# DOCKETED

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| **Docket Number:** | 17-MISC-02 |
| **Project Title:** | Potential Areas of Natural Gas Research and Development for the Proposed Program Plan and Funding Request for 2017/18 |
| **TN #:** | 220083 |
| **Document Title:** | Presentation - Monitor 2017 CEC Meeting - A Year of Progress and Innovation |
| **Description:** | July 7, 2017 by Joseph King from the U.S. Department of Energy |
| **Filer:** | Gina Fontanilla |
| **Organization:** | U.S. Department of Energy |
| **Submitter Role:** | Public Agency |
| **Submission Date:** | 7/7/2017 12:07:41 PM |
| **Docketed Date:** | 7/7/2017 |

# MONITOR 2017 CEC Meeting

## *A Year of Progress and Innovation*

*Joseph King*
*Program Director*

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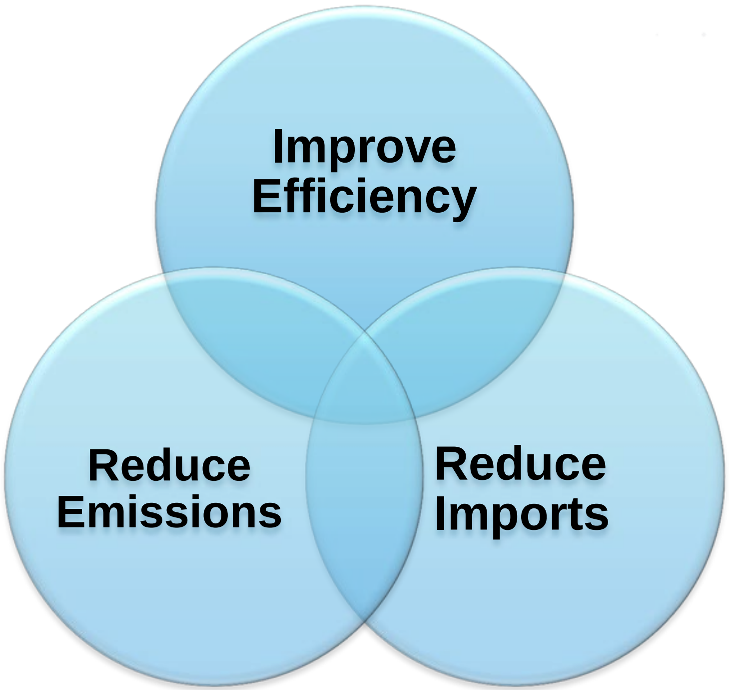
# ARPA-E Authorizing Legislation

*If it works…*
***will it matter?***

**Mission:** To overcome long-term and high-risk technological barriers in the development of energy technologies

**Goals: Ensure America's**

- Economic Security
- Energy Security
- Technological Lead in Advanced Energy Technologies

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# MONITOR

## Methane Observation Networks with Innovative Technology to Obtain Reductions

- **GOALS:**
  - Develop innovative, cost-effective technologies to detect, locate and quantify methane emissions associated with natural gas production
  - Enable reductions in methane leaks, improve safety, promote operational productivity, and reduce the overall GHG impact from natural gas development

- **HIGHLIGHTS:**
  - Advancing SOA for numerous detection and quantification technologies with at least an order magnitude reduction in costs
  - Employs a variety of deployment platforms that will provide quantification coverage throughout the natural gas supply chain
  - Multiple industry, regulatory and environmental relationships developed: early result is explicit technology on-boarding pathway in current EPA and BLM regulations.

| | |
|---|---|
| **Kick-off Year** | 2015 |
| **Projects** | 11 teams<br>1 test site |
| **Investment** | $35$^{+}$ Million |

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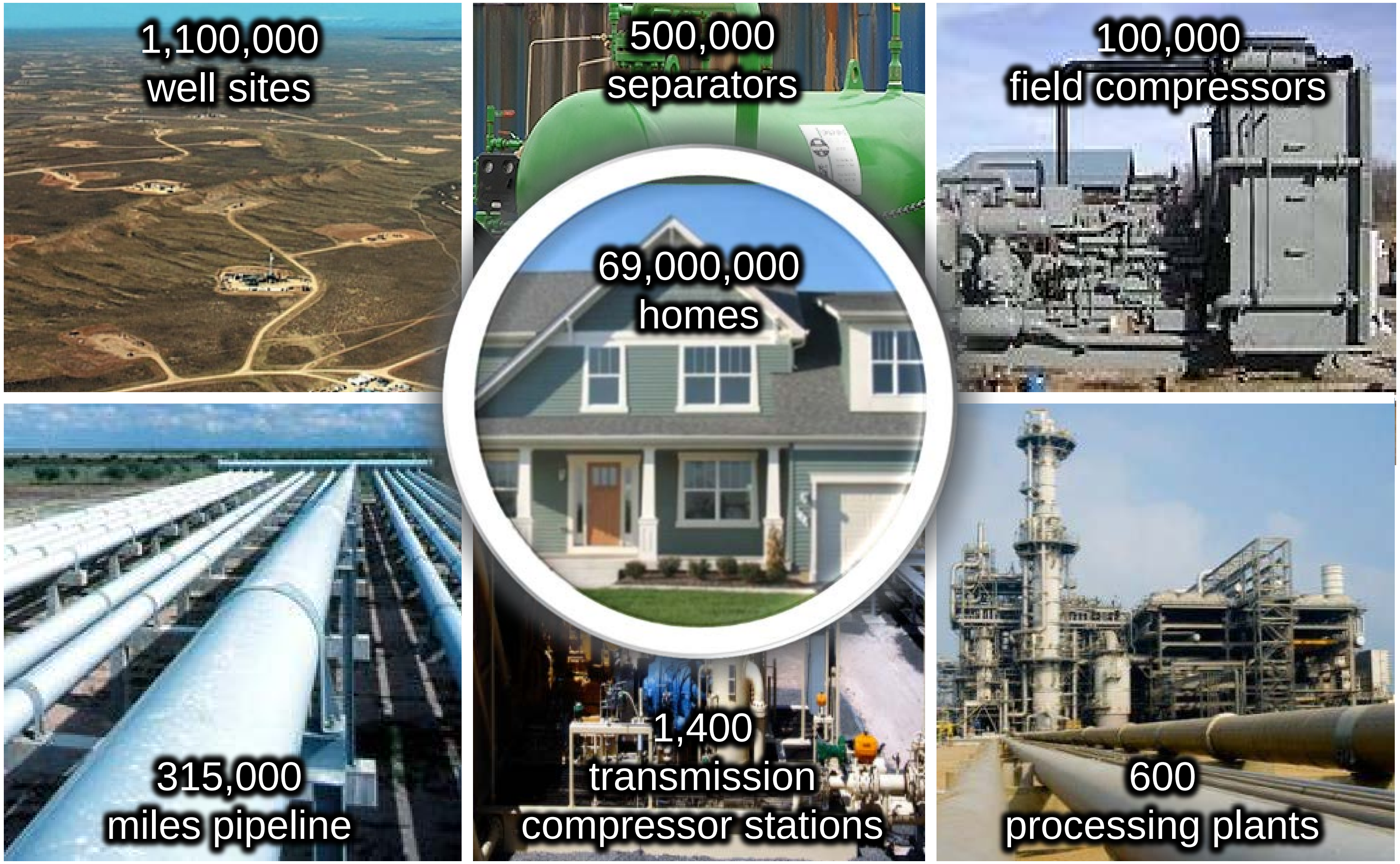
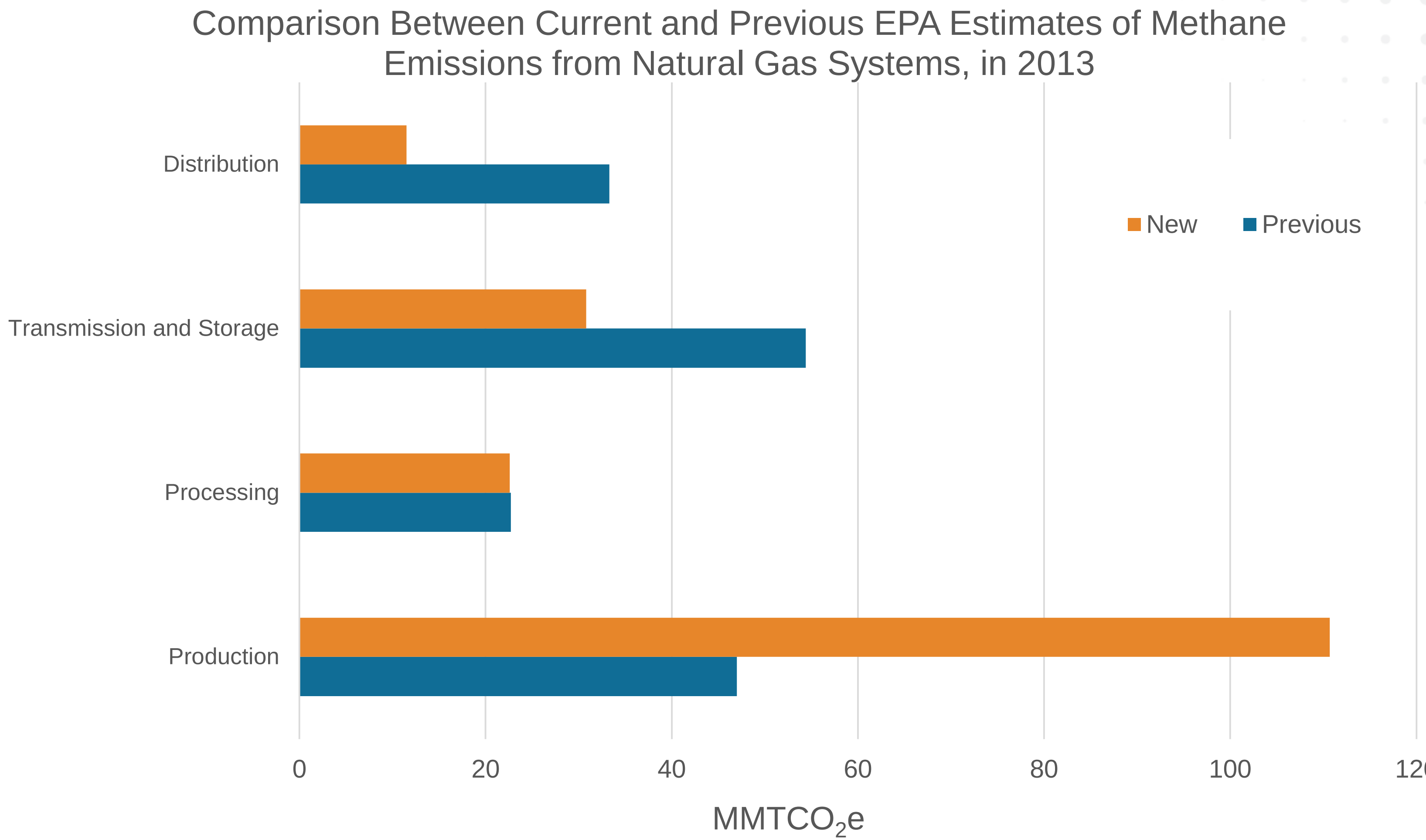
# The U.S. Natural Gas Infrastructure



# More Refined Emissions Data



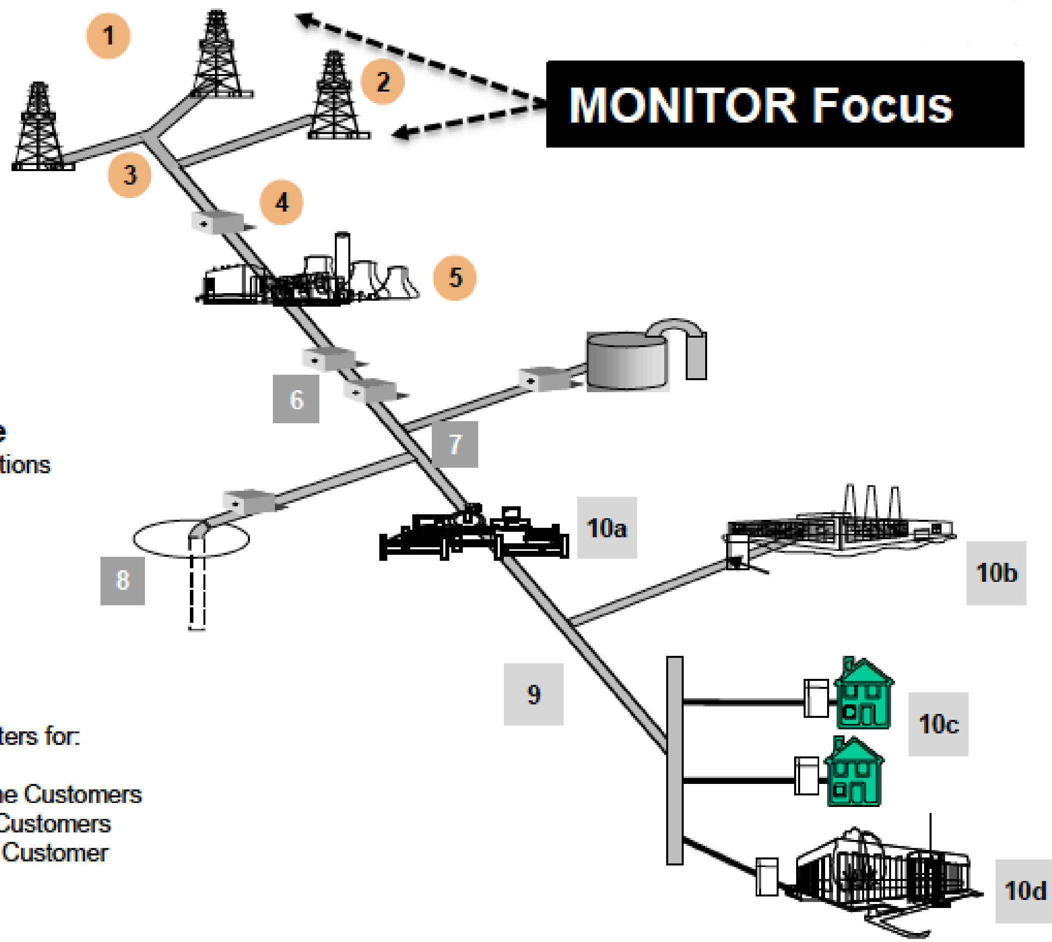
# Monitor's Initial Focus

Natural gas systems encompass wells, gas gathering and processing facilities, storage, and transmission and distribution pipelines.

**Production & Processing**
1. Drilling and Well Completion
2. Producing Wells
3. Gathering Lines
4. Gathering and Boosting Stations
5. Gas Processing Plant

**Natural Gas Transmission & Storage**
6. Transmission Compressor Stations
7. Transmission Pipeline
8. Underground Storage

**Distribution**
9. Distribution Mains
10. Regulators and Meters for:
    a. City Gate
    b. Large Volume Customers
    c. Residential Customers
    d. Commercial Customer




*Source: Adapted from American Gas Association and EPA Natural Gas STAR Program*

# MONITOR Metrics & Targets

| | |
|---|---|
| **Sensitivity** | **1 ton per year (6 standard cubic feet per hour; ~111 grams/h or ~1.9g/min)** |
| **Economical Cost** | **$3,000 per site per year (for basic functionality)** |
| **Actionable Information** | **90% methane leakage reduction with a 90% confidence level** |
| **Quantification** | **Able to estimate mass flow rate within ± 20% margin of error** |
| **Leak Location** | **Able to estimate location ± 1 meter or better** |
| **False Positives** | **≤ 1 per year** |
| **Communications** | **Transmits results wirelessly to remote receiver** |
| **Enhanced Functionality** | **Methane selectivity, speciation capability, thermogenic/biogenic differentiation, continuous measurement, enhanced stability** |

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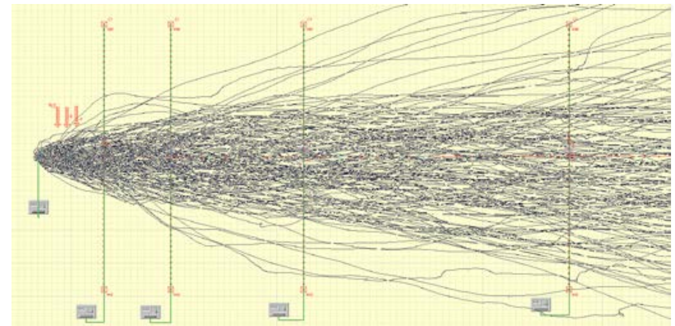
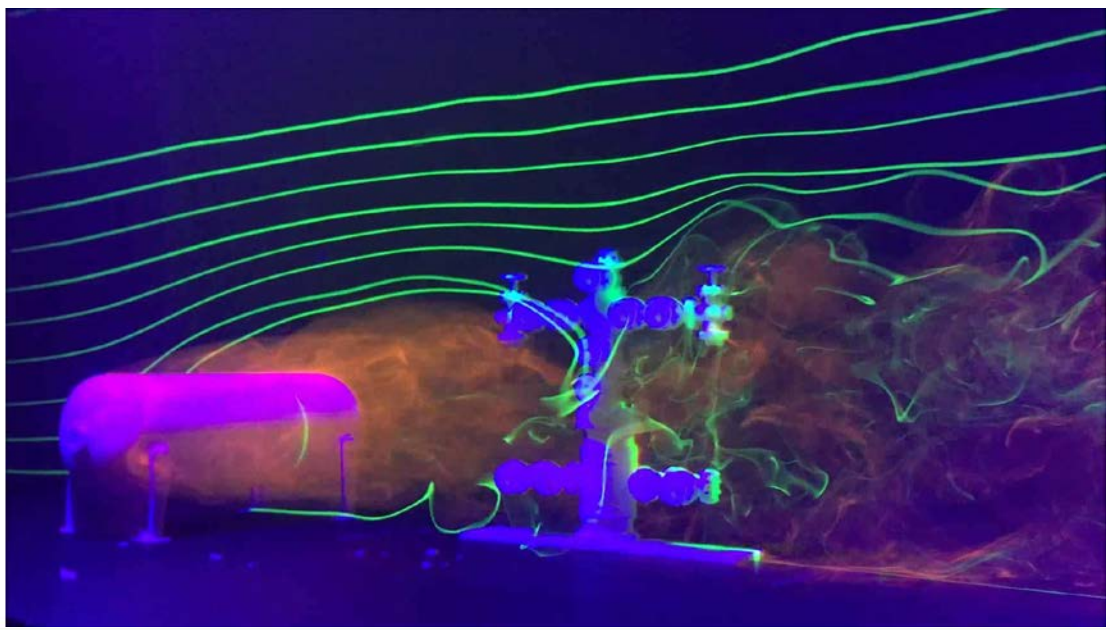
# MONITOR's Methane Detection, Localization and Quantification Challenge

- Leak Detection, Localization and Rate:
  - Source/Receptor Geometry
  - Weather Effects
    - Wind Speed
    - Stability
  - Topography and morphology



Ability to Locate Leaks ✓
Low Cost ✓
Ability to Quantify ✓



# 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

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

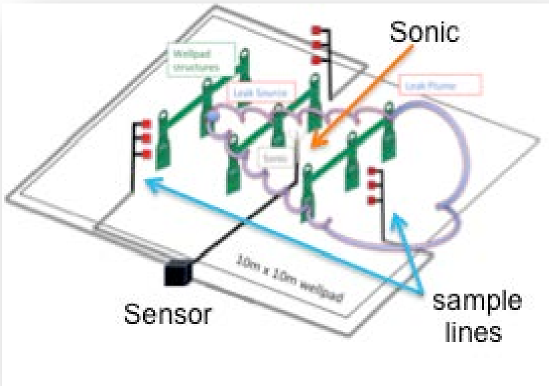
LI-COR — Lincoln, NE

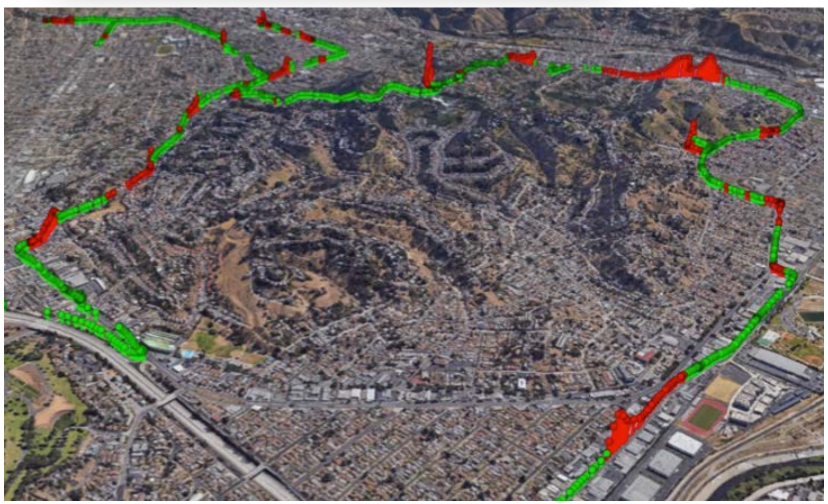
GE — Niskayuna, NY

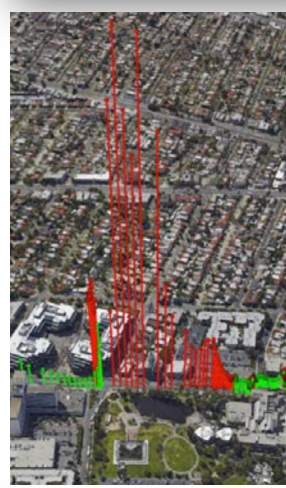
Duke University — Durham, NC

University of Colorado Boulder — Boulder, CO

# Miniature, High Accuracy Tunable Mid-IR Laser Spectrometer for $CH_4$/$C_2H_6$ Leak Detection





**PROJECT HIGHLIGHTS**

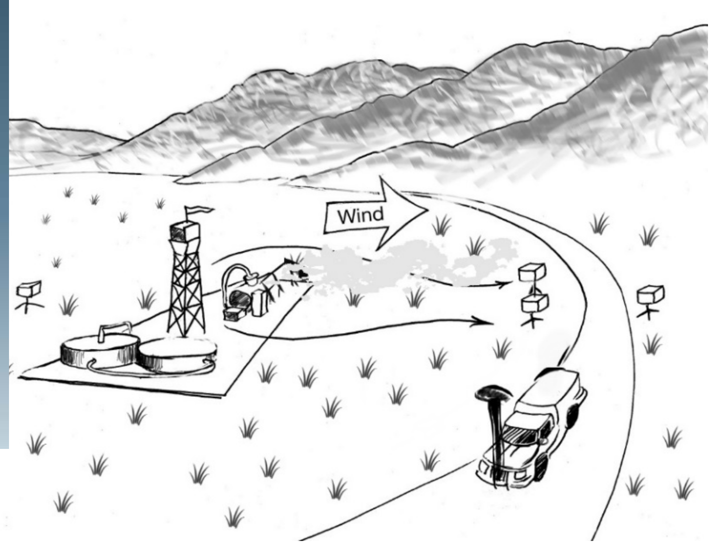
- Enables ppb/s sensitivity via simple and robust direct absorption spectroscopy
- Uniquely discriminates biogenic vs. thermogenic emissions real time
- 1/15th the size and power of existing in-situ laser sensors
- $100^{+}$x more sensitive/accurate than legacy FID/NDIR
- Compatible with other industry applications that require high accuracy, real-time analyses (*e.g*. mobile applications)

**AWARD AMOUNT:** $2.4 million

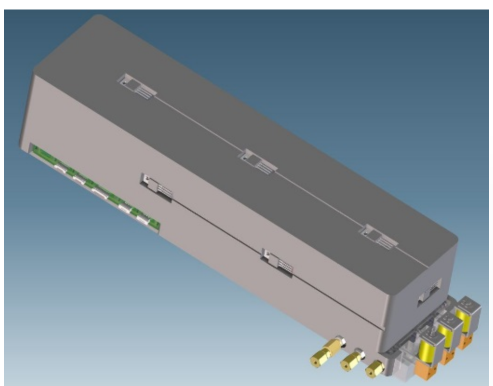
**PROJECT PARTNERS:** Los Alamos National Laboratory, Rice University

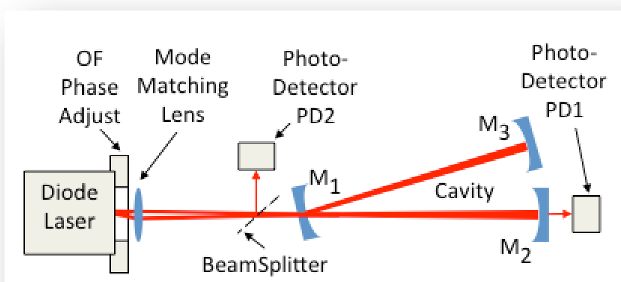
# Laser Spectroscopic Point Sensor for Methane Leak Detection

LI-COR®











**PROJECT HIGHLIGHTS**

- Performance of state of the art cavity-based point sensors at reduced cost
- High sensitivity, selectivity, and stability measurements with low maintenance
- Closed path instrument is weather-proof, high-performance, and low power consumption
- Suitable for continuous or intermittent stationary and mobile applications
- Advanced spectral models and high instrument stability allow unattended operation
- Advanced manufacturing and novel design/alignment enable cost reductions

**AWARD AMOUNT:** $2.85 million

**PROJECT PARTNERS:** Colorado State University, Gener8

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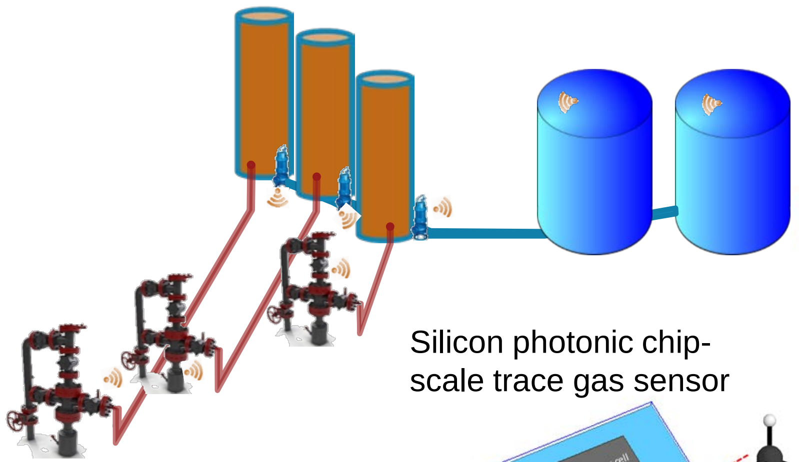
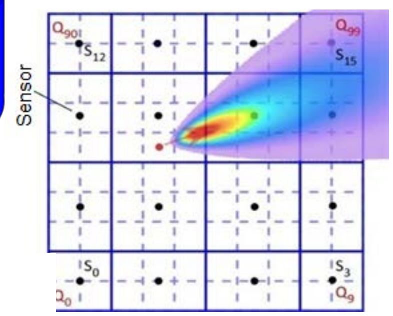
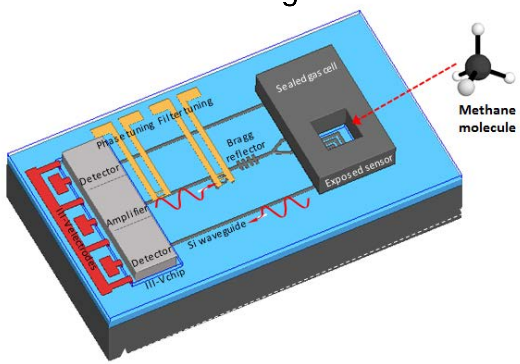
# On-Chip Optical Sensors and Distributed Mesh Networks for Methane Leak Detection

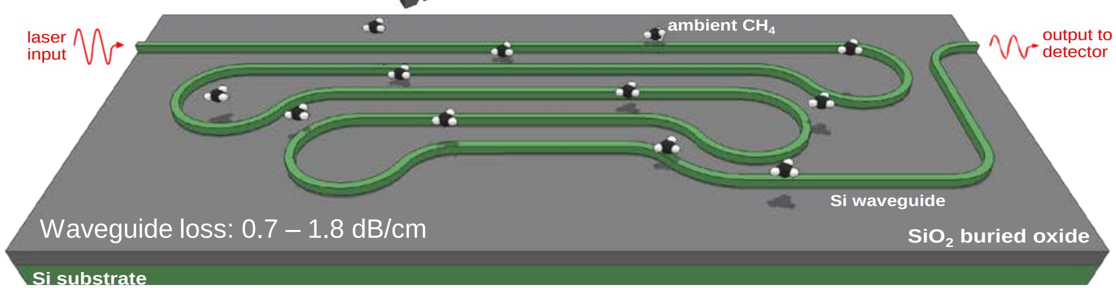
IBM






Silicon photonic chip-scale trace gas sensor




Evanescent field sensing – wave guide

**PROJECT HIGHLIGHTS**

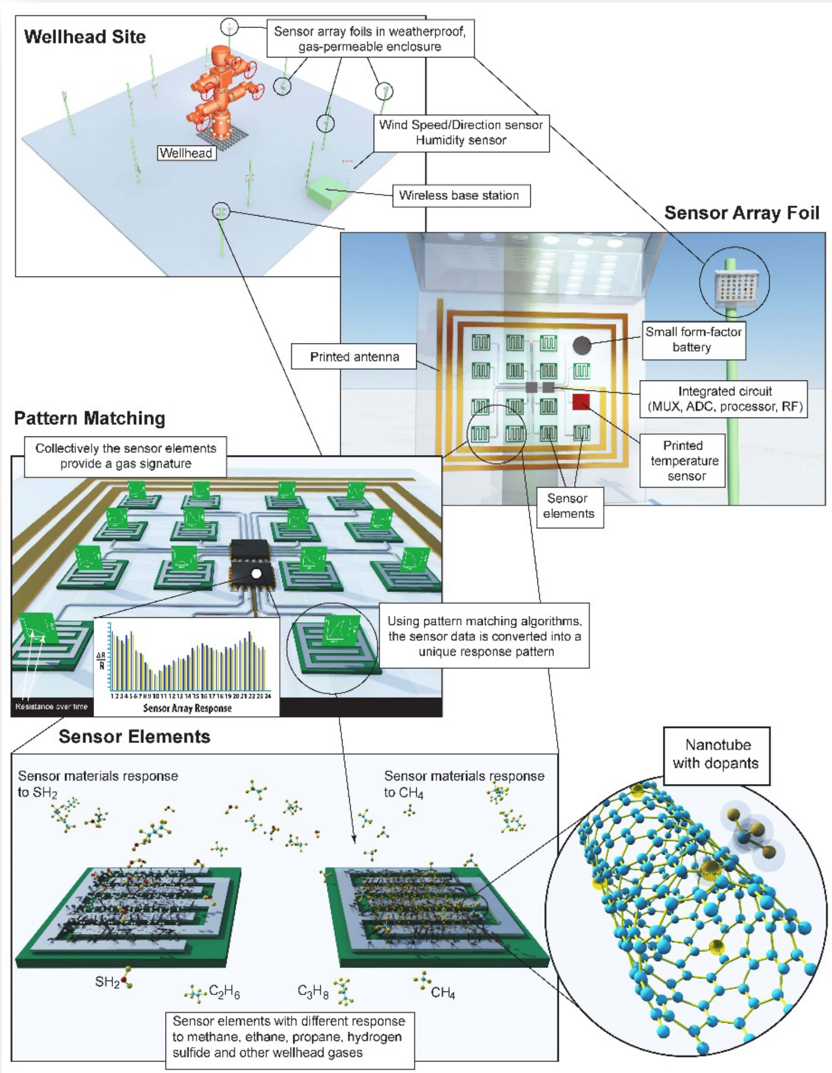
- Developing novel, low cost, on-chip optical sensors with high methane selectivity
- Distributed and modular system with self-organizing network of low-power motes
- State of the art silicon photonics technology for on-chip 1.3-1.65µm TDLAS
- Allows for selectivity to molecule of choice
- Orders of magnitude lower cost ($250/sensor target)
- Low power consumption (<1 Watt)
- 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**

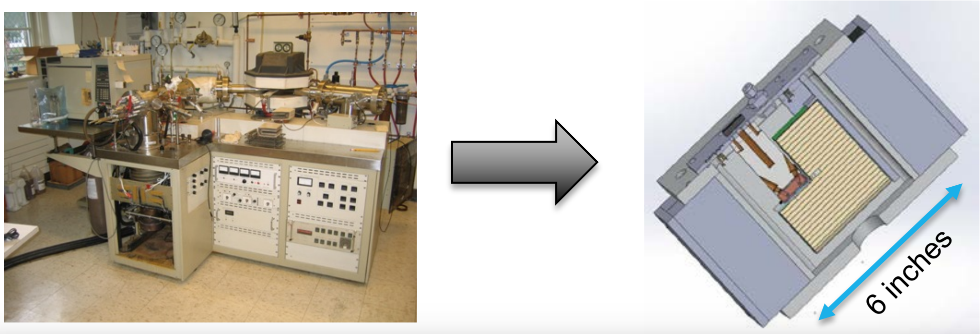
- Developing a mesh network of ultra-low-cost printed sensor arrays that can detect multiple gases
- Uses scalable low-cost, additive printing methods to print chemical sensor arrays based on modified carbon nanotubes
- Sensor elements with different responses to methane, ethane, propane and other wellhead gases
- Total system costs under $350 per site per year; sensor cost target of ≤ $15 each.
- Multiple sensors reduces false positives
- Sub-ppm sensitivity with leak localization within 1 m

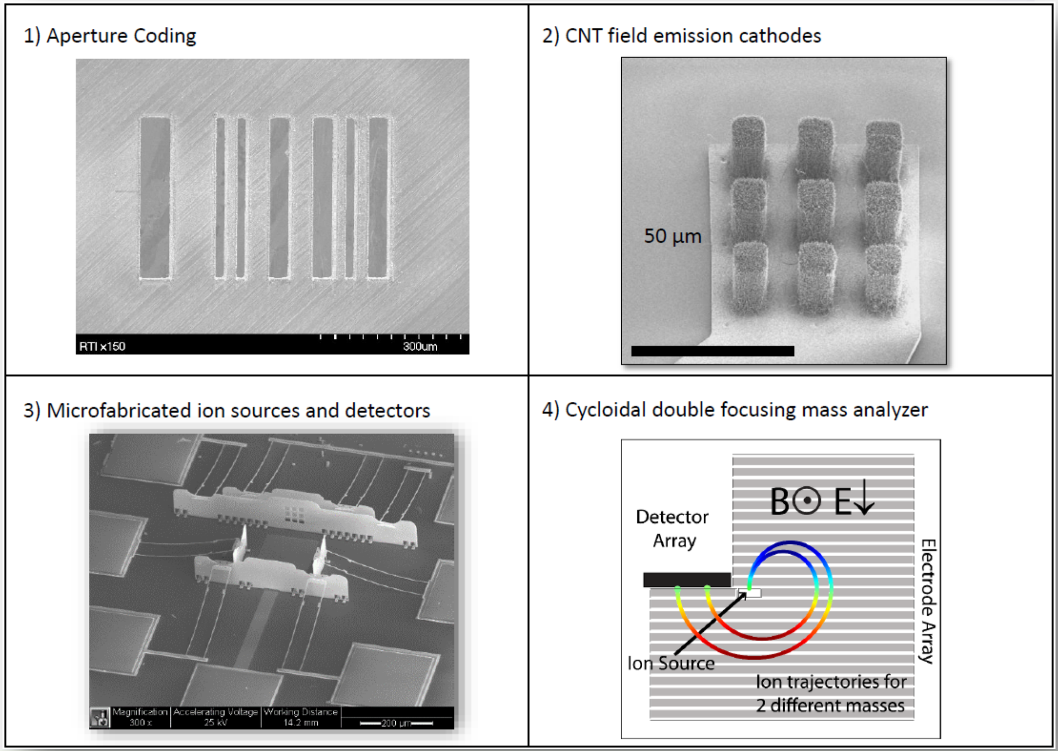
**AWARD AMOUNT:** $3.4 million

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

# Coded Aperture Miniature Mass Spectrometer for Methane Sensing

Duke UNIVERSITY



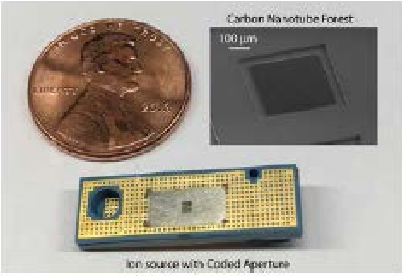




## PROJECT HIGHLIGHTS

- Miniaturizing a mass spectrometer utilizing microfabrication and aperture coding
- High selectivity measurements at short detection times for methane as well as VOC's (such as benzene, $C_2$-$C_7$)
- Capable of thermogenic vs. biogenic differentiation
- Developing advanced search/location algorithms for optimum sampling

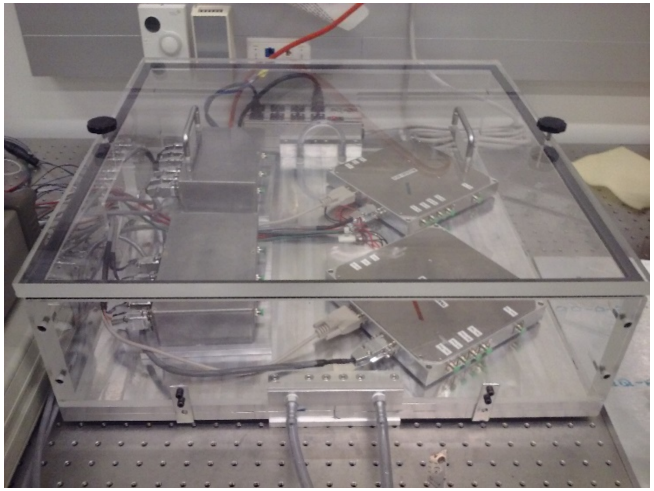
**AWARD AMOUNT:** $2.9 million

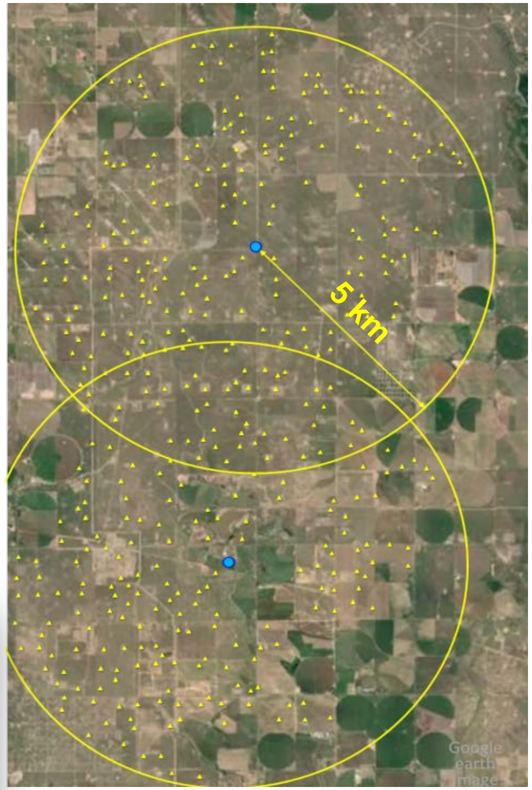
**PROJECT PARTNERS:** RTI International



# Frequency Comb-based Methane Sensing Spectroscopy

University of Colorado Boulder







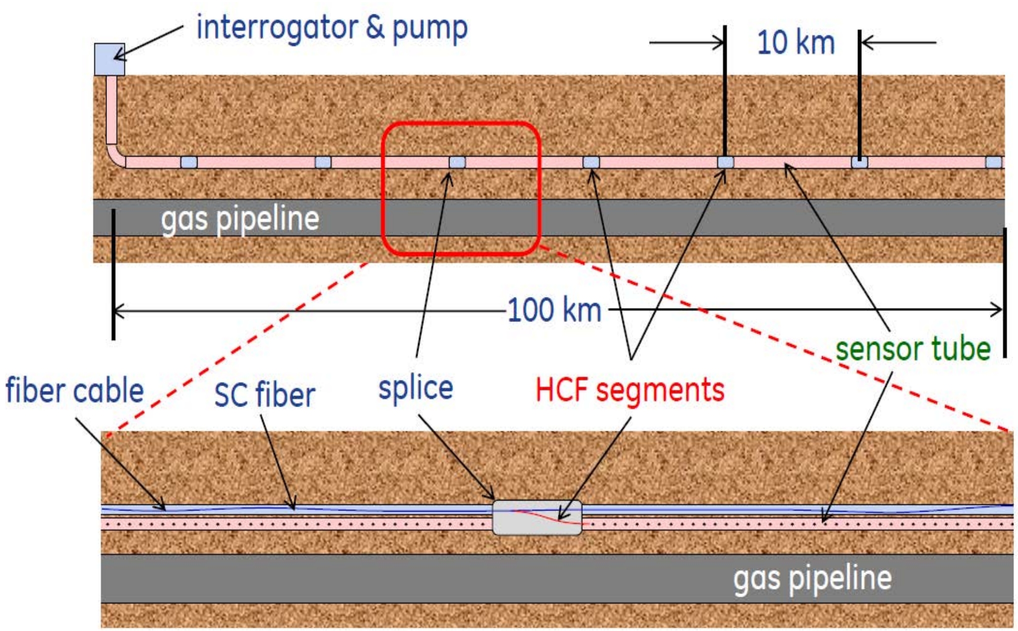
**PROJECT HIGHLIGHTS**

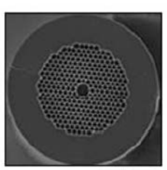
- High sensitivity (ppb-m) kilometer-scale path length measurements with specificity of FTIR: 1.64-1.70µm
- Ability to monitor 100's of sites from a central location with thermogenic-biogenic differentiation
- Simplifying design to reduce the cost of phase locked dual comb spectroscopy
- Multispecies sensing includes $CH_4$, $^{13}CH_4$, $C_2H_6$, $H_2O$, $CO_2$, and propane
- Coupled to large eddy dispersion modeling to provide localization

**AWARD AMOUNT:** $2.1 million

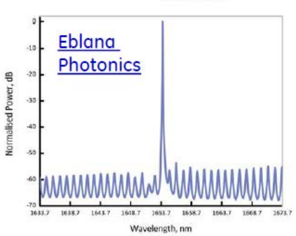
**PROJECT PARTNERS:** NIST, NOAA

# Micro-structured Optical Fiber for Methane Sensing

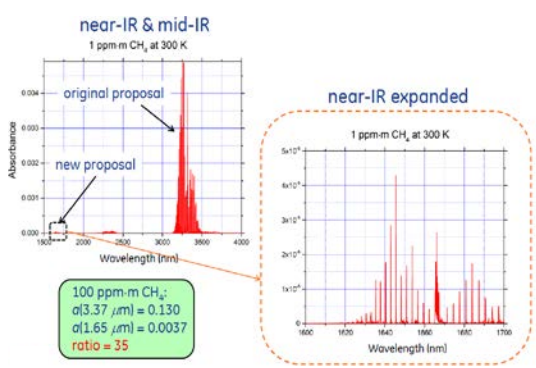


HC-1550


Applied Optoelectronics




## PROJECT HIGHLIGHTS

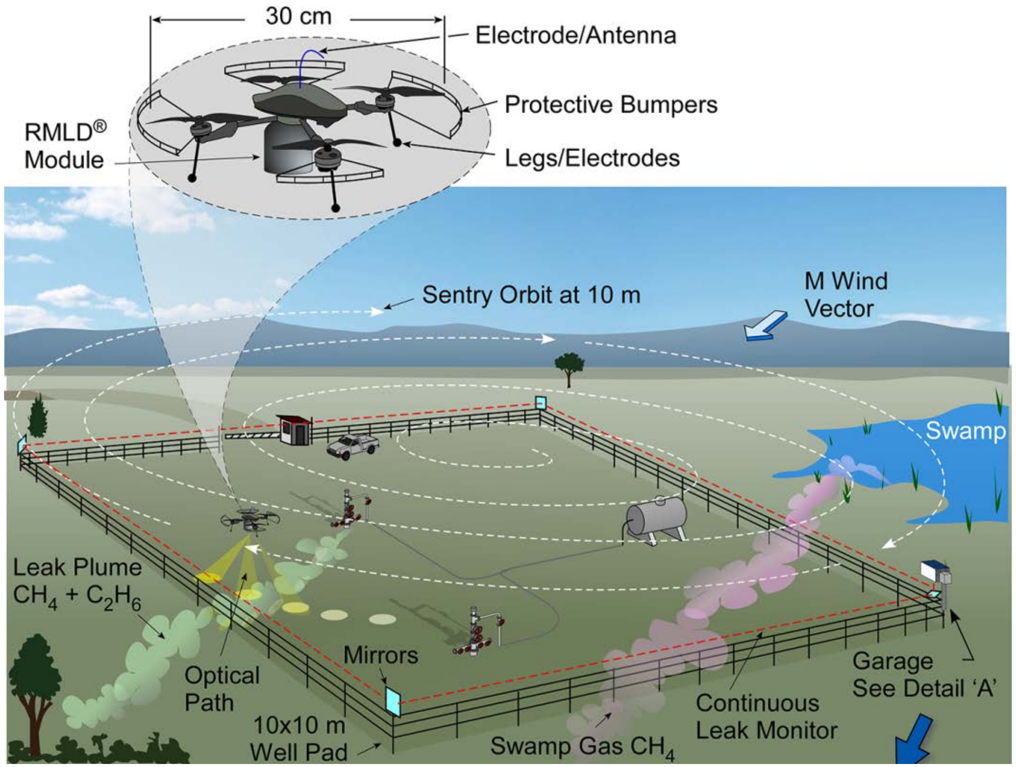
- Fiber optic sensor is broadly applicable throughout the oil and gas industry, particularly for large-scale infrastructure (such as gathering lines and storage facilities)
- Photonic crystal fiber design will minimize optical losses while permitting ambient gas to enter hollow core
- Implement components available in telecommunications to manage price
- Hollow-core fiber segments in a design that can span over 100km and offer continuous pipeline monitoring along its entire length

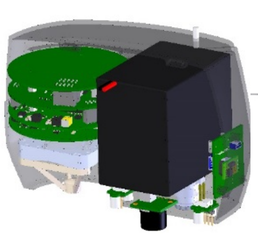
**AWARD AMOUNT:** $1.4 million

**PROJECT PARTNERS:** Virginia Tech

# UAV-based Mid-IR Laser Spectroscopy for Methane Leak Measurement

Physical Sciences Inc.




## PROJECT HIGHLIGHTS

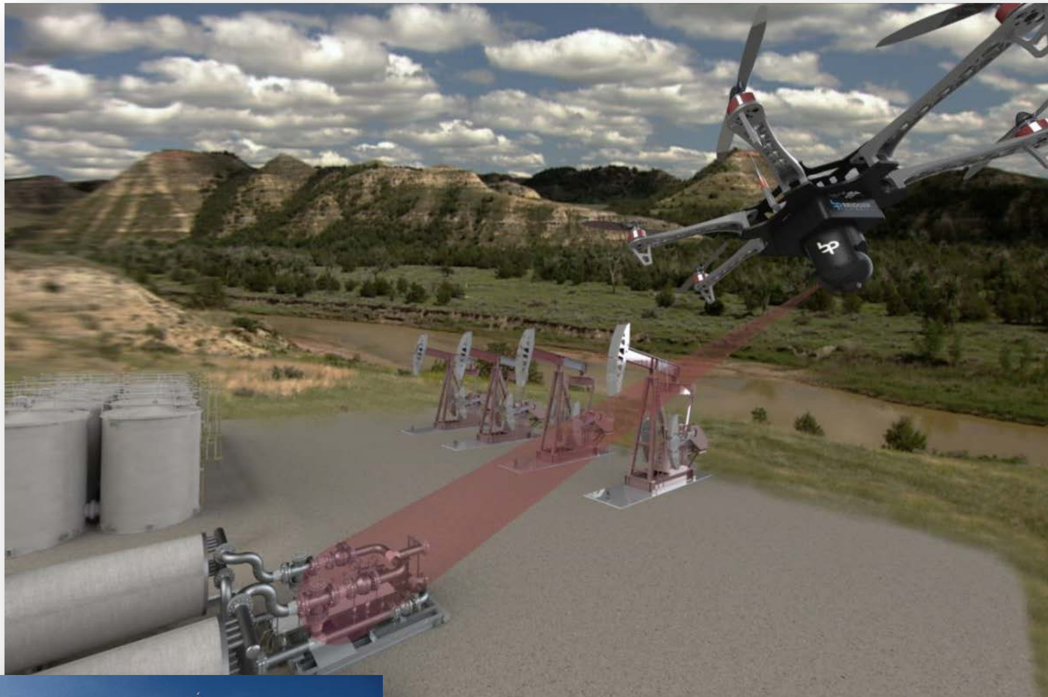
- Continuous leak monitoring with leak quantification and real-time alarm notification
- Two modes of operation: continuous perimeter monitoring and search mode to pinpoint leak location
- Speciation of methane and ethane differentiates thermogenic vs. biogenic emission
- Improved production processes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

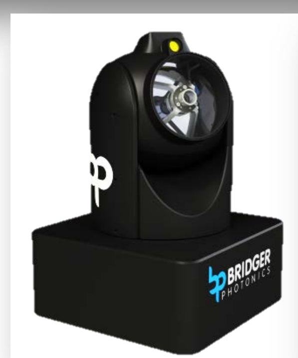
**AWARD AMOUNT:** $2.9 million

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

# Mobile LiDAR Sensors for Methane Leak Detection

BRIDGER PHOTONICS





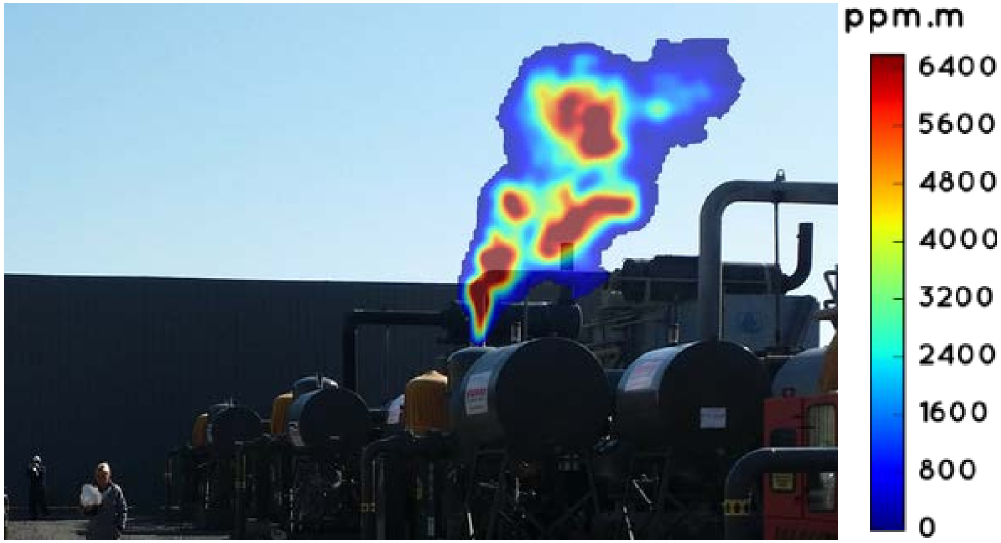

**PROJECT HIGHLIGHTS**

- Simultaneous, rapid, and precise 3D topography and methane gas sensing on fixed or mobile platform
- Capable of covering a broad range: a frequency-swept laser beam is transmitted to a topographical target 1-300 m from the sensor
- Produces detailed situational awareness reports derived from overlaid methane concentration, 3D topography, and RGB picture data
- 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

# Portable Imaging Spectrometer for Methane Leak Detection

REBELLION PHOTONICS



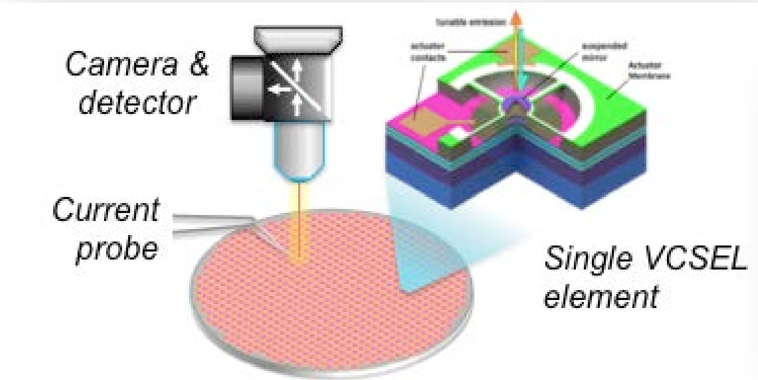

**PROJECT HIGHLIGHTS**

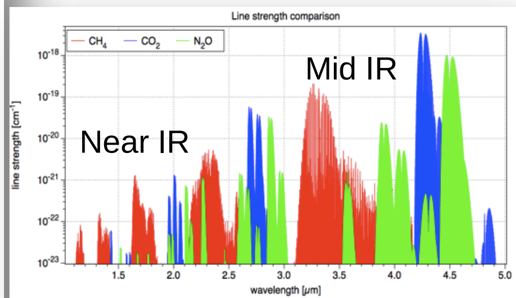
- Miniaturization of Rebellion's Gas Cloud Imager (GCI), a long-wave infrared imaging spectrometer: 7-14µm
- Camera will be lightweight and portable – the size of a Red Bull can - and capable of being incorporated into personal protective equipment
- Data processing uses cloud-based computing architecture that streams results to mobile device

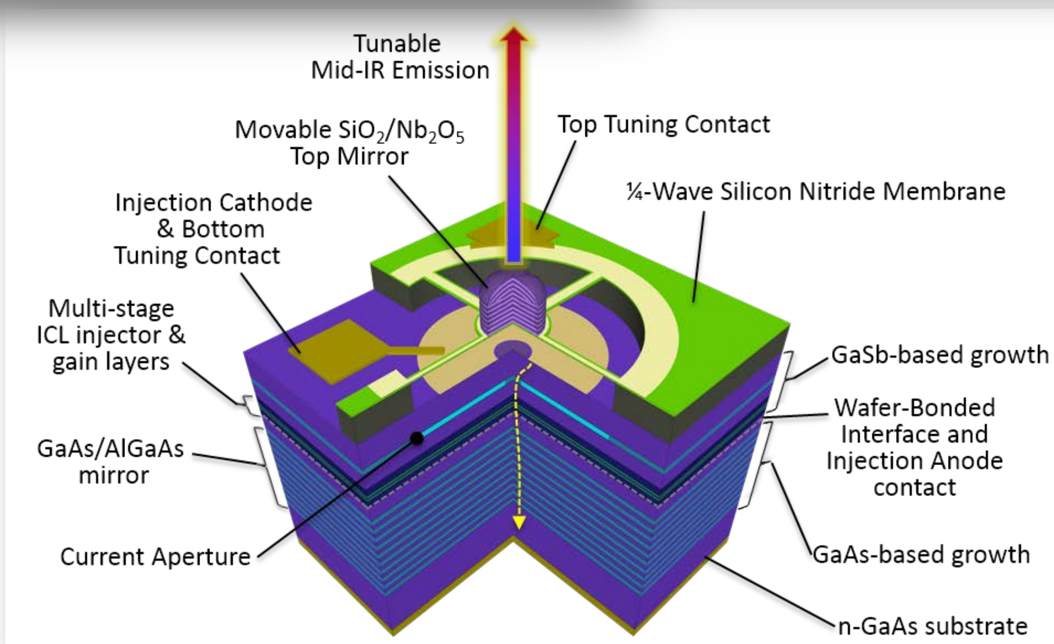
**AWARD AMOUNT:** $4.3 million

# Tunable Mid-infrared Laser for Methane Sensing

THORLABS




**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 Testing

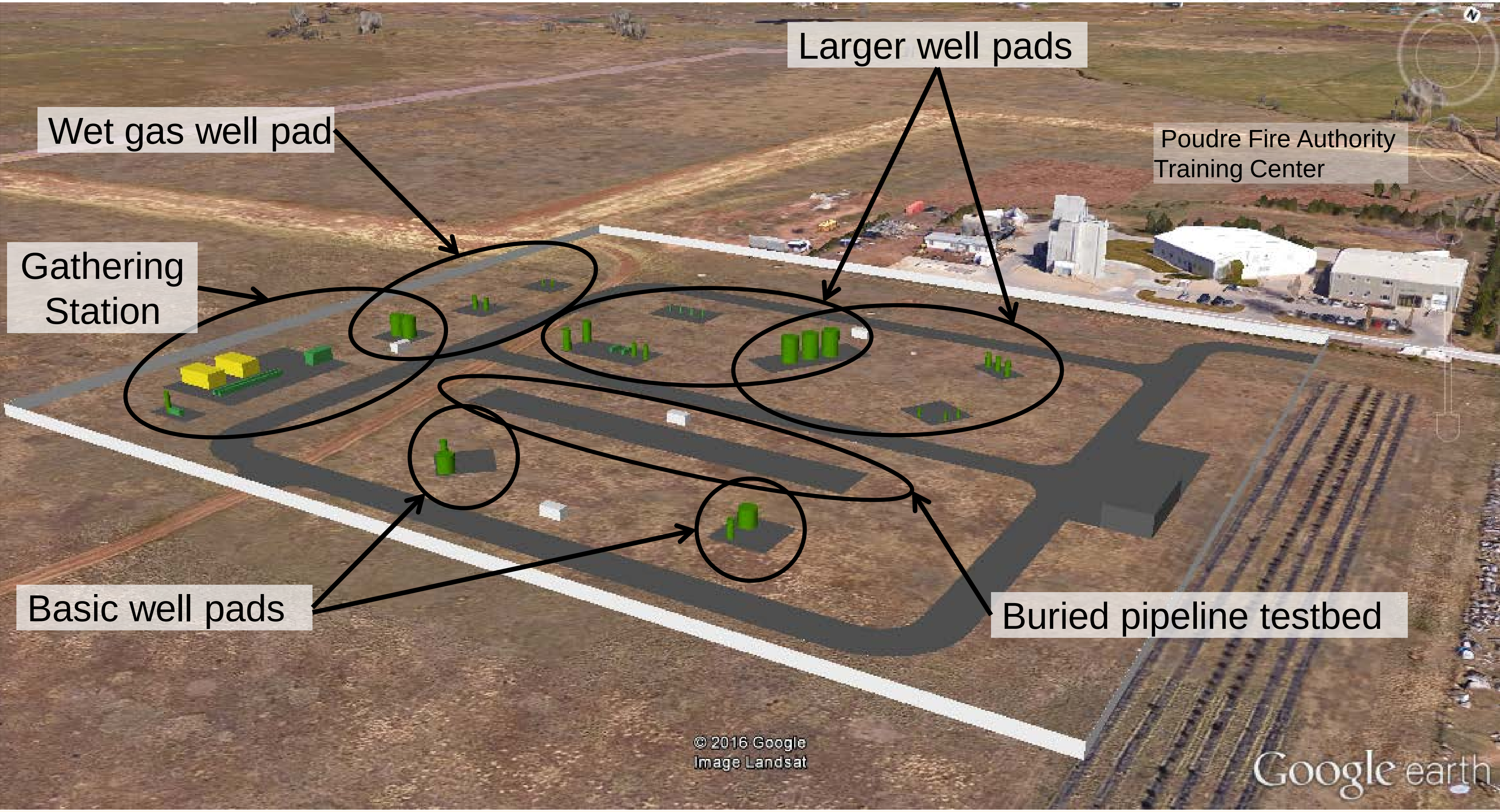
Colorado State University
METEC$H_4$
Methane Emissions Technology Evaluation Center

- **Round 1 - Initial Project Testing -** February 15, 2017 – July 31, 2017
  - First *required* test in an outdoor environment
  - Simplified per run scenario:
    - Single blind
    - Six Single leaks on one of three well pads (0-150 SCFH)
    - Non-elevated $CH_4$ natural background (~ 2ppm)
    - Pure methane or mixture of methane and ethane

- **Round 2 - Final Qualification Testing –** October 15, 2017 – June 26, 2018
  - Single blind
  - Challenging conditions with site structural complexity (*e.g*. more obstacles that disrupt gas flow and varying/multiple emissions rates and locations distributed over the entire site)
  - Multiple, simultaneous leaks
  - Elevated background of methane (≥2ppm)
  - Higher order hydrocarbons ($C_3$ – $C_6$) and $H_2S$ in gas mixture

*Facility at a Glance:*
# Capabilities

Colorado State University
METECH4
Methane Emissions Technology Evaluation Center



# Industrial Advisory Board (IAB)

GAS NATURAL

Anadarko

PIONEER NATURAL RESOURCES

KINDER MORGAN

noble energy

dcp Midstream

Chevron

XTO ENERGY

swn Southwestern Energy®

Williams®

Statoil

bp

Xcel Energy®

# Technology’s Dilemma

“Readers of *Science* are unlikely to be surprised that decision-makers often disregard the best, most empirically informed conclusions.”

Darren Frey’s review of  Hugo Mercier and Dan Sperber’s book, “*The Enigma of Reason*,” in *Science*, 12 May 2017, v. 356, pg. 589.

**Need to Ensure On-boarding of Innovation**

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# Policy Needs

**Main goal:** Avoid technology lock-in; move towards performance-based

- MONITOR technologies will enable:
  - Detection, localization, quantification, continuous monitoring, remote communication - at low-cost and high sensitivity
  - Result: leak prioritization, non-arbitrary measurement intervals or concentration thresholds, and decreased operational costs
- Policy needs:
  - Inclusion of a technology on-boarding mechanism - *i.e.* insurance that yesterday's technologies aren't "locked-in"
- Policy should move towards:
  - Mass flow thresholds and automated, continuous monitoring

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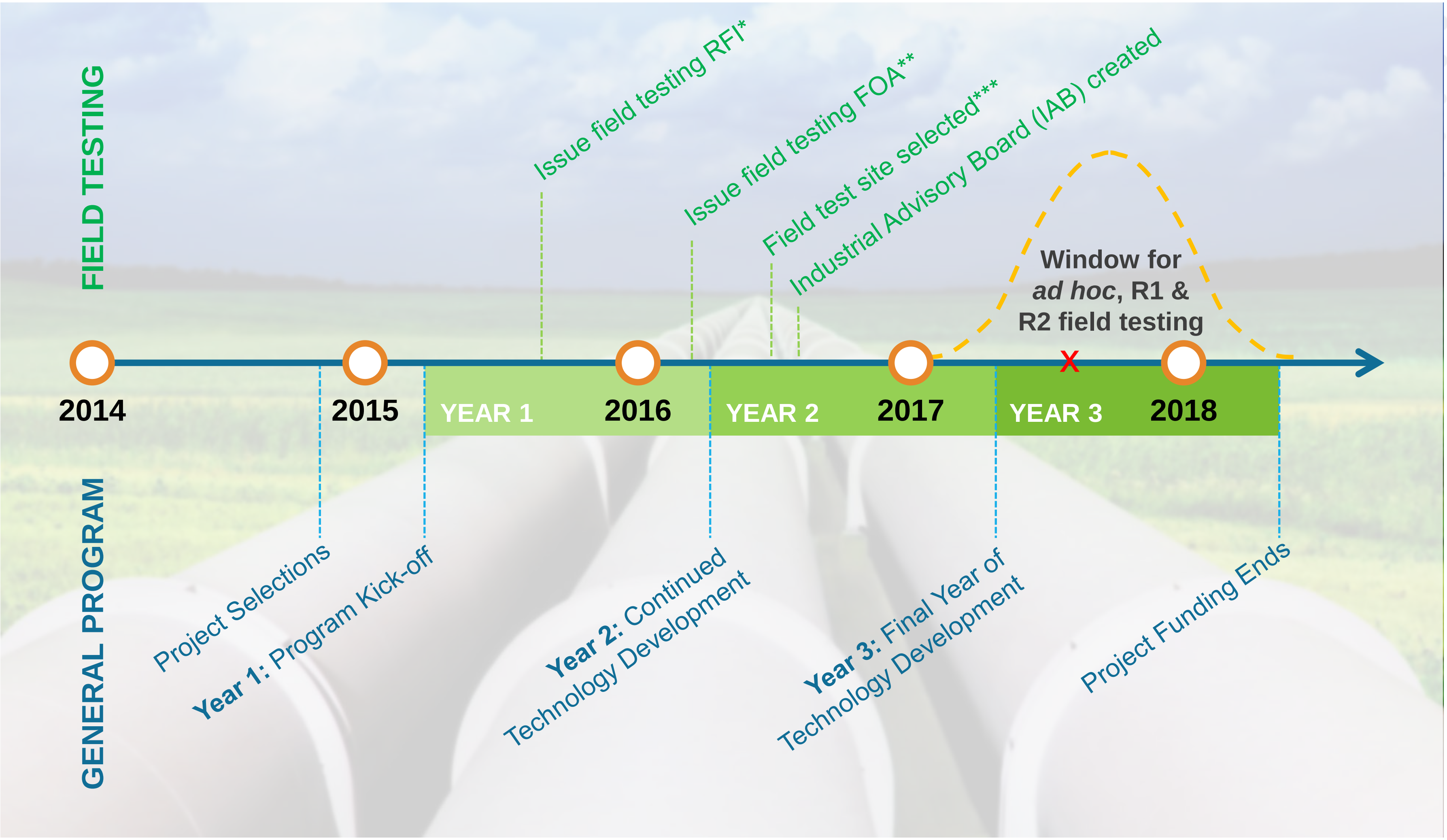
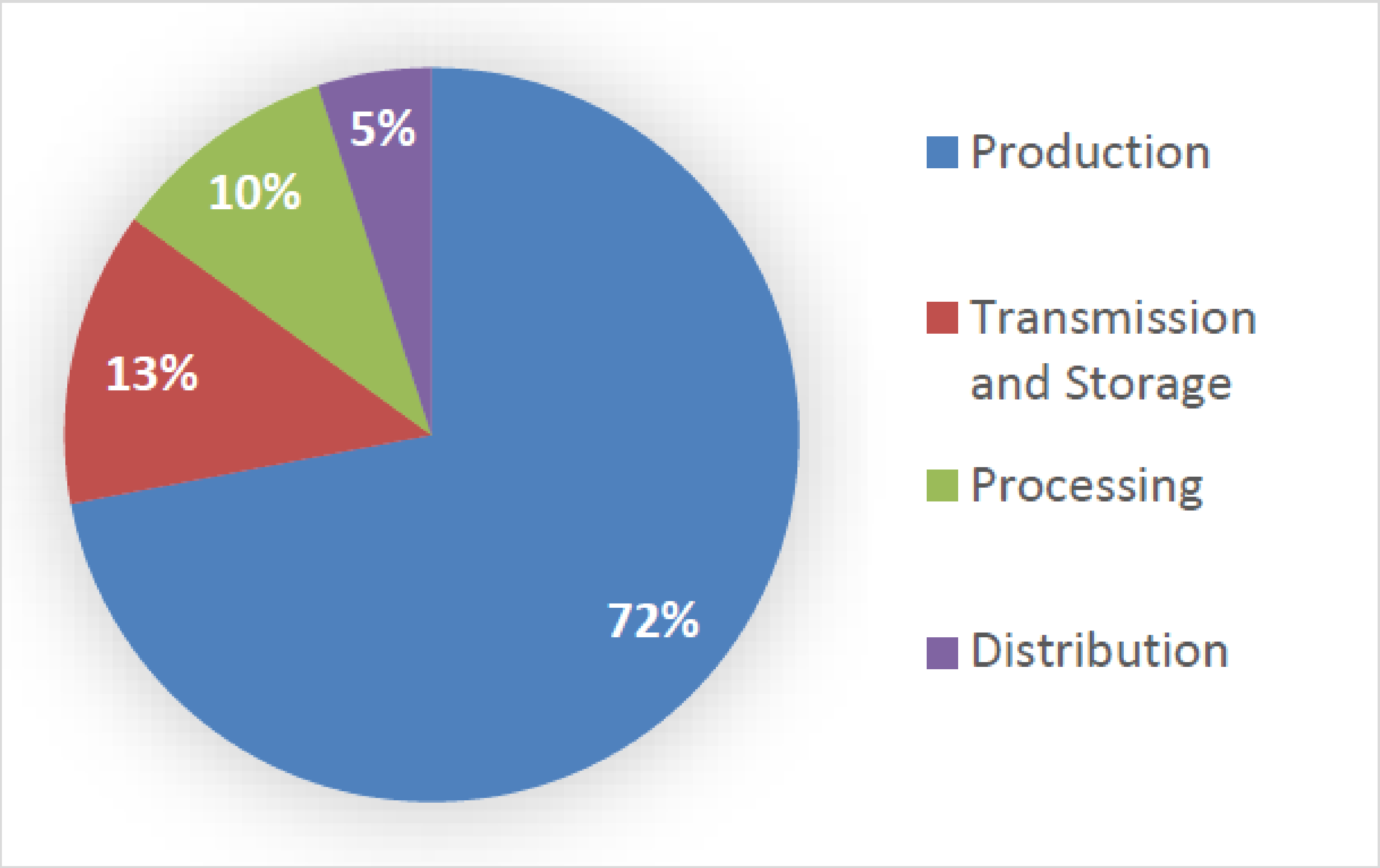
U.S. DEPARTMENT OF ENERGY

Joseph.King@hq.doe.gov

# The MONITOR Timeline: ARPA-E & Beyond



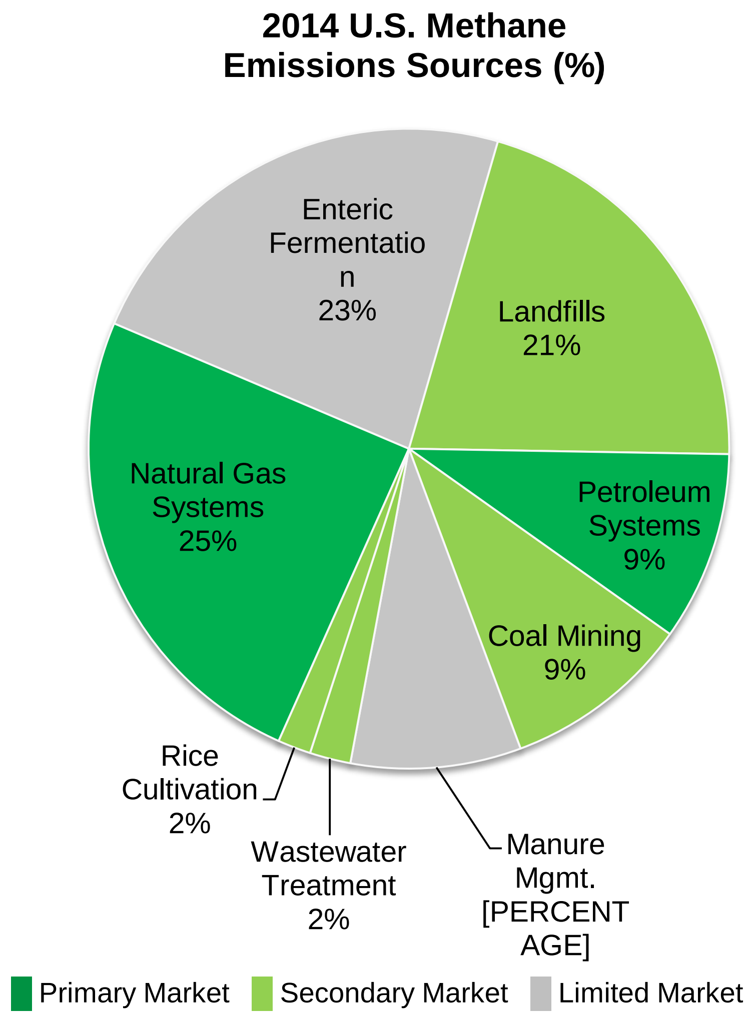

* Request for Information = RFI
** Funding Opportunity Announcement = FOA
*** CSU proposal selected May 31, 2016




Source: EPA Greenhouse Gas Inventory Report (2016)

**Figure 1:Total Methane Emissions from Natural Gas and Petroleum Systems Supply Chains (2014)**

# Roughly one-third of methane emissions come from secondary markets that could benefit from better sensing




## PRIMARY MARKETS

- **Natural Gas and Petroleum Systems**: Advances in drilling technology have enabled natural gas booms across the globe, notably in the U.S. where shale has changed the energy landscape.

## SECONDARY MARKETS

- **Landfills**: Beginning 1-2 years after placing waste in landfills, bacterial decomposition begins releasing methane over the course of several decades.
- **Coal Mining**: Coal extraction released methane stored in the coal bed and surrounding geology; coal consumption is expected to grow significantly on a global scale in the coming decades.
- **Wastewater Treatment**: Natural decomposition of waste material leads to both venting and fugitive methane emissions; this is a larger problem in developing countries that use aerobic treatment.
- **Other**: Rice cultivation, stationary and mobile combustion, chemicals production are significantly smaller sources of $CH_4$ emissions.