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Monitoring Methane

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Low-cost sensors could help natural gas producers plug costly methane leaks.

Natural gas is racing neck-and-neck with coal to be the top fuel for generating electricity in the United States, thanks to increased use of techniques such as hydraulic fracturing that extract the gas from unconventional sources. Since natural gas emits half as much carbon dioxide as coal does when burned, its increased use has helped lower per capita carbon emissions in the U.S. over the past decade.

However, a major downside of natural gas is that it leaks. Millions of tons every year—roughly 9 million tons in the United States alone—spill into the atmosphere during extraction, storage, and transport. Because natural gas is comprised of 95% methane, a greenhouse gas that traps 86 times more heat than carbon dioxide over a 20-year period, just 2–3% of natural gas leaking can wipe out its environmental benefits over coal. "The short-term climate punch of waste methane is equivalent to over 200 coal-fired power plants," says Ben N. Ratner, a senior manager at the nonprofit Environmental Defense Fund (EDF).

Methane is also highly flammable. Leaks have caused fatal explosions in San Bruno, California; New York City; and elsewhere. Plus, leaking natural gas is like scattering money into the wind. According to the policy analysis firm Rhodium Group, fugitive methane emissions cost companies about \$30 billion per year.

These leaks continue in part because there are no regulations requiring their containment. The U.S. Environmental Protection Agency has only a voluntary program. Plus detecting leaks isn't easy: Current options cost tens of thousands of dollars and are cumbersome to employ across long pipelines crossing remote landscapes.

Cheap, accurate, and compact sensors that continuously look for methane leaks could enable widespread monitoring, even along pipelines. These could nip climate-harming leaks in the bud and help companies' bottom lines. Innovators are making strides on improving sensors thanks to challenges issued by the U.S. Department of Energy's Advanced Research Projects Agency–Energy (ARPA-E) and EDF. Forward-thinking natural gas producers and utility companies are starting to test advanced leak detectors. These new technologies could make it easier and cheaper for them to greatly reduce the carbon footprint of natural gas.

Small, inexpensive methane detectors could help natural gas production facilities monitor tanks and pipes for costly leaks. Credit: Shutterstock.

FINDING FUGITIVES

In the United States, natural gas is extracted from roughly half a million well pads, sites where pipes are bored deep into the ground. Monitoring these pads and miles of pipelines for invisible, odorless methane is daunting. The distinctive rotten egg smell that alerts you to gas leaks at home is due to mercaptan added later by utility companies for safety. "If methane emissions were purple this would've been solved years ago," says Ratner.

Today, oil and gas companies and utilities hire inspectors who walk around facilities with infrared cameras that visualize methane swirls. Methane absorbs infrared light, so light from the sun's rays traveling through millions of methane molecules looks different than light that hits the infrared sensors directly.

These cameras can spot around 80% of total leakage at a gas production facility under ideal conditions—low wind, warm weather, clear skies—and at an imaging distance of 10 m, according to researchers from Stanford University.

Published: July 17, 2017

But conditions are not ideal most of the time. Besides, these cameras can only detect methane at levels greater than 10,000 ppm, so they're incapable of catching small leaks, and most companies only get inspections done around once every quarter, so leaks can last months undetected.

Newer laser-based sensors can detect 5 ppm concentrations from 50 m away. These spectrometers shoot pulses from tunable infrared lasers at a target—a storage tank or pipe, for example. Some of the light bounces back to the detector, which senses changes due to absorption by methane. These laser spectrometers can scan large areas from further away than infrared cameras, but they have a hefty price tag of more than $75,000.

The goal for next-generation detectors is something that detects methane at parts-per-million levels from far away; recognizes that it is not coming from, say, the rotting garbage in nearby landfills; and pinpoints where the leak is and estimates how much gas is escaping. Plus it needs to be affordable. Researchers are moving toward these goals by using less expensive, chip-based lasers and detector technologies and automated monitoring. "The vision is...to detect potent natural gas leaks with a speed we would all expect in a digital age," Ratner says. "Automated, continuous methane monitoring that alerts the operator could allow personnel to be dispatched at the right place and time to fix leaks in minutes."

To help this vision become reality, the EDF's Methane Detectors Challenge program, launched in 2014, offered innovators $10,000 and a chance to test their methane-sensing technologies with big oil and gas companies. To qualify, the sensors needed to detect methane at a level of 2 ppm for a market cost of $1,000. Two promising technologies have emerged from the program and are now undergoing pilot testing.

One is a spectroscopy system made by Longmont, Colorado-based startup Quanta3, which repurposed low-cost, low-power, chip-based near-infrared tunable laser diodes used in fiber-optic communications and showed they could detect methane. The system is sensitive to parts-per-billion levels and should cost $3,000 per site per year, says company founder Dirk Richter. Norwegian energy company Statoil began testing the system at its production facility in Eagles Ford, Texas, this past January.

The second device is made by San Francisco startup Acutect. Californian utility Pacific Gas & Electric (PG&E) is testing the device at its natural gas storage facility in Los Medanos, California. The innovation of this device is to include a reflector that bounces back an infrared laser beam shined from up to 30 m away. Methane passing between the reflector and detector decreases the reflected signal. Both Quanta3's and Acutect's systems are solar powered and connected to the cloud so they can analyze data and immediately alert operators to leaks.

Companies such as PG&E and Statoil are taking methane leak-detection seriously. PG&E owns 6,500 miles of large transmission pipelines and 45,000 miles of smaller neighborhood distribution lines, says Francois Rongere, PG&E gas operations R&D innovation manager. PG&E tested Acutect's sensor and is also testing a lightweight laser spectrometer originally made by NASA's Jet Propulsion Laboratory (JPL) for the Mars Curiosity rover to look for signs of life on the red planet. Methane plumes detected there could come from microbes; now JPL is adapting the technology for detecting methane on Earth.

A small drone carries a miniaturized methane gas sensor, originally made by NASA, to detect natural gas leaks from equipment and pipelines. Credit: University of California, Merced.

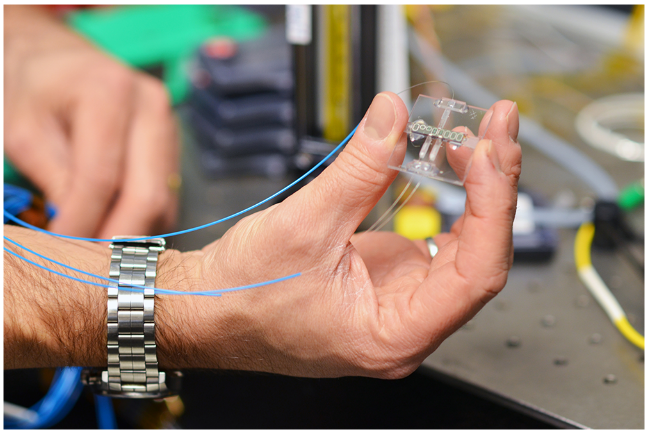
The sensor uses an efficient, ultracompact laser called an interband cascade laser that emits near-infrared light. NASA engineers shrank it down further and mounted it on a drone. It is sensitive to parts-per-billion methane levels and runs on little power, Rongere says, and monitoring remote pipelines with a drone would be far cheaper than driving around looking for leaks.

The EDF program isn't the only one nurturing novel methane sensing technologies. ARPA-E's $60 million MONITOR (Methane Observations Networks with Innovative Technology to Obtain Reductions) program is funding a dozen technologies for monitoring well pads. The goal is to accurately detect small leaks for an annual cost of $3,000, as well as estimate the leaks' locations and flow rates.

In one project, IBM scientists and engineers have made cheap, compact, silicon-chip-based tunable diode lasers and photodetectors. Each 5- by 5-mm sensor should cost about $300, says team leader Hendrik F. Hamann. IBM can

DOI: 10.1021/acscentsci.7b00292
ACS Cent. Sci. 2017, 3, 679−682

fabricate the sensors on silicon wafers using the same technology for putting transistors on a computer chip, which should drastically reduce manufacturing costs and be easy to scale up. Multiple wirelessly connected sensors, placed around a well pad, will send data to cloud-based computers. On the basis of the methane reading combined with weather data, the software can pinpoint the location of the leak and quantify it, Hamann says. Houston-based oil and gas company Southwestern Energy will soon do pilot tests of the device.



IBM is building miniature sensors on silicon chips that detect methane with infrared light brought in via optical fibers. Credit: IBM Research.

BEYOND LASERS

Although they have become the industry standard for gas sensing, optical techniques aren't the only way to go for methane emissions monitoring. Jeffrey T. Glass of Duke University has developed a specialized mass spectrometer that can detect methane and other volatile organics found in natural gas. This ability should help it distinguish between gas leaking from wells versus nearby farms since the two sources would have different chemical signatures, he says.

Mass specs are typically refrigerator-sized beasts, and MS is "neglected for methane monitoring because it's hard to get a field-portable instrument," Glass says. But he has managed to shrink it down to shoebox-size.

In a spectrometer, ionized molecules pass through a slit into a magnetic field. A smaller spectrometer means a smaller slit that allows fewer ions through, decreasing sensitivity. Glass and his team have designed a small instrument with multiple slits that allow up to 12 times as many ions to pass. But that change on its own would lead to "a jumble of information at the end, and you wouldn't know what you're detecting," Glass says.

To make order out of the ions, Glass's instrument has a barcode-like array of slits of different widths. The pattern effectively acts like a code, revealing precisely which spot the ions came from, giving order to the barrage of atoms hitting the detector. The instrument is about half as precise as full-size mass spectrometers, which typically have parts-per-million sensitivity for recognizing methane. But this should be sufficient for detecting most methane leaks, Glass says.

Meanwhile, researchers at the Palo Alto Research Center (PARC) are taking a completely different approach with a nanotube-based sensor. To make the devices, they print arrays of carbon nanotubes in patches 1 mm^2 wide. The nanotubes in each patch are decorated with different chemical groups and nanoparticles that react with various trace chemicals in natural gas, including ethane, propane, hydrogen sulfide, and ammonia. Molecules collecting on the surface change the conductivity of the sensor.

Like the IBM team, PARC also plans to deploy multiple sensors around a well pad in a network to pinpoint leak location within 1 m. The printed sensors are very cheap, about $10 each, says David E. Schwartz, who is leading the development. "ARPA-E wants total monitoring cost per well per year to be $3,000," he says. "Our target is a few hundred dollars."

These and other ARPA-E funded technologies are now undergoing a slew of tests at a mock natural gas well pad in Fort Collins, Colorado. By simulating big and small gas leaks from different equipment and locations under real-world conditions, researchers are testing if the technologies are up to par.

One piece of good news for companies hoping to waste less methane via leaks is that the largest 5% of leaks are responsible for more than half of methane emissions, according to a recent study by Stanford University and EDF. Equipment leaks, open tank hatches, corroded pipelines, or other very large leaks, which the researchers call "superemitters," gush 100 to 1,000 tons of methane per year. If newer monitoring technologies could help companies detect and fix these giant leaks, that could make a huge dent in emissions.

While many companies are pursuing leak detection for the benefit of their bottom lines and to reduce greenhouse gas emissions, others may not have a choice but to look for leaks in the future. In 2016, the EPA and Bureau of Land Management had finalized rules to limit the oil and gas industry's methane emissions from gas venting and leaks. Congress under the Trump administration unsuccessfully tried to roll the BLM rules back. And in July, a federal appeals court blocked the EPA's attempt to delay implementation of the agency's new rules. Meanwhile California and Colorado have set their own stringent methane emission

DOI: 10.1021/acscentsci.7b00292
ACS Cent. Sci. 2017, 3, 679–682

standards. Says Ratner, “Well-crafted regulation can be a strong driver for innovation.”

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ACS Cent. Sci. 2017, 3, 679−682