Methane quantification & ARPA-E's MONITOR Program

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CHANGING WHAT'S POSSIBLE

Nov 18, 2015

Outline

- **Monitoring technology**
- Introduction to ARPA-E
- ARPA-E's MONITOR program
- MONITOR portfolio
- Field Testing & schedule
- Other development efforts

U.S. regulatory requirements for monitoring

Safety – related

1968	Requirements for transmission pipelines to survey for leakage / safety

VOC / HAPS

2004	ZZZZ / NESHAP rule on HAPs, primarily formaldehyde
2012	OOOO NSPS for VOCs

Greenhouse gas mitigation

2014	Colorado AIMM rule: Approved Instrument Monitoring Method (AIMM) iLDAR using infra-red camera, EPA Method 21, or other approved; others followed
2015	Draft EPA methane rule, ammending VOC NSPS to include methane
2015	Draft BLM methane rule

Detection vs. Quantification

Detection

- Basis of LDAR
- Disincentive for improved technology
- Requires on-site operator
- Variability between operators
- Periodic: annual, biannual, or quarterly

Concentration quantification

- Provides numerical value of volume concentration
- Concentration varies with location along plume, windspeed, etc.
- Little additional value over detection

Mass flow quantification

- Provides numerical value of mass flow rate of leakage
- Can be used to prioritize mitigation
- Can be used for inventories
- Can use:
  - Concentration + wind + dispersion model
  - Visualization + image processing
- Enabled by new technology

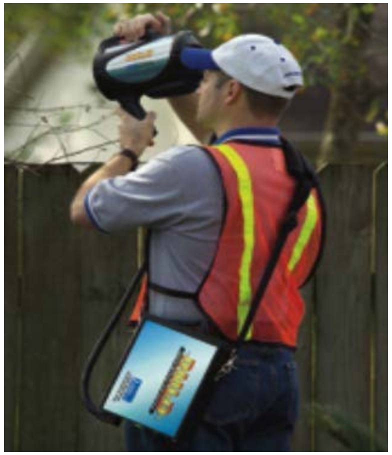
The case for quantification

- To date, regulatory and industry focus has been on detection of leaks, without quantification
- Quantification of individual leaks has been possible – using hi-flow sampler or bagging
- Cost-effective quantification of emissions from entire sites has not been possible

Current Detection / Monitoring Technology

Point sensors

- High resolution / high cost ($100K) – Cavity ringdown, tunable laser diode absorption spectrometer (TLDAS)
- Mid resolution / mid cost ($10K - $50K) – Flame ionization, non-dispersive infrared
- Low resolution / low cost (<$10K) – Catalytic sensors, electrochemical sensors



Path Sensors

- Backscatter TLDAS (tunable laser spectrometer) ($50K)

Mass Sensor

- High flow sampler – pump with an IR ($25K)

Optical Gas Imaging

- Crycooled single-band IR camera ($100K)
- Multi-band IR camera ($250K+)

Assessment of State-of-the-art

What exists

- Focused on detection
- Equipment is expensive, labor is expensive
- Periods between inspections of 3-12 months; cannot catch “fat-tail” events in timely manner

What’s needed

- Continuous or near-continuous quantification solutions at 10X – 100X lower total operating costs

Why it’s hard

- Requires significant advances in sensor technology
- Requires significant advances in dispersion modeling
- Business model obstacle: current regs based on optical imaging for detection and immediate repair; no consideration of threshold analysis & prioritization

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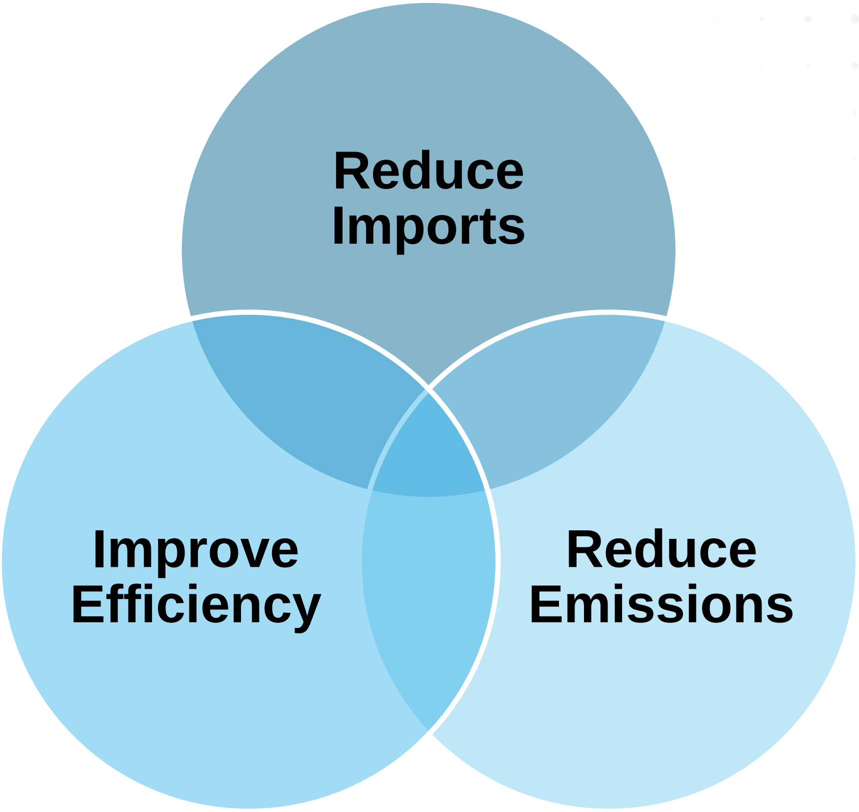
The ARPA-E Mission

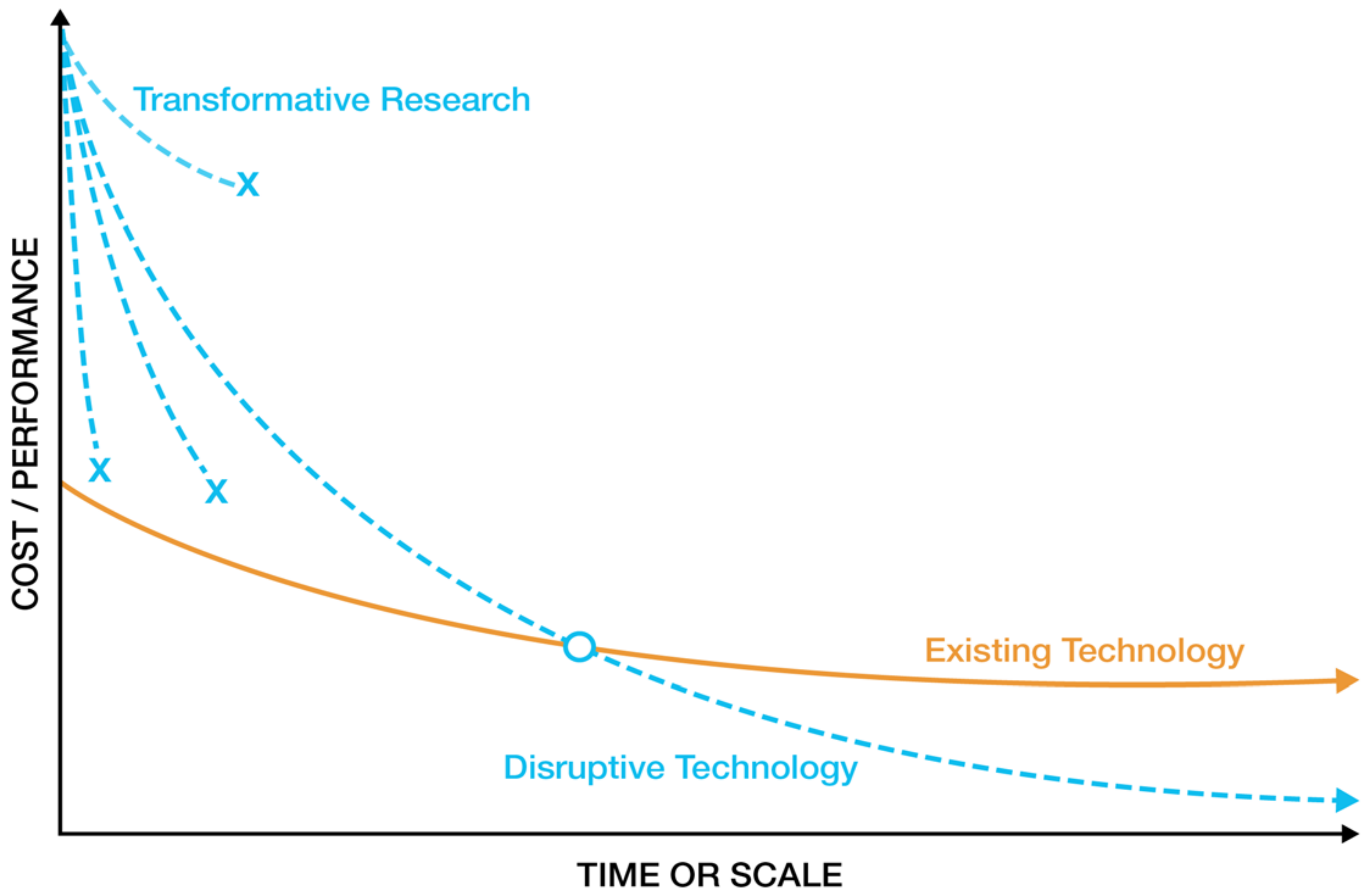
Catalyze and support the development of transformational, high-impact energy technologies

Ensure America's

- Economic Security
- Energy Security
- Technological Lead



Creating New Learning Curves



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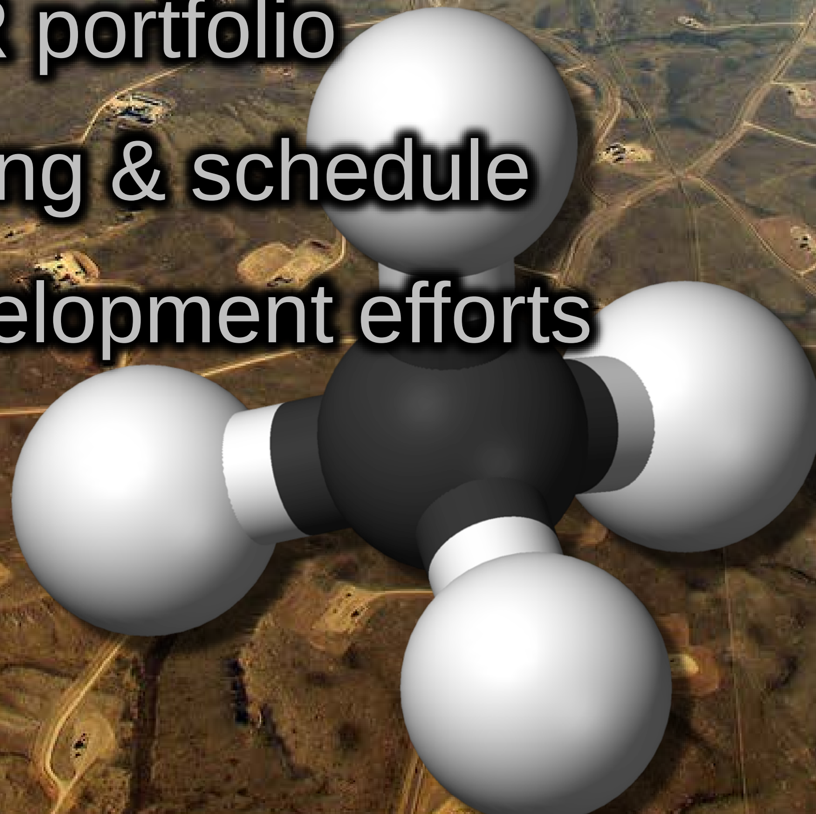
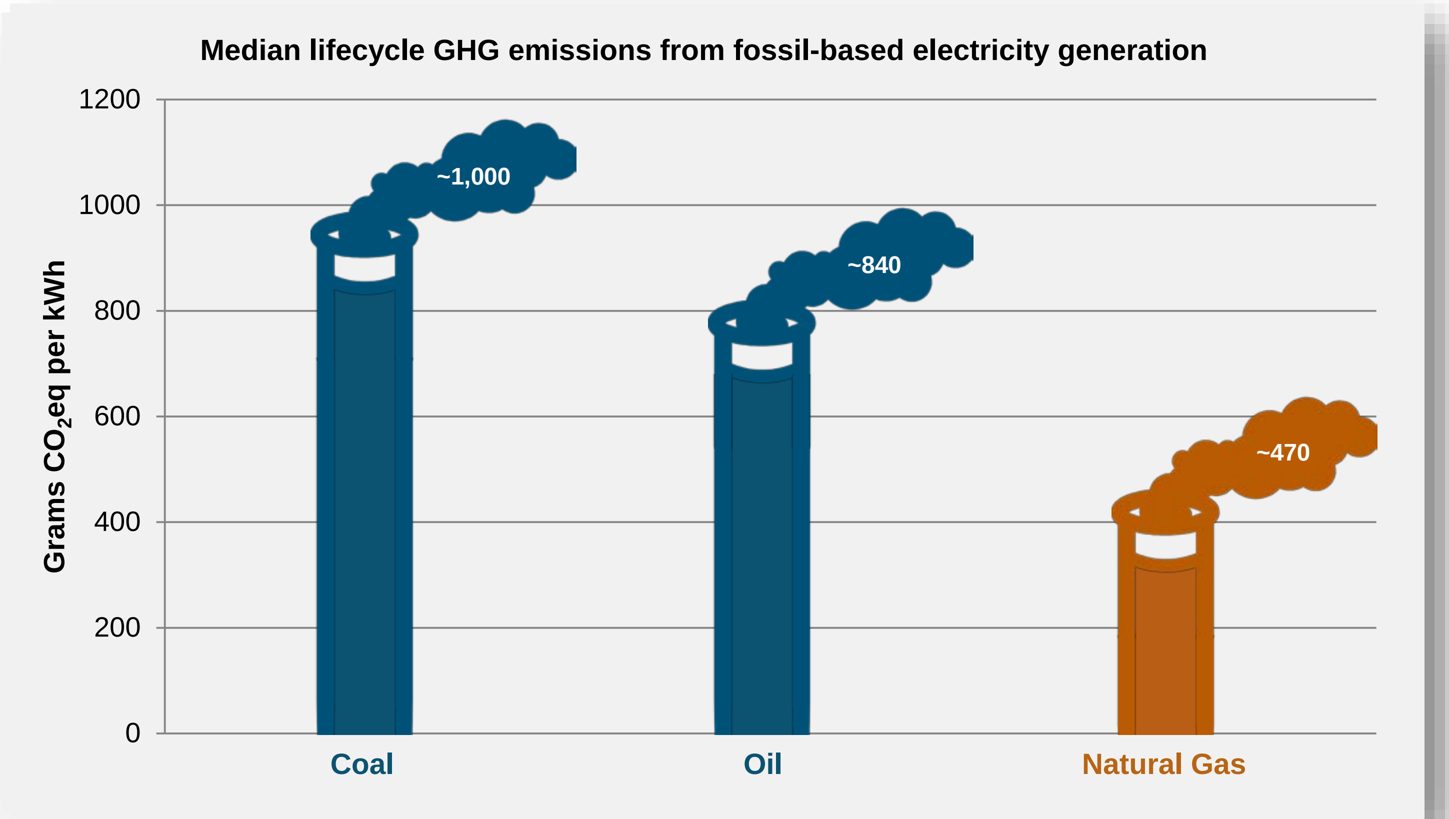


The Environmental Case for Natural Gas

On a lifecycle basis, natural gas emits nearly half the level of greenhouse gases as coal when burned; the challenge is ensuring that environmental risks throughout the supply chain are effectively mitigated

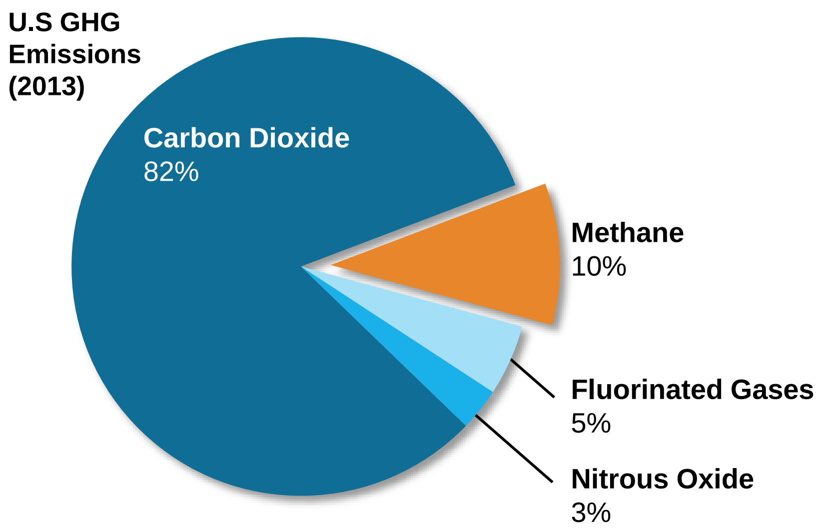


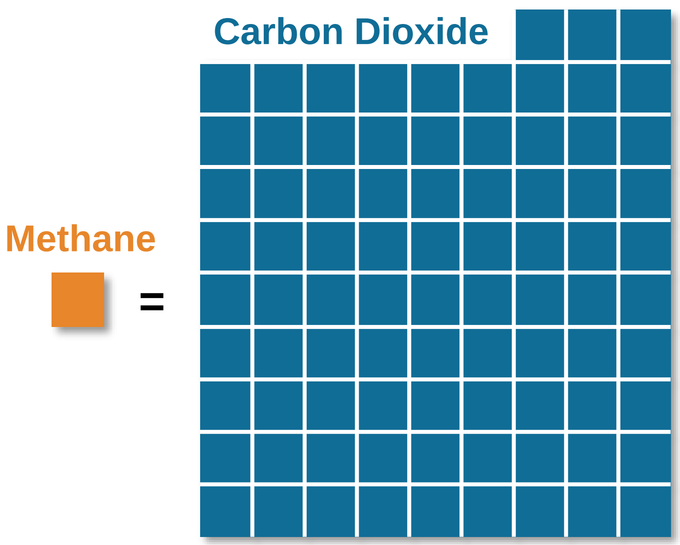
Source: IPCC AR4 Annex II (2007)

The Importance of Focusing on Methane

Methane – the main component of natural gas – accounts for about one-tenth of U.S. greenhouse gas emissions

However, over a 20-year period, one gram of methane has 84 times the global warming potential as the same amount of carbon dioxide





Source: EPA Greenhouse Gas Inventory, IPCC AR5 (2013)

Today's Methane Sensing Solutions

?

Ability to Locate Leaks ✓

Low Cost ✗

Ability to Quantify ✗

Tomorrow's Methane Detection Solutions

CH_4
SCFH

Ability to Locate Leaks ✓

Low Cost ✓

Ability to Quantify ✓

MONITOR Metrics & Targets

Detection Threshold	1 ton per year (6 standard cubic feet per hour)
Cost	$3,000 per site per year (for basic functionality)
Resulting Leak Reduction	90% methane leakage reduction with a 90% confidence level
False Positives	No more than 1 per year
Mass Flow Rate	Able to estimate mass flow rate within 20% margin of error
Leak Location	Able to estimate location within 1 meter
Communications	Transmits results wirelessly to remote receiver
Enhanced Functionality	Methane selectivity, speciation capability, thermogenic/biogenic differentiation, continuous measurement, enhanced stability

Complete & Partial Solutions to Detection

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

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LI-COR
Lincoln, NE

GE
Niskayuna, NY

Duke UNIVERSITY
Durham, NC

University of Colorado Boulder
Boulder, CO

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The Portfolio: 3 Technology Categories

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IBM
GE
AERIS Technologies
LI-COR

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Duke University
Bridger Photonics
Rebellion Photonics
PSI Physical Sciences Inc.

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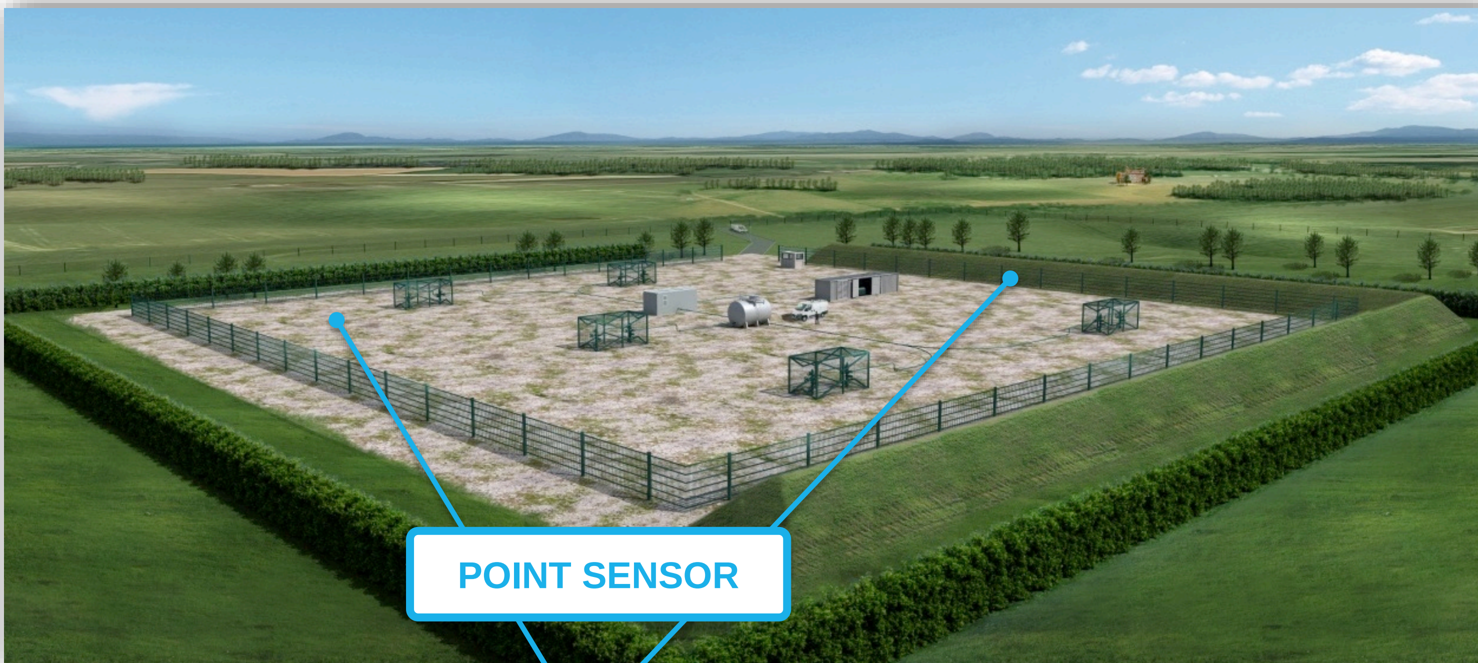
Image courtesy of Cuadrilla Resources

The Portfolio: 3 Technology Categories



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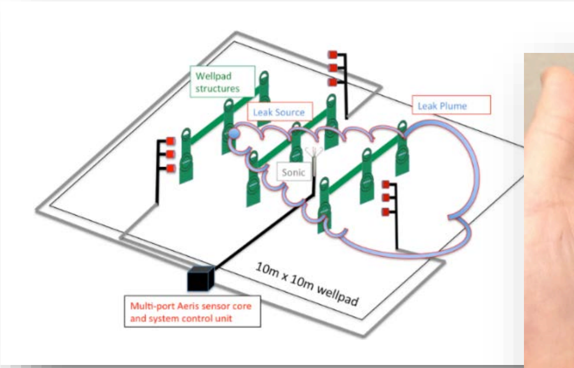
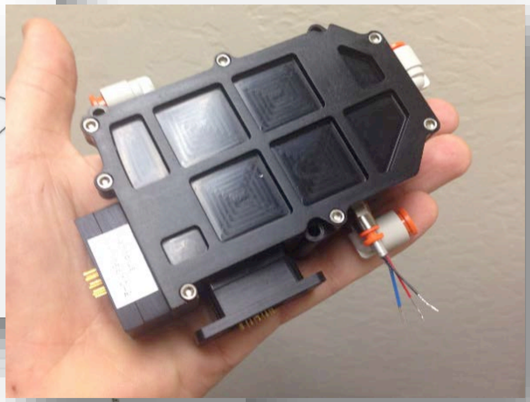
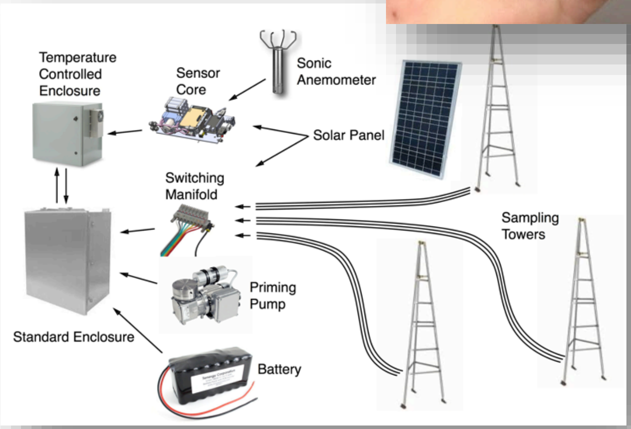
Miniature, High Accuracy Tunable Laser Spectrometer for CH_4/C_2H_6 Leak Detection







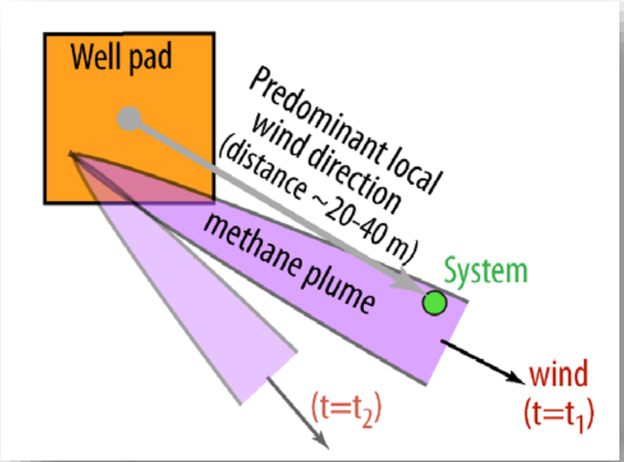
PROJECT HIGHLIGHTS

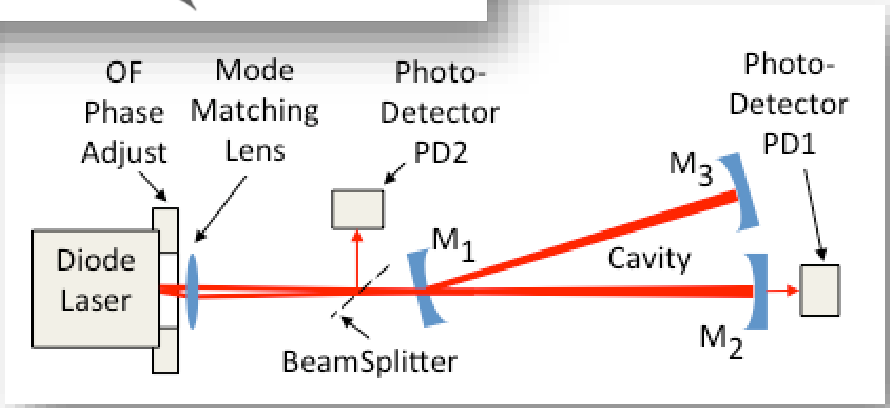
- Enables ppb/s sensitivity via simple and robust direct absorption spectroscopy
- Performance meets/exceeds ICOS or CRDS (<1 ppb at 1 Hz) while being order of magnitude smaller and consuming less power (10-30W)
- Compatible with other industry applications that require high accuracy, real-time analyses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

AWARD AMOUNT: $2.4 million

PROJECT PARTNERS: Los Alamos National Laboratory, Rice University

Laser Spectroscopic Point Sensor for Methane Leak Detection





PROJECT HIGHLIGHTS

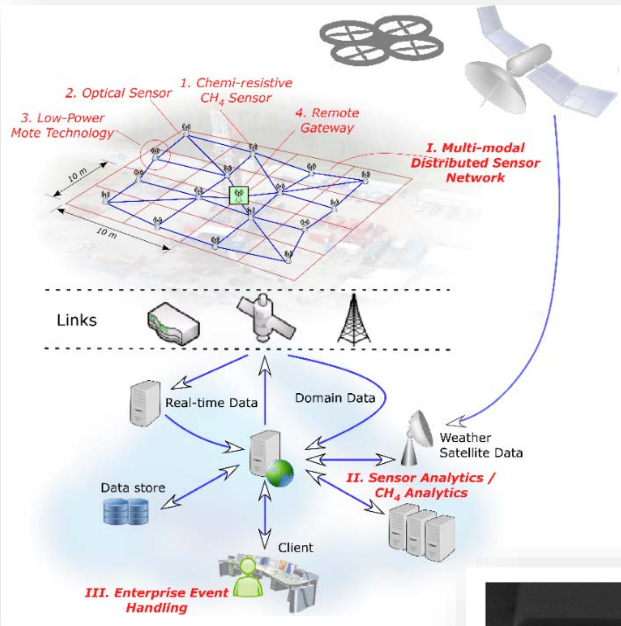
- Performance of state of the art cavity-based point sensors at reduced cost
- High sensitivity, selectivity, and stability measurements with low maintenance
- Suitable for continuous or intermittent stationary and mobile applications
- Advanced manufacturing and novel design enable significant cost reductions

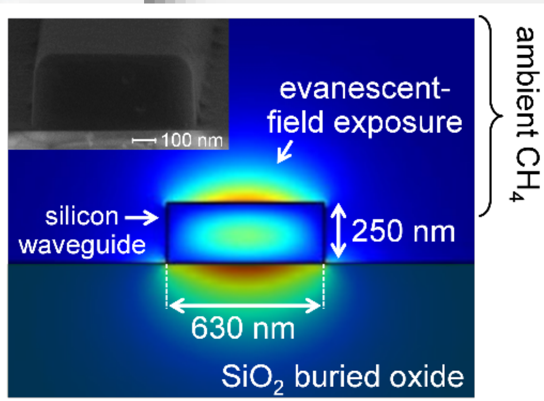
AWARD AMOUNT: $2.85 million

PROJECT PARTNERS: Colorado State University, Gener8

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

IBM





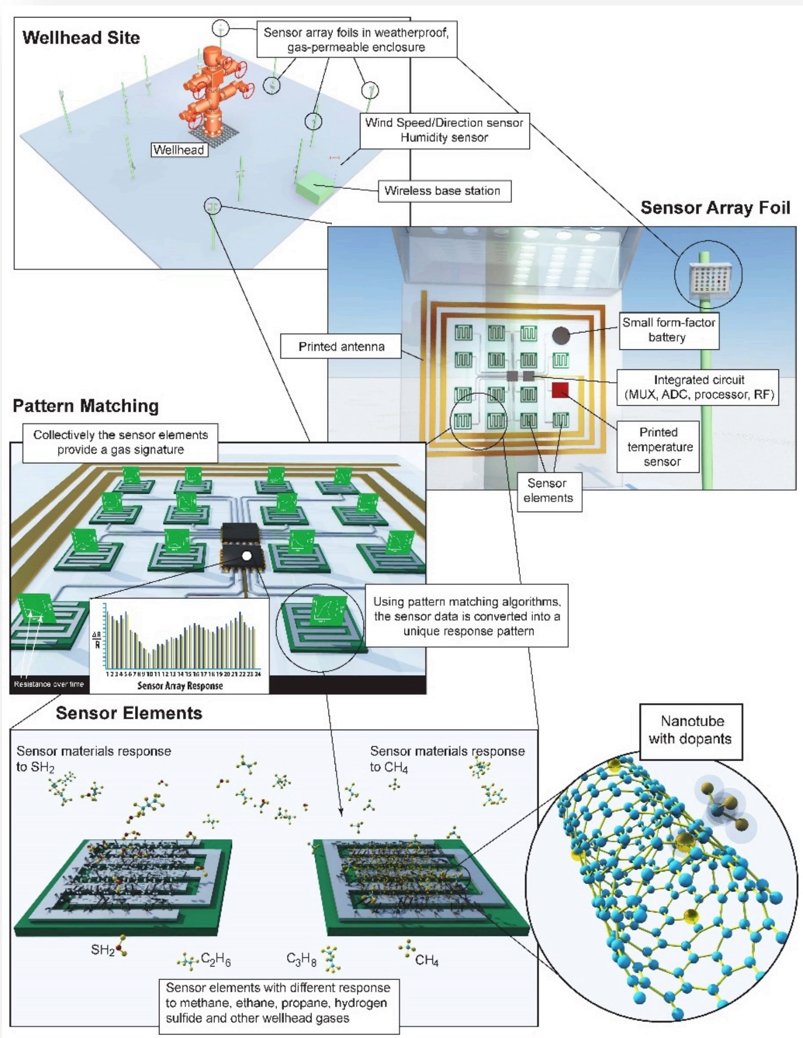
PROJECT HIGHLIGHTS

- 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



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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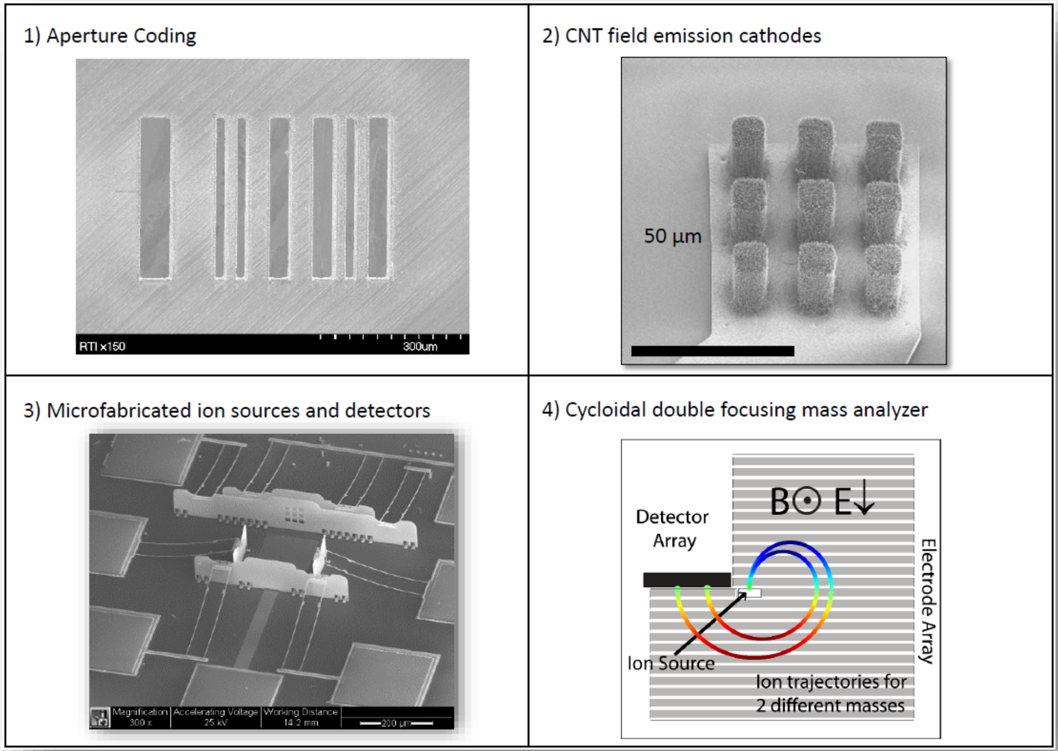
Coded Aperture Miniature Mass Spectrometer for Methane Sensing

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

The Portfolio: 3 Technology Categories

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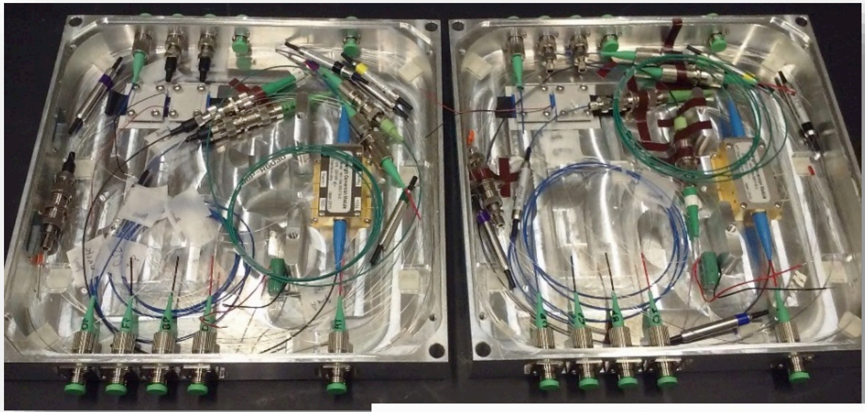
Frequency Comb-based Methane Sensing

University of Colorado Boulder



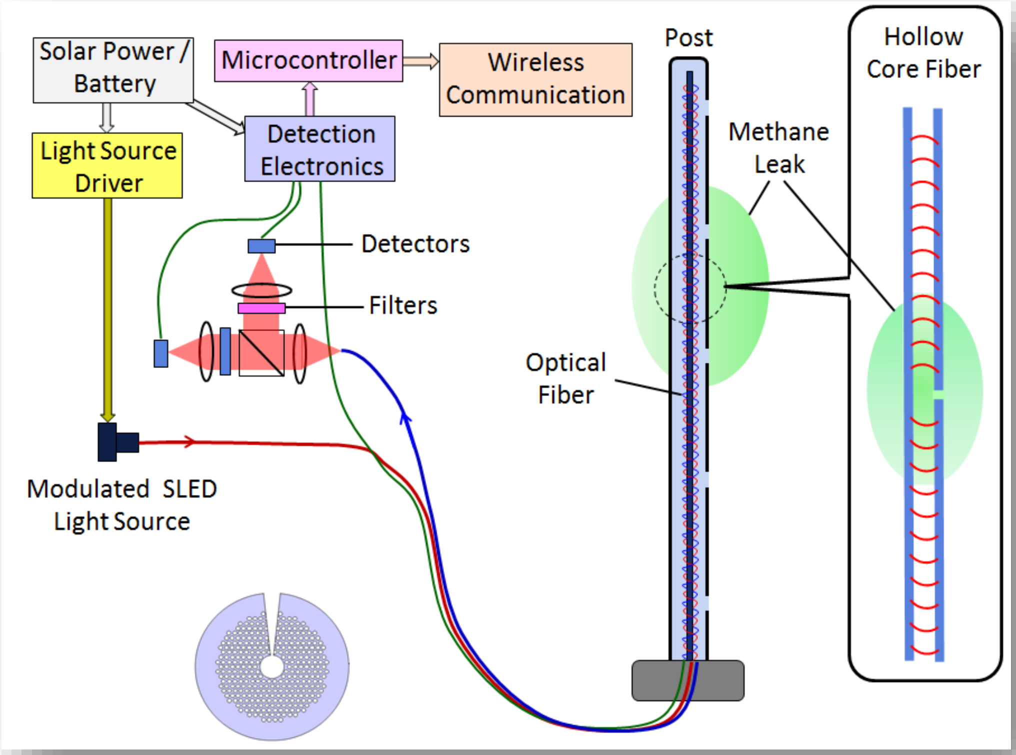
PROJECT HIGHLIGHTS

- 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

Microstructured Optical Fiber for Methane Sensing



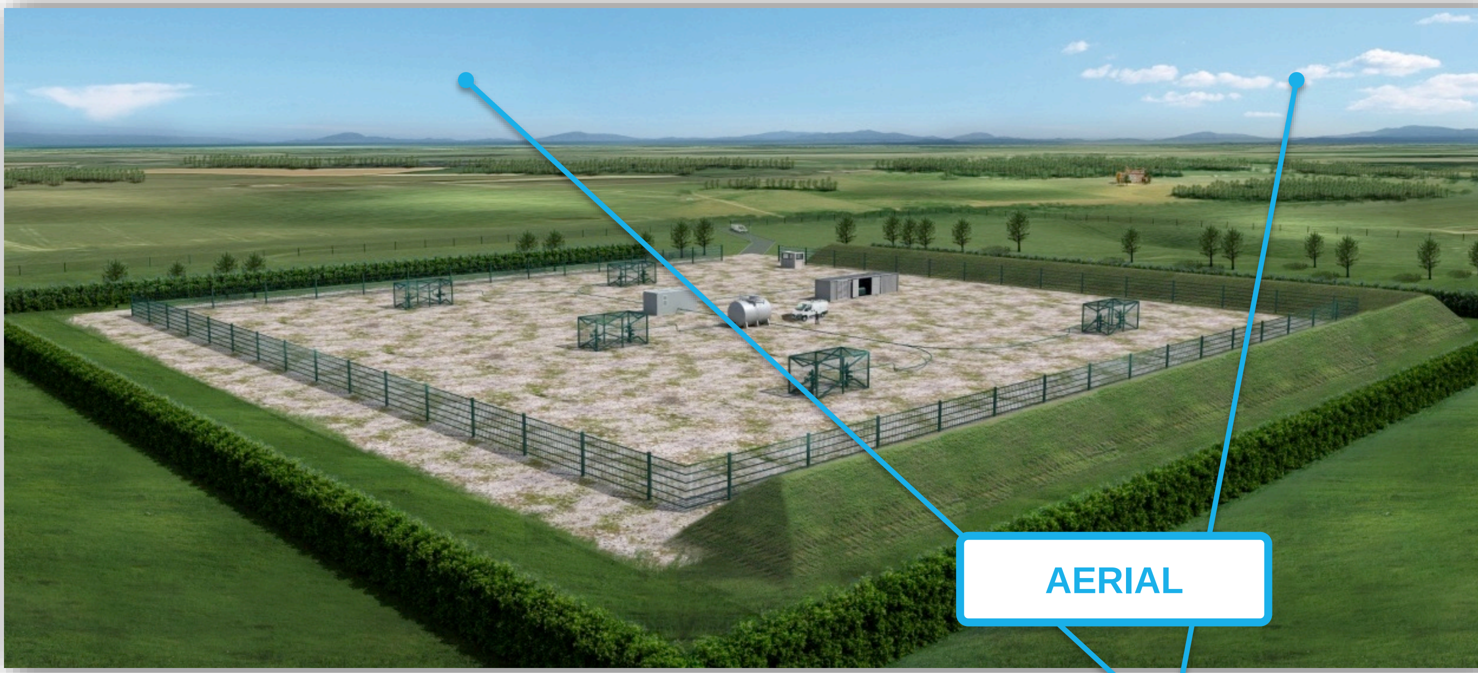
PROJECT HIGHLIGHTS

- 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

The Portfolio: 3 Technology Categories



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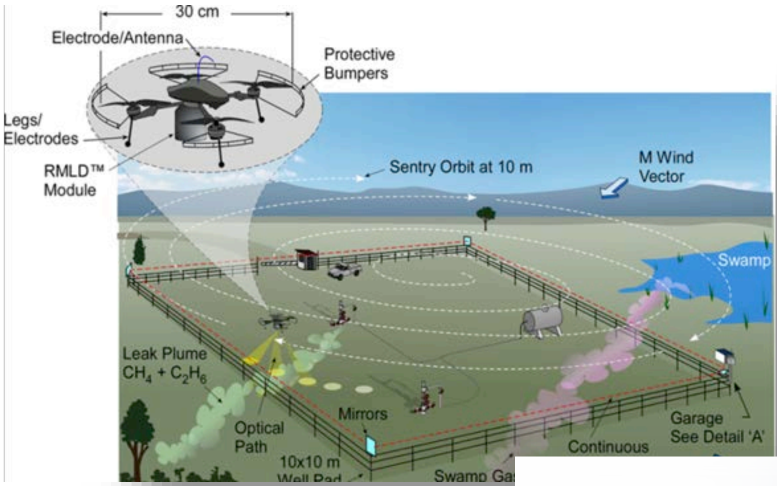
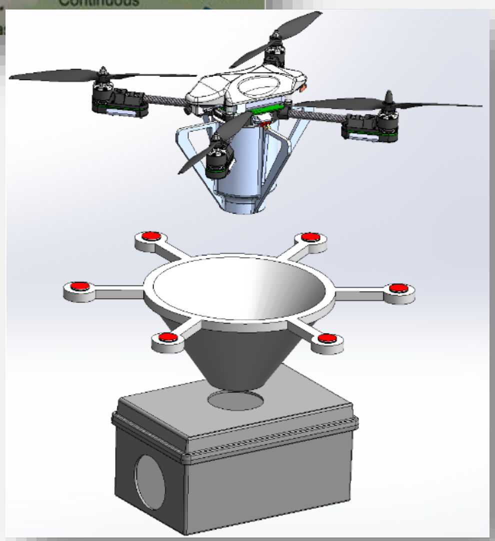
UAV-based Laser Spectroscopy for Methane Leak Measurement

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

Mobile LiDAR Sensors for Methane Leak Detection

BRIDGER PHOTONICS

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

The Portfolio: 3 Technology Categories

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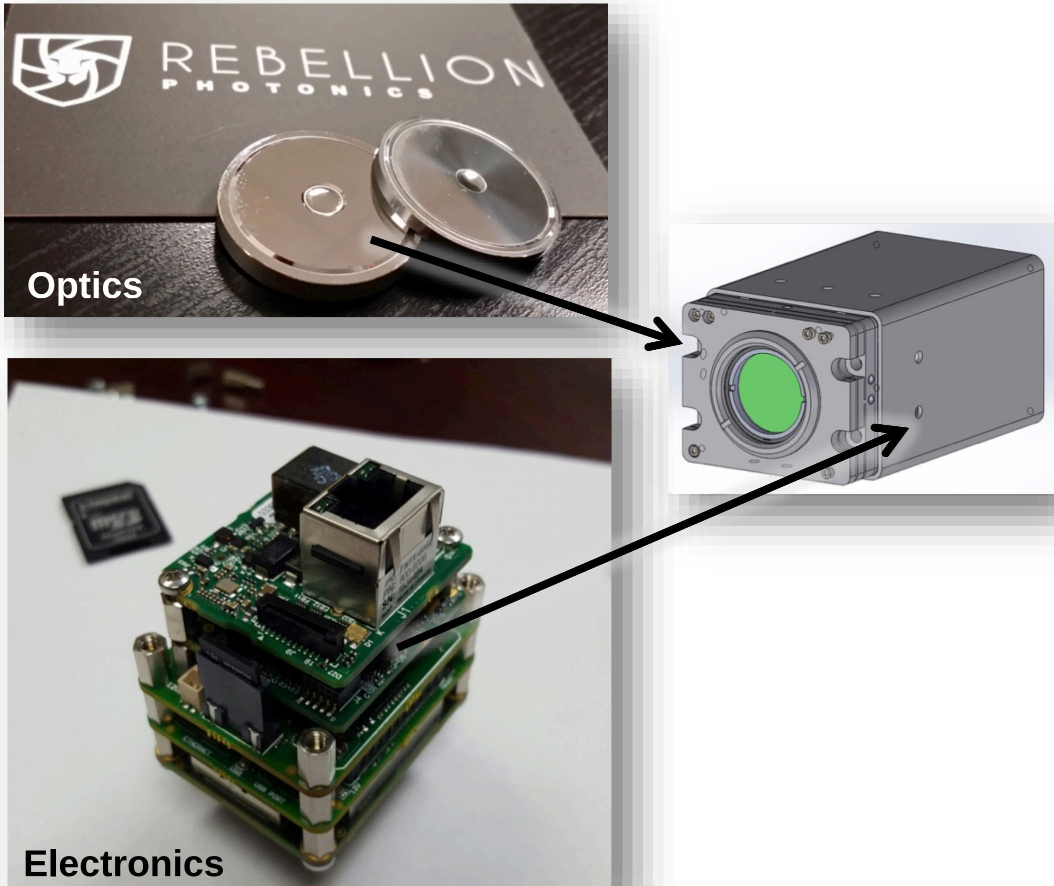
Portable Imaging Spectrometer for Methane Leak Detection

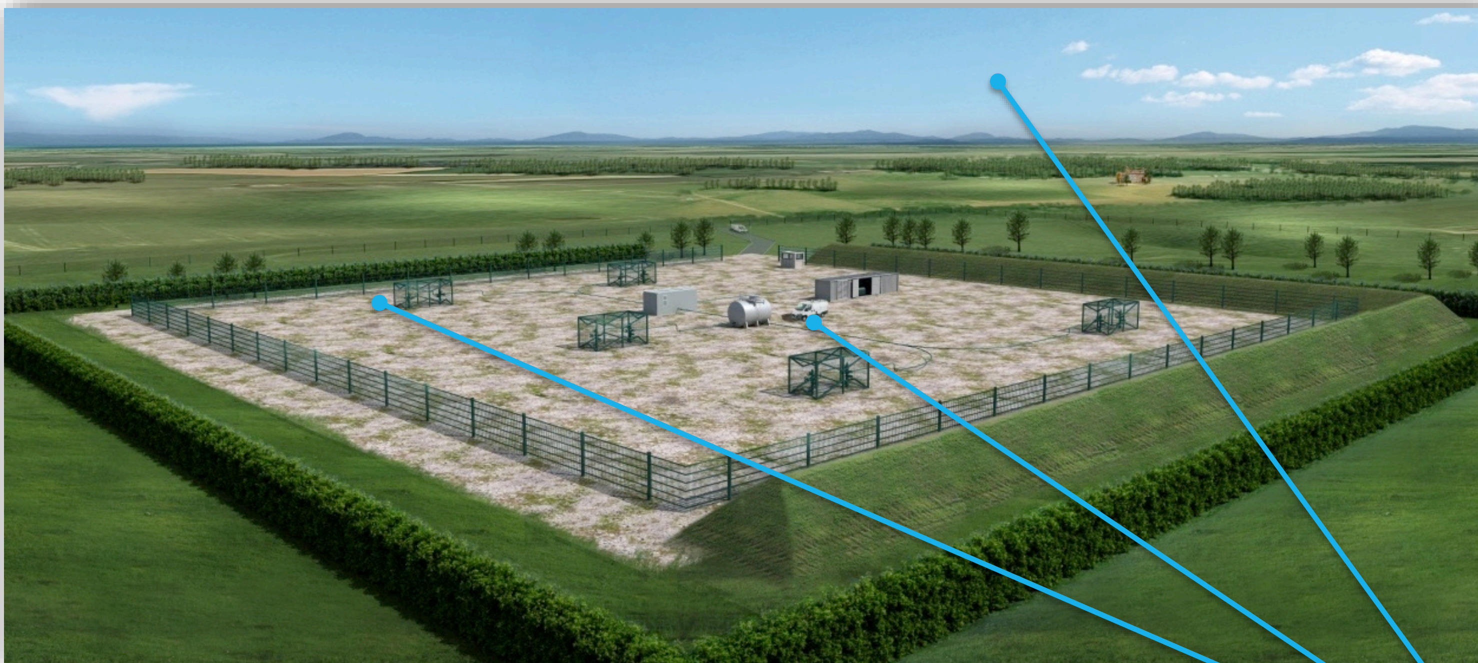


PROJECT HIGHLIGHTS

- 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

The Portfolio: 3 Technology Categories



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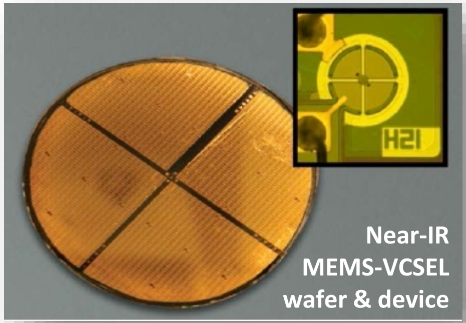
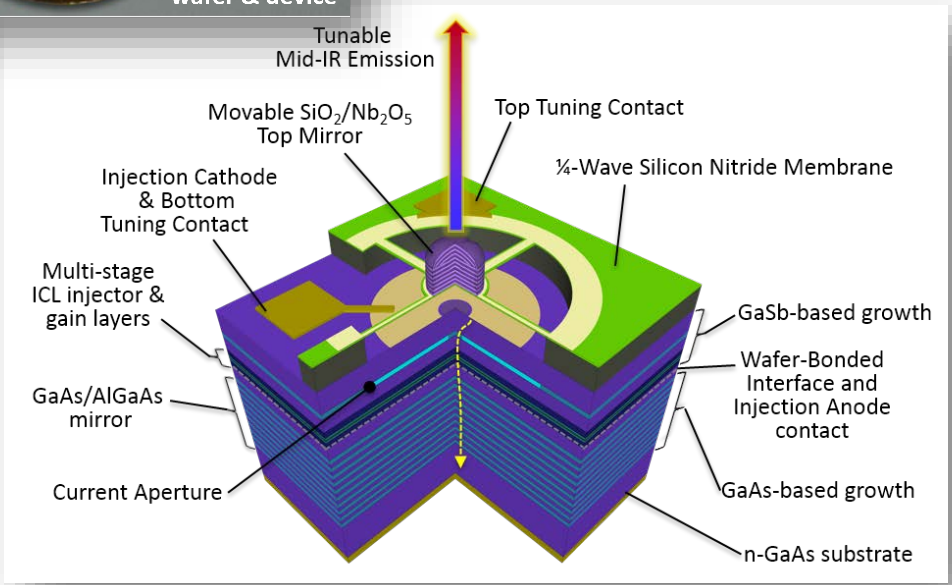
Tunable Mid-infrared Laser for Methane Sensing

MAXION TECHNOLOGIES, INC.
A wholly-owned subsidiary of Thorlabs, Inc.





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

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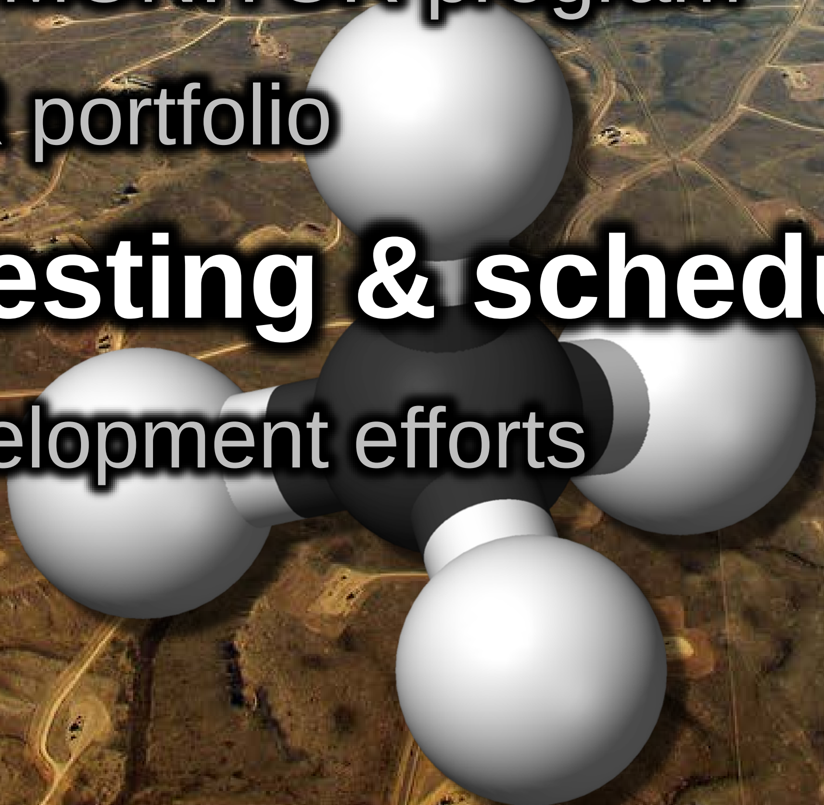

Field Testing of MONITOR Technologies

Goal #1: *Gauge technical performance*

- Independent testing and validation will provide a neutral venue to demonstrate technology and system performance
- **First round testing** (year two) will provide an opportunity to demonstrate technologies outside of laboratory tests; this will ensure technologies are tested in a standardized, realistic environment
- **Second round testing** (year three) will provide an opportunity to assess previously undemonstrated capabilities, as well as technical gains made since the first round of testing

Goal #2: *Engage stakeholder community*

- Establishing a testing site also enables MONITOR to materially engage strategic stakeholders early in the program
- This early engagement with industry leaders could facilitate hand-offs and/or post-MONITOR field demonstrations by developers and/or local distribution companies

Selecting a Field Test Site

ARPA-E will issue a competitive solicitation seeking proposals from highly qualified organizations and will then select a suitable field test host based on the following general criteria:

Technical expertise	**Strong capabilities related to testing, evaluating, and validating emissions detection technologies**
Experience	**Extensive work in the O&G sector, preferably focused on methane emissions detection and/or mitigation**
Reputation	**Recognized for high-caliber work**
Industry exposure	**Familiarity with major O&G industry players**
Impartiality	**Independent and objective**
Government experience	**Experience working with federal entities in research partnerships**
Proximity	**Convenient for ARPA-E and performers; relatively easy access to major airport**

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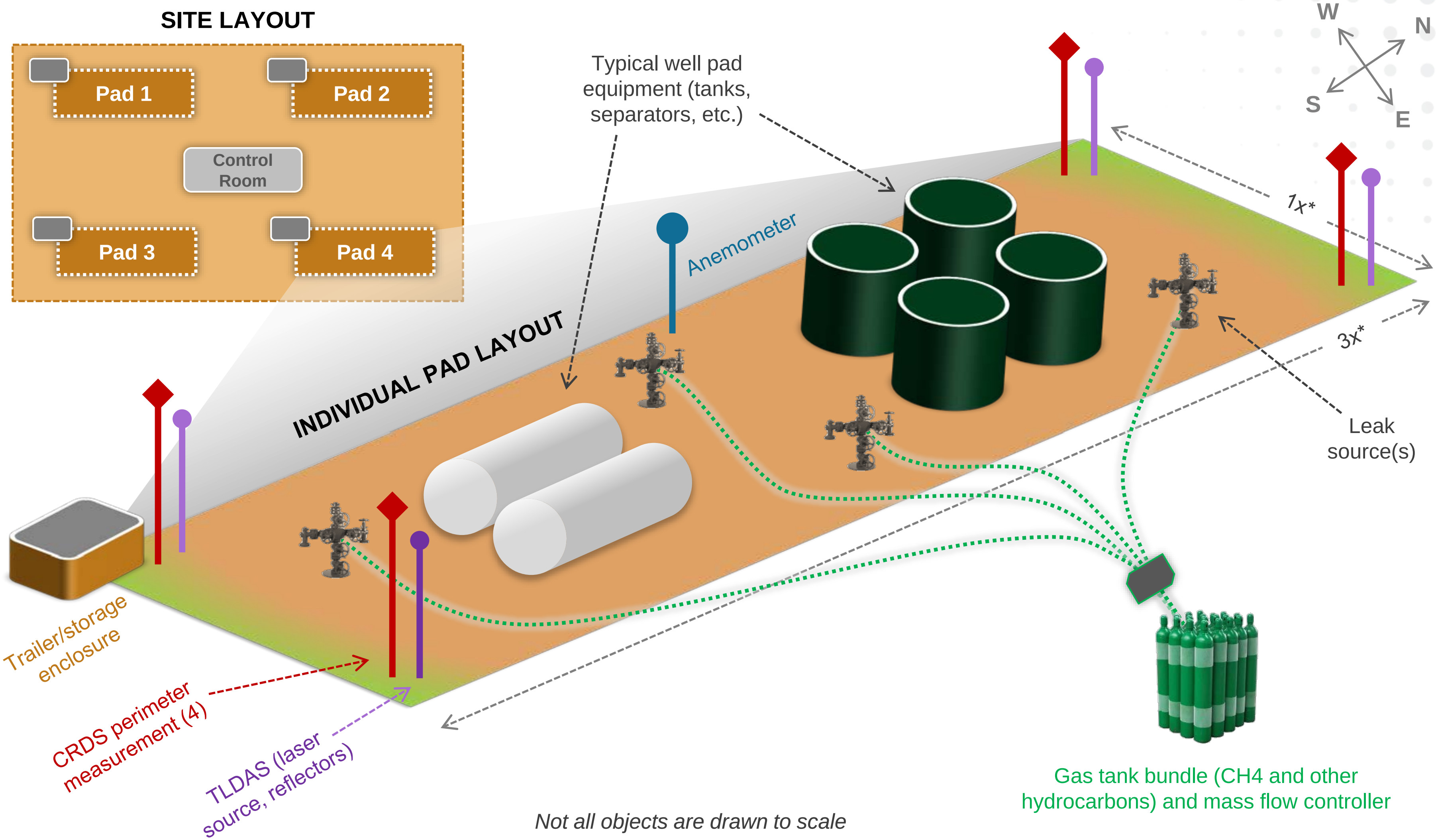
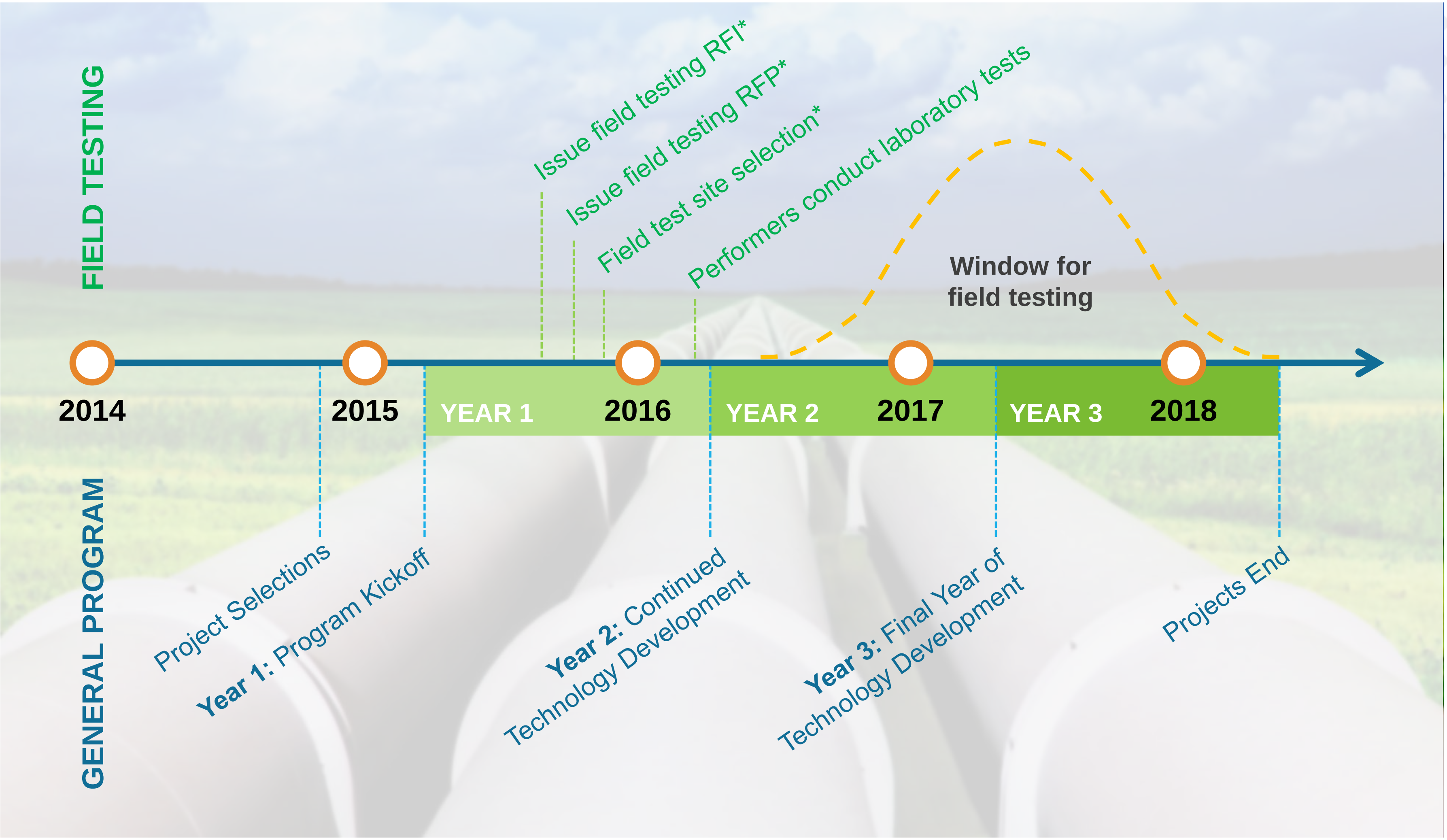
Example Test Site Layout



Not all objects are drawn to scale

*1x3 size ratio is approximate

The MONITOR Timeline: ARPA-E & Beyond



*Subject to change

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EDF Methane Detector Challenge

- Available technology
- Focus on detection
- 10+ TPY
-

- New technology
- Focus on quantification
- Down to 1 TPY

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