Methane quantification &
ARPA-E’s MONITOR Program

Dr. Bryan Willson
- U.S. DOE / ARPA-E
- Colorado State University

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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

<table>
<thead>
<tr>
<th>Year</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1968</td>
<td>Requirements for transmission pipelines to survey for leakage / safety</td>
</tr>
</tbody>
</table>

### VOC / HAPS

<table>
<thead>
<tr>
<th>Year</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>ZZZZ / NESHAP rule on HAPs, primarily formaldehyde</td>
</tr>
<tr>
<td>2012</td>
<td>OOOO NSPS for VOCs</td>
</tr>
</tbody>
</table>

### Greenhouse gas mitigation

<table>
<thead>
<tr>
<th>Year</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td>Colorado AIMM rule: Approved Instrument Monitoring Method (AIMM) iLDAR using infra-red camera, EPA Method 21, or other approved; others followed</td>
</tr>
<tr>
<td>2015</td>
<td>Draft EPA methane rule, ammending VOC NSPS to include methane</td>
</tr>
<tr>
<td>2015</td>
<td>Draft BLM methane rule</td>
</tr>
</tbody>
</table>
# 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

- Transformative Research
- Existing Technology
- Disruptive Technology

CHANGING WHAT’S POSSIBLE
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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

- Low Cost
- Ability to Locate Leaks
- Ability to Quantify

[Image of methane sensing equipment]
Tomorrow’s Methane Detection Solutions

- Ability to Locate Leaks
- Low Cost
- Ability to Quantify

\[ \text{CH}_4 \text{ SCFH} \]
### MONITOR Metrics & Targets

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

**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

**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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The Portfolio: 3 Technology Categories

Image courtesy of Cuadrilla Resources
The Portfolio: 3 Technology Categories

- **FIXED**
  - parc
  - IBM
  - AERIS Technologies
  - LI-COR

- **MOBILE**
  - Duke University
  - Bridger Photonics
  - TSI Physical Sciences Inc.
  - REBELLION Photonics

- **POINT SENSOR**

**ENABLING**

- Maxion
Miniature, High Accuracy Tunable Laser Spectrometer for CH₄/C₂H₆ Leak Detection

AWARD AMOUNT: $2.4 million
PROJECT PARTNERS: Los Alamos National Laboratory, Rice University

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)
Laser Spectroscopic Point Sensor for Methane Leak Detection

**Award Amount:** $2.85 million

**Project Partners:** Colorado State University, Gener8

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

**AWARD AMOUNT:** $4.5 million

**PROJECT PARTNERS:** Princeton University, Harvard University, Southwestern Energy

**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
Printed Carbon Nanotube Sensors for Methane Leak Detection

AWARD AMOUNT: $3.4 million

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

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
Coded Aperture Miniature Mass Spectrometer for Methane Sensing

AWARD AMOUNT: $2.9 million
PROJECT PARTNERS: RTI International

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)
The Portfolio: 3 Technology Categories

LONG DISTANCE

FIXED

MOBILE

ENABLING
Frequency Comb-based Methane Sensing

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 CH₄, ¹³CH₄, H₂O, 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

AWARD AMOUNT: $1.4 million
PROJECT PARTNERS: Virginia Tech

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
The Portfolio: 3 Technology Categories

AERIAL

FIXED

MOBILE

ENABLING
UAV-based Laser Spectroscopy for Methane Leak Measurement

AWARD AMOUNT: $2.9 million
PROJECT PARTNERS: Heath Consultants, Thorlabs, Princeton University, University of Houston, Cascodium

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
Mobile LiDAR Sensors for Methane Leak Detection

AWARD AMOUNT: $1.5 million

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
The Portfolio: 3 Technology Categories
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

- University of Colorado Boulder
- parc
- IBM

- Duke University
- BRIDGER PHOTONICS
- REBELLION PHOTONICS

- TSI Physical Sciences Inc.

- FIXED
- MOBILE
- ENABLING
Tunable Mid-infrared Laser for Methane Sensing

AWARD AMOUNT: $1.9 million

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

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
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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
Example Test Site Layout

SITE LAYOUT

INDIVIDUAL PAD LAYOUT

Typical well pad equipment (tanks, separators, etc.)

Anemometer

Gas tank bundle (CH4 and other hydrocarbons) and mass flow controller

Not all objects are drawn to scale

*1x3 size ratio is approximate
The MONITOR Timeline: ARPA-E & Beyond

**General Program**
- Project Selections
- Year 1: Program Kickoff
- Year 2: Continued Technology Development
- Year 3: Final Year of Technology Development
- Projects End

**Field Testing**
- Year 1
- Year 2
- Year 3
- 2014
- 2015
- 2016
- 2017
- 2018

*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