New Technologies for Flaring Elimination & Methane Emissions Measurement

Daniel Palmer and Audrey Mascarenhas

September 8, 2021

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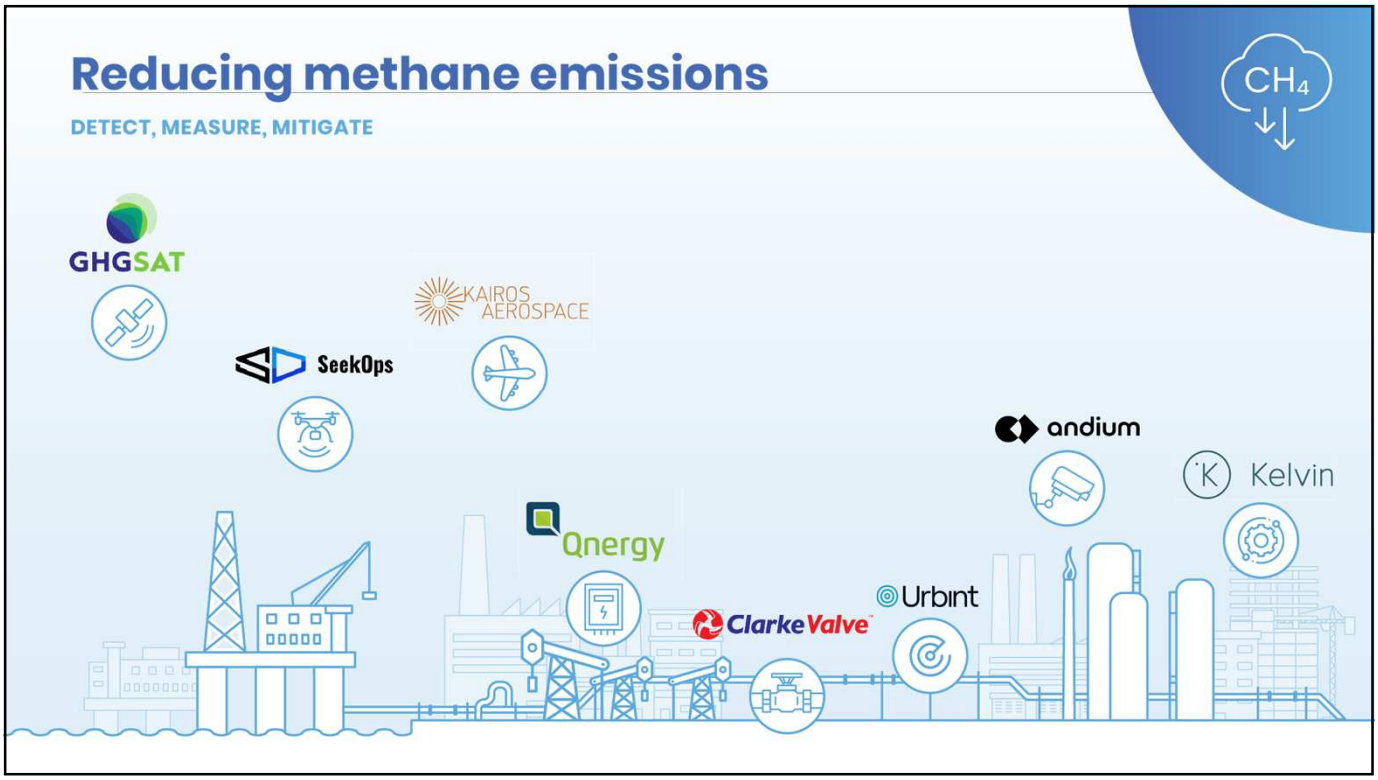
Advances in Methane Remote Sensing Technology

Daniel Palmer

September 2021



Contents

US Methane Emissions Estimates

Onshore Technology:

- Aerial Surveys of US Onshore Oilfields
- Comparison of Technology for Onshore LDAR
  - Public Satellites
  - Private Satellites (GHGSAT)
  - Aircraft Surveys
  - Site level monitoring with drones
  - Offshore Surveys
- Solutions based on LDAR
- References and further reading

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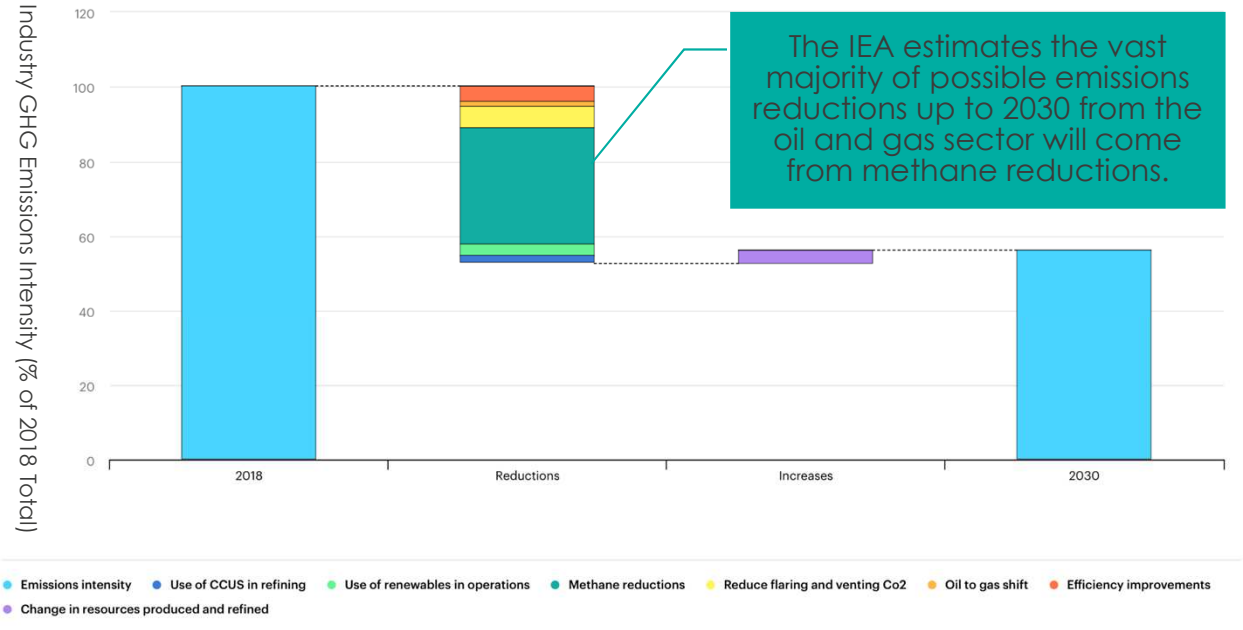
IEA Data Shows the Impact of Methane Emissions Reductions



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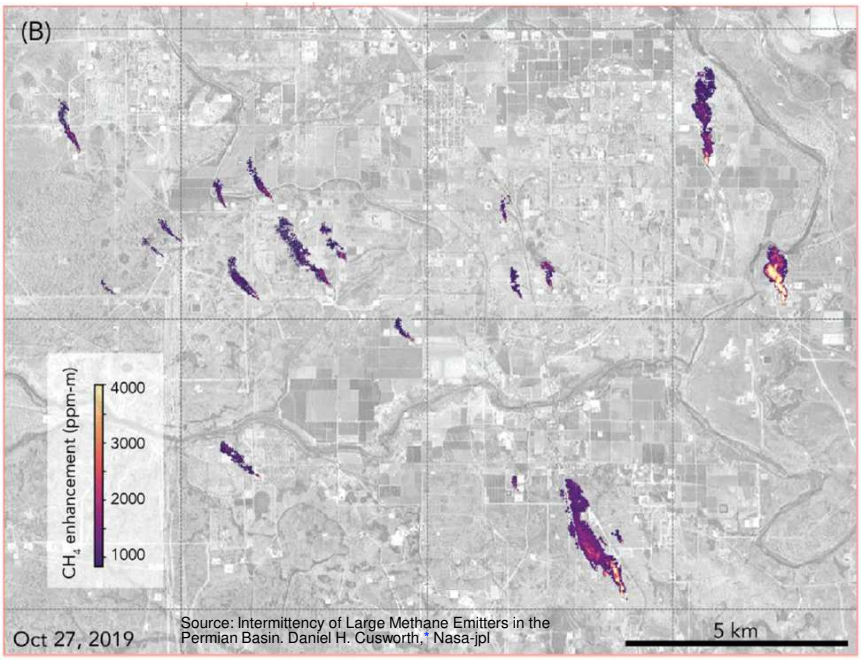
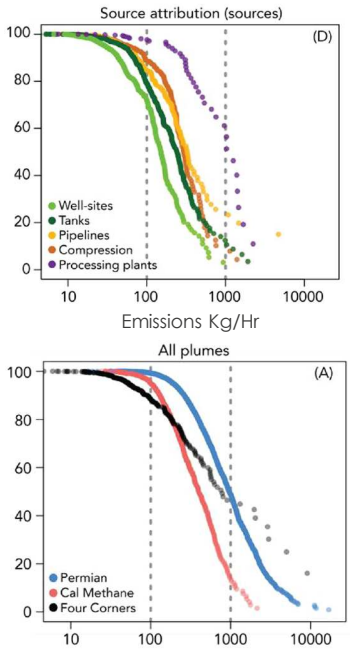
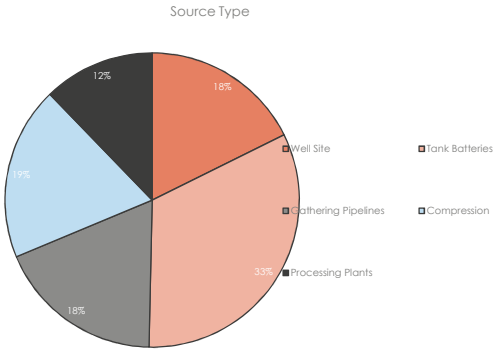
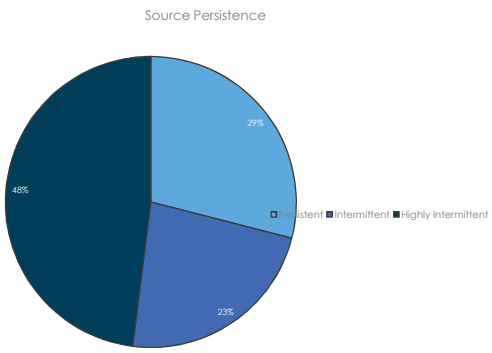
Nasa-JPL (Passive Infra-Red) Survey of the Permian





Comparison of major sources of emissions from JPL Survey





Based on this, criteria for effective LDAR and monitoring of Oil and Gas Operations are;
- Cover everything across upstream and midstream; tanks, wells, flares, processing plants, gathering lines and compressors.
- Make regular flights to catch and analyze root cause of intermittent emitters
- Venting and unlit flares represent low hanging fruit for reductions

To cover everything regularly, requires highly efficient (airborne) monitoring.

Source: Intermittency of Large Methane Emitters in the Permian Basin. Daniel H. Cusworth,* Nasa-jpl

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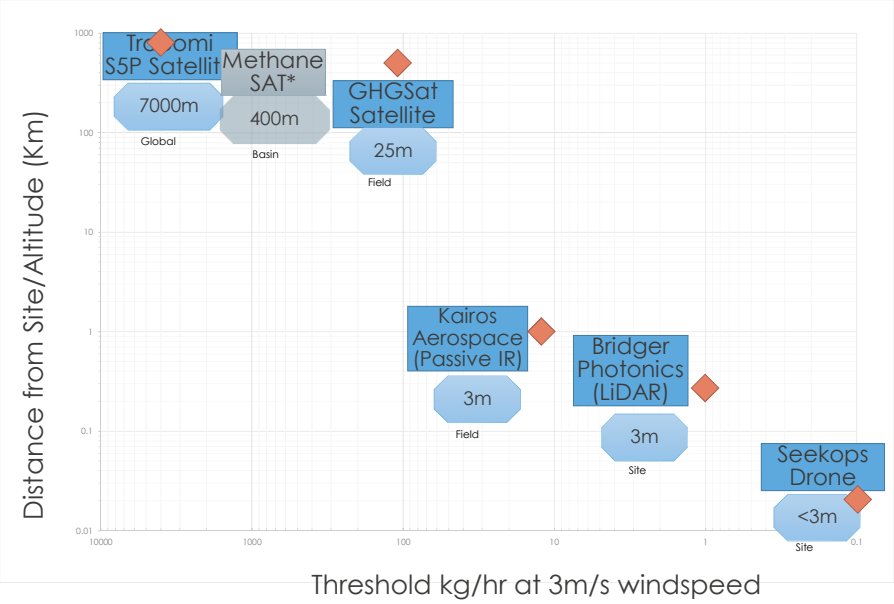
Scale and Threshold for Remote Sensing



Physical trade off between speed, coverage, altitude, Threshold, resolution and ultimately cost per site.

Technology

Resolution (meters)

Coverage

Other Passive IR Sensors are (AVIRIS-NG)& Global Airborne Observatory (GAO)

GHGSat also has aircraft passive IR Sensor

*MethaneSat Planed launch Q4 2022.

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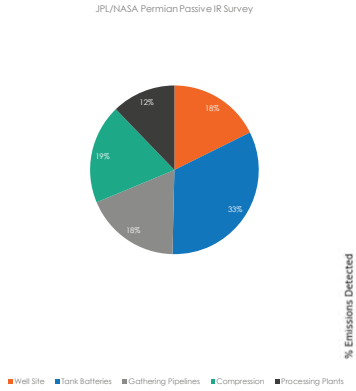
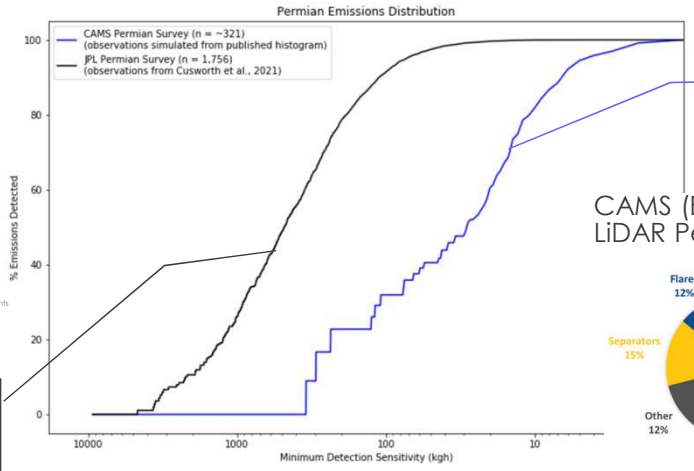
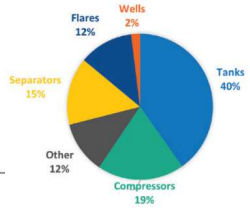
Different Scales of Surveys Give Different Results





Smaller more sensitive CAMS survey sees more small onsite emissions

CAMS (Bridger Photonics) LiDAR Permian Survey



Larger, wider scale JPL survey sees larger emissions and more from gathering lines and well sites

Figure 1. Percent share by equipment type of total methane emissions (from the GML data and aerial photography gathered during two weeks by Bridger-Photonics)

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OGCI Climate Investments Methane Technology Portfolio

	Sensor Platform & Altitude	Survey Rate / Coverage	Detection Threshold *	Spatial Resolution	Requires Sunlight	Offshore Over water	Cloud
GHGSAT	Passive IR spectroscopy Satellite (300 mi)	Global 1,200 sq mi/day	~120 mscf/d	80ft x 80ft	Yes	No	No
KAIROS AEROSPACE	Passive IR spectroscopy Fixed wing (3200 ft)	100-150 sq mi/day	~12 mscf/d	10ft x 10ft	Yes	No	VFR Only
SeekOps	Point concentration Drone (5 to 300ft)	5-15 sites/day	<24 scf/d (site level)	~3 -10ft	No	Yes	yes

**All sensors have dependency on wind speed for threshold, number quoted are for low wind speeds ~3 m/s
*Kairos Guarantees detection of any source above 40mcf/d
GHGSat also has passive IR Aircraft variant in operation in the US with excellent performance
Source METEC trials, Stanford blind testing of Kairos, and company public specifications

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Methane Satellite Comparison

Instrument / Satellite	Coverage (swath)	Operator/ Class	Launch	Detection Threshold (Kg/h)	Pixel size/ resolution (m)	Reference
TROPOMI Sentinel 5-P	**Global**	Public /spectrometer	2017	4,000*	7,000 x 5,500	http://www.tropomi.eu/
GHGSAT D	Targeted 12x12km	Commercial/ spectrometer	2020 2021	**120**	**25 x 25**	www.GHGSAT.com
PRISMA	Push broom 30km	Public/ 250 band Hyperspectral	2019	>3,000**	30 x 30	https://earth.esa.int/web/eoportal/satellite-missions/p/prisma-hyperspectral
Sentinel 2 (A/B)	Push broom 290km	Public/ 13 band Hyperspectral	2015	>3,000**	20 x 20	https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-210m visible/
Worldview3 (Maxar)	Push broom 13km	Commercial/ 28 band Hyperspectral	2014	Unknown >500? **	1.2 x 1.2 / 30 x 30	https://earth.esa.int/web/eoportal/satellite-missions/v-w-x-y-z/worldview-3
Methane SAT	Targeted 200km x?	NGO – Public / spectrometer	2022/23	500-1,000 (site level)	130 x 400	https://www.methanesat.org/
Carbon MAPPER	Push broom 18km?	NGO – Public / spectrometer	After 2023?	50-150 Estimated?	30 x 30	https://carbonmapper.org/

*Note threshold estimated by U.Columbia, not proven by controlled release
**Unknown estimated based on spectral resolution or literature

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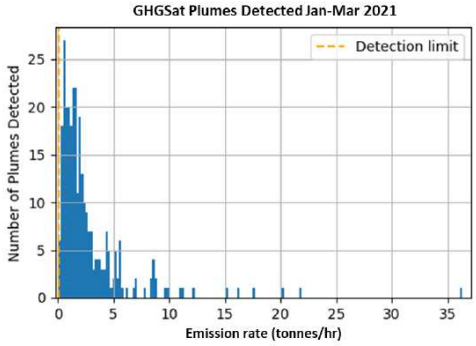
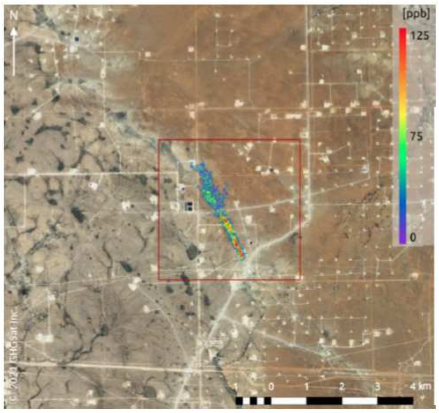
GHGSAT Capabilities





Measured by GHGSat-C2 on Feb 1st, 2021;
background is © 2021 Google Map Data

GHGSat offers the current state of the art, with detection threshold of 100 $kgCH_4/hr$ and 25m resolution

- Each satellite can get an 7 mile square "image" on each overpass
- GHGSAT has 3 satellites today, increasing to constellation of 10 in the near future
- More satellites means more frequent observations, 10 satellites gives near daily observations

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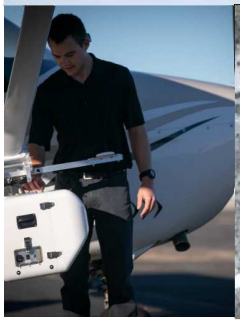
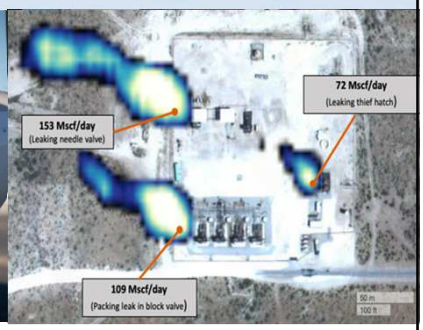
Kairos Aerospace Capabilities

- Architecture: Simultaneous methane & high-res optical imaging
- Detection method: Aerial absorption IR spectroscopy
- Computed Values: Leak rates
- Sensitivity:
  - 3 MCF/day (2.4 kg/hr) –Ideal conditions
  - 40 MCF/day (32 kg/hr) – Guaranteed threshold.
- Calibration: Software continuously monitors performance
- Coverage: 100 to 150 sq. miles/day/plane
- Ground Resolution: 10 ft. (methane), 18 in. (optical)
- Altitude: 3,000 ft
- Operator surveys only, not regulators & NGO's





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Drone Sensor Technology based on NASA Mars Rover Sensors

SeekOps sensors are drone-mounted methane detectors which **detect, localize, and measure** site level total gas emissions.

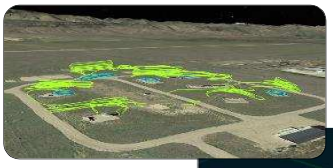
Efficient: Up to 5x faster than OGI leak detection surveys.

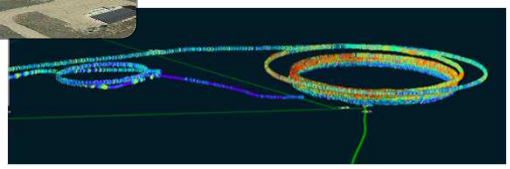
Versatile: Unlimited mobility in 3D

- ✓ Measure site level total emissions
- ✓ Parts-per-billion sensitivity
- ✓ Actionable Data

Platforms: Unmanned Aerial Systems

- ✓ Multirotor Systems
- ✓ Fixed-Wing long range UAV's operating offshore





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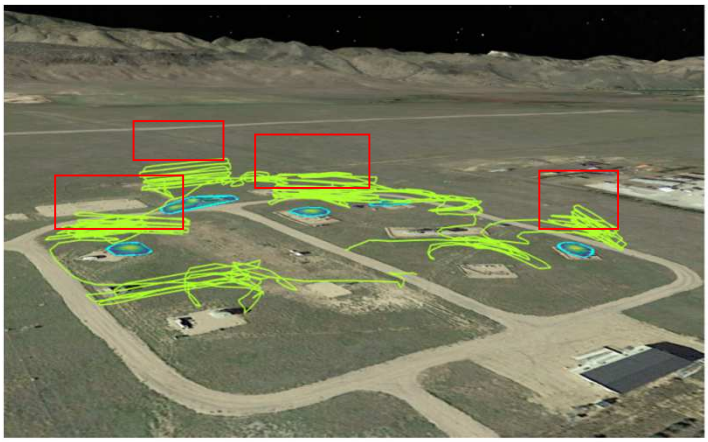
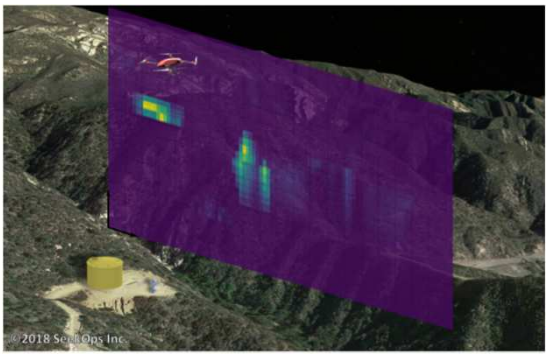
SeekOps: Ultra Low Threshold, Site Quantification

- **SeekIR® Drone Emissions Surveys**
- **Detection & quantification down to 0.1kg/hr**



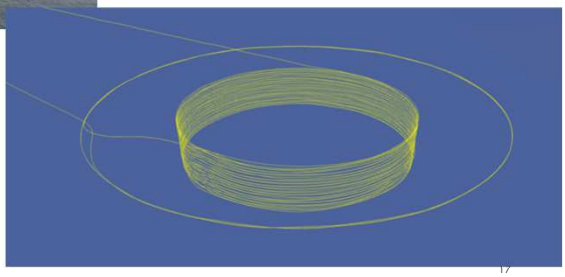


Site Level Quantification

Source: METEC

SeekOps Inc.

Offshore Applications: UK North Sea (OGTC Project)



Development Of Methods For Top-down Methane Emission Measurements Of Oil And Gas Facilities In An Offshore Environment Using A Miniature Methane Spectrometer And Long-endurance UAS

B.J. Smith, S. Buckingham, SeekOps Inc.; D. Touzel, BP; A.M. Corbett, SeekOps Inc.; C.A. Tavner, Flylogix

SPE ATCE - Thursday, 23 September

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LDAR With Aircraft Case Study: Permian Basin

Aerial survey results have allowed Pioneer to significantly reduce methane emissions while simultaneously improving safety and efficiency, reducing costs, and reducing vehicle traffic.

Reduced	Improved Detection Accuracy	Reduced
40% Methane Emissions	**77%** to **96%**	**200+** work hours **1000+** driving hours By each aerial Survey

Between 2016 and 2018, Pioneer Natural Resources' methane intensity has declined approximately 41%.

Multi-year case study with Pioneer Natural Resources
SPE-201312-MS

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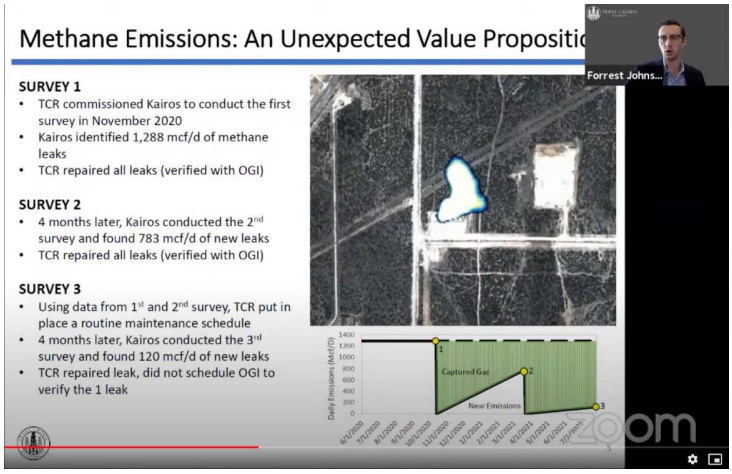
Solutions Based on LDAR: Feedback to EPA



Operator feedback showing aerial technology for LDAR led to >80% reduction in methane in one year.

Presented to EPA Methane Workshop

Source: https://eartharxiv.org/repository/object/2532/download/5160/

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Aerial Detection Technology Summary

- Distribution and type of emissions are now well known from aerial surveys
- Aerial and Satellite detection methods are proven effective in real world applications
- Operators report finding larger volume of methane than with OGI Surveys at the same sites
- Rapid reductions in methane emissions are reported as a result of aerial surveys
- Surveys should be regular and cover all potential leak sources
- Finding and repairing large leaks quickly is cost effective or profitable
- Aerial Surveys should be a reasonable first step for all upstream and midstream operators.

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References and Further Reading

1. Recent EPA workshop presented excellent content on all areas of methane monitoring.
   - https://www.epa.gov/system/files/documents/2021-08/epa-methane-detection-virtual-workshop-august-2021-final-agenda.pdf
   - https://www.youtube.com/watch?v=KfY50npQ0sM
   - https://www.youtube.com/watch?v=lQcUhMG24X0
2. JPL study on emissions in the Permian (Cusworth et al)
   - https://pubs.acs.org/doi/10.1021/acs.estlett.1c00173
3. Summary of Satellite Monitoring by University of Columbia
   - https://www.energypolicy.columbia.edu/research/commentary/nowhere-hide-implications-policy-industry-and-finance-satellite-based-methane-detection
4. Multi-year case study with Pioneer Natural Resources: SPE-201312-MS
   - https://onepetro.org/SPEATCE/proceedings-abstract/20ATCE/3-20ATCE/D031S034R004/449845
5. Blind testing of technology at METEC facility
   - https://ngi.stanford.edu/sites/g/files/sbiybj14406/f/373-6463-1-PB.pdf
6. Blind testing of Kairos Aerospace technology
   - Single-blind test of airplane-based hyperspectral methane detection via controlled releases (eartharxiv.org)

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Questions

Questor
Clear Solutions Clean Skies

ClearPower SYSTEMS Inc.

DEEP DIVE INTO

NEW TECHNOLOGIES FOR FLARING AND VENTING ELIMINATION

25 Years Perfecting the Way the World Handles Waste Gases

Audrey Mascarenhas
President and CEO
Questor Technology Inc

SPE International · Interstate Oil & Gas Compact Commission · EDF Environmental Defense Fund

Insights — Transparent Emissions Data
Series — Reduce Emissions
Power — Optimize Efficiency

OUR FLARING AND VENTING PROBLEM

The oil & gas industry alone globally flares over

14.5 billion standard cubic feet per day[1]

35% of the worlds GHG emissions:

Problem – Impacts air quality, emits particulates, VOC's, methane and it's a significant waste of energy

Kayrros estimates from satellite imagery that over 1Gt CO_2e annually comes from non-routine venting

Methane emissions have been significantly underestimated

1. Global Gas Flaring Tracker Report, GGFR, The World Bank, July 2020

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WHY METHANE CONTRIBUTES SIGNIFICANTLY TO CLIMATE CHANGE

Methane global warming potential is 86x higher than CO_2 over a 20 year period. Forms toxic compounds, VOC's and Ozone and ultimately CO_2

14.5 billion cubic feet of gas is flared and vented daily [1]

Cleanly combusting these streams instead of flaring and venting

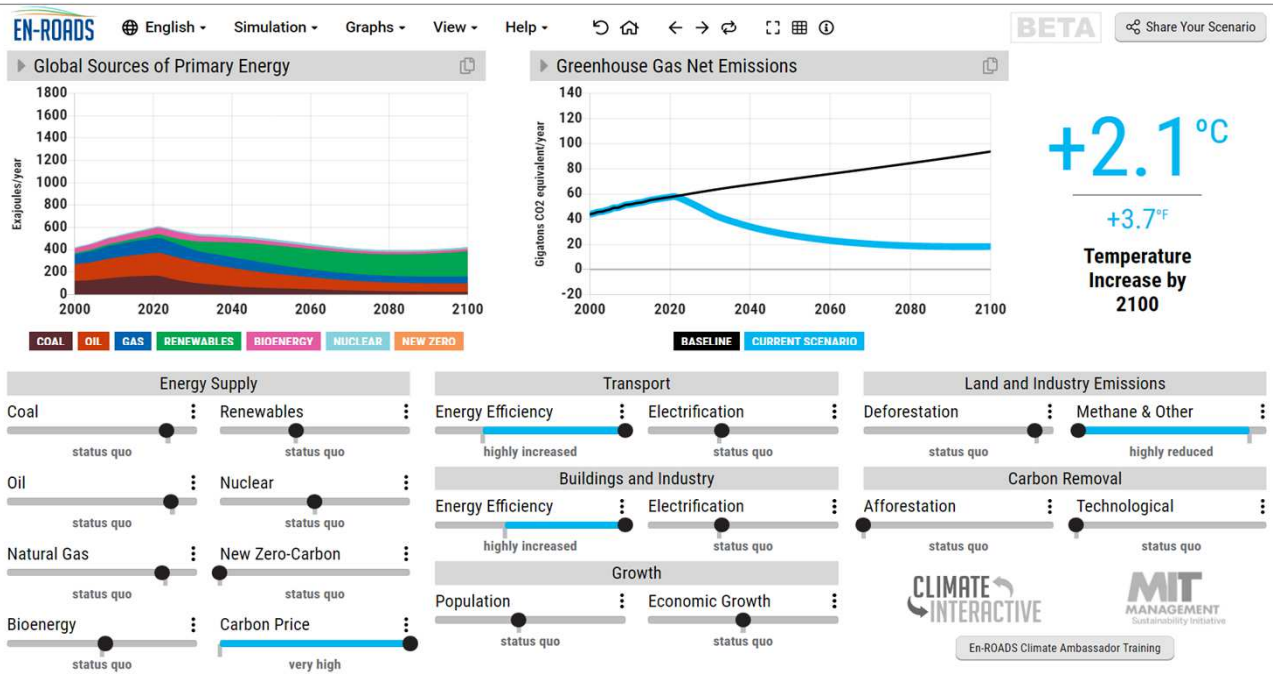
Cost $3.63B ➡ 2.6MMt CO_2e/d or 1Gt CO_2e/yr.

Over a 10 year project life < $0.50/t$CO_2$e

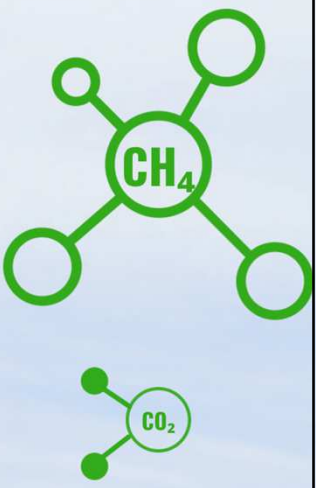
Assumptions
- 65% flared and 35% vented - 80% methane in the stream
- Flare combustion efficiency is 80%
- 3MMscf/d can be cleanly combusted in a Questor Q5000 at 99.99%
- GWP of 25 over a 100 year period

1. Global Gas Flaring Tracker Report, GGFR, The World Bank, July 2020

METHANE AND ENERGY EFFICIENCY



OPPORTUNITY FOR CLEAN POWER



Each Q5000 can generate 9MW power at a cost of $22MM

$110B investment would supply 45 GW power ($2500/kW)

Replacing approximately 20 average size nuclear plants.

Assuming $0.08/kWh - $32B revenue / yr.

Over a 10 year project life

Capital $110B
Revenue $320B
Reduce GHG emissions 10G tCO_2e at a (- $21/$tCO_2e$)

Clean energy and clean air for disadvantage populations

1. Global Gas Flaring Tracker Report, GGFR, The World Bank, July 2020

SOURCES OF METHANE EMISSIONS

Oil and Gas production, Gas processing, Oil processing, Refining and Petrochemical, Pipelines and Utility distribution

Current focus: Leaks, Tank vapours, Pneumatics and Compressor seals

- Engine/Compressor, Facility and Pipeline maintenance
- Engine/Compressor soft starts
- Process units – dehydration, amine, etc.
- Well unloading, Flow backs, well testing and workovers
- Truck, Rail and Ship loading
- Emergency Shut Downs - ESD's, PSV's
- Abandoned and Suspended wells

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ROUTINE AND NON-ROUTINE FLARING AND VENTING

Its not just about Climate Change

Sustainability, Energy Efficiency, Trust and Doing the Right Thing

Air Quality and GHG Emission Reductions

VOCs, HAPs, Methane, GHG emissions

Methane is 86x worse than CO_2 from a GHG warming perspective

Community Acceptance and ESG Initiatives

Safety, Operating & Capital Cost Reductions

Energy Efficiency

Power generation from waste heat, reduce op costs, reduced diesel usage, minimize fuel gas usage

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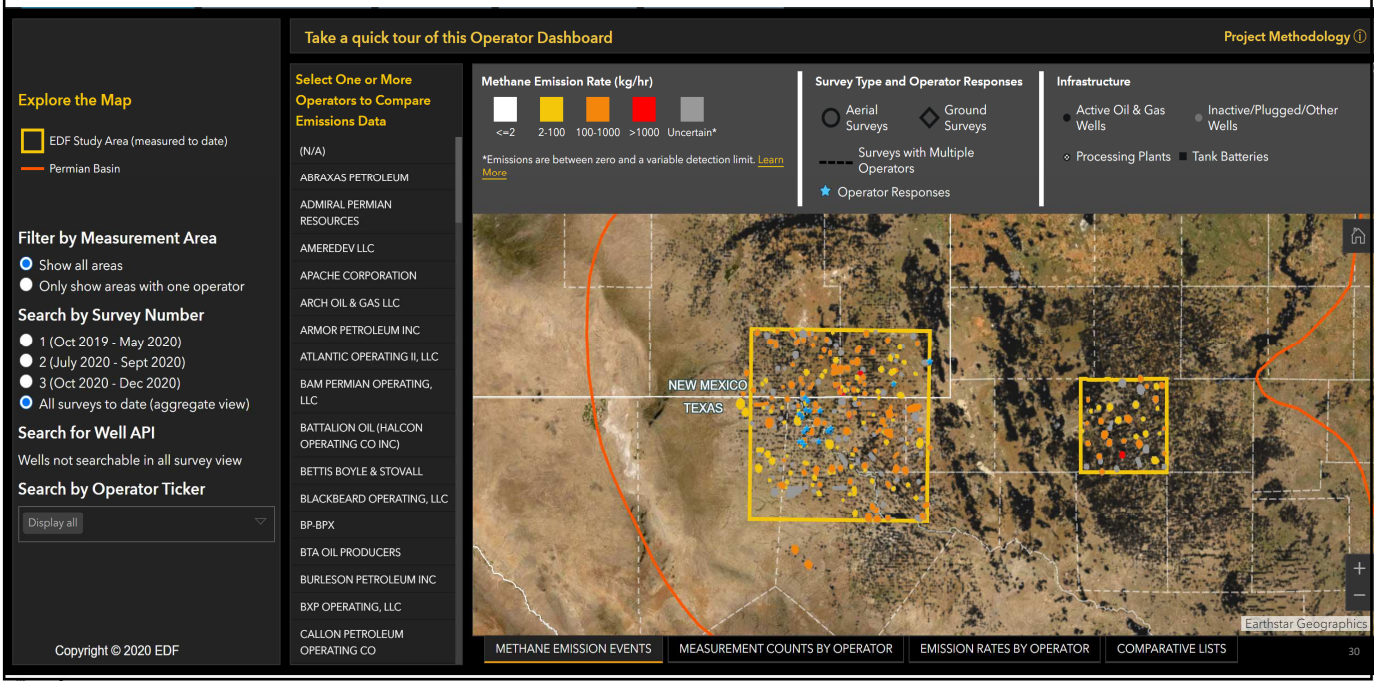
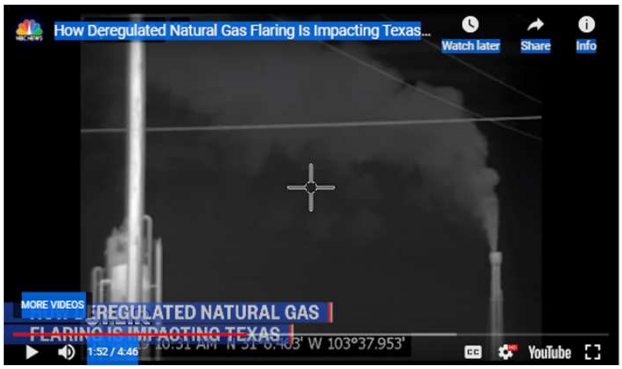
NOWHERE TO HIDE – ACTION NEEDED FAST



ELEPHANT IN THE ROOM

- Assumption that a flare is 98% efficient
- 10% Flares unlit
- Vented volumes unreported - Maintenance, well unloading and soft starts



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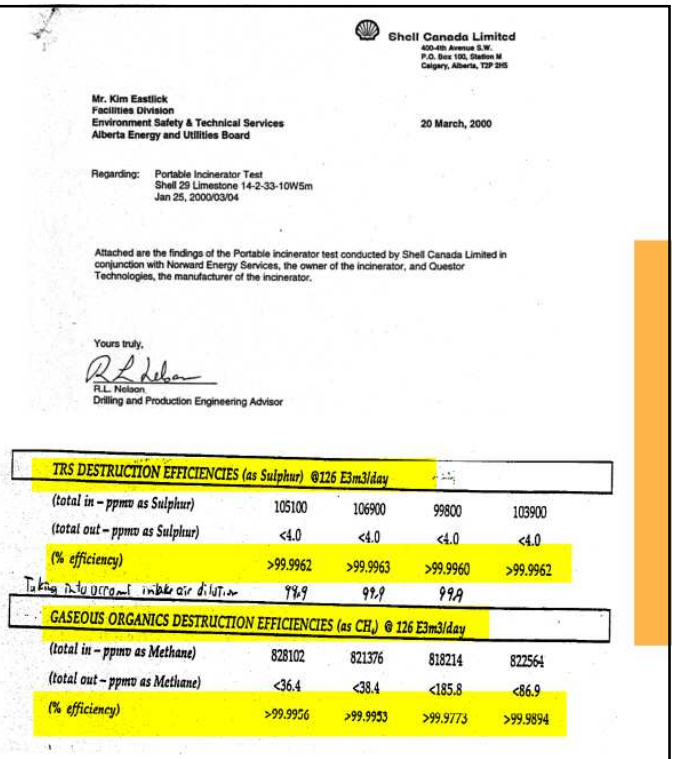
SHELL TESTING 2000

- Shell 29 Limestone 14-2-33-10 W5M
- 11% H_2S – Q5000
- 99.99% Combustion efficiency at 2.5 and 4.8MMscf/d with 100% excess air
- Plume rise of over 400 meters
- SO2 dispersion from 40ft combustion stack equivalent to a 110ft flare operating at 98% efficiency. No ground level violations of SO_2 or H_2S



Shell Canada Limited
400-4th Avenue S.W.
P.O. Box 100, Station M
Calgary, Alberta, T2P 2H5

Mr. Kim Eastlick
Facilities Division
Environment Safety & Technical Services
Alberta Energy and Utilities Board

20 March, 2000

Regarding: Portable Incinerator Test
Shell 29 Limestone 14-2-33-10W5m
Jan 25, 2000/03/04

Attached are the findings of the Portable incinerator test conducted by Shell Canada Limited in conjunction with Norward Energy Services, the owner of the incinerator, and Questor Technologies, the manufacturer of the incinerator.

Yours truly,

R.L. Nelson
Drilling and Production Engineering Advisor

TRS DESTRUCTION EFFICIENCIES (as Sulphur) @126 E3m3/day				
(total in – ppmv as Sulphur)	105100	106900	99800	103900
(total out – ppmv as Sulphur)	<4.0	<4.0	<4.0	<4.0
(% efficiency)	>99.9962	>99.9963	>99.9960	>99.9962
Taking into account intake air dilution	99.9	99.9	99.9	
GASEOUS ORGANICS DESTRUCTION EFFICIENCIES (as CH_4) @ 126 E3m3/day				
(total in – ppmv as Methane)	828102	821376	818214	822564
(total out – ppmv as Methane)	<36.4	<38.4	<185.8	<86.9
(% efficiency)	>99.9956	>99.9953	>99.9773	>99.9894

PROVEN PERFORMANCE

NORTH DAKOTA FIELD TESTING

Combustor	Parameter	Test Result				
		Test 1	Test 2	Test 3	Test 4	Average
SITE 1 Q5000-17-164 (west)	VOC DRE %	99.997%	99.998%	100%	100%	100%
	NOx (lb/MMBtu)	0.158	0.200	0.233	0.232	0.206
	CO (lb/MMBtu)	0.110	0.074	0.017	0.067	0.067
	Stack Temperature (°F)	1125	1412	1649	1823	1502
SITE 1 Q5000-17-173 (west)	VOC DRE %	100%	100%	100%	100%	100%
	NOx (lb/MMBtu)	0.140	0.182	0.220	0.287	0.207
	CO (lb/MMBtu)	0.049	0.008	0.002	0.011	0.018
	Stack Temperature (°F)	1046	1348	1522	1852	1442

		Test 1	Test 2		Average
SITE 2 Q5000-17-183 (east)	VOC DRE %	100%	100%	VERIFIED ISO 14034	100%
	NOx (lb/MMBtu)	0.279	0.258		0.263
	CO (lb/MMBtu)	0.001	0.002		0.001
	Stack Temperature (°F)	1758	1860		1792
SITE 2 Q5000-17-173 (west)	VOC DRE %	100%	100%	100%	100%
	NOx (lb/MMBtu)	0.244	0.279	0.281	0.268
	CO (lb/MMBtu)	0.002	0.004	0.002	0.003
	Stack Temperature (°F)	1743	1763	1775	1760

		Test 1	Test 2	Test 3	Average
SITE 3 Q5000-17-123 (east)	VOC DRE %	100%	100%	100%	100%
	NOx (lb/MMBtu)	0.178	0.173	0.202	0.184
	CO (lb/MMBtu)	0.092	0.013	0.005	0.037
	Stack Temperature (°F)	1737	1706	1688	1710
SITE 3 Q5000-17-164 (west)	VOC DRE %	100%	100%	100%	100%
	NOx (lb/MMBtu)	0.205	0.198	0.204	0.202
	CO (lb/MMBtu)	0.046	0.049	0.042	0.046
	Stack Temperature (°F)	1735	1754.000	1745	1745

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THE CHALLENGE IN ND

- ND State recognizes 99.5% efficient technology – High efficiency program
- Federal lands (EPA) allows the assumption that a flare is 98% with no requirement for proof
- Industry and the community know this is not true
- Industry willing to adopt technology to address the community concerns
- Dis-incentive to do the right thing
- Challenges in other states; PA, NM, TX……
- Searching for the loop holes
- Disconnect with what's actually going on in the field and the CEO statements

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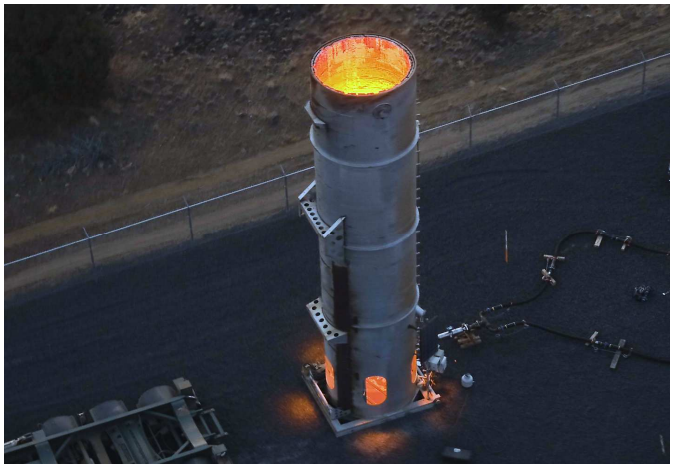
PIPELINE AND PLANT MAINTENANCE - VENTED BLOWDOWNS



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•Metal Building 40’ Away

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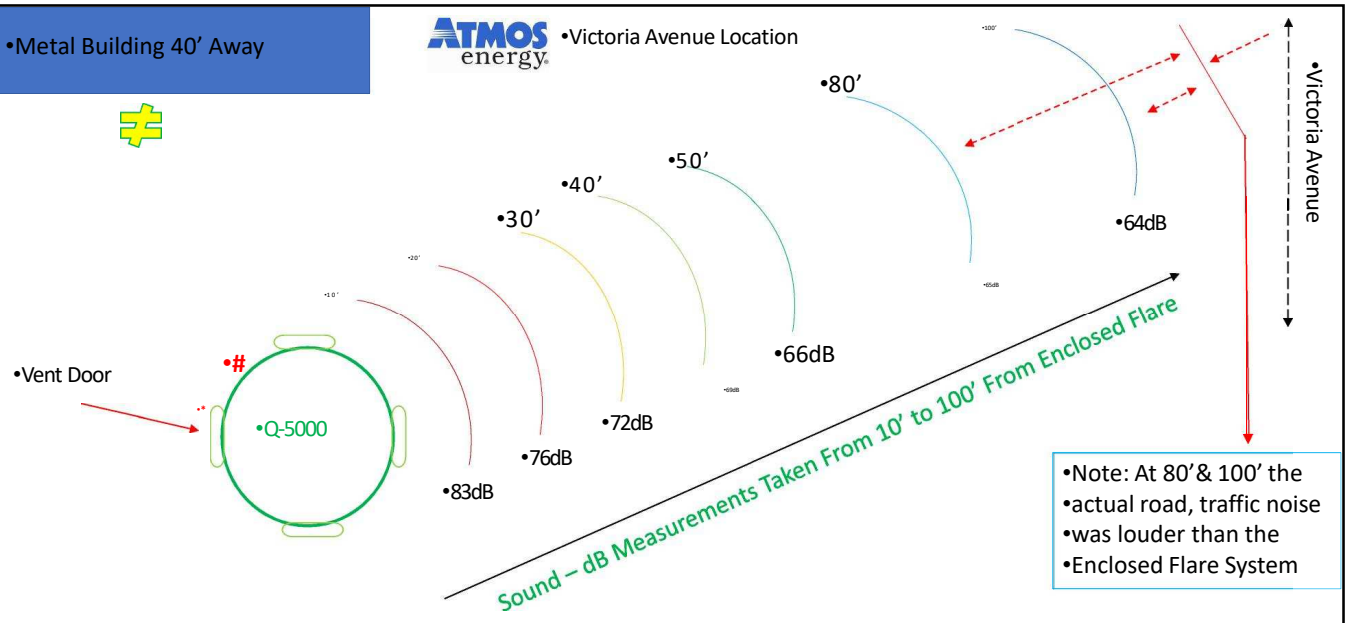
ATMOS energy •Victoria Avenue Location



•Note: At 80’& 100’ the
•actual road, traffic noise
•was louder than the
•Enclosed Flare System

Temperature Readings:
#Side of Q5000 – **182 Deg.**
*Vent Door on Q5000 – **565 Deg**.
Side of Building, @ 40’ away was **10 Deg. Above Ambient**

≠

EXPRO
MIDSTREAM – PIPELINE SERVICES

LOW GROUND HEAT RADIATION

SAFETY

- Facility integration
- Personnel safety
- No harmful pollutions emitted
- H_2S safety

MINIMAL GROUND LEVEL HEAT RADIATION

- Low forest fire risk
- Permafrost protection
- Air intakes can be flash arrested
- No water curtain need

PORTABLE AND EASY SETUP

SET IT AND FORGET IT

- Patented Hydraulic trailer
- Setup and takedown in less than 10 minutes
- Detachable trailer
- Eliminates crane and pickup costs
- Improved safety
- Over 120 unit rental fleet

DRILLING, COMPLETIONS AND PRODUCTION

ALL VAPORS TIED IN

- High capacity - 5MMscf/d methane eq. per unit
- 99.99% guaranteed combustion efficiency
- No black smoke, odors, or visible flame and compliant sound

TYPICAL GAS SOURCE TIED IN

- Wellbore gases from HP and LP separation
- Liquid storage tanks
- Truck-out vapors
- The single unit handles multiple streams with varying pressures and flowrates

DESIGN AND TESTING

- Sturdy portable design; Hydraulic trailer
- TX, CO, PA, CA, NM Basin tested and proven
- Sales and rental units available - units capable of 5mcf/d - 5MMscf/d

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INNOVATIVE SOLUTIONS

GLYCOL DEHYDRATION

- Still column vapors directly piped in
- Close spacing enables a small footprint and significant cost reductions
- Eliminates condensing, storage, transportation and disposal of water
- Minimal fuel gas usage
- Guaranteed zero BTEX emissions

SINGLE UNIT FOR THE ENTIRE SITE

MAINTENANCE AND BLOWDOWNS

- 4.5MMscf/d used for engine/compressor maintenance and unloading, pipeline blowdowns and pigging, ESD's, and PSV's. No flaring or venting at the site.

DEHY, TANK, AMINE VAPORS, PROCESS UNITS

- Unit also combusts low pressure (LP) still column vapors from 3 x 125 MMscfd glycol dehydration processes, flash gas, and tank vapors

WASTE HEAT TO POWER OPPORTUNITY

HARNESS HEAT

- Harness the heat from our combustion unit
- Large quantity of low-grade heat

SUPERIOR TECHNOLOGY

- Zero emissions power
- Simple battery (hot water tank)
- Consistent operation (Available 24/7)
- Small footprint

NET ZERO AT AN OIL BATTERY

- 300 Mscf/d flared at 95% efficiency
- Cleanly combusting the gas at 100% efficiency reduces GHG emissions 2190 t CO_2e/yr.
- Generate 200kW from the waste heat reduces GHG emissions 1000 t CO_2e/yr. At $0.08/kWh this generates a revenue of $140k/yr
- Assuming a 10 year project life
  - Capital $1MM
  - Revenue $1.4MM
  - 31,900 t CO2e reduced at a -$13/t
- Assuming an carbon offset is worth $50/t – 1.6MM or >100% ROI

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OPTIONS TO NET ZERO - CCUS VS METHANE

CCS

- 2 CCS projects in Canada
- Boundary dam - $1.5 billion – 1MMt/yr
- Quest - $1.35 billion – 1MMt/yr

Methane Abatement

- 13 oil battery sites venting associated gas - $8.5MM – 450,000t/yr.
- Costs included 3-200kW waste heat to power units to eliminate diesel power generation
- $20MM – 1MMt/yr

"Methane abatement is the low hanging fruit"

The CO_2 generated from cleanly combusting the methane in an enclosed system can easily be fed to any CCUS facility – a "double benefit impact"

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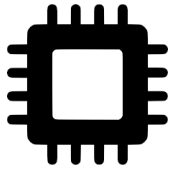
COMMUNITY IMPACT

Nexen in Calgary - 34% H_2S

Compton Petroleum Corporation

ESG Social License

CONTINUOUS EMISSIONS MONITORING



Detection via drones, satellites, handheld devices, and mixed monitors

BTEX

HAP's

VOC's

Methane

Hydrogen Sulphide

Questor unit sensors monitor

Pressure flow Temperature BMS Pilot Status

Predictive emissions monitoring

Transmitting on 30-sec intervals

Emissions Excellence Center

Quantification of Carbon offsets for trading

CLEAN COMBUSTION OPPORTUNITY IN NEW MEXICO

Being able to detect and quantify those emissions and provide abatement solutions such as clean combustion with a stable efficiency would lead to approximately 6.9 Mtonne CO2e/year (based on methane GWP of 25) of emissions avoidance based on the reported average methane emission rate of 310,000 tonne/year [5]. In a voluntary market with the price of carbon at 5 $/tonne CO2e, providing abatement solutions in a holistic approach by identifying the major contributors to the reported emissions and solving the right problem will result in an approximately $ 34.7 M / year of carbon offsets in only New Mexico.

Source: Robertson, A.M.; Edie, R.; Field, R.A.; Lyon, D.; McVay, R.; Omara, M.; Zavala-Araiza, D.; Murphy, S.M. New Mexico Permian basin measured well pad methane emissions are a factor of 5–9 times higher than U.S. EPA estimates. Environ. Sci. Technol. ***2020****, 54, 13926–13934.*

CONCLUSIONS

- *Time for action is now – we know we have a problem*
- *Missed 90%* of the emissions with the current regulations.
- *Flares assumed to be 95-98%* efficient hence perpetuate the status quo
- The *cost effective proven path to reducing GHG emission* - eliminating flaring and venting of methane and waste heat to power energy efficiency solutions
- Low cost abatement technology solutions available - *80% of the way*
- The solution to climate change is counterintuitive – changing one green house gas to another – *methane to CO_2*
- Data has changed the game – no greenwashing
- *Clear performance based regulation*
- *At stake is investment $, market for our products, social licence to operate, our planet*
- Marginalized communities impacted the most

"We need to create the future that our children deserve"

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Questor

Clear Solutions. Clean Skies

PRESENTOR

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President and CEO

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BOOK A MEETING

Scan the QR code for a calendar link

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