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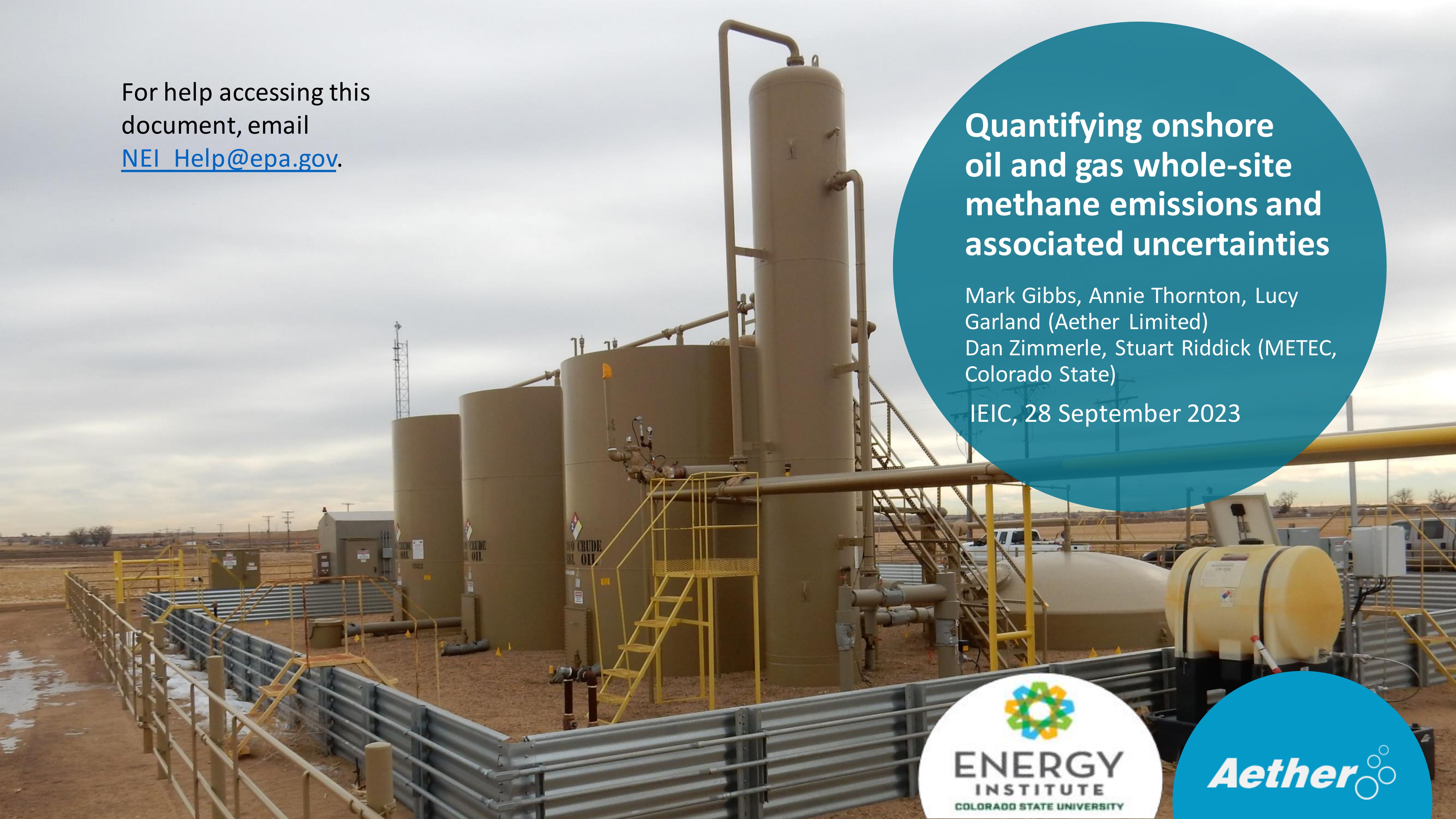

Quantifying onshore oil and gas whole-site methane emissions and associated uncertainties

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Project overview

- Onshore oil and gas (OOG) sites typically contain a range of equipment types that have multiple operating and failure modes
  - Whole-site (or full-facility) emissions includes emissions from all sources at a site
  - Can be significant variation in these emissions, temporally and spatially
- Understanding and quantifying whole-site emissions is important in terms of prioritising action to reduce methane (and VOC) emissions
- What is the accounting period for quantifying emissions?
  - A snapshot in time or a longer period (such as a year)?
- What is the uncertainty over the relevant accounting period?
  - Uncertainty is often cursorily treated
  - But we need to be able to compare methods
  - How confident can we be in the results?

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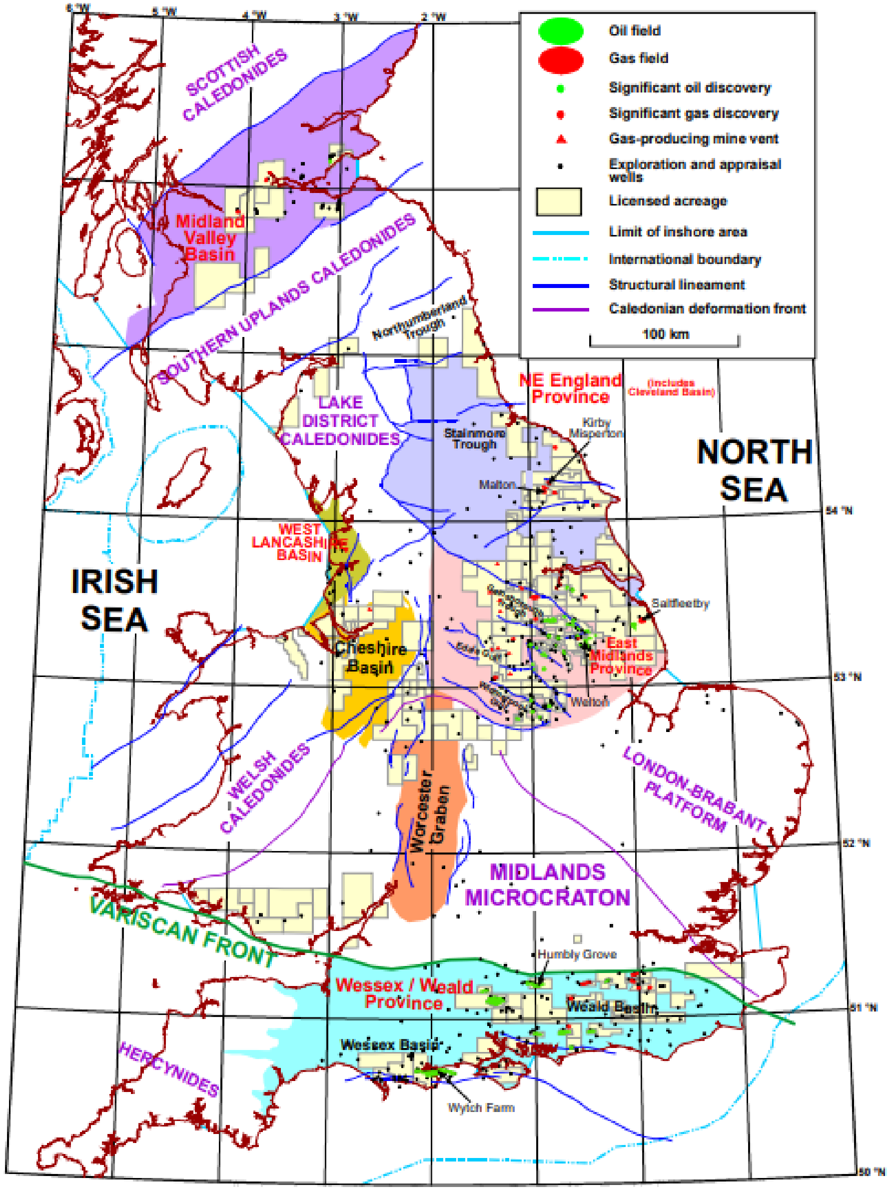
Project overview

- English Environment Agency Project SC21006, completed March 2022, published Nov 2022
  - Available at: https://www.gov.uk/government/publications/onshore-oil-and-gas-quantifying-whole-site-methane-emissions-and-associated-uncertainties
  - Reviewed suitable methods for quantifying whole-site methane emissions from OOG sites in England (the 'upstream' and 'midstream' sectors of the oil & gas industry)
    - Evaluated a wide range of approaches
    - Recommended best methods to use for different sites and different purposes
  - Considered the components of the *combined* or *total* uncertainty
  - Identified transferability to other pollutants and sources

- Environment Agency Project Manager: Mark Bourn
- Contractors: Aether Limited and the Methane Emissions Technology Evaluation Center (METEC), Colorado State University

OOG production in England



- 2,000 onshore wells have been drilled in the UK
- Currently:
  - 120 sites
  - 250 operating wells
  - Producing 20,000 to 25,000 barrels of oil equivalent per day

Sources: DECC, UKOOG

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Types of OOG sites

Aerodynamically simple topography versus aerodynamically complex locations:

Types of OOG sites in England

There are 4 main types of OOG sites in England:

- **Small production sites located in aerodynamically complex topography areas:** Site size of up to 200 m x 200 m. As well as wellheads, separators and condensate tanks may include some processing equipment. ***Surrounded by trees up to 30 m tall***.

- **Small production sites located in aerodynamically simple topography areas:** Smaller site size (typically 80 m x 40 m) and smaller configuration (typically wellheads, separators and condensate tanks) compared to small production sites in wooded areas. ***Surrounded by open land***.

- **Large production sites located in aerodynamically complex topography areas:** Site size of 500 m x 300 m containing multiple wellheads and extensive on-site processing equipment. ***Surrounded by trees up to 30 m tall***.

- **Large processing sites located in aerodynamically simple topography areas:** Site size of up to 1 km x 1 km with a collection of multiple individual sources of different heights. Includes gas pipeline terminals and large compressor stations. These sites are usually ***surrounded by open land***.

Suitable measurement techniques also depend on the type of processing at a facility

- For small facilities, the highest sources of emissions depend on whether there is liquid separation (e.g., well field separators) and treating equipment (e.g., dehydrators)

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Taxonomy of methane detection and quantification methods

All Methods
Detect emissions, identify approximate leak locations, possibly quantify

"Continuous" Monitors
Stationary, installed on site, semi-autonomous, no operator

- Facility
- Regional Sensing (towers, satellites)

Survey Methods
Mobile, deployed periodically, with operator, detect, quantify, localize

- Component Inspection *Current regulatory approach*
- Facility ← *Wide range of mobility options – foot, robots, drones, aircraft …*
- Remote Sensing *Satellites* ← *Currently not sensitive enough for facility-scale measurement … focused on very large emitters or regional emission estimates*

Screening Methods
Mobile, deployed periodically, identify possible emissions without localization or quantification

Similar tech subsets as survey methods

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Approaches for detecting an emissions plume from a facility

Continuous monitors: Using point sensors to measure concentrations in or near the emissions plume from a facility

Continuous monitors or survey methods: Using line (laser) sensors (yellow lines) to measure concentrations in or near the emissions plume from a facility

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Approaches for detecting an emissions plume from a facility

Survey methods: Using a concentration survey of the emissions plume from a facility

Survey methods: Using a flux plane method to survey the emissions plume from a facility

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Selecting methods for detailed consideration

Two main criteria were used to select the most suitable methods:

1. They either:
   - have been tested substantially by use in scientific studies

     (e.g, tracer flux, plume-based flux recovery, component-level measurements)

     and may also have been approved by a major regulator

     (e.g., plume-based flux recovery, component-level measurements)

   or

   - are rapidly gaining traction for use in whole-site measurements

     (e.g. flux plane, fenceline monitors)

2. They can quantify whole-site methane emissions

   - **Not just emissions from the largest sources**

Qualitative evaluation of methods

		Whole-site tracer flux	Plume-based flux recovery	Flux plane methods	Plume imaging & quantification	Solar occultation flux	Bayesian convergence survey	Fenceline monitors (point & line sensors)	Eddy covariance	Backward Lagrangian stochastic	Component-level measurements
Main criteria	Tested substantially in a number of studies?	Highly/very suitable	Highly/very suitable	Intermediate	Highly/very suitable	Poor/ not suitable	Poor/ not suitable	Highly/very suitable	Intermediate	Intermediate	Highly/very suitable
	Approved by a major regulator?	Poor/ not suitable	Highly/very suitable	Poor/ not suitable	Poor/ not suitable	Poor/ not suitable	Poor/ not suitable	Poor/ not suitable	Poor/ not suitable	Poor/ not suitable	Highly/very suitable
	Suitable for whole-site emissions?	Highly/very suitable	Intermediate	Highly/very suitable	Poor/ not suitable	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate
	Proven for OOG operations?	Highly/very suitable	Highly/very suitable	Highly/very suitable	Highly/very suitable	Intermediate	Intermediate	Highly/very suitable	Poor/ not suitable	Poor/ not suitable	Highly/very suitable
	Implemented by more than one vendor or academic group?	Highly/very suitable	Highly/very suitable	Highly/very suitable	Highly/very suitable	Poor/ not suitable	Poor/ not suitable	Highly/very suitable	Intermediate	Intermediate	Highly/very suitable
Additional criteria	Controlled release validation?	Highly/very suitable	Highly/very suitable	Highly/very suitable	Highly/very suitable	Poor/ not suitable	Highly/very suitable	Poor/ not suitable	Highly/very suitable	Highly/very suitable	Highly/very suitable
	Speed of method?	Intermediate	Highly/very suitable	Intermediate	Highly/very suitable	Highly/very suitable	Intermediate	Highly/very suitable	Intermediate	Highly/very suitable	Highly/very suitable
	Ease of use?	Poor/ not suitable	Intermediate	Intermediate	Highly/very suitable	Highly/very suitable	Intermediate	Highly/very suitable	Intermediate	Intermediate	Highly/very suitable
	Suitable for small facilities?	Highly/very suitable	Highly/very suitable	Highly/very suitable	Intermediate	Highly/very suitable	Highly/very suitable	Highly/very suitable	Highly/very suitable	Intermediate	Highly/very suitable
	Suitable for larger facilities?	Highly/very suitable	Poor/ not suitable	Highly/very suitable	Poor/ not suitable	Intermediate	Intermediate	Intermediate	Intermediate	Poor/ not suitable	Poor/ not suitable
	Access restrictions?	Intermediate	Highly/very suitable	Highly/very suitable	Highly/very suitable	Highly/very suitable	Highly/very suitable	Highly/very suitable	Intermediate	Highly/very suitable	Intermediate
	Suitable for a complex fetch?	Highly/very suitable	Intermediate	Poor/ not suitable	Poor/ not suitable	Intermediate	Intermediate	Highly/very suitable	Intermediate	Intermediate	Highly/very suitable
	Suitable for sites surrounded by woodland?	Highly/very suitable	Poor/ not suitable	Highly/very suitable	Poor/ not suitable	Intermediate	Highly/very suitable	Highly/very suitable	Highly/very suitable	Poor/ not suitable	Highly/very suitable
	Suitable for continuous measurement?	Poor/ not suitable	Poor/ not suitable	Poor/ not suitable	Poor/ not suitable	Poor/ not suitable	Poor/ not suitable	Highly/very suitable	Highly/very suitable	Highly/very suitable	Poor/ not suitable
	Summary - Recommended for detailed study?	**Yes**	**Yes**	**Yes**	No	No	No	**Yes**	No	No	**Yes**

Highly/very suitable

Intermediate

Poor/ not suitable

Five classes of methods that best meet the selection criteria

- Plume-based flux recovery
  - US EPA Other Test Method 33a (OTM33a) – Geospatial Measurement of Air Pollution
  - A gaussian plume assumption is key
- Component-level measurements
  - US EPA Method 21 / EN 15446 or optical gas imaging plus high flow sampling
- Mass balance
  - Characterising incoming and outgoing concentrations of target gas
- Fenceline monitoring
  - Continuous monitors have low accuracy
- Tracer method
  - Release of tracer gases at a known rate, is a complex method

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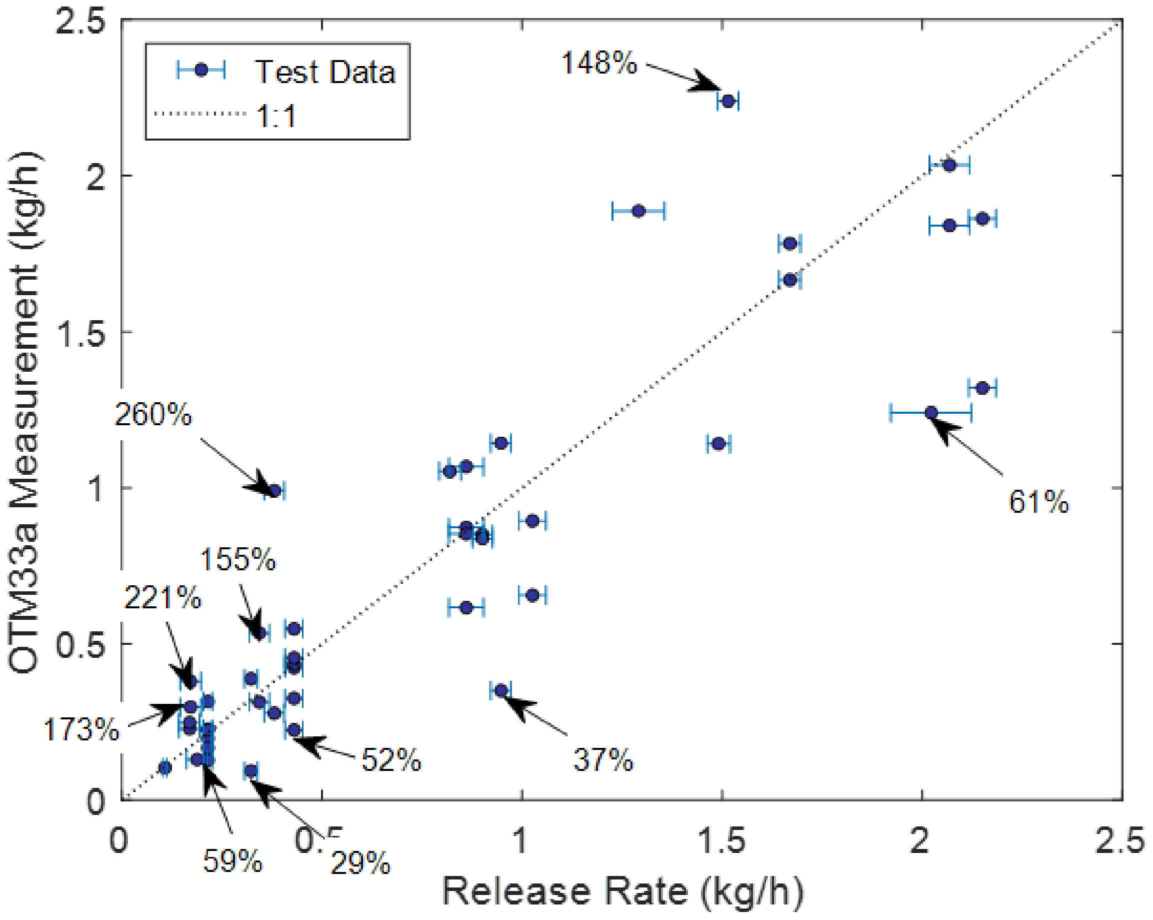
OTM33a – method uncertainty

Test data for OTM33a controlled testing (Edie and others, 2020)



- One particular measurement can be way off
- How representative will it be?
- More measurements will yield a better result
- How much effort can you invest for a particular campaign?

Site type	Description of location	Potential emission sources	Preferred methods	1	2	3	4	5	Prohibitively uncertain methods
Small production site, complex topography	Wooded with complex aerodynamics	Relatively complex with some processing	**Method**	Tracer method	Mass balance	OTM33a	Component-level measurement		Fenceline measurement
			Method Uncertainty	2	2	1	1		
			Cost	£	££-£££	£	£		
Small production site, simple topography	Open setting	Wellheads, separator and condensate tanks only	**Method**	OTM33a	Component-level measurement	Tracer method	Fenceline measurement	Mass balance	
			Method Uncertainty	1	1	2	3	2	
			Cost	£	£	£	£	££-£££	
Large production site, complex topography	Wooded with complex aerodynamics	Multiple wellheads, on-site processing	**Method**	Tracer method	Mass balance	OTM33a			Fenceline and component-level measurement
			Method Uncertainty	2	2	1			
			Cost	££	££-£££	£			
Large processing sites	Very large and complex site. More open setting but aero-dynamically complex topography	Large number of individual sources	**Method**	Tracer method	OTM33a	Mass balance	Fenceline measurement		Component-level measurement
			Method Uncertainty	2	1	2	3		
			Cost	££	£	££	£-££		

Uncertainty range colour code	Uncertainty bounds
	<±20%
	±20% to ±50%
	>±50%

Uncertainty approach code	Approach used to determine uncertainty bounds
1	Controlled release with published data
2	Published, desk-based analysis
3	No data – Analysis through modelling

Other sources of uncertainty

- Other uncertainty may be as large or larger than the measurement uncertainty
  - Is one measurement at one site at one point in time sufficient?
  - **Sampling:** OOG emission rates are often highly skewed
  - **Emission type uncertainty:** Is there a need to differentiate emissions from routine operations versus unexpected/unpermitted/abnormal emissions?
    - Not a problem if looking at 'total emissions' from a facility
  - **Temporal variability**: maintenance operations or failure conditions may vary substantially over time; methods are often limited by sampling speed and averaging time
  - **Method implementation uncertainty:** controlled testing conditions vs field conditions, sufficiently trained and experienced personnel, standardised application of methods

A method with higher uncertainty but lower cost (enabling larger sample sizes, repeat sampling, or more frequent sampling) may produce lower uncertainty than an expensive, highly accurate method that can only be used for small sample sizes.

Can consider pairing lower-cost higher-uncertainty methods with higher-cost lower-uncertainty methods

Assessing total uncertainty

- To assess total uncertainty for any measurement effort:
  - Simulate the measurement effort, e.g. using a Monte Carlo simulation, to compute a net uncertainty
  - Where possible, empirical uncertainty distributions (actual controlled testing results) should be used for measurement methods
  - Combine these with a robust prior estimate of emissions that includes the:
    - Size of the emissions
    - Skew in the emissions distribution
    - Temporal variation if used with long-duration measurements
- Temporal or facility-to-facility variability and skew in emissions will often contribute uncertainty ‘in the same order of magnitude’ as the method uncertainty

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Conclusions

- There is limited published data on the accuracy of different measurement methods
- Evaluation with controlled releases is the best way to assess method uncertainty
  - Many papers mention controlled testing but do not publish such data, or rely on previous publications
- Practitioners making wide-ranging modifications to a particular method provides a degree of optimisation but may decrease comparability
- In addition to measurement method uncertainty, variability, skew and prevalence of outliers in measured facilities' emissions affects total uncertainty
- If the objective is to identify and repair the majority of emissions quickly, using methods to just identify large emitters may be preferable
- Fenceline monitoring methods are developing rapidly but most of these developments are also proprietary and difficult to assess without controlled testing
- Implications for annual emissions inventories:
  - Is spatial and temporal variability (especially intermittency) sufficiently understood?
  - Extrapolation to annual values should be done with care
  - Total uncertainty can be significantly greater than ±50%

Epilogue: Recent work at METEC

- Some recent studies provide more insight into causes and nature of uncertainties
  - Bell, C., Ilonze, C., Duggan, A. & Zimmerle, D. Performance of Continuous Emission Monitoring Solutions under a Single-Blind Controlled Testing Protocol. Environ. Sci. Technol. 57, 5794–5805 (2023)
  - Zimmerle, D., Alden, C. B. & Bokaemper, S. Comment on EPA Supplementary Proposal EPA Docket No. EPA-HQ-OAR-2020-0317. https://www.regulations.gov/comment/EPA-HQ-OAR-2021-0317-2387 (2023)
  - Bell, C. et al. Single-blind determination of methane detection limits and quantification accuracy using aircraft-based LiDAR. Elementa: Science of the Anthropocene 10, 00080 (2022)
  - Zimmerle, D. et al. Open-source high flow sampler for natural gas leak quantification. https://mountainscholar.org/handle/10217/235420 (2022)
- Implications for handling intermittent sources
  - Field observations indicate intermittency is a key characteristic of OOG sources

Studies address:

- Performance of continuous monitors in controlled test conditions
- How surveys are impacted by emitter intermittency using field data from continuous monitors
- Updated aerial method performance
- Testing of next-generation high flow instruments

Key messages

- Fenceline sensors still require refinement of the algorithms used to convert measured concentrations to emissions. Also, their performance at real sites may deviate substantially from controlled testing conditions. More sophisticated testing may be required to guarantee a method's performance in field conditions

- Continuous monitors may be better suited than survey methods to detect intermittent sources
  - But they may do poorly at quantification

- *How frequently you look* and for *how long you look* matters

- When designing detection or quantification programs need to consider:
  - Intermittency
  - Type of method being used
  - The total uncertainty of that method

Thank You

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