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News & Highlights

Climate Change Action Alights on Satellite Detection of Methane

Sean O'Neill

Senior Technology Writer

In an era of unwelcome broken records in climate change, 2021 delivered yet another. According to figures released in January 2022 by the US National Oceanic and Atmospheric Administration (NOAA) [1,2], the record for the annual net increase in atmospheric methane was broken for the second year in a row, hitting an estimated 17 parts per billion (ppb). The increase puts methane's atmospheric concentration at 1909 ppb (Fig. 1), more than 2.5 times its pre-industrial levels [3].

Although CO_2, the primary driver of climate change, is 200 times more abundant, methane's global warming potential (GWP) is markedly greater [4]. Indeed, it has been described as a climate "blowtorch" for its potential to exacerbate global warming [5]. Measure for measure, methane's GWP is around 30 times that of CO_2 over 100 years, but around 80 times higher on a 20-year timescale. The difference over these time scales comes from chemical reactions in the stratosphere eliminating most methane after about a decade, whereas the warming effect of CO_2 can last hundreds, even thousands, of years.

Global warming experts have increasingly recognized methane as a pressing and actionable aspect of the climate change challenge. Accordingly, a range of scientific, political, and technological forces are now aligning to develop and pursue strategies to measure, mitigate, and even remove atmospheric methane. The goal is not simply to reduce methane emissions to below the level that Earth's natural systems can counter, but to reduce methane and its blowtorch effect as much as is practically possible.

Estimates suggest that methane accounts for about a quarter of the global warming underlying climate change [6]. Roughly 580 million tonnes (Mt) of methane are emitted every year, about 350 Mt of that a result of human activity [7]. While chemical reactions in the atmosphere, and to a lesser extent at the Earth's surface, quickly transform most of these annual global emissions, these natural processes leave—estimates vary—as much as an additional 50 Mt of methane in the atmosphere annually [8].

In November 2021, highlighting the growing recognition of methane's importance, the United States, Europe, and other partners announced the Global Methane Pledge at the Conference of Parties 26 (COP26) climate summit in Glasgow, United Kingdom [9]. The now more than 110 countries signed up to the pledge have agreed on the collective goal of cutting global methane emissions by 30% from 2020 levels by 2030 to reduce warming by at least 0.2 °C by 2050. The same goal is called for in the latest report (4 April 2022) from the Intergovernmental Panel on Climate Change [10].

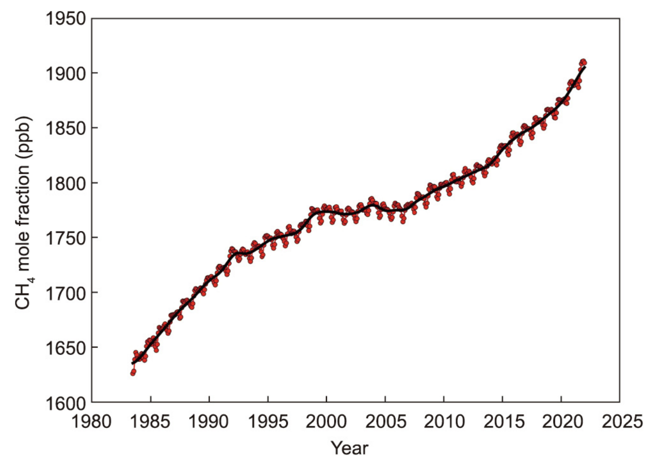

Fig. 1. The globally averaged abundance of atmospheric methane (in atmospheric parts per billion) since 1983, when the US governmental agency NOAA started making these measurements. The values for 2022 are preliminary. Credit: NOAA, with permission.

"The announcement of the pledge contributed to what we call the 'methane moment.' It just exploded," said Ilissa Ocko, a senior climate scientist at the New York City, NY, USA-headquartered Environmental Defence Fund (EDF). "Methane is now being taken seriously separately from CO_2. It is going to be on the global radar from here on out, which is great." However, of the four biggest national methane emitters, China, India, the United States, and Russia (Fig. 2), the United States signed the pledge [11].

According to a research study by Ocko and colleagues, global methane emissions could be halved using existing technology across a range of industries [12]. In addition, cutting about a quarter of global emissions could be achieved at no net cost, by measures including preventing escapes of natural gas, which mostly consists of methane (Fig. 3) [12], so that it can be sold. Burning natural gas as fuel does produce CO_2, but this is preferable to the direct release of methane into the atmosphere because it is such a powerful greenhouse gas.

Estimates peg about 30%–40% of total global methane emissions as coming from agriculture, primarily from raising livestock (whose digestive processes release methane), manure management, and rice farming [7,13]. And agricultural emissions of methane are rising [3], powered by rapid increases in meat

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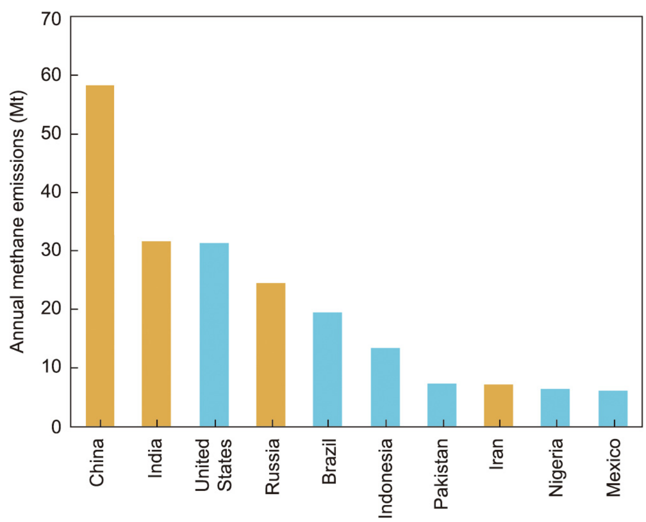

Fig. 2. Annual methane emissions by selected countries. The nations shown in blue are signatories to the new Global Methane Pledge, while those shown in orange are not. Credit: International Energy Agency, with permission.

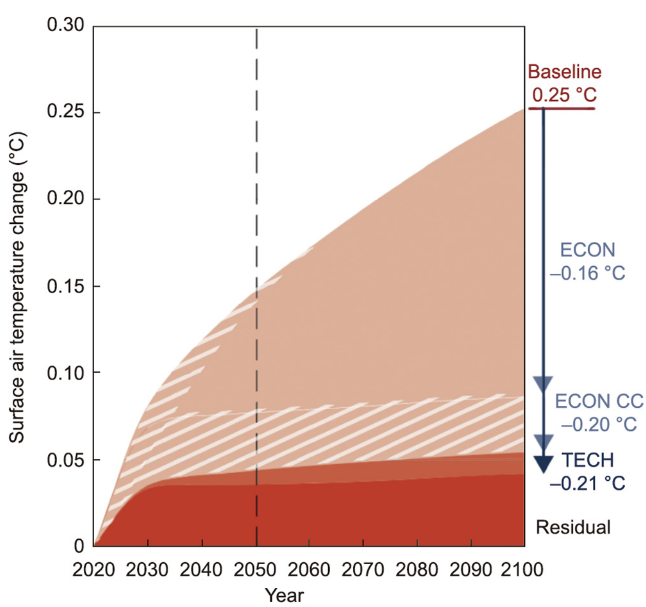

Fig. 3. The projected global warming contribution of the oil and gas industry by 2100 is 0.25 °C. This could be reduced by 0.16 °C by 2100 through economically feasible (ECON) no-net-cost options, such as preventing methane leaks; current company commitments (ECON CC), if met, could drop this reduction to 0.20 °C. If the oil and gas industry also employed readily available technologies (TECH) to avoid warming beyond the no-net-cost options (ECON CC), a cumulative 0.21 °C of warming could be prevented. Credit: Environmental Research Letters (CC BY 4.0).

consumption in middle-income countries [14]. Estimates of total global emissions from oil and gas operations fall in the 20%–25% range [7,15].

For methane produced by livestock, trials have shown the potential of feed additives to effectively curb these emissions. In one recent study, adding the marine red algae *Asparagopsis taxiformis* to the diet of beef steers reduced methane by over 80% [16]; in another, adding a related seaweed, *Asparagopsis armata*, to the diet of dairy cows reduced their methane emissions by over 50% [17]. While it remains unclear whether producers will use such feed additives, commercialization has begun. Early in 2022 the California Department of Food and Agriculture approved for sale a red seaweed additive for dairy cow feed [18]. Estimates suggest that dairies account for about half of California's methane emissions [19].

But the area of methane abatement that has attracted the most focus is the oil and gas industry, whose annual methane emissions rose from 62 to 80 Mt between 2000 and 2019, according to the International Energy Agency [20]. Other sources, however, suggest these quantities may be underestimates [7,15]. In 2021, because estimates of methane emissions are so hard to verify, the United Nations Environment Programme launched the International Methane Emissions Observatory. The body will collect and integrate emissions data from variety of sources to "establish a global public record of empirically verified methane emissions at an unprecedented level of accuracy and granularity," with an initial focus on the energy sector [21].

The key development in enabling such verification—and in making such methane emitters aware of and accountable for their leaks—is the growing availability and capability of satellites carrying instruments that can monitor and precisely measure atmospheric methane. Until recently, tools to spot and measure methane emissions were limited to short-term aircraft surveys, *in situ* sensor networks, or sparsely sampled, low-resolution satellite analysis of methane in atmospheric columns [8]. Global tracking of methane began to improve in 2017 with the launch of the Tropospheric Monitoring Instrument (TROPOMI) into orbit aboard the European Space Agency's Sentinel-5 Precursor satellite.

With a spatial resolution of 5.5 km × 7.0 km, and sensitivity to methane of 5–10 ppb, TROPOMI orbits the Earth every 100 min in low Earth orbit, resulting—in the absence of clouds—in daily, near full-surface coverage of methane concentrations [22]. This enables it to track large concentrations of methane, around oil and gas fields, for example. In February 2022, a team co-led by Philippe Ciais, head of the Atmospheric Composition Department at France's Laboratory of Climate and Environmental Sciences in Saint-Aubin, identified and quantified the methane released by the worst emitters around the world during 2019 and 2020. The survey captured 1800 instances of very large releases of methane—that is, more than 20 $t{\cdot}h^{-1}$.

Among the ultra-emitters, Turkmenistan's oil and gas industry topped the chart, releasing 1.18 Mt of methane per year [8]. It is in the economic interest of ultra-emitters to shore up their practices, and indeed their infrastructure, because the methane that does not leak could be a valuable product to sell [12]. Turkmenistan, for example, could realise an estimated net benefit of about 6 billion USD if it plugged and was able to sell its leaking methane [8]. But the ultra-emitters are only a small part of the problem. "Although these ultra-leaks are super important, they only account for about of 5% of global fossil methane emissions. It is just the tip of the iceberg," said Ciais.

The rest of the iceberg, which includes smaller leaks and the non-emergency venting and flaring of methane, will soon become clearer courtesy of a new crop of satellites scheduled to launch in 2023. An EDF subsidiary called MethaneSAT plans to launch a satellite of the same name by early 2023 [23]. With spatial resolution of 130 m × 400 m, and a sensitivity to methane of about 3 ppb, MethaneSAT will cover the globe every three to four days, and rapidly make its data freely available. And an anticipated constellation of satellites from Carbon Mapper—a US alliance including the National Aeronautics and Space Administration's Jet Propulsion Laboratory, the University of Arizona, and others—will soon provide extensive and accurate tracking of selected, high-priority point sources, courtesy of the satellites' 30 m × 30 m resolution. The first two Carbon Mapper demonstration satellites are planned to launch in 2023 [24].

"MethaneSAT will take us down to the level of the methane-emitting facility," said Alex Turner, assistant professor of atmospheric sciences at the University of Washington in Seattle, WA, USA. "It is tricky to study methane sources from satellites because you are seeing the total air column below the satellite, which could have formed from many different spatial patterns. It is like measuring the depth of a river to figure out where it rained upstream."

Multi-satellite monitoring makes the task of pinpointing emitters easier (Fig. 4). For example, TROPOMI's coverage data, combined with higher-resolution data from more targeted satellites, including the Greenhouse Gas Satellite Demonstrator (GHGSat-D; resolution 50 m × 50 m [25]) and PRecursore IperSpettrale della Missione Applicativa (PRISMA; resolution 30 m × 30 m), accurately monitored a gas well blowout reported in November 2019 at the Ford Eagle Shale region of east Texas, in which nearly 5000 t of methane escaped during a 20-day event [26]. In January 2022, GHGSat-D identified an underground coal mine in south-central Russia emitting methane at a rate of 87 $t \cdot h^{-1}$, the biggest leak the GHGSat-D network has ever identified [27].

Given the reluctance of the oil and gas industry to change, the next few decades may also see the beginnings of "negative-emission technologies" to remove methane directly from the atmosphere, inspired by the nascent field of direct air capture (DAC) of CO_2 [28]. While captured CO_2 will be buried in geological formations deep underground or converted into fuels, the likely route with methane is to capture it for sale or to oxidise it into CO_2 (plus water).

The reaction to oxidize methane is thermodynamically favorable and several types of material are showing promise in trapping methane, such as nanoporous zeolites embedded with metal catalysts [29]. "Scientists have screened almost 100 000 zeolite minerals as potential methane concentrating agents," said Rob Jackson, professor of Earth systems science at Stanford University, CA, USA, speaking at a University of Cambridge online conference, Methane Removal and Emerging Technologies, in September 2021 [30].

The low concentration of methane in the atmosphere is likely to mean fans will be required to increase the flow of air or the air pressure during any removal process, the cost of which may prove prohibitive. "I think hybrid systems may provide a good compromise: combining DAC for CO_2 removal and methane oxidation in the same infrastructure makes sense," said Jackson. "You pay to move the air once and remove more than one greenhouse gas from it when you do."

Ciais sees an additional upside of direct removal. "In principle, if such technology could be scaled up safely, we could cut methane to below preindustrial levels, creating a very nice cooling effect that would compensate for some CO_2 warming," he said.

As with many geoengineering schemes, it remains unclear what methane removal technologies, if any, will be commercially feasible at scale [3]. And as methane will effectively take care of itself with sufficient reductions, some argue that mitigation will be sufficient. As Professor Klaus Lackner, DAC pioneer and director of the Center for Negative Carbon Emissions at Arizona State University in Tempe, AZ, USA, put it [31]: "If the water level in a bathtub with a wide-open drain is rising, turning down the faucet may be a better strategy than bailing."

What is clear is that the experts expect reducing methane emissions to yield rapid benefits for climate change, not only because it is a powerful greenhouse gas, but also because its removal triggers a positive feedback process. "If methane concentrations go up, the molecule that oxidizes methane in the atmosphere—the hydroxyl radical, $\cdot$OH—decreases, so the remaining methane lasts longer in the atmosphere," said Turner. "Conversely, if we reduce our methane emissions, there is more $\cdot$OH around to destroy the remaining methane more rapidly."

According to Turner and his colleagues, atmospheric chemistry could also explain up to 80% of 2020's record annual increase in global methane concentration, in combination with another global phenomenon—the coronavirus disease 2019 pandemic. The pandemic lockdowns caused a large reduction in polluting emissions from transportation, including nitrogen oxides (NO_x). But NO_x in the atmosphere promotes the production of $\cdot$OH, so its sudden drop meant less $\cdot$OH, which in turn likely slowed down the oxidation of methane, allowing it to accumulate more quickly in the atmosphere [32].

But there is more to methane than human-caused emissions, said Ciais. "Since 2006, half of the growth is attributed to increasing wetland emissions—including in the Amazon, perhaps in the Arctic, and Africa as well. So even if we mitigate anthropogenic emissions, there is still a possibility for methane to increase." But with growing satellite capability to track this climate blowtorch, at least the ambiguities around methane's role in global warming could start to dissipate.

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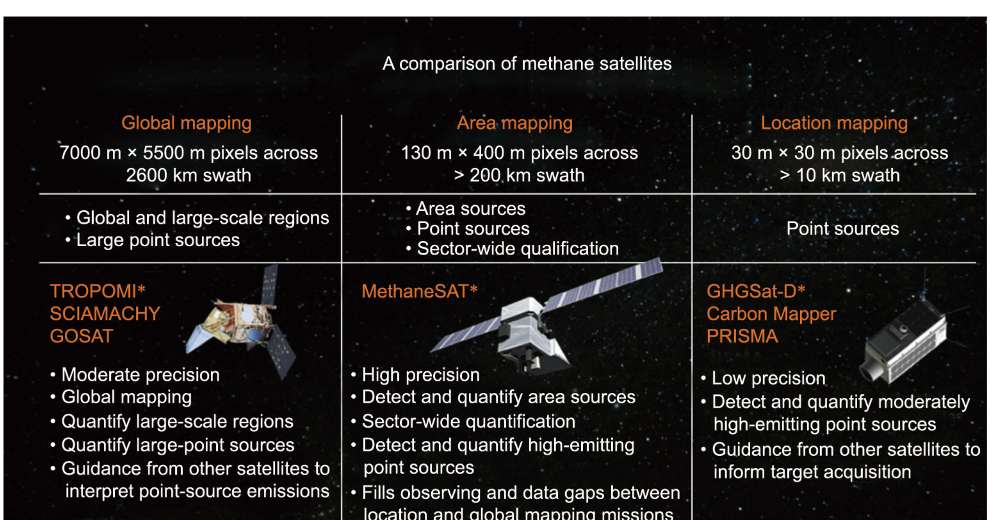

Fig. 4. A comparison of the capabilities of methane-detecting satellites already in orbit and launching soon. MethaneSAT and the first two Carbon Mapper satellites are expected to enter orbit in 2023. SCIAMACHY: Scanning Imaging Absorption Spectrometer for Atmospheric Cartography; GOSAT: Greenhouse Gases Observing Satellite; GHGSat-D: Greenhouse Gas Satellite Demonstrator; PRISMA: PRecursore IperSpettrale della Missione Applicativa. Credit: MethaneSAT, with permission.

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