A QUANTUM SOLUTION TO QUANTIFICATION: INDUSTRIAL DEPLOYMENT OF QUANTUM GAS LIDAR CAMERA FOR CONTINUOUS, AUTONOMOUS MONITORING AND QUANTIFICATION OF METHANE EMISSIONS

Methane (CH_4), the main component of natural gas, presents an increasingly documented threat to climate change mitigation. CH_4 has 84 times the global warming potential (GWP) of CO_2 over a 20-year period(1,2), and is emitted in >100 Mt amounts per year across multiple industry sectors worldwide.

Unlike CO_2, however, CH_4 has a relatively short lifespan in the atmosphere(3), and this presents an opportunity to those seeking rapid strategies to mitigate climate change. Just as emitting CH_4 represents a major threat, reducing CH_4 emissions can have a major impact, helping to achieve short-term net zero targets and buying time to deal with the longer-term problem of CO_2 emission. Reducing CH_4 emissions has therefore been identified as a key goal for reducing global warming, and a focus for international net zero strategies across multiple industries(4).

Almost one third of anthropogenic CH_4 emissions are from the oil and gas sector(5,6,7). There are over 500,000 active gas well pads in the USA alone, as well as many industrial sites, and recent measurement campaigns have shown that many sites are leaking much more than expected. For example, up to 3.7% of CH_4 extracted from the Permian basin is emitted into the atmosphere, which is over 60% more than initial emissions studies predicted(8). The energy industry is therefore increasingly making major commitments towards effective CH_4 emissions monitoring and reduction in compliance with, and often ahead of, expanding government regulations.

However, while the energy sector contributes significantly to the global CH_4 budget, it is not the sole contributor. The agriculture and waste management industries also emit large quantities of CH_4 into the atmosphere, and face the same challenges to reduce their contributions in line with the requirements of increasingly strict regulations.

Existing CH_4 emissions monitoring is based either on estimations using emissions factors, or on intermittent leak detection and quantification (LDAQ) surveys that are slow, laborious, and only provide a snapshot in time of the facility: If a good component springs a leak the day after the survey, it is missed until the next survey (perhaps as much as twelve months down the line) picks it up. Worse still, short-lived emissions (which are frequently large and/or unplanned) may be missed entirely.

The solution to this problem lies in monitoring all of the time, on a continuous, autonomous basis. Continuous monitoring identifies emissions in real time, and enables action to be taken immediately, ensuring regulatory compliance and fulfilling social responsibility.

Left-to-right: Doug Millington-Smith (QLM Global Applications Lead), Kevin Hollinrake MP (UK Minister for Small Business), John Bennett (QLM Head of Electronics), Chris Wardle (QLM Chief Manufacturing Officer), and Xiao Ai (Founder and CTO). Taken at the minister's visit to QLM's Cardiff facility.

QLM Technology, a UK-based photonics technology company with headquarters in Cardiff and operations in Bristol, Paignton and San Francisco, has developed a new type of LiDAR (laser imaging, detection, and ranging) camera based on quantum technology that can see and accurately quantify these CH_4 emissions on a continuous basis.

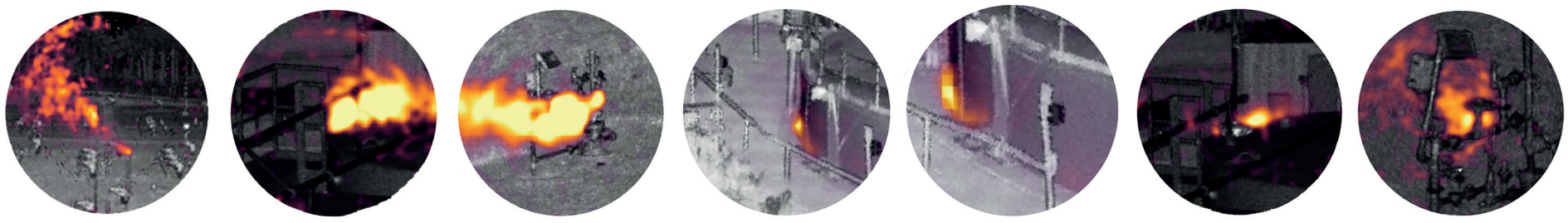
QLM's novel remote gas imaging sensor uses Tunable Diode Lidar (TDLidar), combining aspects of Tunable Diode Laser Absorption Spectroscopy (TDLAS) with Differential Absorption Lidar (DIAL) and Time

Quantum gas lidar camera

Correlated Single Photon Counting (TCSPC) to enable remote spectroscopy and ranging with low power semiconductor diode lasers. The first commercially-produced sensor, scheduled for commercial availability at the start of 2023, uses diode lasers with wavelengths around the CH_4 absorption line at 1650.9 nm, and Peltier-cooled Single Photon Avalanche Diode (SPAD) detectors, in a Random Modulation Continuous Wave (RM-CW) Lidar system. This combination of technologies allows long range accurate imaging of gas similar to that obtained by DIAL, but in a much smaller, easily portable form factor. TDLidar offers a simple, robust, precise visualisation and quantification of gas emissions on a continuous basis, from a compact, relatively low-cost platform.

QLM's revolutionary potential has been recognised by energy industry heavyweights SLB, who recently lead investors in the completion of a £12 million Series-A funding round, and signed a Collaboration Agreement with QLM, which will see QLM's technology become part of the new SLB End-to-end Emissions Solutions (SEES) business offering for the oil and gas industry. SEES' CH_4 monitoring offering is based on previous investments in satellite-, airplane-, and drone-mounted sensors, along with additional sensors developed internally. QLM's differentiated LiDAR technology complements those mobile monitors by providing accurate and sensitive measurements where continuous monitoring is required.

QLM's technology has been successfully demonstrated in multiple controlled release trials over the course of the last 18 months, notably at Colorado State University's METEC facility in the first half of 2022. However, while controlled release studies are good for validation of accuracy and uncertainty, crucial for



Plumes of gas characterised at QLM's recent trials at NGG's Bacton Terminal, METEC, and Severn Trent's Minworth Sewage Treatment Works, showing methane concentration as a "heat map" over the lidar background

The quantum gas lidar camera on trial at National Grid Gas' Bacton Terminal in association with the National Physical Laboratory, featuring (L-R) Physicist Chris Goldsack, Global Applications Lead Doug Millington-Smith, and NPL Senior Research Scientist Jon Helmore.

industrial adoption of a new measurement technique, they will never replicate the realistic, congested conditions of a real-world site where emissions are suspected, but unknown. It is in these conditions that QLM has sought to demonstrate effectiveness across multiple industries, complementing the tests in sealed conditions.

Collaborating with National Grid Gas (NGG) and the National Physical Laboratory (NPL) under the Innovate UK-backed SPLICE project, QLM has trialled the quantum gas lidar camera at NGG's Bacton Terminal facility. The trial focused on surveying for leaks and quantifying emissions on a portion of the site, while NPL carried out traditional walkover leak survey using industry standard methods of OGI and handheld "sniffers".

The trial was highly successful for QLM, identifying and quantifying emission sources from assets confirmed to be leaking by NPL, as well as characterising highly temporally-resolved venting operations across the site, which took place at heights and over short durations that a walkover survey would not be able to catch and quantify.

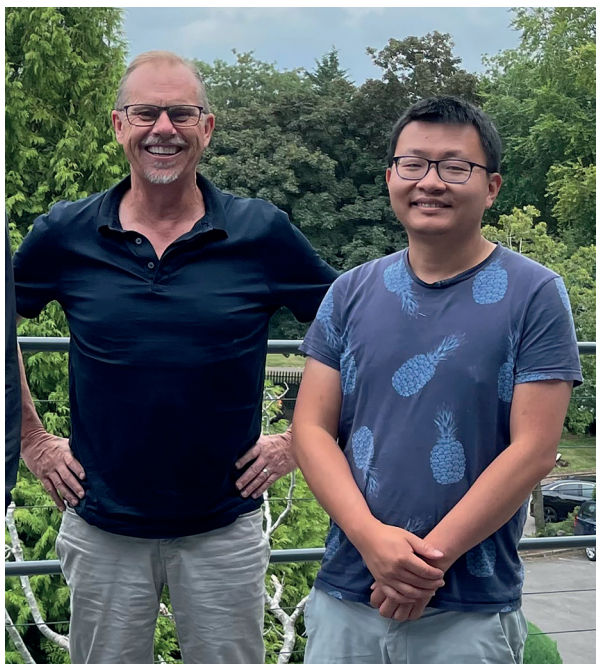
Outside of the oil and gas sphere, the waste water industry faces an escalation of the emissions monitoring challenge, with the onset of biogas production via anaerobic digestion of sludge products as a source of both on-site energy and additional revenue from gas-to-grid production. Many wastewater treatment plants now incorporate some form of anaerobic digestion plant, producing and processing biogas, similar in content to natural gas but normally requiring removal of undesirable components such as H_2S and CO_2 before it can be burned for energy or fed to the grid. These new, sustainability-driven, plants are expected to be efficient and gas tight, so keeping leaks and emissions to a minimum is a permanent challenge to which the current standard practice of intermittent "walkover" LDAQ studies is not well-suited.

To demonstrate the effectiveness of CH_4 monitoring in waste water treatment operations, QLM recently collaborated with Severn Trent in a one-day field trial of the camera over a portion of the sixteen-tank sludge digester array at Severn Trent's Minworth Sewage Treatment Works. Severn Trent were assessing QLM's emissions quantification solution as part of their Triple Pledge to achieve net zero carbon emissions by 2030. As with the trial at NGG's Bacton Terminal, the camera was surveying for real leaks rather than controlled emissions, with the intention of providing a business case for a wider deployment across multiple operating facilities.

Even with only a short time to identify and measure any emissions that were present, the trial was once again successful, detecting, localising and quantifying small leaks not identified by previous recently performed studies. The trial also monitored unlocalised CH_4 in the vicinity above the digester array, suggesting the presence of further small emissions that would be suited to a more in-depth study than the trial schedule allowed.

Emissions monitoring and reporting on a continuous, automated basis represents the future of any LDAQ operation that seeks to support strategies for net zero and beyond. With the strategic financial backing of SLB's flagship SEES program and a range of cleantech investors, QLM is well-placed to scale production over the course of 2023 to meet the demands of multiple industries becoming increasingly aware of the necessity for a smarter commitment to LDAQ than the current industry standard.

The quantum gas lidar camera in the field at Bacton Terminal



QLM's founders – CTO Xiao Ai and CEO Murray Reed

1. T. Stocker, D. Qin, G. Plattner, M. Tignor, and S. Allen, "Climate Change 2013: The physical science basis. contribution of working group I to the fifth assessment report of IPCC the intergovernmental panel on," 2014, Accessed: Jan. 22, 2021. [Online]. Available: https://boris.unibe.ch/71452/.

2. M. Etminan, G. Myhre, E. J. Highwood, and K. P. Shine, "Radiative forcing of carbon dioxide, methane, and nitrous oxide: A significant revision of the methane radiative forcing," Geophys. Res. Lett., vol. 43, no. 24, pp. 12,614-12,623, Dec. 2016, doi: 10.1002/2016GL071930.

3. R. L. Thompson et al., "Methane emissions in East Asia for 2000-2011 estimated using an atmospheric Bayesian inversion," J. Geophys. Res. Atmos., vol. 120, no. 9, pp. 4352–4369, May 2015, doi: 10.1002/2014JD022394.

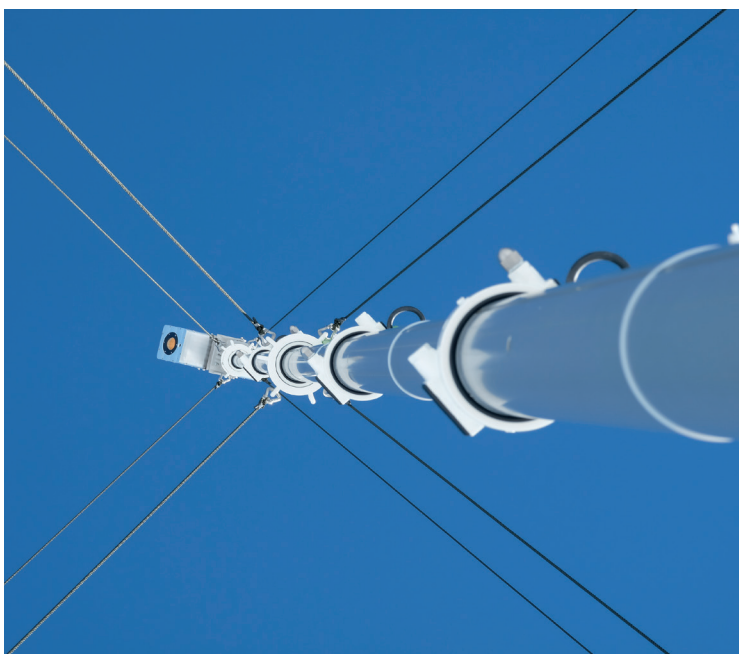
4. D. Shindell et al., "Simultaneously mitigating near-term climate change and improving human health and food security," Science (80-.)., vol. 335, no. 6065, pp. 183–189, Jan. 2012, doi: 10.1126/science.1210026.

5. J. D. Maasakkers et al., "Global distribution of methane emissions, emission trends, and OH concentrations and trends inferred from an inversion of GOSAT satellite data for 2010–2015," Atmos. Chem. Phys., vol. 19, no. 11, pp. 7859–7881, Jun. 2019, doi: 10.5194/acp-19-7859-2019.

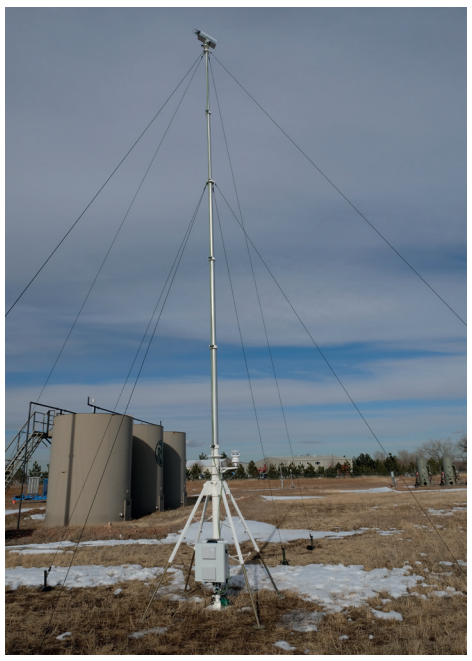
6. S. Schwietzke et al., "Upward revision of global fossil fuel methane emissions based on isotope database," Nature, vol. 538, no. 7623, pp. 88–91, Oct. 2016, doi: 10.1038/nature19797.

7. M. Saunois et al., "The global methane budget 2000-2012," Earth Syst. Sci. Data, vol. 8, no. 2, pp. 697–751, Dec. 2016, doi: 10.5194/essd-8-697-2016.

8. Y. Zhang et al., "Quantifying methane emissions from the largest oil-producing basin in the United States from space," Sci. Adv., vol. 6, no. 17, Apr. 2020, doi: 10.1126/sciadv.aaz5120.



The quantum gas lidar camera in the field at METEC



Author Contact Details

Doug Millington-Smith, Global Applications Lead • QLM Technology Ltd

- Address: HERE Bristol, 470 Bath Road, Bristol BS4 3AP, UK • Tel: +44(0)7813 534499
- Email: doug@qlmtec.com • **Web: www.qlmtec.com**