crater, alarming volcanologists in the nearby city of Goma. Then, on 17 January 2002, lava fountained from a fracture on Nyiragongo's southern flank. The molten rock snaked down the sides of the volcano and razed the centre of Goma, engulfing houses and setting off a string of explosions at fuel stations and power plants. That evening, the lava streamed into nearby Lake Kivu, generating a plume of water vapour that clouded the area for days¹.

More than 100 people were killed and nearly 300,000 people fled their homes. The only obvious refuge for the displaced people was along the shores of the lake. But Kivu poses its own threats. Beneath its placid surface, the lake contains 300 cubic kilometres of carbon dioxide and 60 cubic kilometres of methane. A disruption to the lake — such as a bigger, closer eruption — could cause a gas burst, with potentially deadly consequences for the roughly 2 million people who live along Kivu's shores. The risks are hard to quantify, however. Although scientists have studied the lake for decades, basic details about Kivu and its gases are still relatively scarce, and there is now debate about how hazardous the situation is.

The issue is complicated by the lake's economic potential. The valuable methane dissolved in the water has started a feeding frenzy among energy companies working with the DRC and Rwanda, the other nation bordering the lake.

In deals worth hundreds of millions of dollars, companies have started to siphon off the methane, in some cases working with the very scientists who have been assessing the lake's hazards. Proponents say that those degassing efforts will reduce the risk of gas eruption, but some researchers are worried that schemes to extract methane could make the situation more dangerous if they upset the lake's equilibrium.

"It could be one of the great remediation projects of all time: mitigating a lethal natural hazard and at the same time bringing power to people who desperately need it," says George Kling, a biogeochemist from the University of Michigan in Ann Arbor. "If it is done right."

An expanding problem

Lake Kivu lies in the Great Rift Valley, where tectonic forces are slowly ripping Africa apart. That movement brings up molten rock, which releases carbon dioxide that seeps into the bottom of Lake Kivu. Bacteria convert some of the carbon dioxide into methane, and other bacteria produce methane by breaking down organic matter in the deep waters (see graphic, overleaf).

Kivu is permanently stratified, with layers of dense salt-rich water below fresh water at the surface. Deeper than about 50–80 metres, the lake is anoxic and the concentrations of dissolved carbon dioxide and methane increase with depth². The differences in density prevent

the layers of water from vertically mixing, and so trap the gases at the bottom of the lake.

Residents around the lake have known about the dissolved gases for many decades, but it wasn't generally thought to be a hazard. Then, in 1984, carbon dioxide erupted from Lake Monoun in Cameroon, killing 37 people. Two years later, another Cameroonian lake, Lake Nyos, spat up 0.3–1 cubic kilometres of carbon dioxide, asphyxiating more than 1,700 people.

Kling was part of a team that visited Lake Nyos in the weeks following the eruption. "The animals were all dead, thousands of cattle just lying about," he says. Kling had been to

Nyos the year before, but had only sampled surface waters. "We knew nothing about the gas bomb in the bottom of the lake," he says.

It turned out that the deep waters of Lake Nyos were nearly saturated with carbon dioxide and, like in Lake Kivu, the gases were kept in solution by the pressure of the overlying water. Kling postulates that a landslide disturbed the lake's stratification, forcing gas-rich waters to move upwards³. That started a chain reaction. The reduction in pressure caused carbon dioxide to come out of solution and form bubbles, much like what happens when a bottle of champagne is uncorked. The rising bubbles dragged up the surrounding water, which also degassed, leading to a violent gas burst — a limnic eruption.

Carbon dioxide is denser than air so, when

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THE UNDERWATER THREAT

If the dissolved gas accumulating in the depths of Lake Kivu bursts to the surface, it could threaten millions of lives.

it emerged, it hugged the ground, smothering everything as it spread up to 26 kilometres from the lake. The scale of the disaster compelled scientists to assess the risk at Kivu, the other lake known for its dissolved gases.

Latent threat

There are no historic records of limnic eruptions in Lake Kivu. But gaps in layers of plankton fossils at the bottom of the lake suggest that such paroxysms have struck several times in the past 5,000 years⁴. If Kivu were to undergo a limnic eruption soon, it would dwarf the Nyos disaster. Kivu is more than 3,000 times larger and contains more than 350 times as much gas as was released by Lake Nyos. Kivu's shores are also densely populated. "Kivu is basically the nasty big brother of Nyos," says Kling. But there is no scientific consensus on the current risks of that kind of a disaster.

Gas concentrations measured in 1974 and a limited study conducted in 2004 (ref. 5) show that there has been a 15–20% increase in methane and a 10% increase in carbon dioxide levels in the lake in the past 30 years, says Martin Schmid, a researcher at the Swiss Federal Institute of Aquatic Science and Technology in Kastanienbaum. If this trend continues, the lake will be saturated within the century and, like Lake Nyos, it could erupt with even the slightest disturbance. At the moment, however, the closest Kivu comes to gas overload is at a depth of 330 metres,

where the water is 55% saturated — 10% with carbon dioxide and 45% with methane — says Schmid, so an eruption is less likely. (Methane contributes most of the gas pressure and the risk of eruption because it is less soluble than carbon dioxide.) According to modelling work, only an intense eruption in the gas-rich depths would be powerful enough to overturn the lake⁶. The 2002 eruption barely affected its stability because the magma did not reach those depths⁷. "The probability is low," says Schmid. "At least I am not afraid of swimming in Lake Kivu."

But Dario Tedesco, a volcanologist from the Second University of Naples in Caserta, Italy, who is writing the DRC's Mount Nyiragongo eruption contingency plan for the United Nations, says an eruption at the bottom of

Lake Kivu is a possibility. Tedesco has studied bathymetric surveys of the lake and found cone-like structures that are probably volcanic in origin, he says.

That evidence matches some other signs. During the 2002

Nyiragongo eruption, new fractures opened on the south side of the volcano, just a few kilometres from the lake. The lava from the fractures was also compositionally different from the volcano's crater lake¹, suggesting that there are separate reservoirs of magma in the region, some of which could extend under the lake. "Nyiragongo is going to erupt again," says Tedesco. "The only real question is where."

"I'm not afraid of swimming in Lake Kivu."

— Martin Schmid

Tedesco's research at Kivu highlights its complexity. The lake contains at least five basins, with different characteristics and different probabilities of turnover². The Kabuno basin, in the lake's northwest corner, has high gas concentrations only 12 metres below the surface. An eruption in Kabuno could release at least three times more gas than Lake Nyos did.

Researchers agree that it is important to relieve gas pressure at Lake Kivu to avoid a natural disaster — and the economic incentives are pushing that work forwards. The 60 cubic kilometres of methane equals roughly ten times the combined annual commercial energy needs of both the DRC and Rwanda.

Tapping that reserve is particularly attractive to energy-starved Rwanda, and Lake Kivu has become the centrepiece of the country's plans to expand electricity production.

Extracting methane from Kivu is not a new idea. A brewery in Rwanda burned the lake's methane to heat its boilers for 40 years before it shifted to electricity. But commercial interest in using methane to generate electricity only burgeoned in recent years, in part because of growing political stability in Rwanda. Around 60 companies, most of them from foreign countries, have approached the government for access to the lake since 2005, says Albert Butare, Rwanda's minister responsible for energy, water and sanitation.

Rwanda has already handed out methane concessions totalling hundreds of megawatts to five consortia, including a US\$325 million, 100-megawatt deal with ContourGlobal, an energy company based in New York. And in June, Rwanda and the DRC announced a new joint plan to develop an additional 200 megawatts from the lake.

The growing interest in Kivu has kept scientists busy discussing best practices for methane removal. Most of the proposed models use a floating platform to suspend a vertical pipe down into the gas-rich layers. A small pump initially pulls up some of the bottom water to lower pressures, until it becomes saturated with gas and starts forming bubbles. After this priming, the bubbling drives water up the pipe without additional pumping. The extraction works like a controlled limnic eruption.

The methane, being less soluble than the carbon dioxide, comes out of solution first. It is then piped onshore where it is burned to generate electricity. The problem is what to do with the carbon-dioxide-laden water.

From the standpoint of safety, it would be ideal to extract the carbon dioxide and reinsert the degassed water into the deep parts of the

Close call: lava from Mount Nyiragongo didn't go deep enough into lake Kivu in January 2002 to set off a limnic eruption, but next time it could.

lake, where it wouldn't disturb the equilibrium, says Kling. But removing the carbon dioxide makes the water lighter, hence less stable at depth. "We don't want to generate any sinking or rising of water masses that will cause mixing," he says. Only water from the very bottom of the lake would still be dense enough to be reinserted in the deepest layers once it was degassed, but that would be prohibitively expensive. So Kling suggests keeping the carbon dioxide in the water. "Every solution is a compromise," he says.

Conflict of interests?

Klaus Tietze, a geophysicist and the director of Physik-Design-Technology, a consulting company based in Celle, Germany, argues that with carbon dioxide concentrations in the lake increasing at a rate of more than 3% a decade, "leaving the carbon dioxide in the lake is a very bad solution". He is pushing for removing both methane and carbon dioxide as quickly as possible and reinserting the water above the main gas accumulations in the lake, so that it doesn't dilute the methane resource.

Schmid discounts that plan, however, because the nutrients in the degassed deep water would overload the lake's upper layers.

With so much disagreement among scientists, the best way forwards for developers is unclear, especially because the extraction technology has been problematic. So far only one 4-megawatt platform, called KP, is sporadically generating electricity for Rwanda's national grid. Another, a 3.6-megawatt project funded by the Rwandan Investment Group, sank last year a week before it was scheduled to begin production. Some have attributed the loss to sabotage but others have blamed bad engineering.

Complicating the situation is the potential for conflicts of interest; some of the scientists who studied the lake and identified its hazard are now involved in the methane extraction projects.

For example, Michel Halbwachs, a recently retired physicist from University of Savoie in France, has spent two decades studying Nyos and Kivu and now spearheads the Rwandan Investment Group's project. He says that the engineering of the sunken platform was sound and the company is now rebuilding it. Halbwachs says that his previous work on the lake is not a conflict of interest, but rather makes him uniquely knowledgeable about how to extract gases safely.

Tietze agrees that only the few scientists who "know the whole lake" through decades of experience are qualified to run the methane projects. He is also trying to get into the extraction game and is now looking for investors.

But other scientists worry that the safety of the lake could be compromised if the researchers who are assessing the gas hazard are also working on commercial methane extraction. The best interests of the lake's two million inhabitants could get lost along the way, says Tedesco, who calls the plans for tapping methane "pure business". "This has nothing to do with the hazard of the situation," he adds.

"It's a little bit like someone has dropped free money on the street and everyone's running around trying to gather it up," says Kling. He is part of an international team that is working with the World Bank and the involved nations to create rules for methane extraction in the lake. The team wants every project to be monitored through a local institute, which then reports to an international group of experts.

"There has to be a separation between who is doing the work and who is checking the work," he says. In mid-June, the team came out with its first draft of legislation, which will now have to get parliamentary backing both in Rwanda and in the DRC.

Although, in theory, removing the methane should make the lake safer, it remains unclear whether the hazard will be reduced. The plans for degassing are preliminary, and no one knows how they will affect the lake's stability.

The chances of avoiding a disaster depend on many factors, some well beyond the control of the scientists or even the governments in that region. Armed militias in the DRC recently took over four of the area's seven seismic monitoring stations, hampering the ability of volcanologists to predict when Nyiragongo will erupt. And in the past few months, renewed fighting in rural areas has displaced hundreds of thousands of people.

Goma's population has almost tripled since the 2002 Nyiragongo eruption, to an estimated 1.2 million people. There are shanties crammed into every usable piece of land, many constructed from lava blocks from the volcano's last eruption. So as scientists and developers fight over Lake Kivu's methane resource, the displaced people remain pinned between a volcano, the militias and an explosive lake.

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