QUADRENNIAL ENERGY REVIEW

ENERGY TRANSMISSION, STORAGE, AND DISTRIBUTION INFRASTRUCTURE

July 14, 2015

NARUC Summer Committee Meetings – Committee on Gas

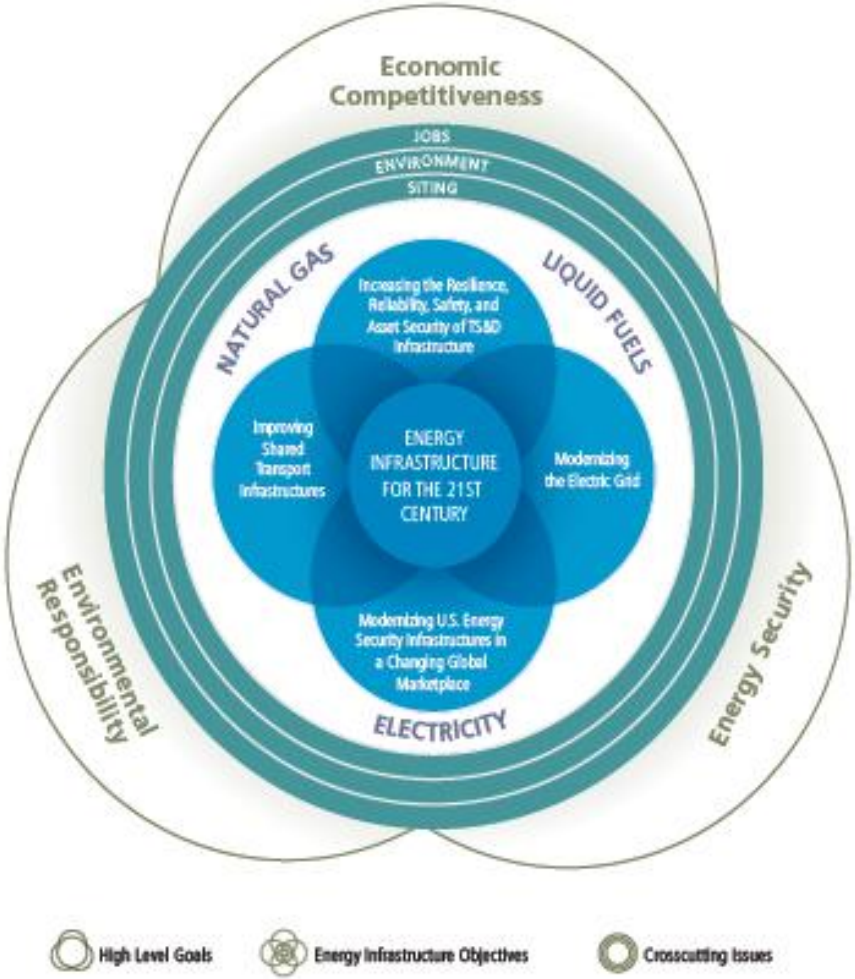
James Bradbury, Ph.D.
Senior Policy Advisor for Climate, Environment and Efficiency
Office of Energy Policy and Systems Analysis

OVERVIEW

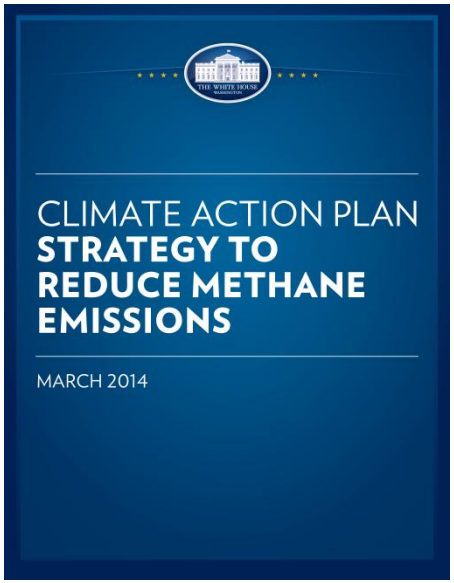
- QER overview
- Climate Action Plan – Methane Strategy
  - Secretary of Energy Roundtable Meetings
  - DOE – Natural Gas Modernization Initiative
- QER findings
- QER recommendations

An Unconventional Look at Energy Systems

- The United States has one of the most advanced energy systems in the world
- The energy transmission, storage, and distribution (TS&D) infrastructure is increasingly complex and interdependent
- It must handle demanding system requirements (e.g., 24/365, on-demand, highly-reliable energy)
- The longevity and high capital costs mean that TS&D infrastructure decisions today will affect the national energy system for decades to come



President's Climate Action Plan



"Curbing emissions of methane is critical to our overall effort to address global climate change. … To achieve additional progress, the Administration will":

- Develop a comprehensive Interagency Methane Strategy (*completed March 2014)*
- *Take a* collaborative approach with state governments and the private sector to cover all methane emitting sectors
- *UPDATE*: Set a 2025 target for the O&G sector to reduce methane emissions by 40 to 45% below 2012 levels, plus additional actions (*January 2015*)

Three Pillars

Assessing current emissions data and addressing data gaps	Identifying Technologies and Best Practices for Reducing Emissions	Identifying Existing Authorities and Incentive-based Opportunities for Reducing Emissions

Secretary's Methane Stakeholder Roundtables

Convened broad range of stakeholders, discussing opportunities to *modernize natural gas infrastructure & reduce mid- and downstream methane emissions*

Dr. Ernest Moniz
Secretary of Energy

Key lessons learned:

- *There is broad stakeholder support for taking action*
- *The drivers for action vary by stakeholder group*
  - Improve safety
  - Conserve energy and save money
  - promote efficiency
  - protect the climate
  - create jobs

A capstone roundtable took place at the White House on July 29, 2014. Afterward, Secretary of Energy Ernest Moniz announced several new initiatives as DOE's part of the larger Administration Strategy to Reduce Methane Emissions.

DOE's Natural Gas Modernization Initiative

- **December, 2014: ARPA-E** announced funding for 11 new projects developing low-cost methane sensing for the oil and gas sector
- **April, 2015: FERC** issued a Policy Statement on cost recovery for midstream natural gas infrastructure upgrades
- **DOE continues the dialogue with stakeholders** to advance a DOE-wide RD&D strategy:
  - DOE program offices hosted "Natural Gas Infrastructure R&D and Methane Emissions Mitigation Workshop" (November 12-13, 2014 – Pittsburgh PA)
  - DOE proposed
- **DOE is working with NARUC** to launch a DOE-NARUC partnership for technical assistance
- **DOE Launched the Natural Gas Modernization Clearinghouse**
- **Stakeholder action is key.** We are following-up with stakeholders who announced commitments to action at the Capstone.

New DOE Website: Natural Gas Modernization Clearinghouse

Goal

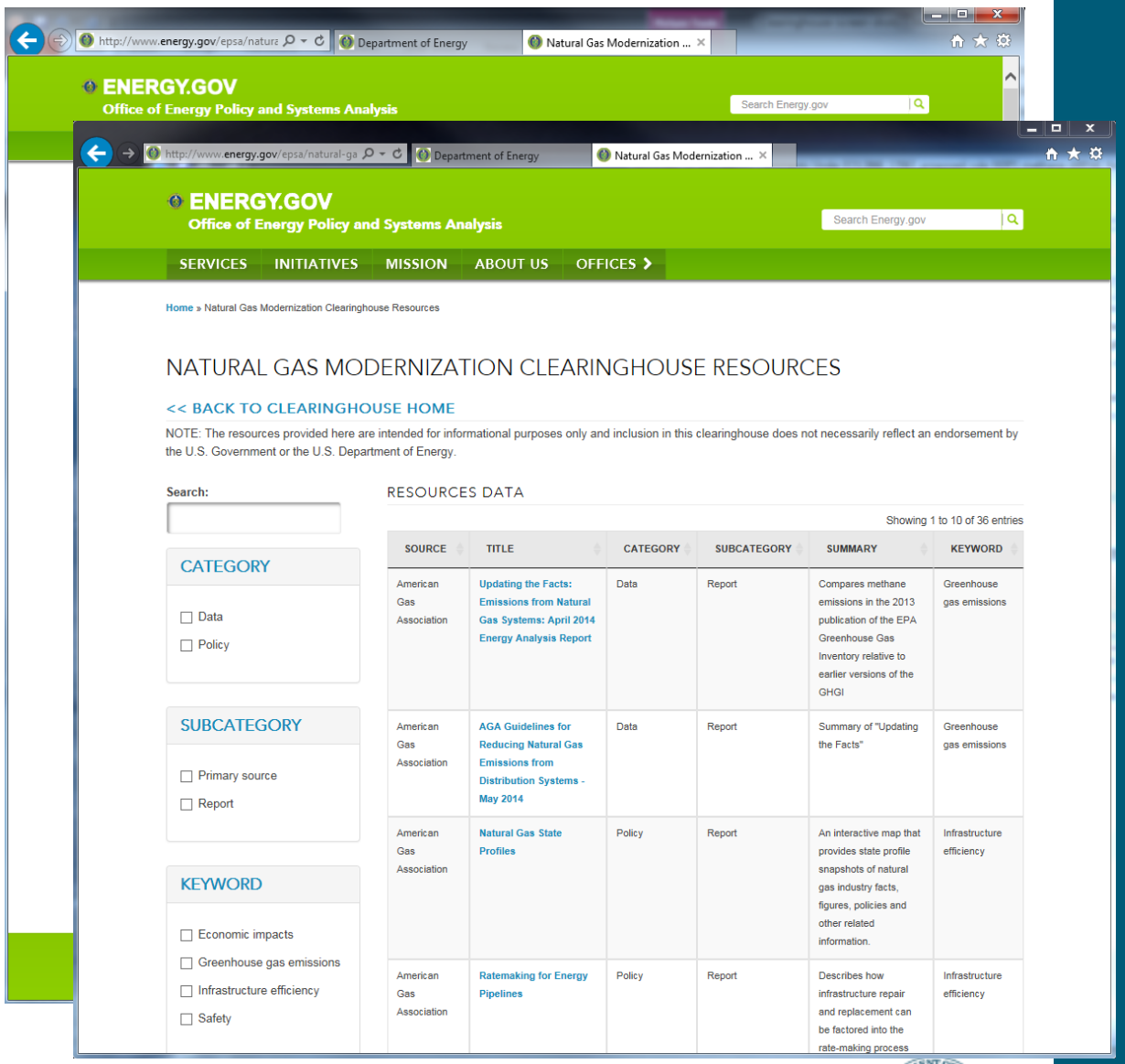
To provide information on the implications of natural gas infrastructure modernization, including:

- safety benefits
- methane emissions
- technology R&D
- job creation
- policies and incentives

Contact & Feedback

DOE welcomes stakeholder feedback on the content of this clearinghouse:

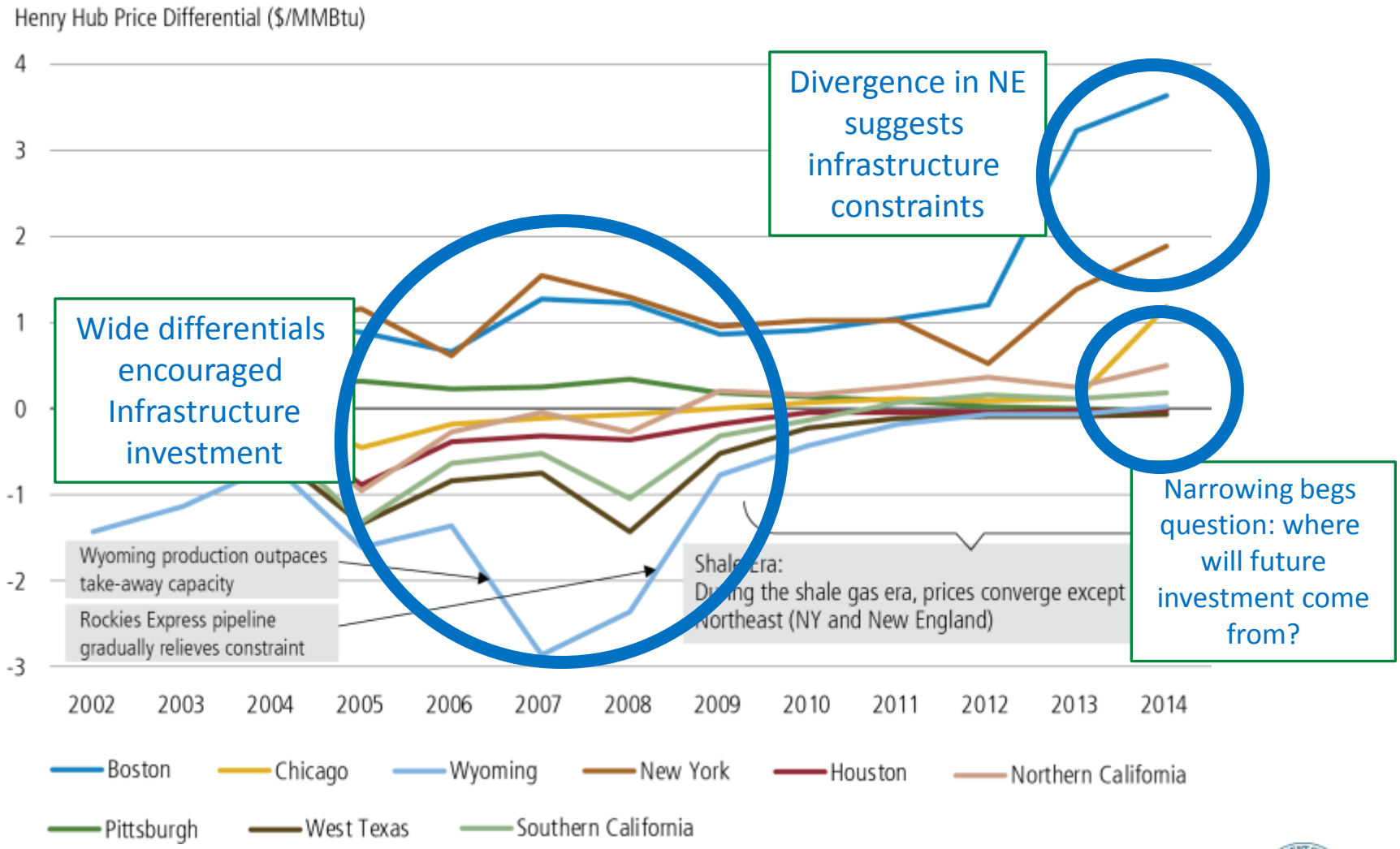
ngmclearinghouse@hq.doe.gov



http://www.energy.gov/epsa/natural-gas-modernization-clearinghouse

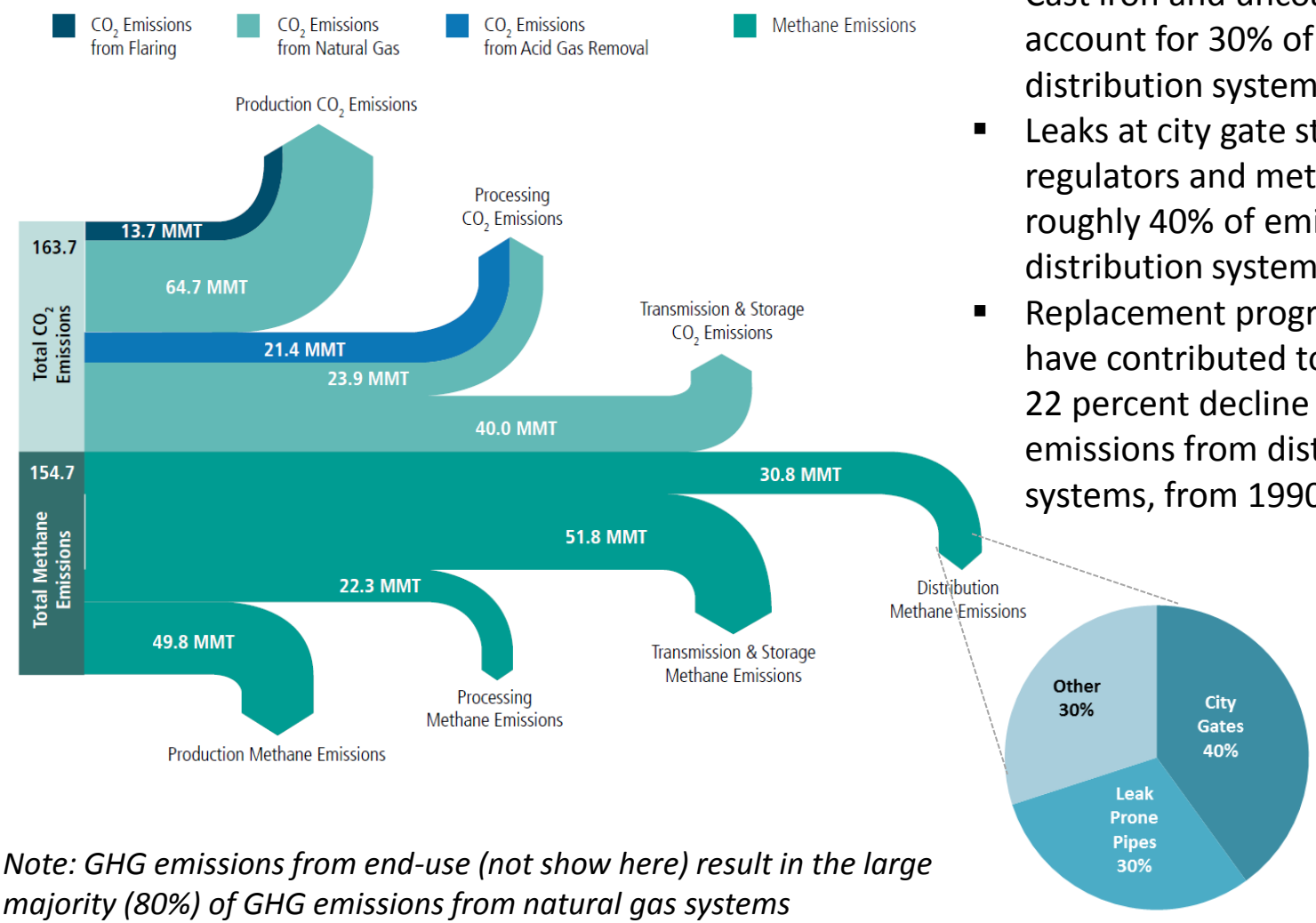
QER: SELECT NATURAL GAS SECTOR FINDINGS AND RECOMMENDATIONS

Importance of Gas Transmission Infrastructure



GHG Emissions from Natural Gas Systems

Distribution systems account for 20% of methane emissions from the natural gas sector.



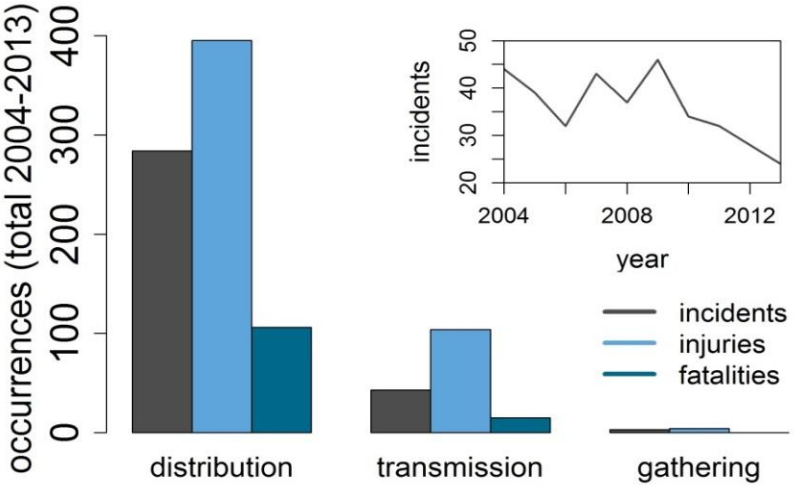
- Cast iron and uncoated steel pipes account for 30% of emissions from distribution systems.
- Leaks at city gate stations (from regulators and meters) account for roughly 40% of emissions from distribution systems.
- Replacement programs to date have contributed to an estimated 22 percent decline in methane emissions from distribution systems, from 1990 to 2012.

Note: GHG emissions from end-use (not show here) result in the large majority (80%) of GHG emissions from natural gas systems

Data sources: EPA, 2014; EIA, 2014 (see QER for details)

STEADY IMPROVEMENTS IN PIPELINE SAFETY REQUIRES PERSISTENT ATTENTION FROM POLICYMAKERS

Total Incidents, Injuries, and Fatalities Associated with U.S. Natural Gas Pipelines (PHMSA, 2014)



*** Note: most gathering pipelines are unregulated and not subject to PHMSA's reporting requirements

- Most serious incidents involve distribution pipelines***
- Frequency of incidents is variable, but declining
- Excavation damage is the leading cause of serious incidents
- Other causes include corrosion, equipment failure, and incorrect operation

- *Federal Policy Efforts:*
  - In 2011, DOT issued a "Call to Action" on pipeline safety
  - The Pipeline Safety, Regulatory Certainty, and Job Creation Act of 2011
  - PHMSA is developing new safety rules, including a proposed transmission pipeline safety rule expected this year

Miles to Go with Pipeline Replacement

10 states with the Most Leak-Prone Distribution Mains

Rank	State	Leak Prone Iron Mains (mi)	Leak Prone Steel Mains (mi)
1	PA	3,300	8,600
2	NY	4,200	7,500
3	OH	570	9,500
4	CA	29	8,200
5	NJ	4,900	2,200
6	MA	3,600	2,600
7	TX	820	5,000
8	MI	3,000	2,300
9	WV	13	3,000
10	AL	1,200	820

- Approximately 9% of distribution pipelines in the United States are leak-prone.
- Replacement costs nationally are estimated to be $270 billion.
- States with leak prone pipelines in need of replacement are from all regions of the country.
- At least a dozen utilities will require two decades or more to replace their leak-prone pipelines.
- 39 states have trackers or surcharges to enable cost-recovery for pipeline replacement programs
- Most state programs have cost caps or other limitations that slow the rates of investment.

DIRECTED INSPECTION AND MAINTENANCE AT REGULATORS AND METERS (CITY GATE STATIONS)

- 40% of methane emissions from distribution systems are from leaks at meters and regulators at city gate stations.
- Directed inspection and maintenance (DI&M) programs can reduce survey costs and enhance profitable leak repair (Targeting problem stations and components saves time and money by prioritizing equipment to focus on with future surveys)
- Quarterly leak detection and repair, could reduce emissions from city gate stations by 60%.
- Recent study confirmed that facility upgrades substantially reduce these leaks.

- *In general:* new technologies and approaches to using methane sensing technologies can help prioritize investment, yielding improved safety and greater emission reductions

QER Recommendation: Rate Relief to Increase Investments in NG Distribution Safety and Emissions Abatement

- **$2.5 to 3.5 Billion competitive funding program** to help LDC's achieve the *dual goals of enhanced safety and lower emissions* through pipeline replacement, DI&M and other innovative approaches to improving the performance of natural gas distribution systems.
  - Federal funding would provide rate-relief for low-income households to help leverage broader, accelerated investments in infrastructure modernization.
  - To expedite projects and reduce costs, State governments would be encouraged to coordinate permitting processes between agencies.
  - Goal is to support a "portfolio approach" to investments that are most cost-effective within each individual context. Quantifiable benefits could include a combination of gas conservation, avoided fatalities and injuries and reduced GHG emissions (accounting for Social Cost of Carbon).

Other Recommendations to Help Reduce Methane Emissions

- **Improve quantification of emissions from natural gas infrastructure.** $10 million requested in the FY 2016 Budget to help update Greenhouse Gas Inventory estimates of methane emissions from natural gas systems. DOE and EPA should undertake a coordinated approach.

- **Expand DOE research and development (R&D) programs** on cost-effective technologies to detect and reduce losses from natural gas TS&D systems. $15 million requested in the FY 2016 Budget for DOE's midstream natural gas infrastructure program.

- **Demonstrate and Deploy continuous emissions monitoring equipment.** Continuous emissions monitoring can be a valuable component of leak detection and repair programs. DOE should provide the additional funding needed to ensure that the most successful MONITOR projects are field tested and deployed.

QUESTIONS?

James Bradbury

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Office of Energy Policy and Systems Analysis
U.S. Department of Energy

http://www.energy.gov/qer

http://www.energy.gov/epsa/natural-gas-modernization-clearinghouse

QER Recommendation: Improve Data Collection, Analysis and Coordination

- The National Transportation Safety Board found in 2015 that many types of basic data necessary for comprehensive probabilistic risk modeling of natural gas pipelines are not currently available.
- The Board's recommendations included the development of better-quality spatial data on pipelines that can be more easily accessed by regulators and operators.

QER Recommendation

Improve environmental data collection, analysis, and coordination:

- DOE should work with other Federal agencies to improve data and analysis on the environmental characteristics and impacts of TS&D infrastructures. This work should be designed to fill the host of data gaps on environment, safety, and public health issues with respect to TS&D infrastructure.

MONITOR

Developing low-cost, highly-sensitive systems that detect and measure methane associated with the production and transportation of oil and natural gas

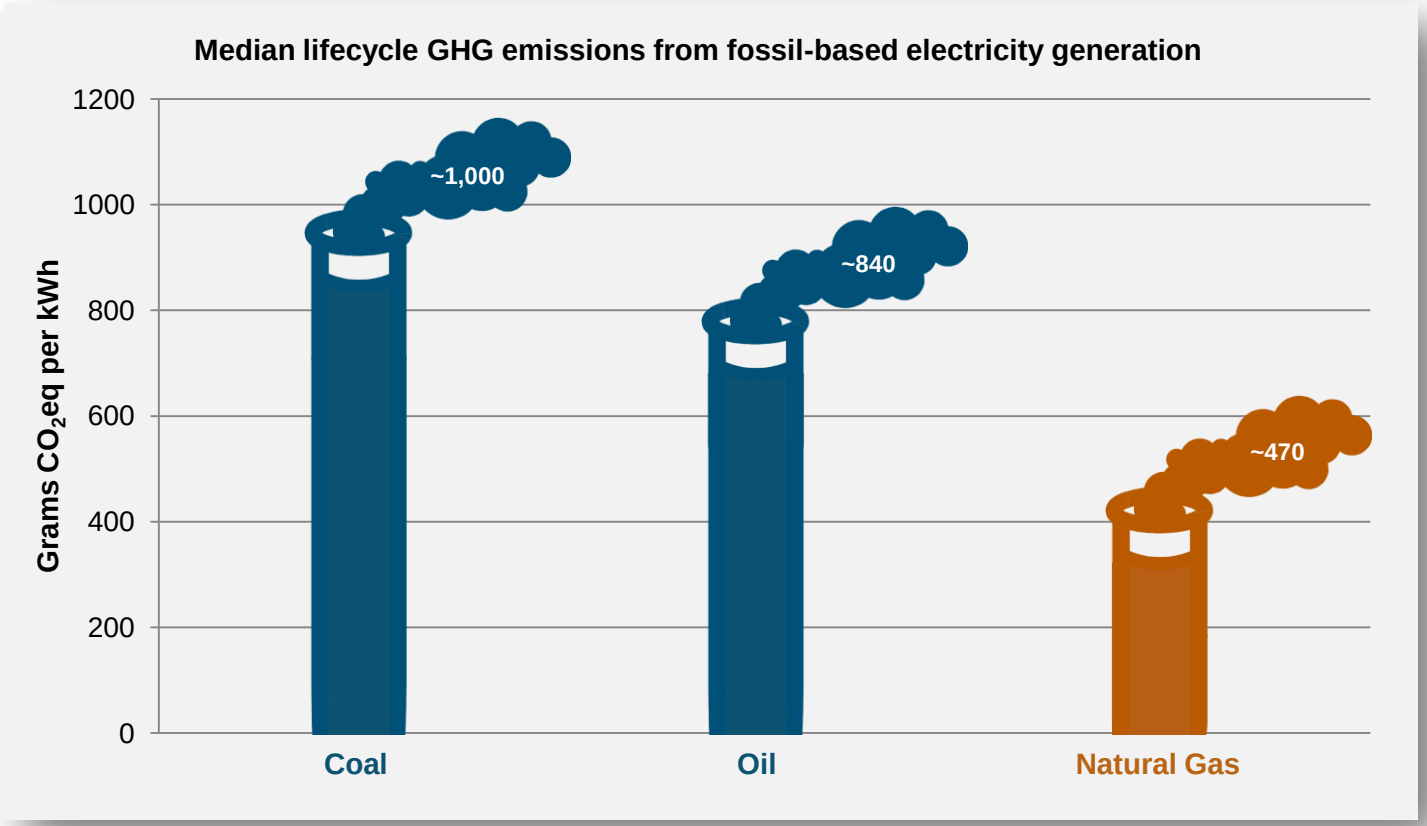
Dr. Bryan Willson, Program Director
Bryan.Willson@ColoState.edu

arpa·e
CHANGING WHAT'S POSSIBLE

CSU Energy Institute

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

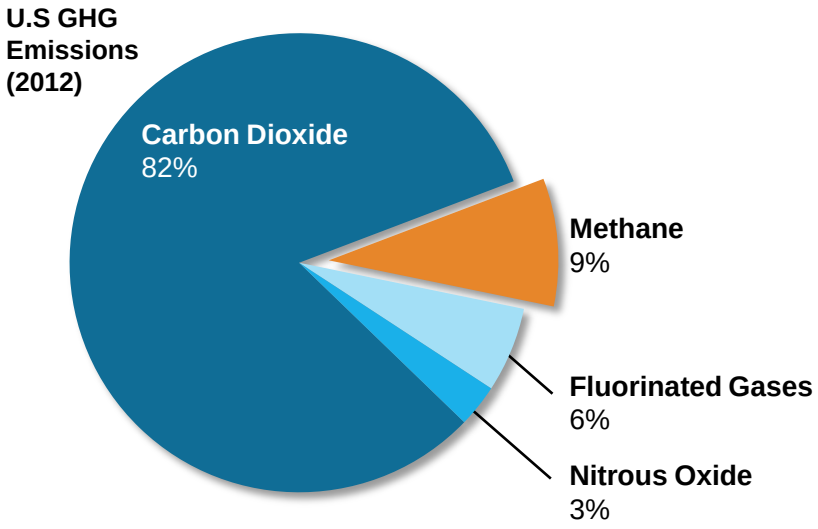


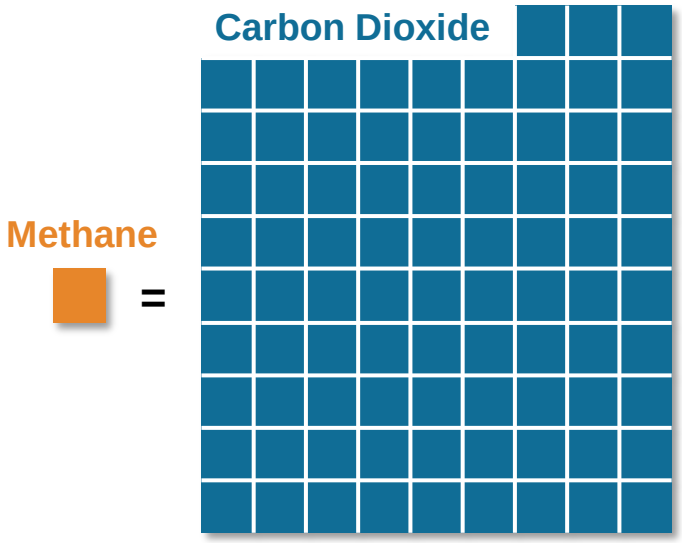
Source: IPCC AR4 Annex II (2007)

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)

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

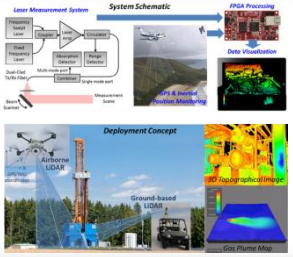
The Portfolio: 11 Projects in 9 States

SYSTEM SOLUTIONS

BRIDGER PHOTONICS

Mobile LiDAR Sensors for Methane Leak Detection

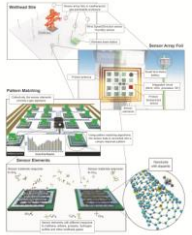
Bozeman, MT



parc
A Xerox Company

Printed Carbon Nanotube Sensors for Methane Leak Detection

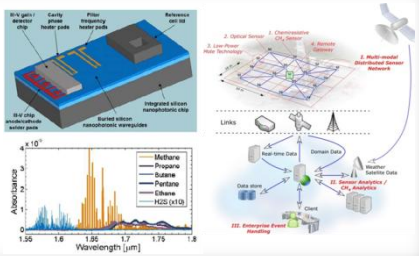
Palo Alto, CA



IBM

On-Chip Optical Sensors and Network for Methane Leak Detection

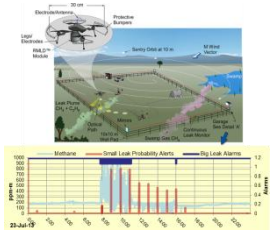
Yorktown Heights, NY



PSI Physical Sciences Inc.

UAV-based Laser Spectroscopy for Methane Leak Detection

Andover, MA



RebellionPhotonics

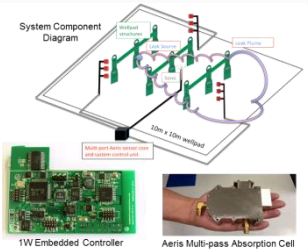
Portable Imaging Spectrometer for Methane Leak Detection

Houston, TX

AERIS TECHNOLOGIES

Miniaturized Tunable Laser Spectrometer for Methane Leak Detection

Redwood City, CA



Miniaturized Tunable Laser Spectrometer for CH4 Leak Detection

Aeris Technologies
$2.4 million

TECHNOLOGY SUMMARY

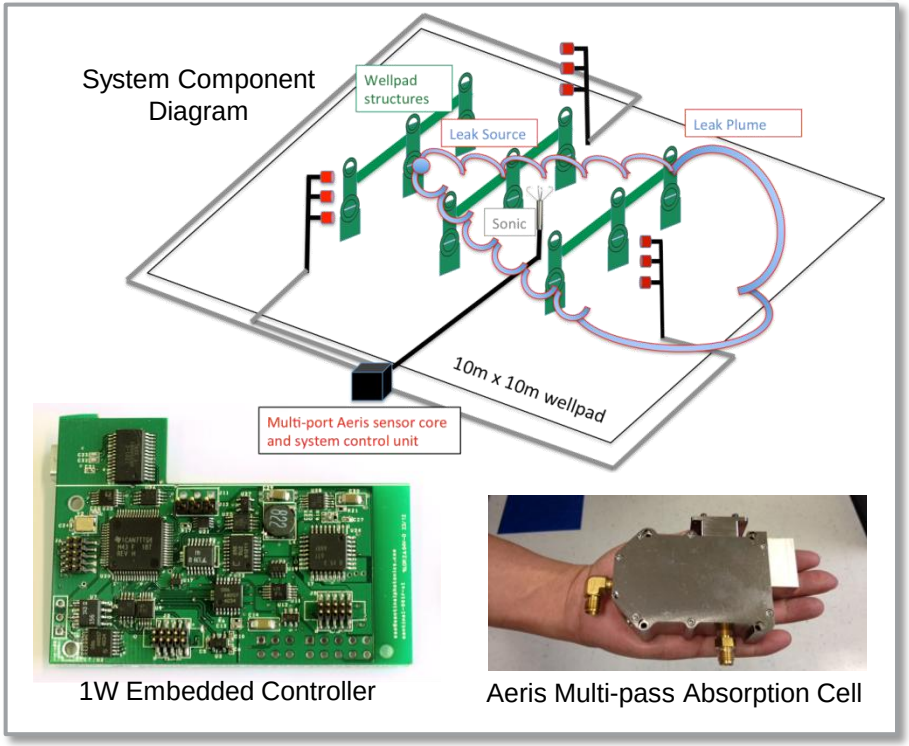
- Compact mid-IR CH4 sensor with Aeris' patent pending multi-pass absorption cell enabling ppb/s detection using simple direct absorption spectroscopy
- New architecture to achieve a long path length in a small volume
- Artificial neural network-leak characterization algorithm (ANN-LCA) to allow abstraction of complexity through pre-deployment, sophisticated-forward-model training.

TECHNOLOGY IMPACT

- Equivalent performance of ICOS or CRDS (2 ppb at 1 Hz) while being order of magnitude smaller and consuming less power (20-30W)
- ANN-LCA approach will lead to other energy industry impacts through in-situ meteorology-aware real-time decision-making (e.g. wind turbine/farm control systems)

PROJECT PARTNERS

- Los Alamos National Laboratory
- Rice University



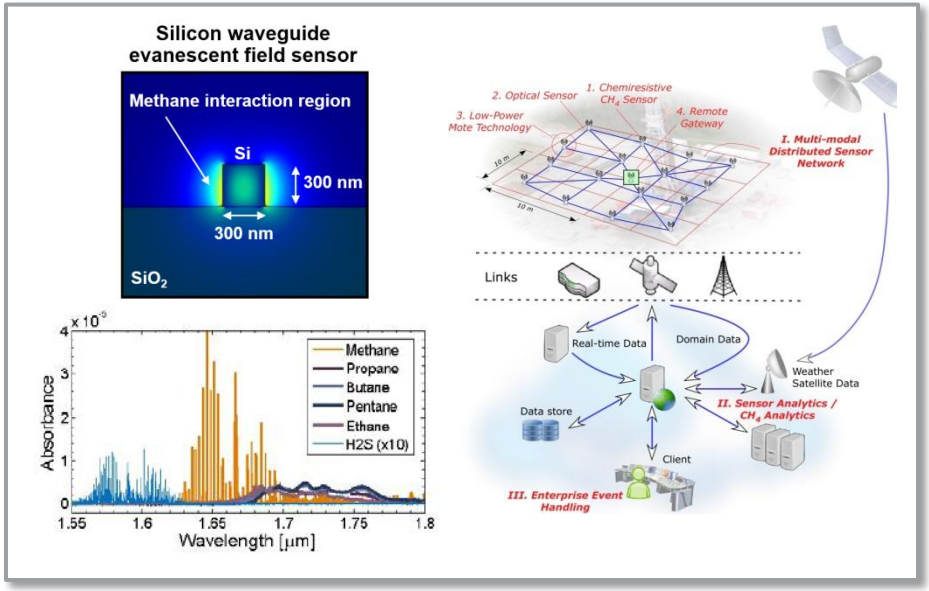
AERIS TECHNOLOGIES

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

IBM
$4.5 million

TECHNOLOGY SUMMARY

- Multi-modal, highly secure and reliable distributed methane monitoring and management system
- Novel on-chip optical sensors with high methane selectivity using state of the art silicon photonics technology
- Highly energy efficient , time-synchronized mesh networks
- Intelligent remote gateway
- Cloud-based analytics for source detection and localization as well as system self-verification coupled with enterprise-level integration capabilities



TECHNOLOGY IMPACT

- Cost is < $300 per sensor, 10-100x lower than current commercial TDLAS
- Low maintenance, robust, continuous measurement
- Low power requirements enables long-term solar-powered battery operation

PROJECT PARTNERS

- Princeton University
- Harvard University

UAV-based Laser Spectroscopy for Methane Leak Measurement

Physical Sciences, Inc.
$2.9 million

TECHNOLOGY SUMMARY

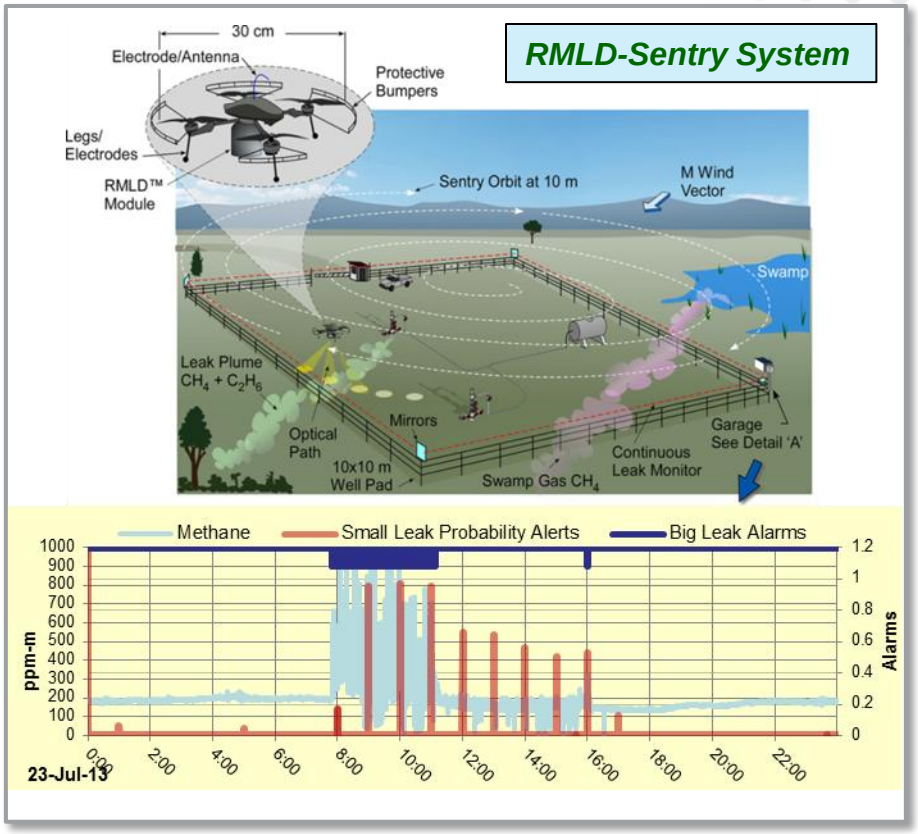
- Autonomous natural gas leak detection, measurement, and reporting system
- Innovative system combines:
  - Laser Backscatter Detection
  - Miniature fully-autonomous quadrotor aircraft
    - Field-validated by DoD
  - Algorithms for plume transport, leak detection, localization and mass flux quantification

TECHNOLOGY IMPACT

- Continuous leak monitoring with real-time alarm notification
- Speciation of methane and ethane differentiates thermogenic vs. biogenic emission
- Improved production processes reduce costs of mid-IR Interband Cascade Laser (ICL) sources
- Provides foundation for rapid commercialization

PROJECT PARTNERS

- Heath Consultants Inc.
- Thorlabs Quantum Electronics, Inc.
- Princeton University
- University of Houston
- Cascodium Inc.



Mobile LiDAR Sensors for Methane Leak Detection

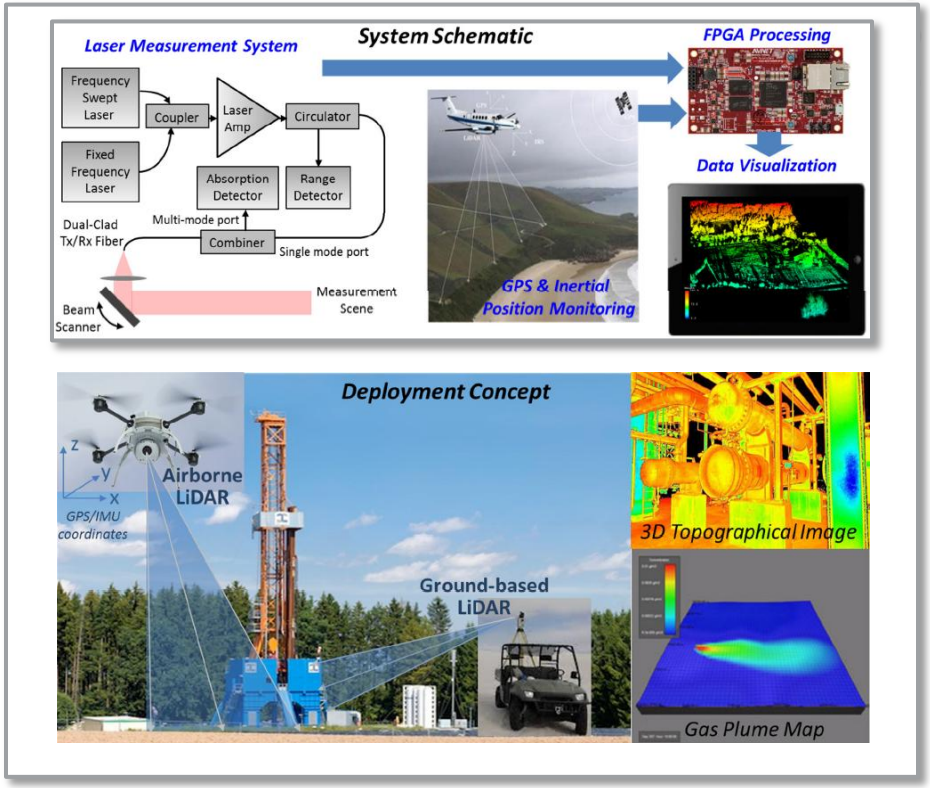
Bridger Photonics
$1.5 million

TECHNOLOGY SUMMARY

- Light-detection and ranging (LiDAR) system capable of simultaneous, rapid, and precise 3D topography and methane gas sensing
- Measurements performed from an airborne or ground vehicle
- Novel near-IR fiber laser source and a mobile measurement strategy for rapid and sensitive pinpointing of methane leak plumes across multiple well platforms per day

TECHNOLOGY IMPACT

- Long range: a frequency-swept laser beam is transmitted to a topographical target ranging from 1 to 300 m from the sensor
- Potentially achieve a minimum leak rate detection of 1 gram per minute
- Low cost: proposed system estimated between ~$1.4k and $2.2k per well per year



BRIDGER PHOTONICS

Printed Carbon Nanotube Sensors for Methane Leak Detection

PARC
$3.4 million

TECHNOLOGY SUMMARY

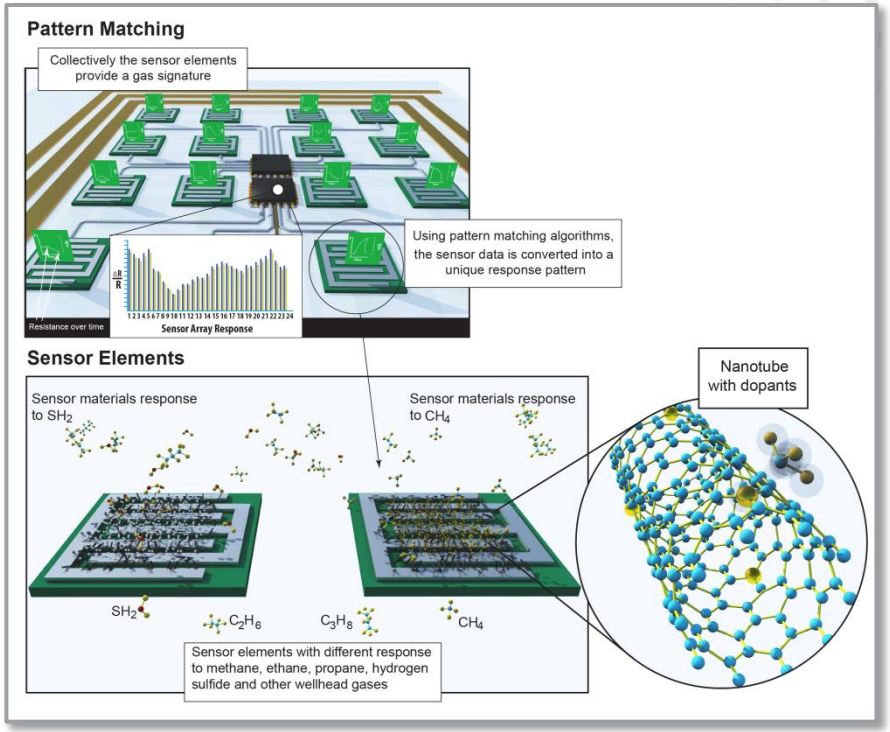
- High-sensitivity, high-selectivity, robust gas leak detection system with low-cost printed chemical sensor arrays based on doped carbon nanotubes
- Leverages previous gas sensor development by NASA and combines with PARC's scalable, low-cost additive printing methods
- Sensor multiplicity reduces false positives and enables accurate calculation of leak location and leak rate with parameter estimation algorithms

TECHNOLOGY IMPACT

- A total system cost of under $350/site/year, to enable a low-cost disruptive approach to deploy and operate leak-detection systems
- 1 ppm sensitivity and leak localization of 1 m
- Technology transfer support from BP and Xerox
- Printing-enabled distributed gas leak detection at market-disruptive cost

PROJECT PARTNERS

- NASA Ames Research Center
- BP
- Xerox Corporation



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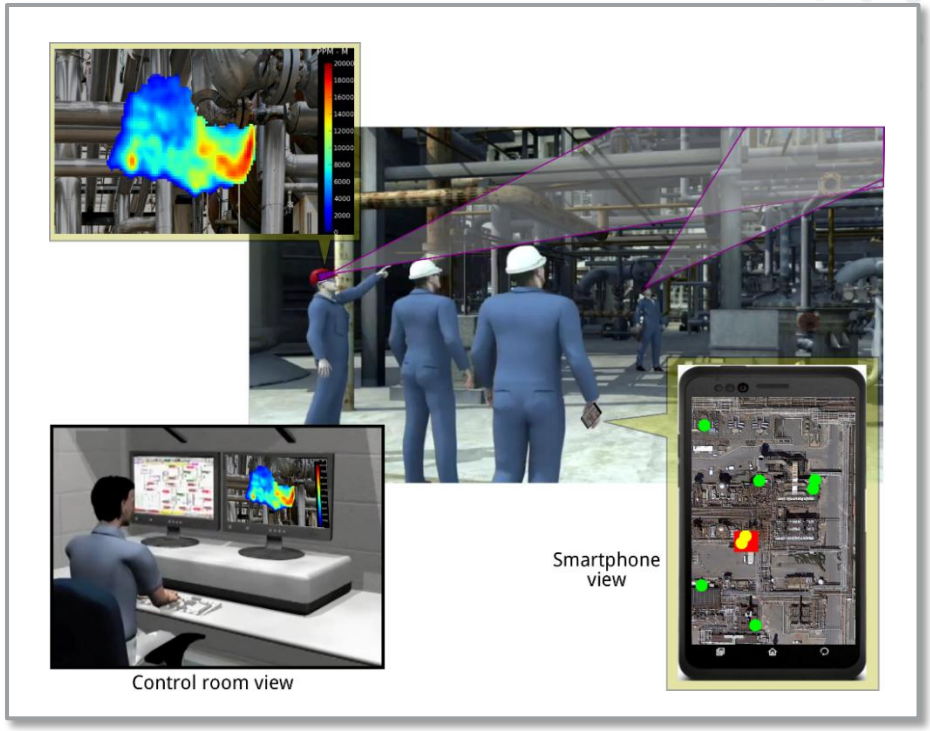
Portable Imaging Spectrometer for Methane Leak Detection

Rebellion Photonics
$4.3 million

TECHNOLOGY SUMMARY

- Miniaturization of Rebellion's Gas Cloud Imager (GCI), a long-wave infrared imaging spectrometer
- Image contains multiple bands of spectral data for detection and quantification of methane leaks
- Camera will be lightweight and incorporated with hard-hat/protective equipment for portability
- Data processing performed using a cloud-based computing architecture that streams results to smartphones or Google glass



TECHNOLOGY IMPACT

- High portability will enable widespread deployment and fast identification of leaks
- Visualization of leak leads to faster time to fix leak

REBELLION PHOTONICS

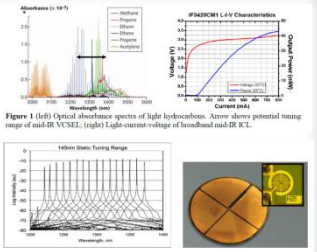
The Portfolio: 11 Projects in 9 States

PARTIAL SOLUTIONS

MAXION

Tunable Mid-infrared Laser for Methane Sensing

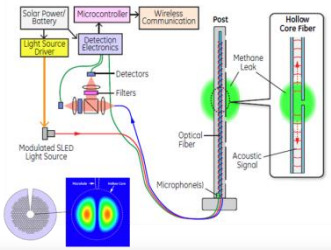
Jessup, MD



GE

Microstructured Optical Fiber for Methane Sensing

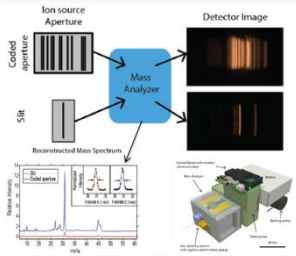
Niskayuna, NY



Duke UNIVERSITY

Miniaturized Coded Aperture Mass Spectrometer for Methane Sensing

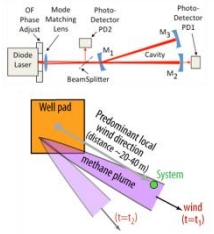
Durham, NC



LI-COR®

Laser Spectroscopic Point Sensor for Methane Leak Detection

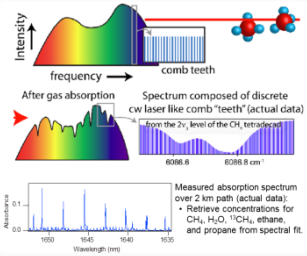
Lincoln, NE



University of Colorado Boulder

Frequency Comb-based Methane Sensing

Boulder, CO



Tunable Mid-infrared Laser for Methane Sensing

Maxion Technologies
$1.9 million

TECHNOLOGY SUMMARY

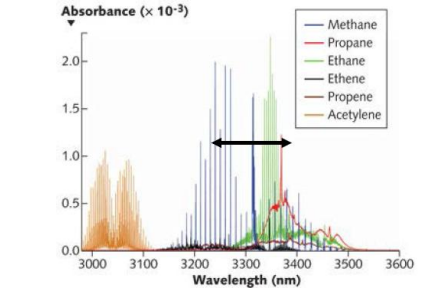
- Mid-infrared vertical cavity surface-emitting laser (VCSEL) based on an interband cascade active region
- Utilizes an integrated micro-electro-mechanical system (MEMS) mirror enabling a wide tuning range around 3.3 micrometers

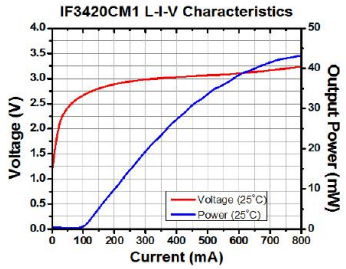
TECHNOLOGY IMPACT

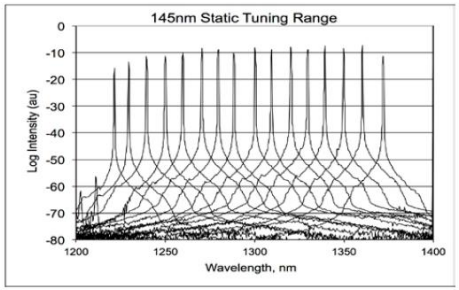
- Innovative, low-cost mid-IR laser with VCSEL architecture
- Approximately 40x reduction in laser cost, enabling a system cost below $2,600 / well pad

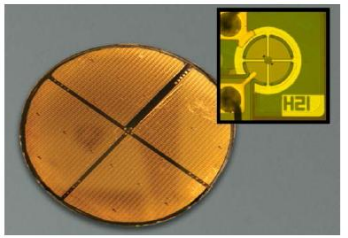
PROJECT PARTNERS

- Thorlabs Quantum Electronics
- Praevium Research
- Rice University









MAXION TECHNOLOGIES, INC.

A wholly-owned subsidiary of Thorlabs, Inc.

Frequency Comb-based Methane Sensing

UC-Boulder
$2.1 million

TECHNOLOGY SUMMARY

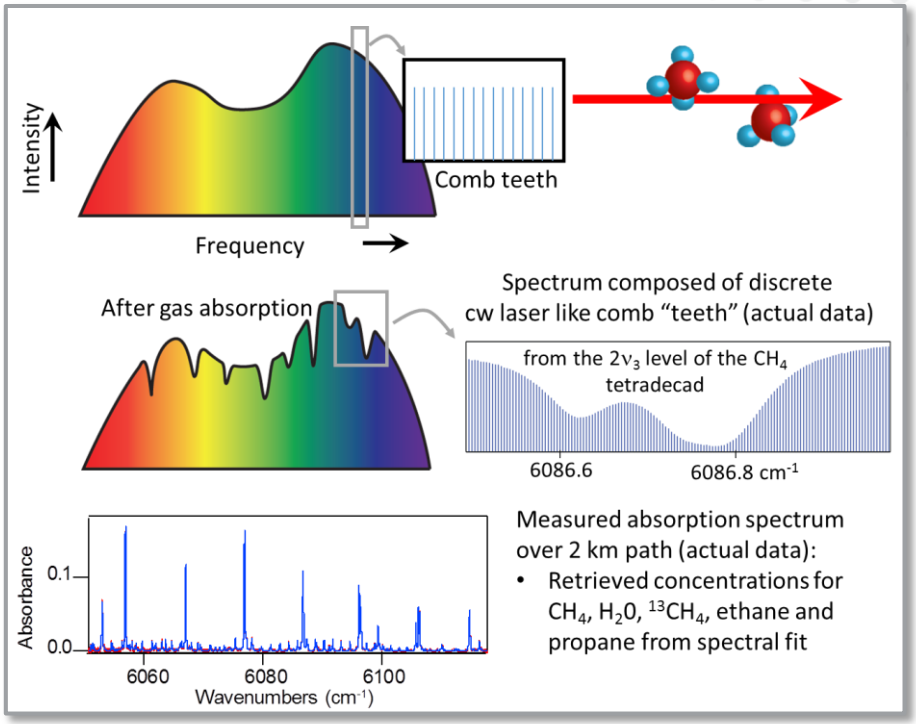
- Produces 10^5 spaced, sharp, single frequency laser lines over a broad bandwidth
- Drift-free intrinsic calibration and high sensitivity
- Long path length (over 2 km)
- Multispecies sensing: CH_4, $^{13}CH_4$, H_2O, propane, ethane
- Capable of being deployed as part of a full methane detection system

TECHNOLOGY IMPACT

- Reduces cost of frequency comb spectroscopy
- High sensitivity (ppb) long-path measurements with specificity of FTIR
- Able to provide enhanced capability (measure multiple species, isotopic differentiation)

PROJECT PARTNERS

- NIST
- CIRES/NOAA



University of Colorado Boulder

Microstructured Optical Fiber for Methane Sensing

GE

$1.4 million

TECHNOLOGY SUMMARY

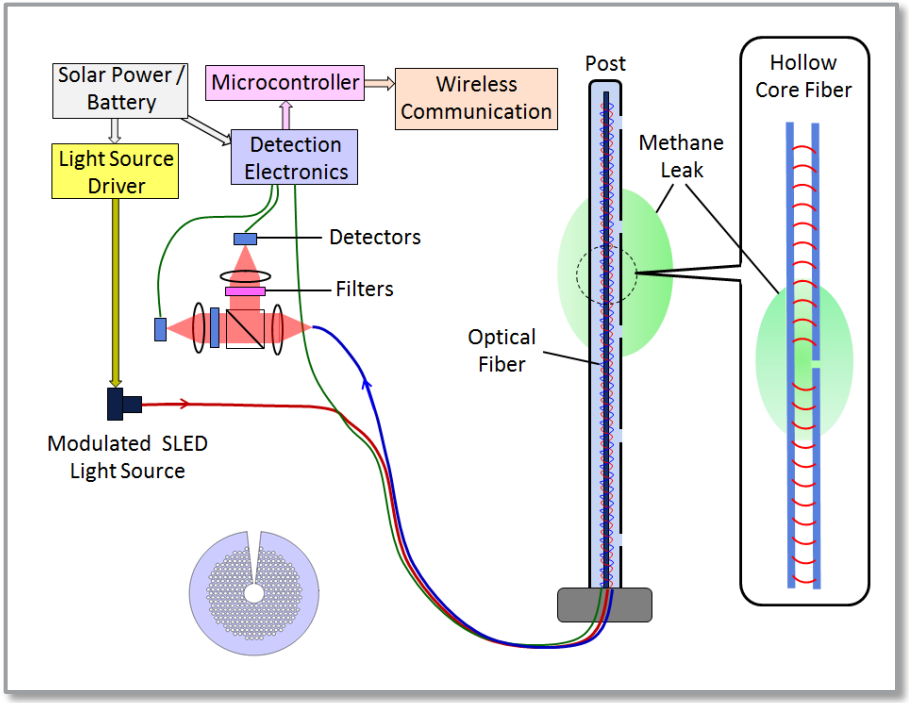
- Hollow core photonic crystal fiber fabricated for long path length transmission of infrared radiation at methane absorption wavelengths
- Includes micro side-holes for fast penetration of gases into the core
- Microstructure of fiber will be designed to minimize optical losses
- Capable of being deployed as part of a full methane detection system

TECHNOLOGY IMPACT

- High sensitivity technique broadly applicable in the oil and gas industry
- Enables low cost, high sensitivity measurements of methane

PROJECT PARTNERS

- Virginia Tech



Coded Aperture Miniature Mass Spectrometer for Methane Sensing

Duke University
$2.9 million

TECHNOLOGY SUMMARY

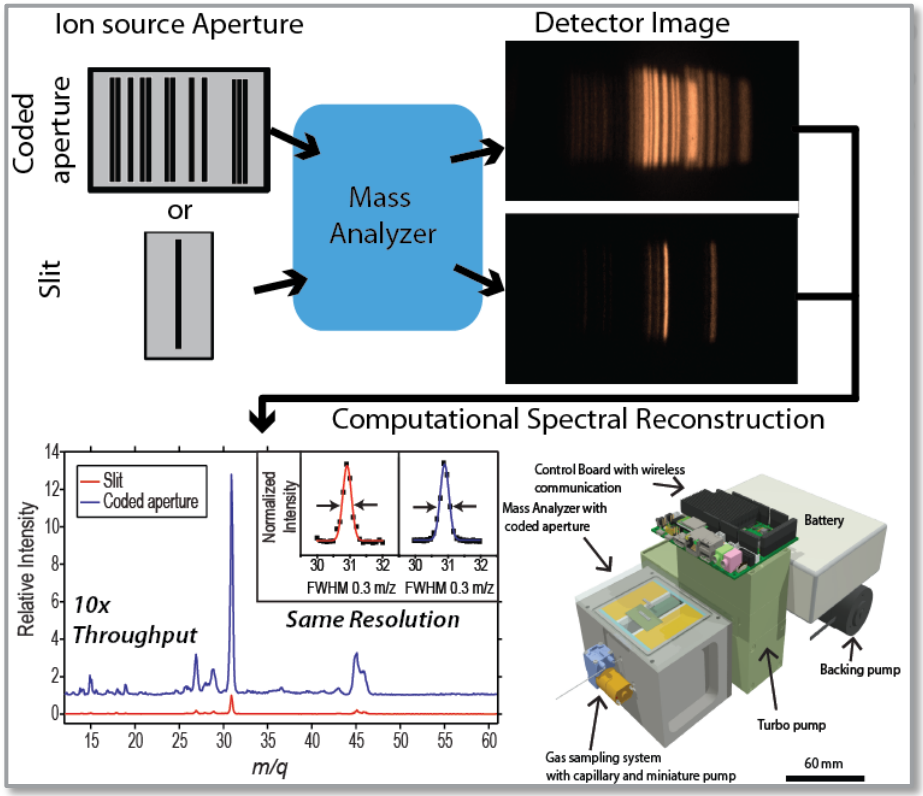
- Miniature mass spectrometer enabled by coded apertures optimized for natural gas and methane
- Combines aperture coding, microfabrication, computational sensing, double focusing sector mass analyzer, and search/location algorithms
- Natural gas speciation and identification of volatile organic compounds (VOCs), such as benzene
- Provides:
  - Short time to detection
  - High selectivity
  - High performance with low SWAP-C

TECHNOLOGY IMPACT

- Miniature mass spectrometer that can be used for methane detection, natural gas speciation, and a variety of other environmental sensing applications (e.g. CO_2 detection from carbon sequestration)

PROJECT PARTNERS

- RTI International



Duke UNIVERSITY

Laser Spectroscopic Point Sensor for Methane Leak Detection

LI-COR Biosciences
$2.7 million

TECHNOLOGY SUMMARY

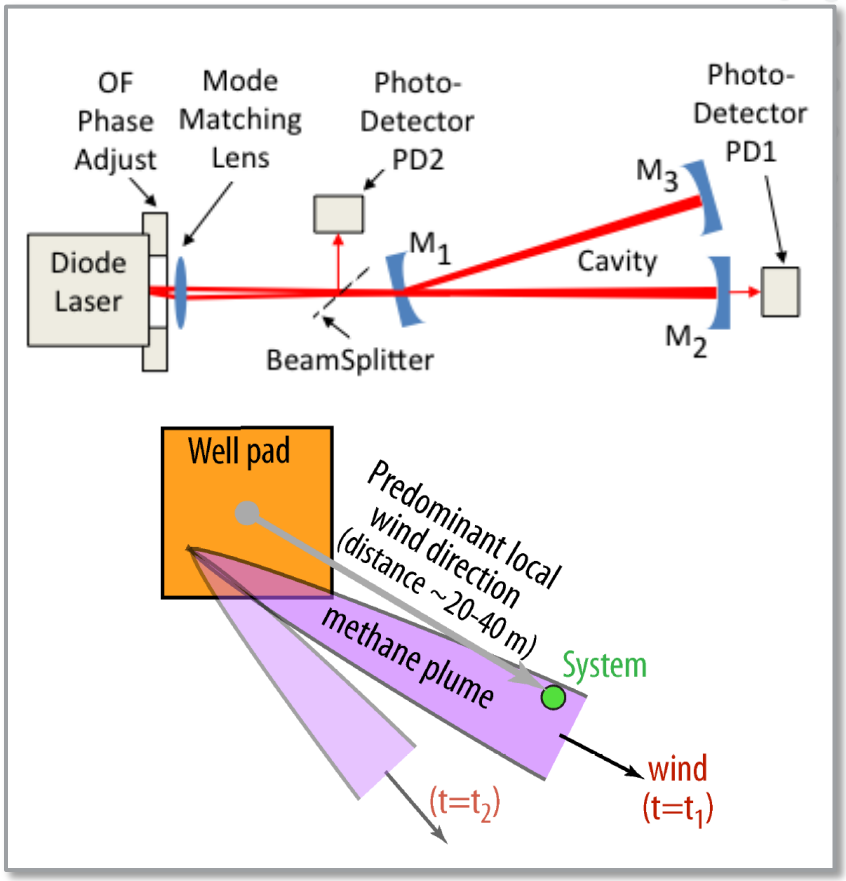
- Laser spectroscopic CH_4 sensor that improves upon optical feedback-cavity enhanced absorption spectroscopy (OF-CEAS)
- Exploits an optical cavity with a small sampling volume (30 cc) and long optical path length (1000s m) for high sensitivity
- Advanced manufacturing to further reduce cost

TECHNOLOGY IMPACT

- Same cost as tunable laser diode absorption spectroscopy (TLDAS) at better performance
- High stability measurement
- Suitable for both stationary and mobile applications

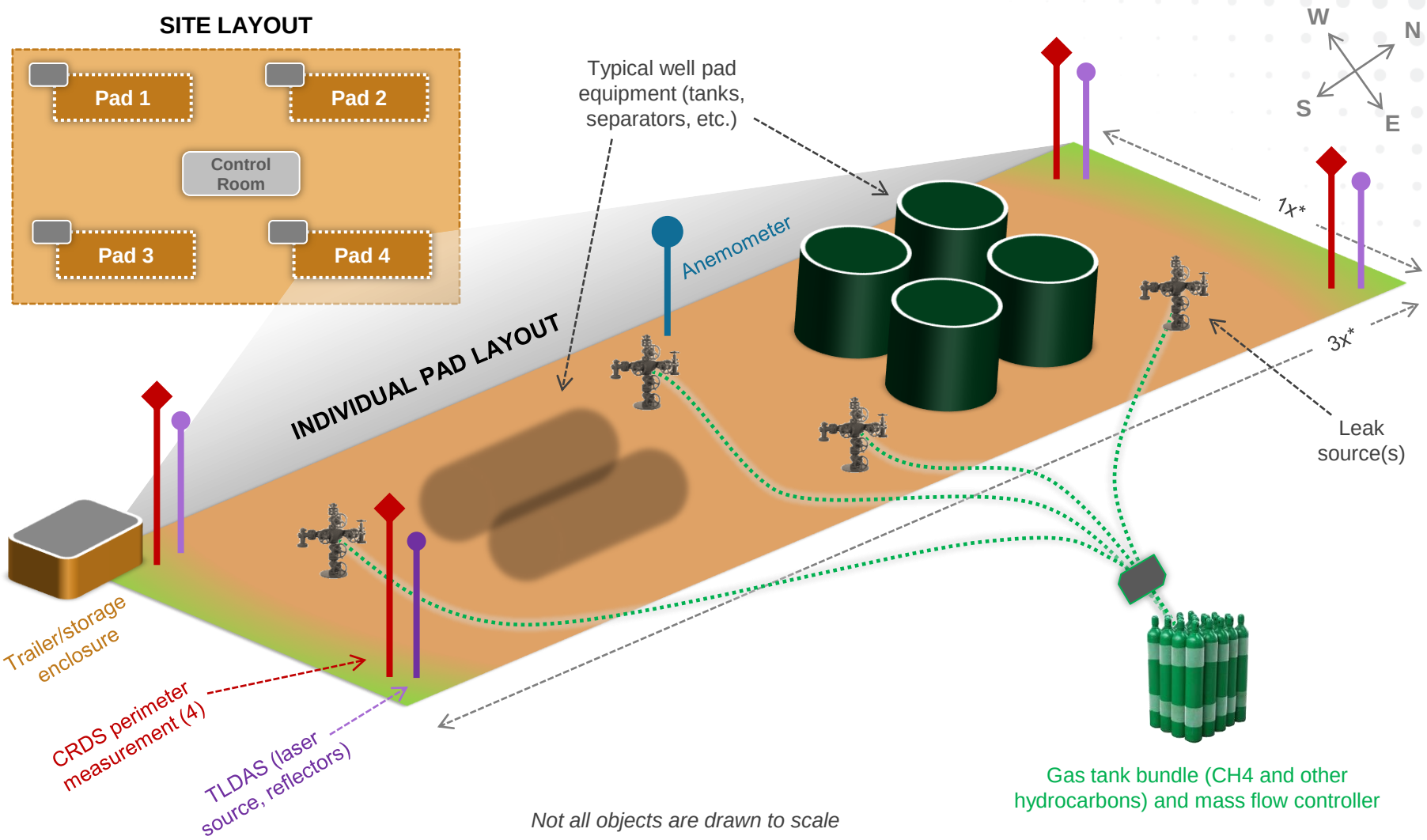
PROJECT PARTNERS

- Colorado State University
- Gener8



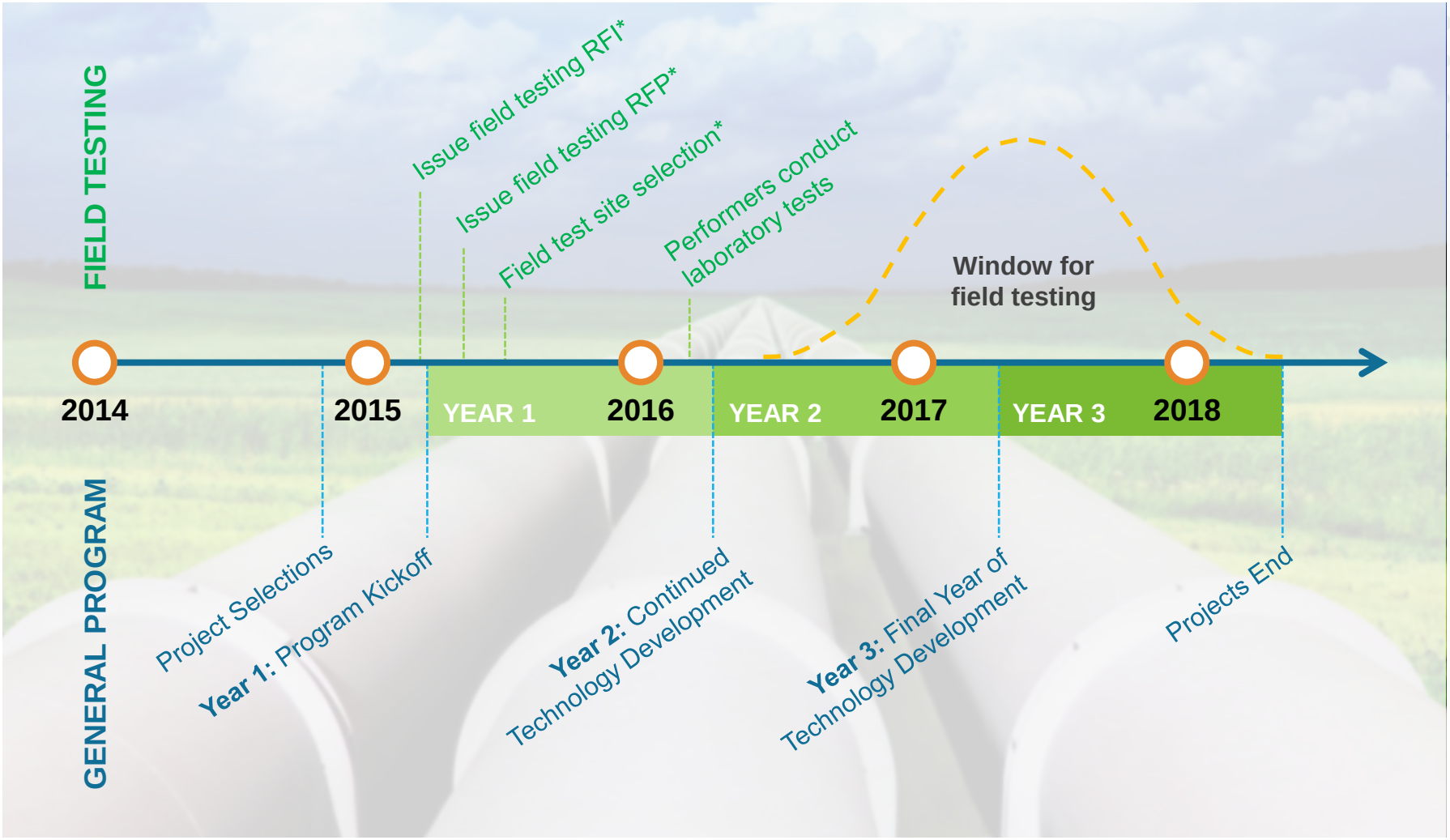
LI-COR®

Example Test Site Layout



*1x3 size ratio is approximate

The MONITOR Timeline: ARPA-E & Beyond



*Subject to change