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CHEMICAL & ENGINEERING NEWS
OCTOBER 25, 2021

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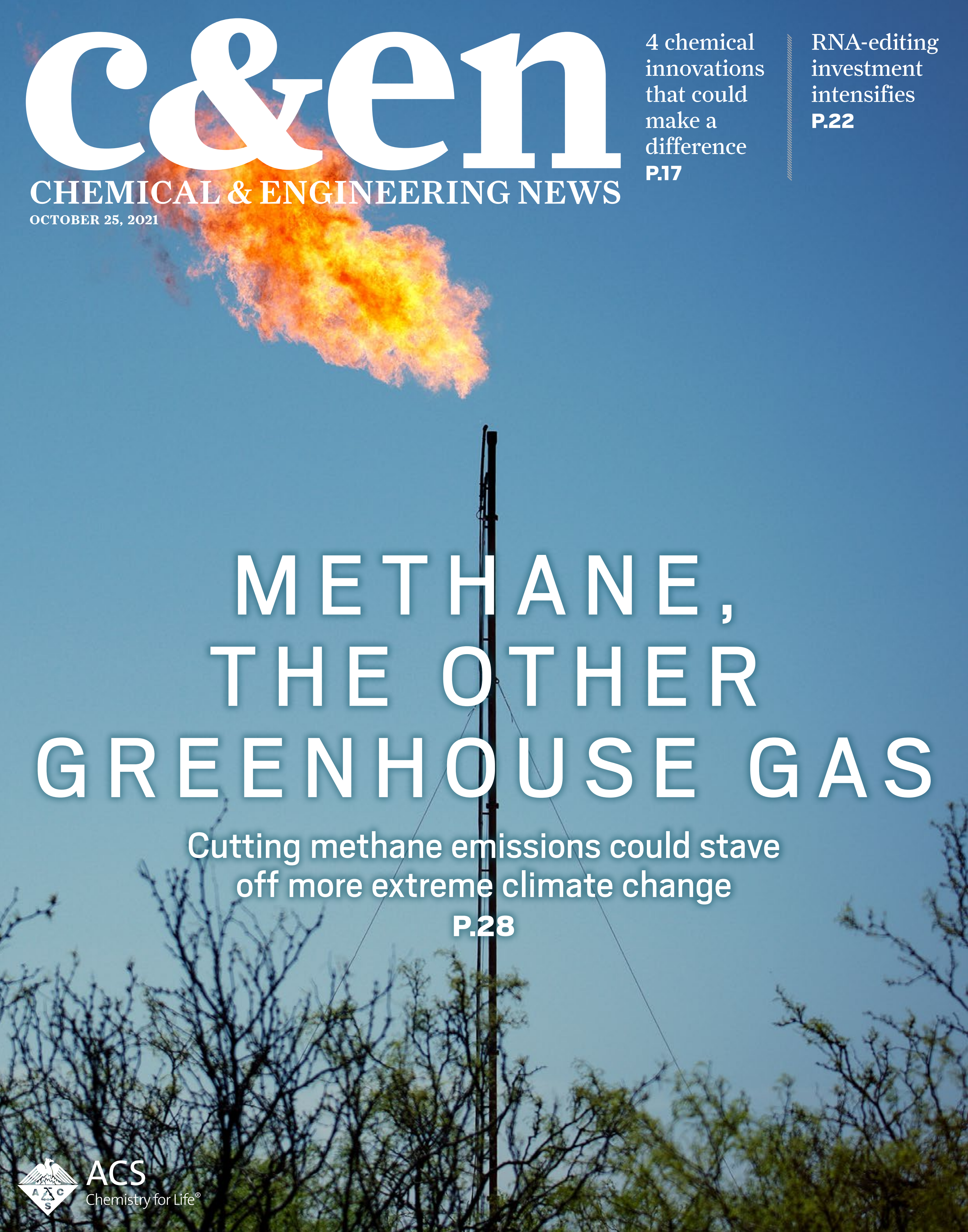

METHANE, THE OTHER GREENHOUSE GAS

Cutting methane emissions could stave off more extreme climate change
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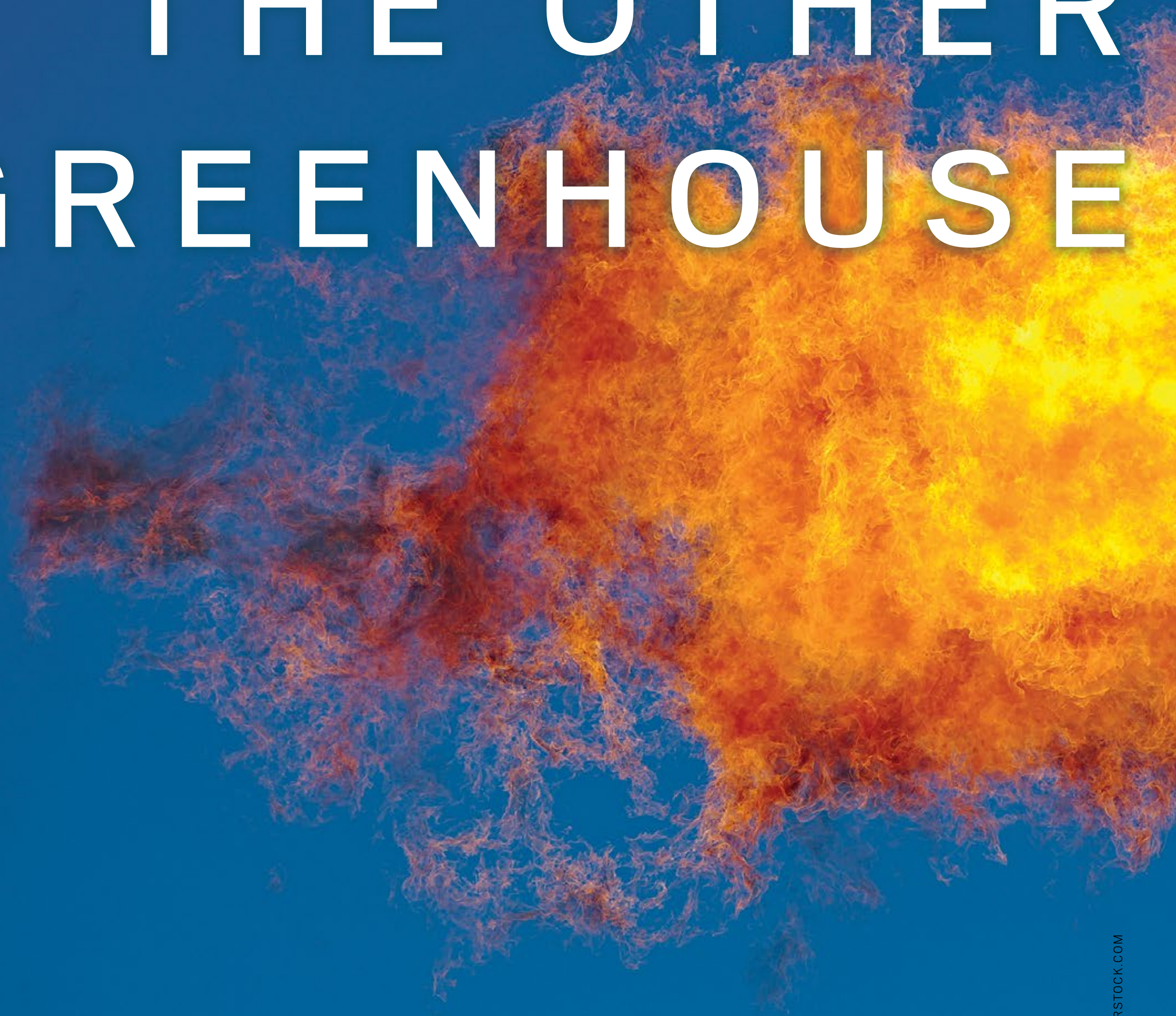
THE OTHER GREENHOUSE



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In brief

Cutting methane emissions rapidly could slow climate change and stave off some of its worst effects. Methane, which is emitted by natural and human sources, including the fossil fuel industry and agriculture, is the second most important greenhouse gas, after carbon dioxide. It's shorter lived than CO_2 but has 84 times the climate-warming effect over 20 years. So cutting it quickly would lead to fast results for slowing global warming. Scientists are ready to support efforts to slash methane: they are modeling cost-effective ways to mitigate the greenhouse gas and launching satellites that will spot methane leaks around the world. And some scientists propose developing new chemistry to capture atmospheric methane and convert it to CO_2.

IMPORTANT GAS

Natural gas is vented and burned at an oil well in Midland County, Texas. But many methane leaks from the fossil fuel industry are not burned or fixed, and the gas is warming the climate.

Cutting methane emissions rapidly could avoid more extreme climate change in coming decades, so scientists are seeking ways to plug pipeline leaks and chemically convert atmospheric methane into something less harmful

KATHERINE BOURZAC, C&EN STAFF

Climate change is already affecting daily life. Depending on where you live, the world's changing climate may have already brought unprecedented drought, heat, wildfires, or record-breaking storms. Meanwhile, sea levels are rising over 3 mm every year as ocean temperatures increase and glaciers melt.

Scientists agree that cutting carbon dioxide emissions is urgent and necessary to slow these changes. But the CO_2 we've already emitted will stay in the atmosphere for hundreds of years, so it will take time for CO_2 mitigation to show climate benefits.

The news isn't all dire, some scientists argue. They think we could slow global warming if we turned our attention to cutting emissions of the second most important greenhouse gas, methane.

Methane has been somewhat neglected in discussions about climate change, but it's been getting more attention lately, including in the most recent scientific report from the Intergovernmental Panel on Climate Change (IPCC). "As hard as reducing CO_2 is, we're not going to meet our temperature targets by tackling CO_2 alone," says Rob Jackson, an earth system scientist at Stanford University and chair of the Global Carbon Project. "We have to tackle methane."

Scientists are ready to get to work. They've developed models to target where different industrial sectors could make emission cuts that would provide the greatest climate benefit with the least economic pain. Most of these cuts will require spotting methane leaks in fossil fuel infrastructure, so scientists are deploying methane-monitoring technologies, including a network of satellites that will provide publicly available data on where the greenhouse gas is being emitted. Other scientists think it's worth investigating technologies that could remove methane from the atmosphere and turn it into something less harmful to the climate.

By deploying measures to reduce methane emissions, "we can slow the rate of global warming by 30%" over the next few decades, says Ilissa Ocko, a senior climate scientist at the Environmental Defense Fund, a nonprofit environmental research and advocacy group. "This is an amazing opportunity, one that is rare. We're trying to make people aware that this opportunity exists."

MITIGATING METHANE

Methane emissions grow every year. According to the Global Carbon Project, by the end of 2019, the concentration of methane in the atmosphere was 1,875 ppb, over 2.5 times as high as in preindustrial times.

Some methane comes from natural sources, particularly wetlands, where bacteria feed on organic carbon and emit the greenhouse gas. But about 60% of methane emissions are from human sources. The fossil fuel industry and agriculture are the largest two human emitters; waste management and other activities provide the rest.

The global average temperature has increased about 1.07 °C from the period 1850–1900 to the period 2010–19, according to the IPCC. Before the cooling effect of other human emissions, such as aerosols, is subtracted, methane emissions alone are responsible for about half a degree of that warming.

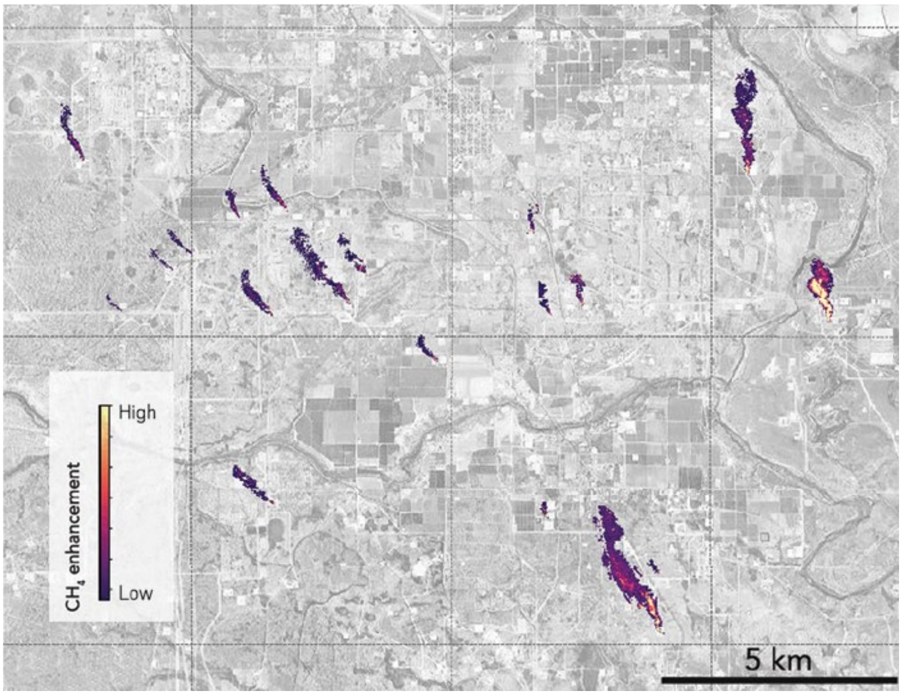
A degree or half a degree may not sound like much, but small average global temperature increases have large effects on the weather, making extreme events like floods and droughts more frequent and more intense. For example, according to the IPCC, a 1 °C temperature increase has turned once-a-decade heat extremes into events that occur about 2.8 times a decade. Add another half degree of warming, and those heat events will likely occur 4.1 times a decade.

Ocko's research suggests that taking all possible measures to cut methane emissions would have a big impact: if they were put into place today, the mean rate of warming per decade could be slowed by 30% over the next few decades. And the world would avoid 0.25 °C of warming by the end of this century (*Environ. Res. Lett.* 2021, DOI: 10.1088/1748-9326/abf9c8).

Cutting methane emissions would pay off quickly because of the gas's chemistry. Methane has a strong influence on the climate: it has 84 times the warming effect of CO_2 in the first 20 years after emission. And it doesn't stick around long: its average lifetime is 12 years. Over time, it gets oxidized to form CO_2 and water, or it can participate in reactions that generate ground-level ozone. Because methane is both potent and short lived, if emissions decrease, current atmospheric methane can break down and take some pressure off the climate.

Ocko's analysis focused on cost-effective, currently available mitigation strategies and didn't count on policies like a carbon tax or mass behavioral changes, such as people switching to vegan diets. "If we don't have much money, here's what we can do," Ocko says of the list of options from her research.

Most cost-effective measures to mitigate methane involve the fossil fuel industry. Changes in this sector provide 80% of the avoided warming in Ocko's analysis. Many are easy fixes—such as replacing faulty equipment and mending pipeline leaks—and are not cost prohibitive, because methane that's not emitted into the atmosphere can be sold on the natural gas market.



Infrared imaging revealed multiple methane leaks in an oil field in the Permian Basin on Oct. 27, 2019. Yellow indicates a higher-intensity emission of methane; purple is a lower intensity.

CREDIT: CARBON MAPPER, NASA JET PROPULSION LABORATORY, U. MICHIGAN, U. ARIZONA

Lena Höglund-Isaksson, an environmental economist at the International Institute for Applied Systems Analysis, agrees that the fossil fuel sector is the most cost-effective place to tackle the methane problem. She has analyzed how much different mitigation measures could lower methane emissions by 2050 compared with doing nothing. For example, flooding abandoned coal mines would reduce their methane emissions by 100%. Programs to detect and repair pipeline leaks and more efforts to capture gas leaks would reduce methane emissions associated with oil production by 92% (*Environ. Res. Commun.* 2020, DOI: 10.1088/2515-7620/ab7457).

"This is not rocket science," Ocko says. "It's a plumbing problem."

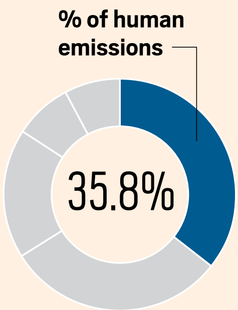
So why are companies not performing these simple repairs that would save money by capturing methane, which could

"This is not rocket science. It's a plumbing problem."

—Ilissa Ocko, senior climate scientist, Environmental Defense Fund

Methane sources

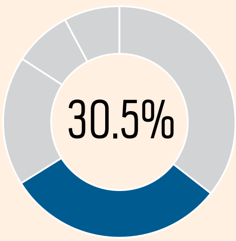
Humans cause about 60% of methane emissions. Natural sources, especially wetlands, provide the rest. In 2017, total methane emissions were about 596 million metric tons (t). Here's a breakdown of where the 364 million t of human emissions came from that year.



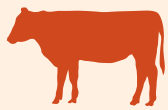
Fossil fuels

▶ **Examples:** Coal mines, oil and gas fields and infrastructure

▶ **Solutions:** Plug leaks and fix faulty equipment; seal abandoned wells.

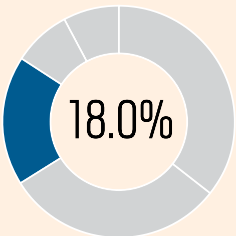


Cattle



▶ **Examples:** Cattle's burps and flatulence

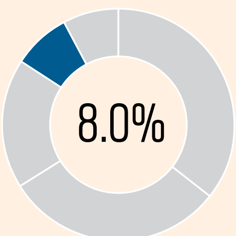
▶ **Solutions:** Breed cattle that produce milk and meat more efficiently; reduce meat consumption; switch feed.



Landfills and waste

▶ **Examples:** Decomposition of organic materials by microbes

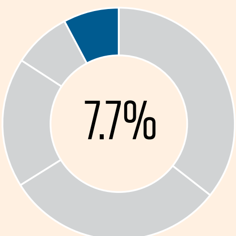
▶ **Solutions:** Capture and treat landfill gas as an energy source; cover landfills with soil to encourage the growth of methane-consuming bacteria.



Rice farming

▶ **Examples:** Methane-producing bacteria that live in flooded rice fields

▶ **Solutions:** Regularly drain the fields; rely on intermittent irrigation.



Biomass and biofuel burning

▶ **Examples:** Agricultural burning

▶ **Solutions:** Ban such burns.

Sources: Global Carbon Project; *Environ. Res. Lett.* 2020, DOI: 10.1088/1748-9326/ab9ed2.
Note: Emissions are based on 2017 numbers compiled by the Global Carbon Project and converted into percentages.

CREDIT: C&EN/SHUTTERSTOCK (ALL)

then be sold? "The profit margins for oil and gas are so high, and it's more profitable to extend production and drill new wells than to contain leaks," Höglund-Isaksson says. "What's missing are policy incentives."

Policy makers have been giving methane more attention in recent months. On Sept. 17, the US and the European Union pledged to cut methane emissions by one-third from 2020 levels over the next decade. And on Oct. 11, the Joe Biden administration announced that seven additional countries had joined the pledge. As of C&EN's deadline, the world's biggest methane emitters—China, India, Russia, and Brazil—had not signed on. The US Congress is debating a fee on methane emissions. Under this program, individual oil and gas facilities could be fined for methane emissions that they report to the US Environmental Protection Agency's Greenhouse Gas Reporting Program. The version of the legislation that cleared the House Committee on Energy and Commerce in late September sets the fine at $1,500 per metric ton of methane released. This idea has faced major opposition, particularly from Republicans. Later this year, the EPA is expected to issue new methane rules, including requirements on fossil fuel companies to meet certain methane control standards for equipment, according to E&E News.

LOOKING FOR LEAKS

Because a lot of the efforts to curb methane emissions in the fossil fuel industry involve leaks, scientists are looking for better ways to spot these emissions. "You can't manage what you don't measure, and you can't mitigate what you don't measure," says Daniel Cusworth, a researcher specializing in methane monitoring at the University of Arizona.

Some emissions result from known problems, such as aging or faulty infrastructure that needs upgrading or abandoned or barely profitable wells that could be sealed off, says Riley Duren, an engineer and earth scientist also at the University of Arizona. But other methane leaks can be challenging to repair because they are hard to spot. At some facilities with thousands of pieces of infrastructure, less than 1% of those pipes, fittings, valves, and other components could be responsible for one-third to one-half of the total methane emissions, Duren estimates.

Spotting leaks—even huge ones called "superemitters"—is not as simple as it sounds. From September to November 2019, Duren and Cusworth's team flew a plane equipped with an imaging spectrometer over the Permian Basin, a swath of Texas and neighboring states that is the largest and fastest-growing oil and gas region in the US. The researchers' study showed that, as in other oil and gas regions, many strongly emitting point sources are intermittent (*Environ. Sci. Technol. Lett.* 2021, DOI: 10.1021/acs.estlett.1c00173). Look at the wrong time, and you'll miss them.

"You have to revisit these measurements frequently and sensitively to identify what's happening," Cusworth says. But putting sensors every few meters on a kilometer-long pipeline, for example, or repeatedly driving a sensor-laden vehicle around a facility is not a practical solution for companies.

Satellites, on the other hand, are well suited to gather those data, taking sensitive readings over huge areas of land every day. A private company called GHGSat sells satellite measurements of methane emissions to customers, particularly in the oil and gas industry, but its data are proprietary. Government satellites currently in orbit can also detect methane plumes, but only particularly large plumes, and they have poor spatial resolution.

Two new methane-monitoring satellite projects aim to provide higher-resolution data and make those data publicly available. The projects' architects hope their efforts will encourage oil and gas companies to fix these leaks.

Duren is CEO of Carbon Mapper, a public-private partnership that is planning to launch a suite of methane-and-CO_2-monitoring satellites, starting with 2 in 2023 and expanding to 10 by 2025. At that time, the nonprofit's satellites will cover 80% of the world's methane point sources and have a spatial resolution of about 30 m. Data at that resolution would allow a facility operator to drive to the right region of an oil field with on-the-ground sensors to readily find and fix the problem. Another organization, MethaneSAT, a subsidiary of the Environmental Defense Fund, has scheduled its first satellite to launch in late 2022. The satellite will take measurements with a 100 m resolution.

By making their data publicly available, Carbon Mapper and MethaneSAT hope to do more than just name and shame companies into fixing leaks. Carbon Mapper has run case studies of sharing methane-leak information with utilities and found that the practice can get good results, Duren says. The organization shared information about rogue emissions with utilities, oil well operators, and landfill owners, and the responsible parties subsequently fixed leaks. Duren says the company is in planning stages on how to scale up this process. He says the organization is building up an arm dedicated to information sharing. Sometimes it can be difficult to determine who should respond to the data—some leaks originate from abandoned wells, for example—and the process might involve contacting dozens of people to find the responsible party.

The publicly available data could also lead to oil and gas companies facing market pressure based on their methane emission report cards. Gas utility customers and shareholders are becoming increasingly concerned about climate change. Utilities could examine a company's record on methane emissions before deciding to purchase natural gas from them; governments could also ban imports of natural gas from suppliers with records of leaks.

THE COW IN THE ROOM

Plugging methane leaks in fossil fuel infrastructure will go a long way to providing short-term global warming relief. But other sources of methane emissions still need to be addressed, and they don't have simple solutions like sealing a leaky pipe. Agriculture, which accounts for 40% of anthropogenic methane emissions, presents a complex mitigation challenge.

For example, cattle burps and farts are big methane offenders. Euan Nisbet, an earth scientist at Royal Holloway, University of London, calls cattle and other ruminants "walking wetlands" because bacteria living in the animals' guts produce methane as they digest food. Farmers could breed cattle that produce meat and milk more efficiently so the world could get the same amount of food with fewer methane-belching animals. Some researchers have suggested that farmers could also switch cattle feed to one that suppresses methane production. Both of those solutions could help mitigate agricultural methane emissions in Europe and the US.

But most of the world's cattle live in places where these solutions might not make sense, given farmers' financial constraints and the climate in which these animals live. For example, Africa is home to almost a quarter of the world's cattle, though the continent's cows account for just 5% of the global milk production, Höglund-Isaksson says. "You cannot just say, 'Replace them with high-producing breeds,' because they are very well adapted to the climate," she says.

For plant-based foods, the biggest methane source is rice, says Atul K. Jain, an atmospheric scientist at the University of Illinois Urbana-Champaign. Methane-producing bacteria thrive in perpetually flooded rice fields. He says adopting intermittent irrigation, in which farmers drain their fields between growing seasons to eliminate the wetland-like conditions and kill off those bacteria, could help. But rice fields that are periodically drained must be treated with more herbicides—so that change has an environmental trade-off.

But some of the world's methane emissions are simply not under direct human control.

Nisbet has analyzed the ratios of carbon isotopes in methane and found a shift in recent years from heavier ^{13}C, which is associated with geological sources such as fossil fuels, to the lighter ^{12}C, associated with biological ones. He suspects that this shift is due to climate change fueling the growth of wetlands in the tropics. As this region gets warmer and wetter, methane-producing bacteria bloom.

And then there's the looming threat contained in the Arctic permafrost. When it melts because of climate change, providing a moist, carbon-rich environment, it could become home to large numbers of methane-emitting microbes. Scientists aren't sure when this might happen, but the Global Carbon Project's Jackson would like to see an insurance policy against it by cutting as much human-based methane emissions as possible.

NEGATIVE EMISSIONS

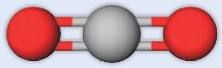
Jackson's fix includes a counterintuitive project: capturing atmospheric methane and converting it into CO_2, releasing the longer-lived but less potent greenhouse gas into the air. Fully oxidizing all the methane in the atmosphere would produce 8.2 billion metric tons of CO_2, which is equivalent to what industry currently emits every few months, according to an analysis by Jackson. This mass methane oxidation would reduce the climate warming potential of the atmosphere's gases by one-sixth (*Nat. Sustainability* 2019, DOI: 10.1038/s41893-019-0299-x).

Chemists contacted by C&EN acknowledge that technology for removing methane from the atmosphere, also called negative emission technology, is an important goal,

CH_4 versus CO_2

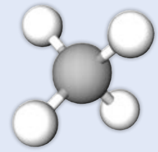
Methane's climate-warming potential is 84 times as high as carbon dioxide's on a 20-year timescale. Here's a look at how the gases compare in other ways.

CO_2



- **Atmospheric concentration:** 410 ppm
- **Radiative forcing:[a]** 1.68 W/m^2
- **How much warming the gas has caused:[b]** >0.75 °C
- **Lifetime in the atmosphere:** Hundreds of years

CH_4



- **Atmospheric concentration:** 1.9 ppm
- **Radiative forcing:[a]** 0.97 W/m^2
- **How much warming the gas has caused:[b]** 0.5 °C
- **Lifetime in the atmosphere:** 12 years, on average

Sources: Intergovernmental Panel on Climate Change, Global Carbon Project.
a A measure of how much heat energy a greenhouse gas traps on Earth.
b An estimate of the temperature increase from the preindustrial era (1850–1900) to the period 2010–19. The world has warmed about 1.07 °C in that period. This increase was calculated after accounting for other emissions' cooling effects.

CREDIT: C&EN/SHUTTERSTOCK (BOTH)

Cattle, like those shown at this 98,000-animal feedlot in Colorado in 2017, are one of the largest sources of methane emissions—and one of the hardest to mitigate.

CREDIT: JIM WEST/ZUMA PRESS/NEWSCOM

but they see basic-science hurdles to making it work. So far, no one has made and tested a material capable of capturing and oxidizing atmospheric methane, though computational work suggests it is possible.

Capturing methane is a bigger challenge than grabbing CO_2 "because of the chemistry of the molecule," says Matteo Cargnello, a chemical engineer at Stanford University and one of the coauthors on Jackson's methane-removal work. "Right now I don't see any material that would be able to do it."

The first hurdle is the relatively low concentration, about 2 ppm, of methane in the atmosphere. It's sufficient to significantly warm the planet but scant enough to be hard to capture.

Cargnello says instead of starting with the open air, methane-capture technologies could work in places where the gas is more abundant, such as in cattle barns, in coal mines, and on fossil fuel infrastructure such as vents.

But it's still not clear what to use to grab methane. Raul Lobo, a zeolite chemist at the University of Delaware, says methane "doesn't really have a handle." It's inert, nonpolar, and symmetrical, limiting the types of molecules that could bind to or adsorb the gas.

Cargnello and Jackson have explored the scientific literature looking for methane-grabbing and oxidizing candidates and determined that zeolites decorated with catalytic copper or iron are the most promising materials. Zeolites are porous aluminosilicate materials that can contain active catalytic sites.

But Lobo says he's not sure the thermodynamics for capturing and oxidizing methane with zeolites will work out. Such a material would need to be hydrophobic, or else water would clog up all the sites for methane. And all existing hydrophobic zeolites require a large input of energy to adsorb the greenhouse gas.

The other roadblock is the energetics of the oxidation reaction. Once the reaction gets going—for example, in the extremely hot flares used to burn off excess methane from natural gas wells—methane oxidation can hum along. But it takes a lot of energy to kick it off.

Keeping temperatures down during the oxidation reactions would be key, Mark Davis, a chemical engineer at the California Institute of Technology, says in an email. Otherwise, scientists might accidentally generate nitrogen oxides, an air pollutant that can spur smog and ozone formation.

> "A single-gas approach isn't going to get the job done."
>
> **—Rob Jackson,** earth system scientist, Stanford University

There are zeolites that can perform the methane-oxidizing step at low temperatures, but firing up those copper- or iron-containing active sites before methane treatment requires high temperatures, Lobo says. These zeolites also tend to have few active sites per unit mass, which would doom the process to inefficiency.

Cargnello sums up the chemical consensus on the approach: negative emission technology for methane is "potentially incredibly impactful, but the challenges are clear."

These challenges, and others involved in mitigating methane emissions, are ones the world must take on, Jackson argues. There's no getting around cutting CO_2 emissions. But the world has to deal with other greenhouse gases to combat climate change—not just methane but also nitrous oxide, among others. "A single-gas approach isn't going to get the job done," he says.

This idea is starting to get more traction in policy and scientific circles, Jackson says. The August report from the IPCC included a chapter on short-lived climate forcers, including methane. "I'm excited to see more attention to it," he says.

Now the methane problem needs not just attention but action, Höglund-Isaksson says. "Policy makers have to get their act together quickly," she says. "We have momentum now that we can't afford to lose." ■