MONITOR Program Update

Technology to Quantify Methane Emissions

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ARPA-E

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CHANGING WHAT'S POSSIBLE

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Motivation

- Increasing focus on methane emissions from the oil & gas industries
- Limitations of current detection technology:
  - Expensive (≈$100K)
  - Periodic 1X – 4X per year
  - Does not quantify leakage
- Objectives of of MONITOR program
  - Enable 90% reduction of methane leakage through continuous / frequent measurement
  - Reduce the cost of quantification to level that enables voluntary adoption: 10X+ reduction

Complete & Partial Solutions

Complete measurement systems: *6 projects*

- Systems that include:
  1) Methane emission sensing
  2) Leak rate characterization and data analytics
  3) Provisions for data quality control
  4) Digital communication
  5) Enhanced functionality

parc, A Xerox Company — Palo Alto, CA

PSI Physical Sciences Inc. — Andover, MA

AERIS Technologies — Redwood City, CA

BRIDGER PHOTONICS — Bozeman, MT

IBM — Yorktown Heights, NY

REBELLION PHOTONICS — Houston, TX

Partial measurement systems: *5 projects*

- Nascent technologies that may be too early in the development process for incorporation into a complete system
- Could significantly contribute to meeting system-level objectives
- Primarily envisioned as advances in detector technology or data analytics

THORLABS — Jessup, MD

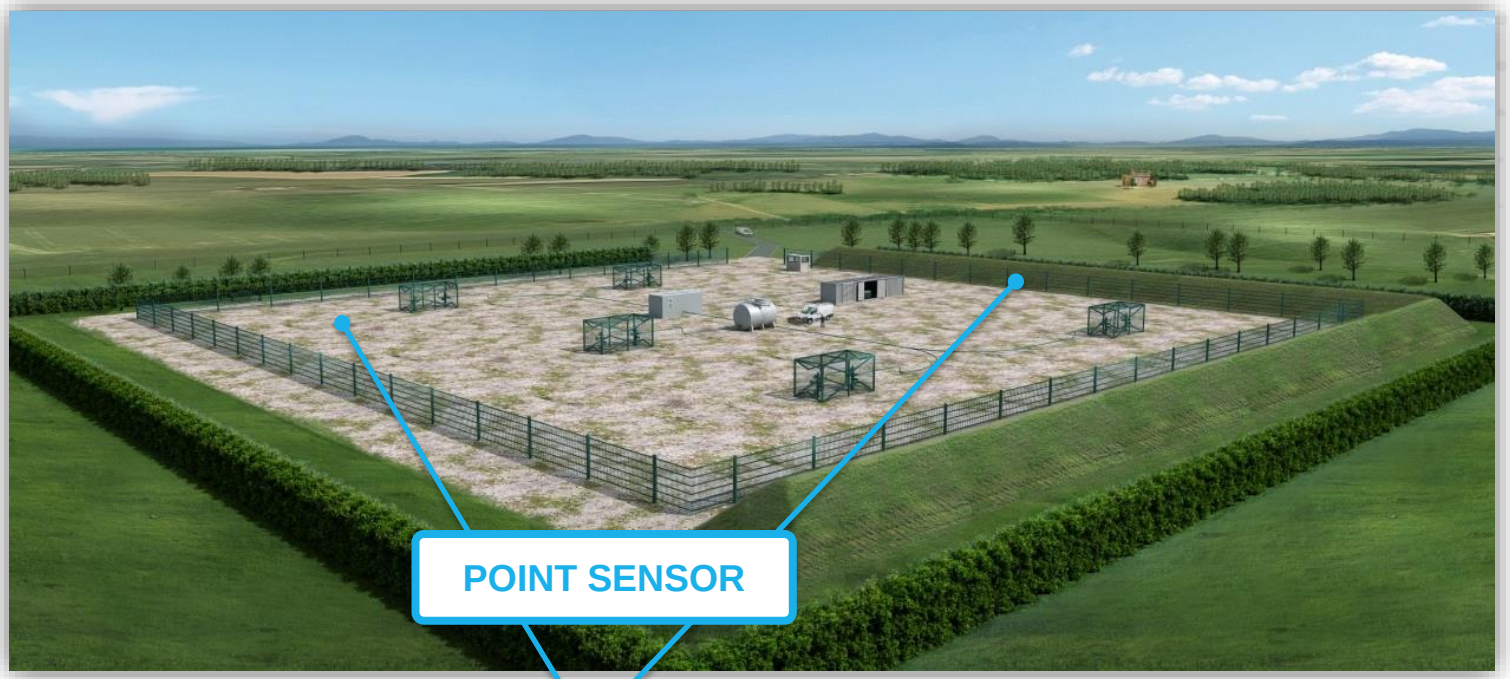
LI-COR — Lincoln, NE

GE — Niskayuna, NY

Duke University — Durham, NC

University of Colorado Boulder — Boulder, CO

Portfolio:
5 Point Sensing Technologies



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IBM
AERIS TECHNOLOGIES
LI-COR

MOBILE

Duke UNIVERSITY
BRIDGER PHOTONICS
REBELLION PHOTONICS
Physical Sciences Inc.

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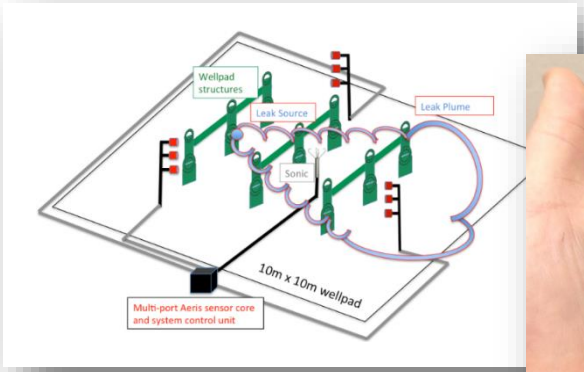
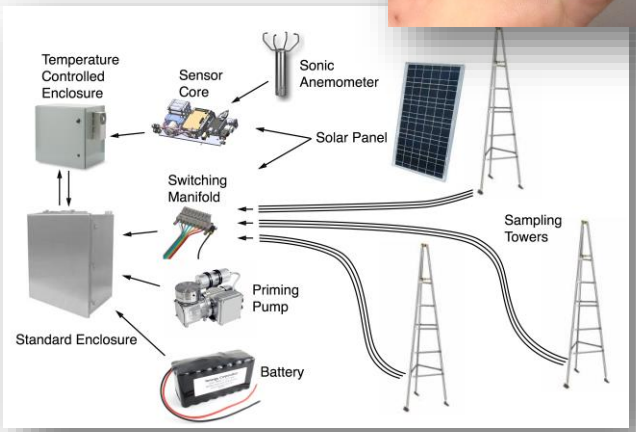
THORLABS

Image courtesy of Cuadrilla Resources

Miniature, High Accuracy Tunable Laser Spectrometer for CH_4/C_2H_6 Leak Detection





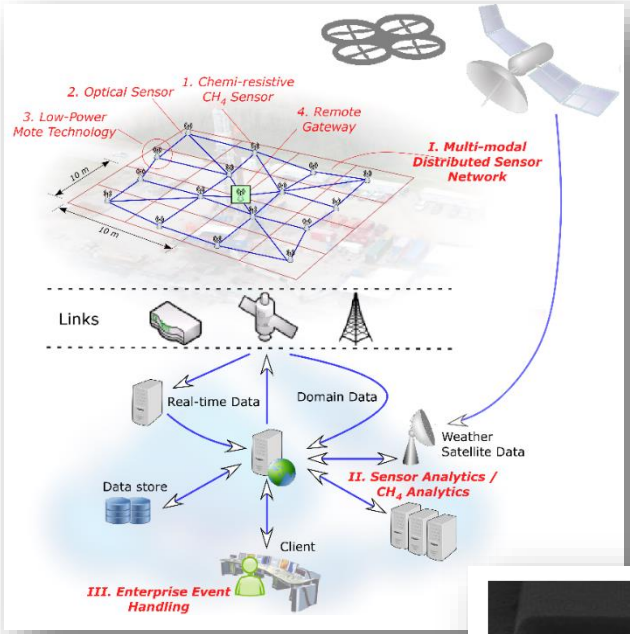
PROJECT HIGHLIGHTS

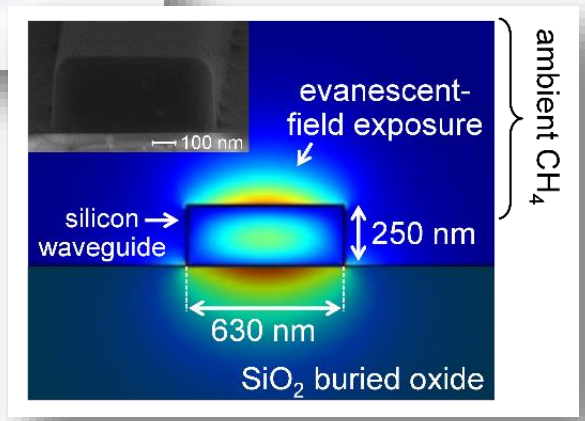
- Enables ppb/s sensitivity via simple and robust direct absorption spectroscopy
- Performance meets/exceeds ICOS or CRDS (<1 ppb at 1 Hz) while being order of magnitude smaller and consuming less power (10-30W)
- Compatible with other industry applications that require high accuracy, real-time analyses (e.g. process control, CEMS, environmental/GHG monitoring)

AWARD AMOUNT: $2.4 million

PROJECT PARTNERS: Los Alamos National Laboratory, Rice University

On-Chip Optical Sensors and Distributed Mesh Networks for Methane Leak Detection





PROJECT HIGHLIGHTS

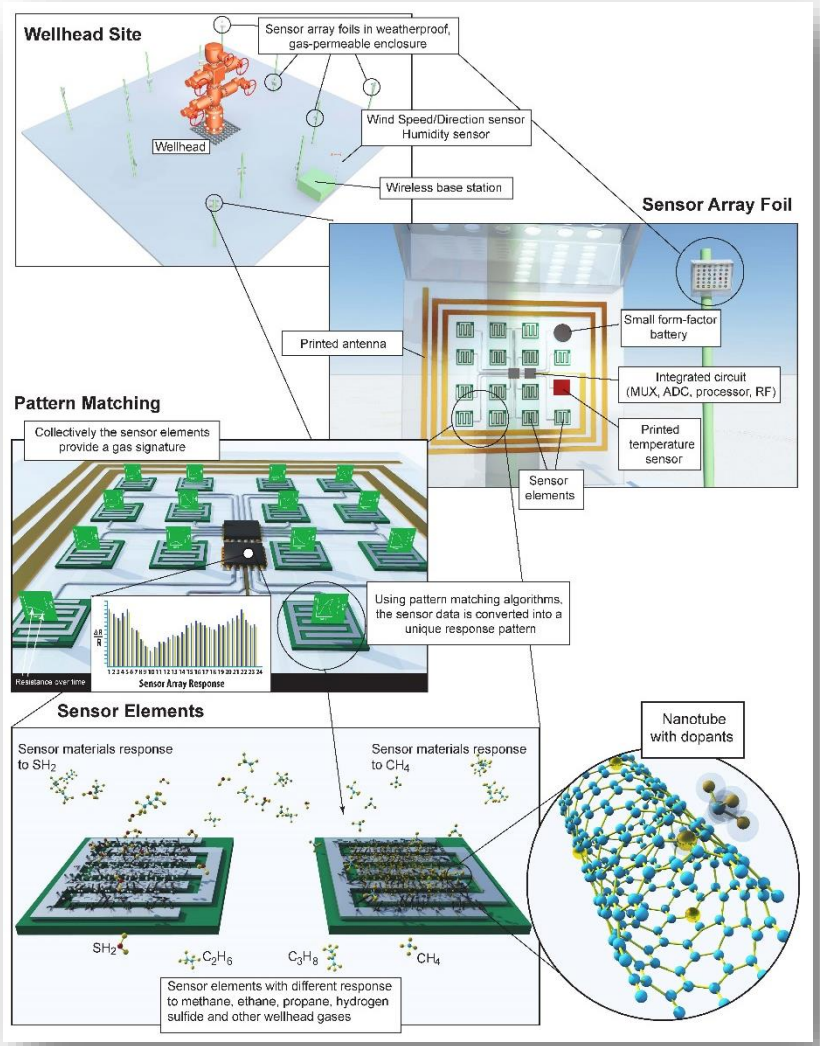
- Developing novel low cost, on-chip optical sensors with high methane selectivity
- State of the art silicon photonics technology for on-chip TDLAS
- Developing system with self-organizing network of low-power motes
- Cloud-based analytics for source detection and localization

AWARD AMOUNT: $4.5 million

PROJECT PARTNERS: Princeton University, Harvard University, Southwestern Energy

Printed Carbon Nanotube Sensors for Methane Leak Detection

parc
A Xerox Company



PROJECT HIGHLIGHTS

- Uses scalable low-cost, additive printing methods to print chemical sensor arrays based on modified carbon nanotubes
- Sensor elements with different responses to methane, ethane, propane and other wellhead gases
- Total system costs under $350 per site per year
- Multiple sensors reduces false positives
- Sensitive to 1 ppm with leak localization within 1 m

AWARD AMOUNT: $3.4 million

PROJECT PARTNERS: NASA Ames Research Center, BP, Xerox Corporation

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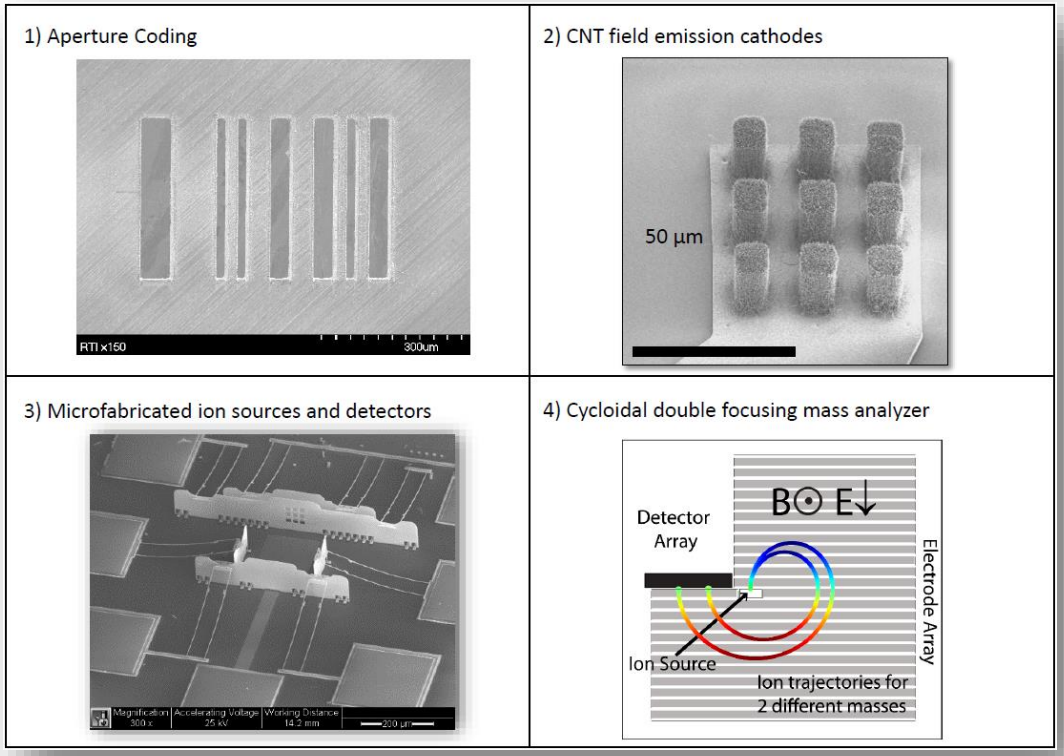
Coded Aperture Miniature Mass Spectrometer for Methane Sensing

Duke UNIVERSITY



PROJECT HIGHLIGHTS

- Miniaturizing a mass spectrometer utilizing microfabrication and aperture coding
- Developing advanced search/location algorithms for optimum sampling
- High selectivity measurements at short detection times for methane as well as VOCs (such as benzene, C2-C7)

AWARD AMOUNT: $2.9 million

PROJECT PARTNERS: RTI International

Portfolio:
2 Long Distance Technologies

University of Colorado Boulder

parc A Xerox Company

IBM

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LI-COR

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BRIDGER PHOTONICS

REBELLION PHOTONICS

Physical Sciences Inc.

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Image courtesy of Cuadrilla Resources

Frequency Comb-based Methane Sensing

University of Colorado Boulder

PROJECT HIGHLIGHTS

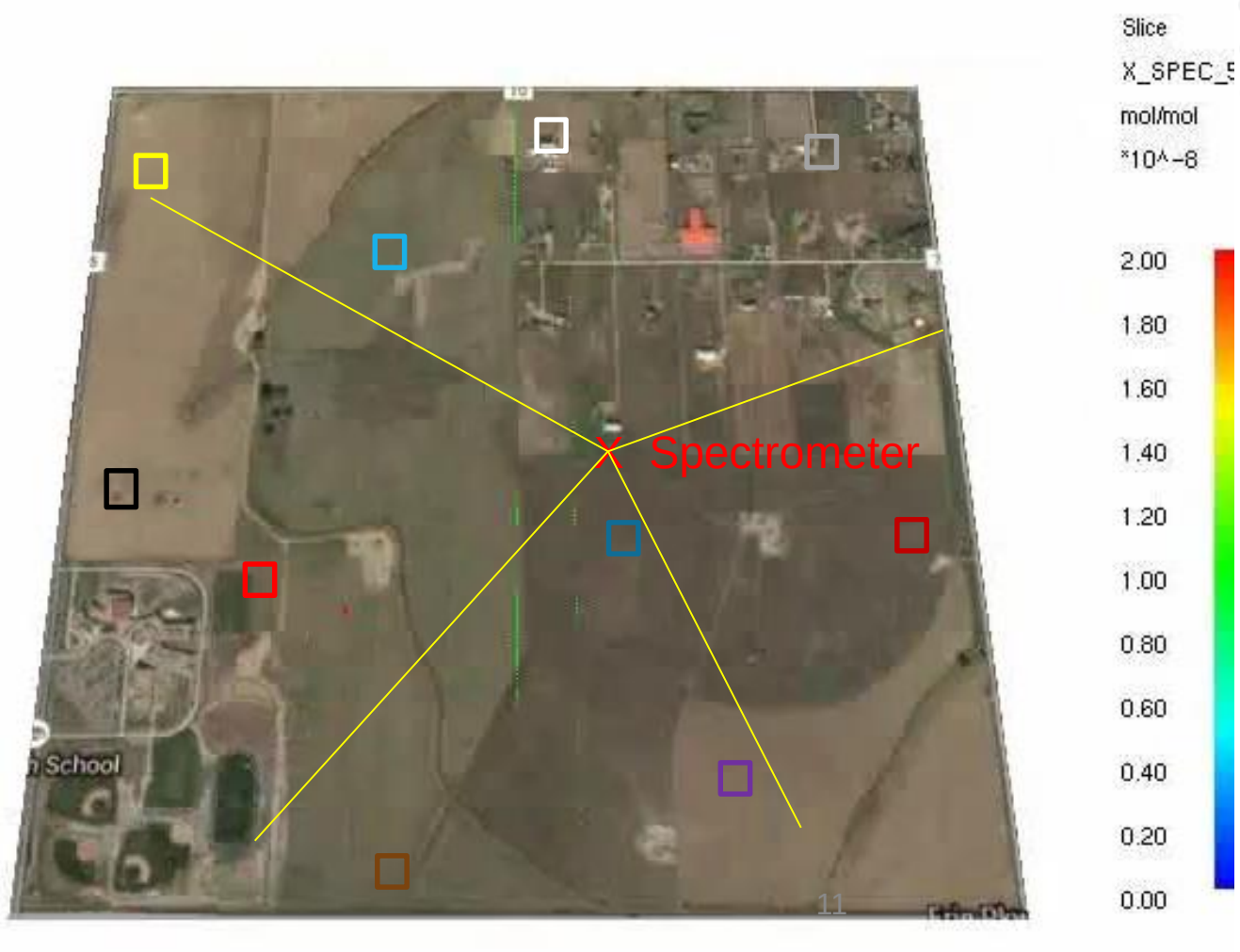
- High sensitivity (ppb-m) kilometer-scale path length measurements with specificity of FTIR
- Simplifying design to reduce the cost of dual comb spectroscopy
- Multispecies sensing includes CH_4, $^{13}CH_4$, H_2O, propane, and ethane
- Coupled to large eddy dispersion modeling to provide localization

AWARD AMOUNT: $2.1 million

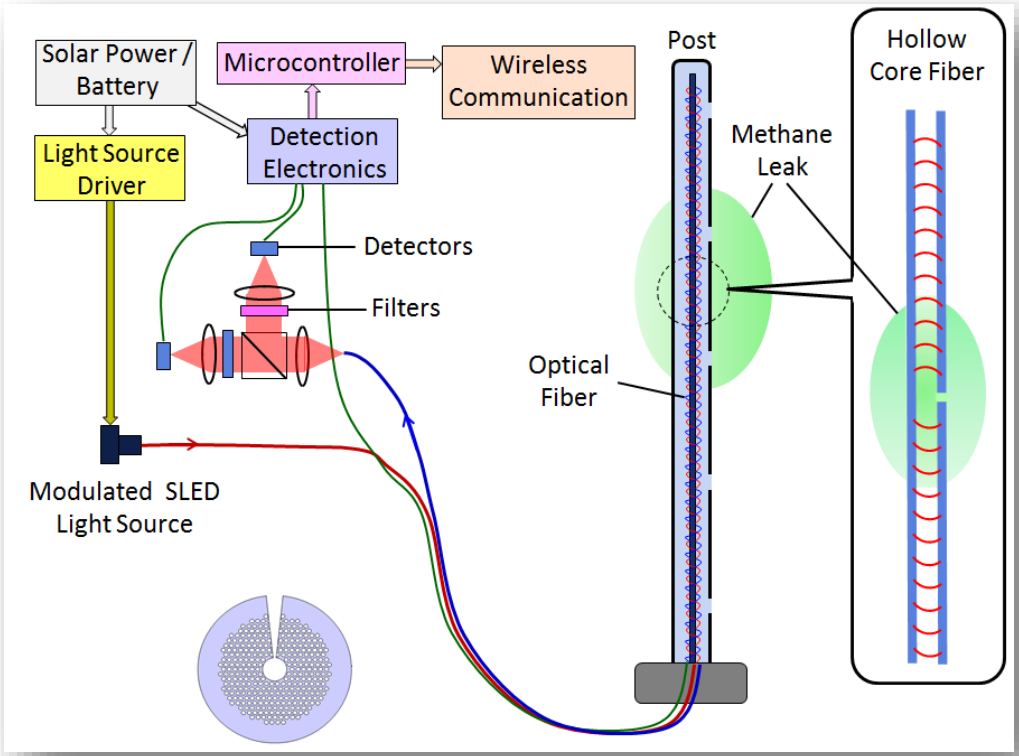
PROJECT PARTNERS: NIST, NOAA

Frequency Comb-based Methane Sensing

University of Colorado Boulder



Microstructured Optical Fiber for Methane Sensing



PROJECT HIGHLIGHTS

- Fiber optic sensor is broadly applicable throughout the oil and gas industry, particularly for large-scale infrastructure (such as transmission lines)
- Photonic crystal fiber design will minimize optical losses while permitting ambient gas to enter hollow core

AWARD AMOUNT: $1.4 million

PROJECT PARTNERS: Virginia Tech

Portfolio:
2 Aerial Technologies

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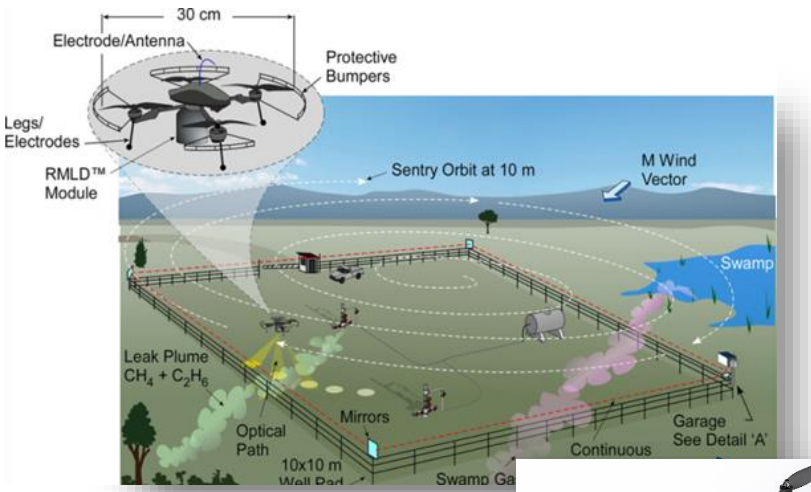
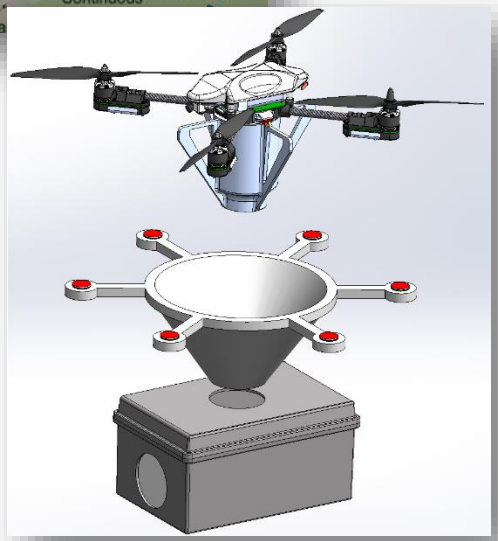
Image courtesy of Cuadrilla Resources

UAV-based Laser Spectroscopy for Methane Leak Measurement

Physical Sciences Inc.





PROJECT HIGHLIGHTS

- Continuous leak monitoring with leak quantification and real-time alarm notification
- Two modes of operation: continuous perimeter monitoring and search mode to pinpoint leak location
- Speciation of methane and ethane differentiates thermogenic vs. biogenic emission
- Improved production processes reduce costs of mid-IR Interband Cascade Laser (ICL) sources

AWARD AMOUNT: $2.9 million

PROJECT PARTNERS: Heath Consultants, Thorlabs, Princeton University, University of Houston, Cascodium

UAV-based Laser Spectroscopy for Methane Leak Measurement

Physical Sciences Inc.

Mobile LiDAR Sensors for Methane Leak Detection

PROJECT HIGHLIGHTS

- Simultaneous, rapid, and precise 3D topography and methane gas sensing
- Capable of covering a broad range: a frequency-swept laser beam is transmitted to a topographical target 1-300 m from the sensor
- Potentially able to achieve a minimum leak rate detection of 1 gram per minute
- Estimated between ~$1,400-2,200 per well per year

AWARD AMOUNT: $1.5 million

Portfolio:
1 Imaging Technology

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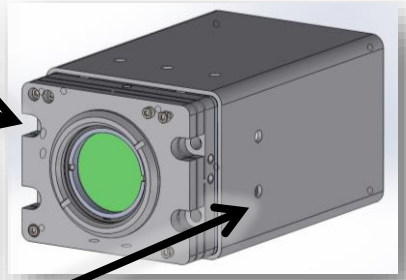
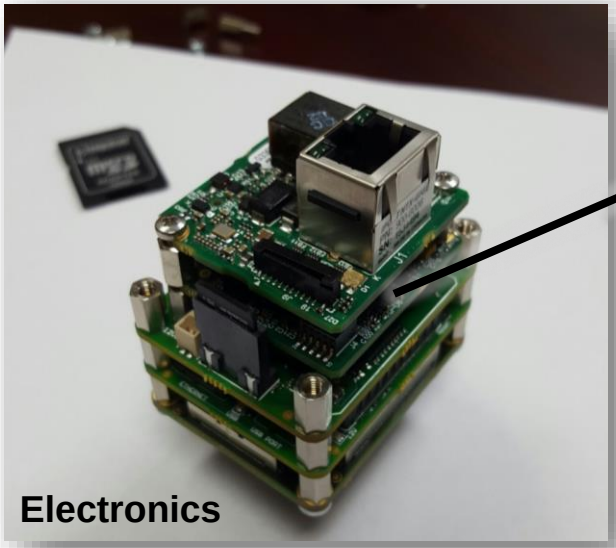
Image courtesy of Cuadrilla Resources

Portable Imaging Spectrometer for Methane Leak Detection

REBELLION PHOTONICS



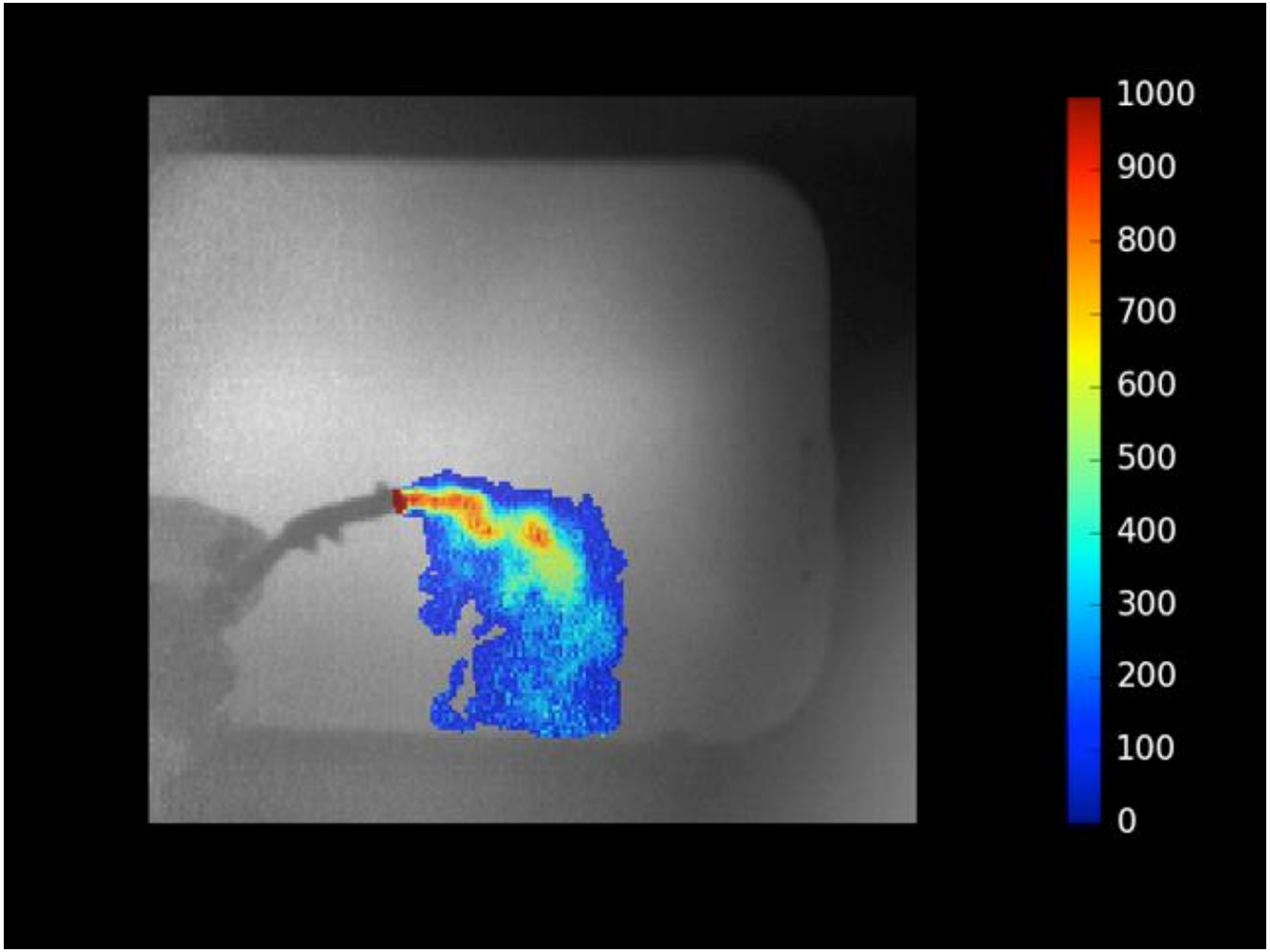


PROJECT HIGHLIGHTS

- Miniaturization of Rebellion's Gas Cloud Imager (GCI), a long-wave infrared imaging spectrometer
- Camera will be lightweight and portable – the size of a Red Bull can - and capable of being incorporated into personal protective equipment
- Data processing uses cloud-based computing architecture that streams results to mobile device

AWARD AMOUNT: $4.3 million

1st GoGCI Results!



Portfolio:
1 Enabling Technology

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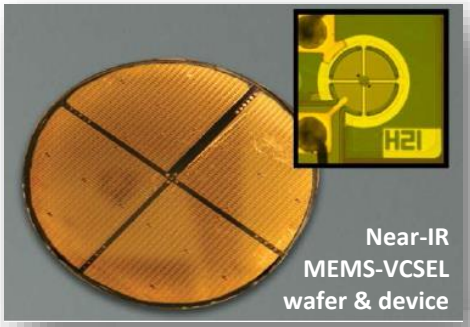
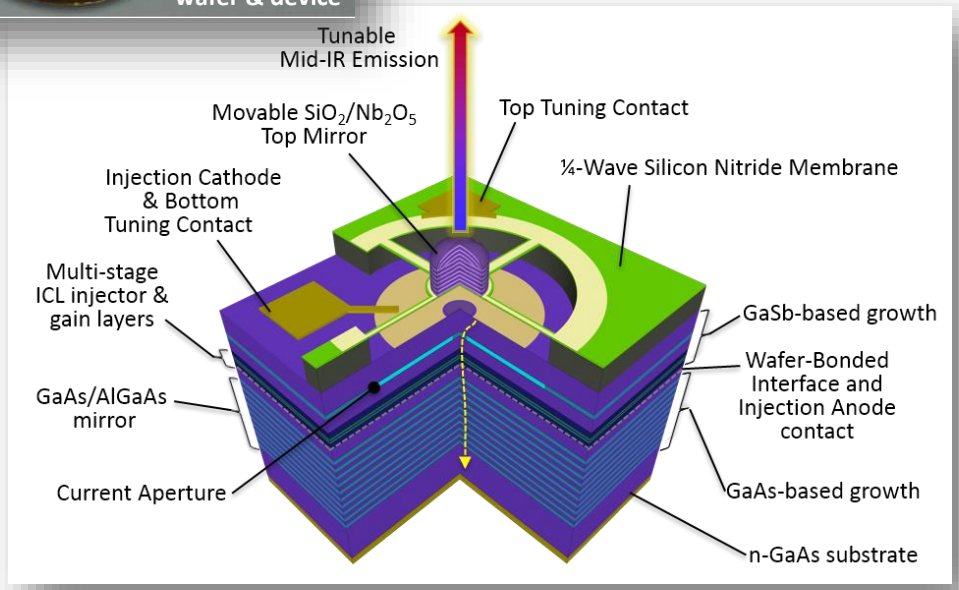
Image courtesy of Cuadrilla Resources

Tunable Mid-infrared Laser for Methane Sensing





PROJECT HIGHLIGHTS

- Innovative, low-cost mid-IR laser with VCSEL architecture
- Integrated micro-electro-mechanical system (MEMS) mirror enables a wide tuning range
- Approximately 40x reduction in laser cost, applicable across a wide array of sensors and applications

AWARD AMOUNT: $1.9 million

PROJECT PARTNERS: Thorlabs Quantum Electronics, Praevium Research, Rice University

MONITOR Program Timeline

(Dates nominal)

2015

Q3	Projects under contract
May	Program kickoff meeting, Denver

2016

Q3	Performers must demonstrate functionality of all major systems at the performer's site
May	Annual MONITOR program meeting, Houston
Q4	Development of the MONITOR field test site

2017

Q3	Performers must demonstrate ability of their systems to meet preliminary metrics at the MONITOR field test site
May	Annual MONITOR program meeting, TBD

2018

Q3	Performers must demonstrate ability of their systems to meet final metrics at the MONITOR field test site
May	Final MONITOR program meeting, TBD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