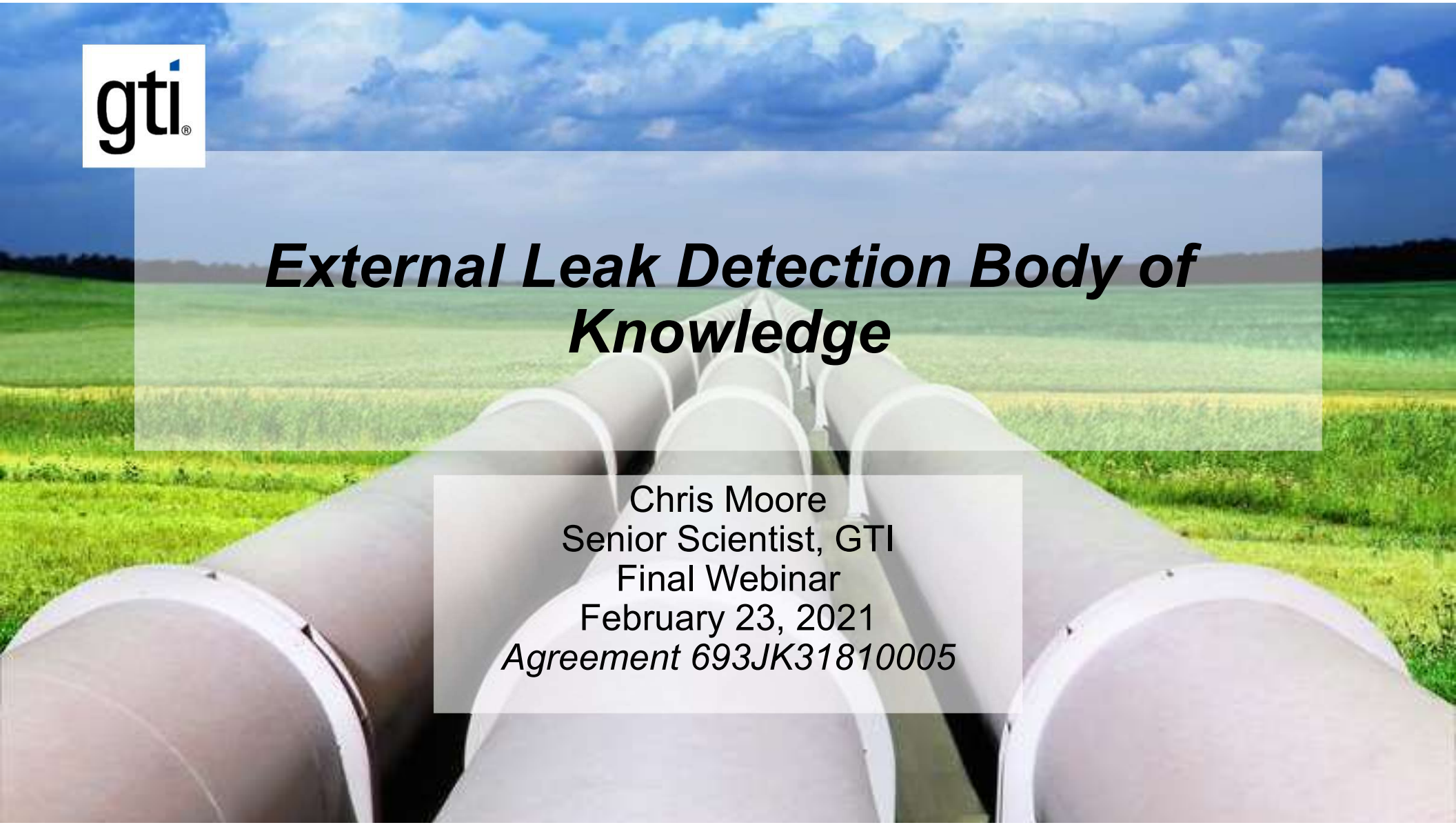
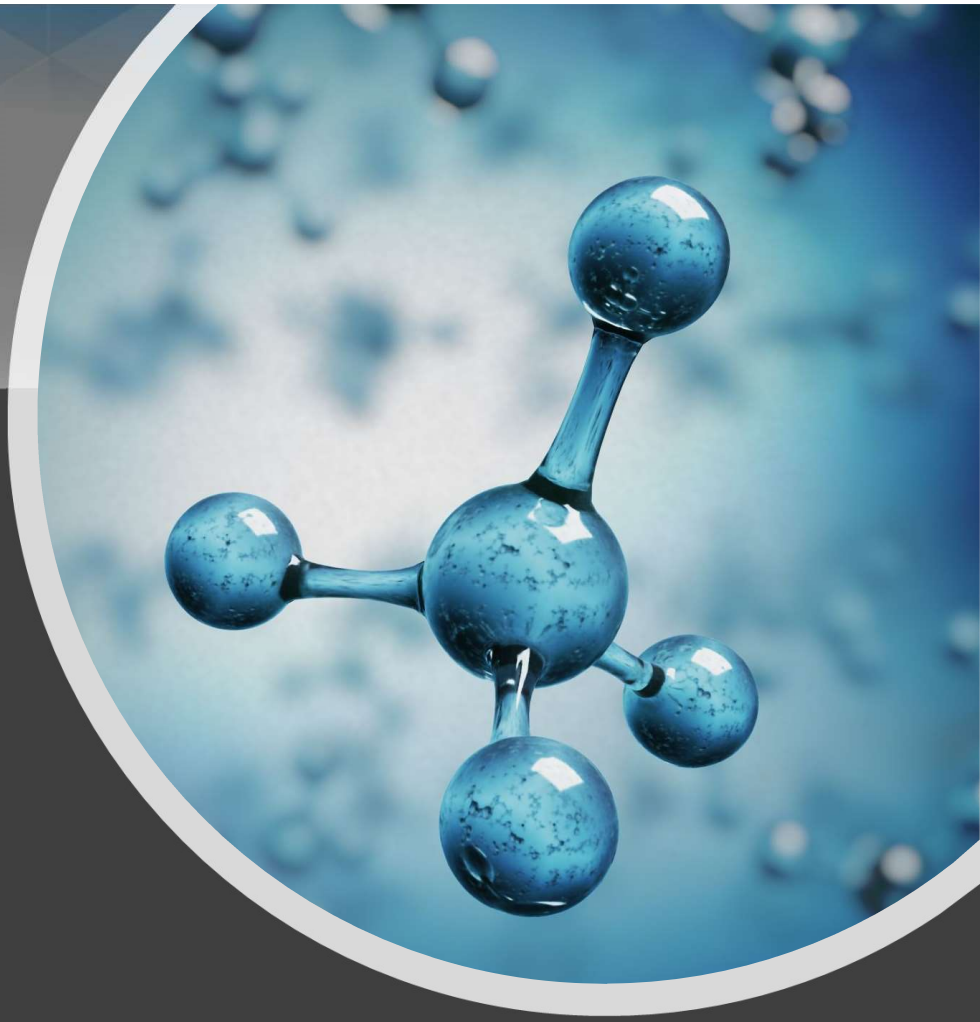


External Leak Detection Body of Knowledge

Chris Moore
Senior Scientist, GTI
Final Webinar
February 23, 2021
Agreement 693JK31810005

Introduction

- PHMSA currently lists over 300,000 miles of natural gas transmission pipeline
- Since 2010 nearly 1300 incidences on natural gas transmission pipelines have been reported
- Many have involved intended and unintended release of gas
- Due to methane (primary component of natural gas) having a GWP potential that is 25 – 86 times greater than CO_2 it is important to monitor and reduce these potential emissions
- Companies also have regulatory requirements to monitor these pipelines for leaks



Leak Detection Systems Have Grown Increasingly Complex

Project Objectives

- *Objective 1* - Conduct a technology assessment and categorize sensor technologies and methodologies for leak detection of transmission pipelines.

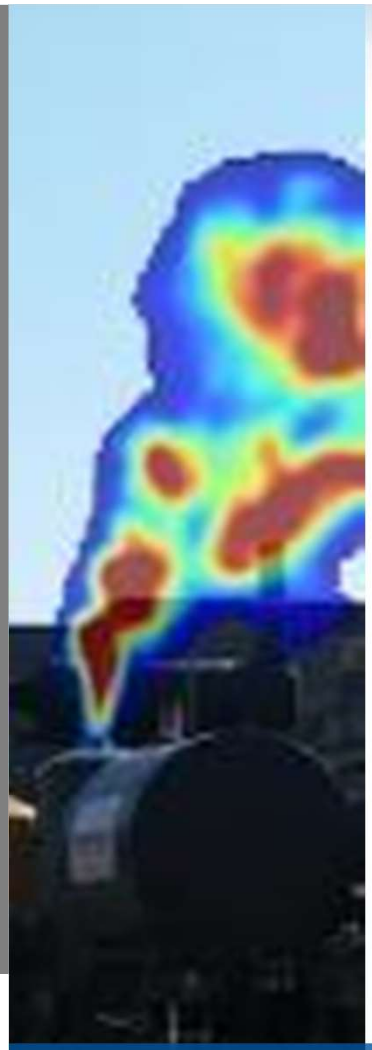
- *Objective 2* - Develop guidelines for a technology certification organization and a full Recommended Practice (RP).

Complex Integrated Systems

Component-Level Survey and Measurement

Aggregate-Level Survey and Measurement

Stationary Continuous Monitoring Systems



Sensor Technology

Auxiliary Systems

Real-time Analytics

Results Interpretation

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Tasks and Budget

Seven main project tasks to break down work

Produced seven interim/summary reports and a framework for the RP

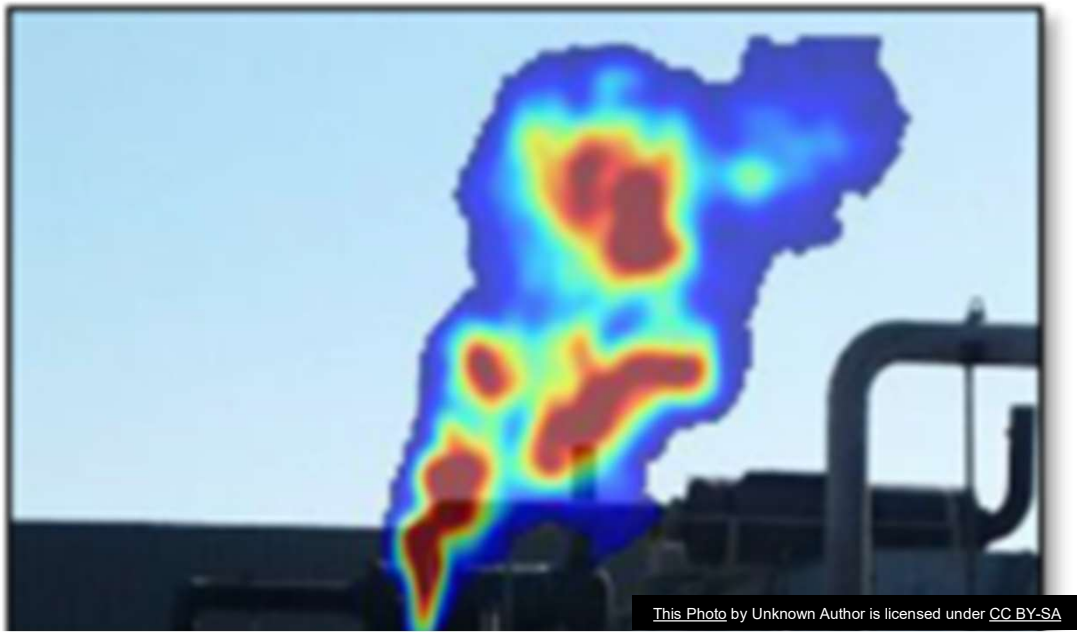
Key Project Components

- Establish Bounds
- Review Technologies
- Certification Center
- Produce RP

Total Budget - $400k

Activity	Date	Milestone/Deliverable
Task 1 - Project scoping and Technical Advisory Panel	3 months	Kick-off team meeting notes detailing any modifications to research tasks and Member list of the Technical Advisory Panel (TAP).
Task 2 - Information gathering and current technology assessment	6 months	Interim report summarizing the preliminary bounds of the leak detection systems to be addressed in the RP.
Task 2 - Information gathering and current technology assessment	9 months	Interim report of current leak detection technologies, methods and evaluation frameworks.
Task 3 - Establish standardized sensor specifications and testing practices	9 months	Interim report of the target sensors/technologies.
Task 3 - Establish standardized sensor specifications and testing practices	12 months	Interim report of technology performance specifications.
Task 3 - Establish standardized sensor specifications and testing practices	15 months	Summary report of target sensors/technologies, performance specifications and technology evaluation procedures.
Task 4 - Develop certification organization framework	18 months	Interim report of certification center requirements.
Task 5 – Develop RP	18 months	Framework for RP.
Task 4 – Develop certification organization framework	21 months	Summary report of certification center requirements.
Task 5 - Develop RP	24 months	Final RP for external based leak detection
Task 6 - Final Report	24 months 27 months	Draft and Final Report
Task 7 - Project Management	27 months	Ongoing: Monthly Updates, Quarterly Reports, Peer Reviews, and Public Presentation/Paper

Bounds of the Project and RP



- Project was focused on belowground natural gas transmission pipeline infrastructure
- Technology could apply across a variety of facilities and assets
- Broad leak detection systems were identified that could be deployed in other segments

Instrument Method Classes

- Leak detection systems were categorized by
  - Method Class
  - Deployment Platform
  - Technology Class
  - Instrument/System Type
- Method Classes
  - Component – Level
  - Aggregate – Level
    - Also called Site – Level
  - Continuous Monitoring

Method Class	Deployment Platform	Technology Class	Example Instrument Types
Component-Level Survey and Measurement	Handheld and Vehicle-Mounted	Ranged Laser	TDLAS
		In-Plume Laser	Miniature OPLAS
		Etalons	CIPS
		Nondispersive IR	NDIR
		Flame Ionization (FI)	FID
		Photo Ionization	PID
		Thermal Conductivity	Thermal Conductivity
		IR Imaging	OGI
		Catalytic Combustion/Pellistor	Catalytic Pellistor
Aggregate-Level Survey and Measurement	Vehicle-Mounted	Ranged Laser	TDLAS
		In-Plume Laser	WMS, CRDS, OA-ICOS
		IR Imaging	OGI
	Unmanned Rotary (Drone) Mounted	Ranged Laser	TDLAS, LiDAR
		In-Plume Laser	Miniature OPLAS
	Manned Rotary (Helicopter) Mounted	Ranged Laser	TDLAS, DIAL
	Unmanned Fixed-Wing (Drone) Mounted	In-Plume Laser	TDLAS, OA-ICOS, WMS, Miniature OPLAS
	Manned Fixed-Wing (Airplane) Mounted	Ranged Laser	DIAL
		In-Plume Laser	CRDS, OA-ICOS, WMS
		IR Imaging	Imaging Spectrometer (i.e., Hyperspectral)
	Satellite Mounted	IR Imaging	Imaging Spectrometer (i.e., Hyperspectral)
Stationary Continuous Monitoring Systems	Semi-Permanent (Tripod or Truck) or Permanent (Tower)	Ranged Laser	OPFTIR, TDLAS
		In-Plume Laser	WMS, CRDS, ICOS, TDLAS, MCS
		In-Plume Point Sensor	CNT
		Catalytic Combustion/Pellistor	Catalytic Pellistor
		Metal Oxide Senor	MOS
		Nondispersive IR	NDIR
		IR Imaging	Imaging Spectrometer (i.e., Hyperspectral)

Recommended Practice

Development of the Recommended Practice

- Based on feedback from
  - Industry Partners
  - Academia
  - Instrument Vendors
  - Instrument Evaluators
- Performed site visits of facilities

- Main Sections of the RP
  - Leak Detection System Management Processes
  - Selection of Leak Detection Methods, Platforms, and Instrumentation
  - Framework for Certification Organizations
  - Framework for Human-System Interface Certification

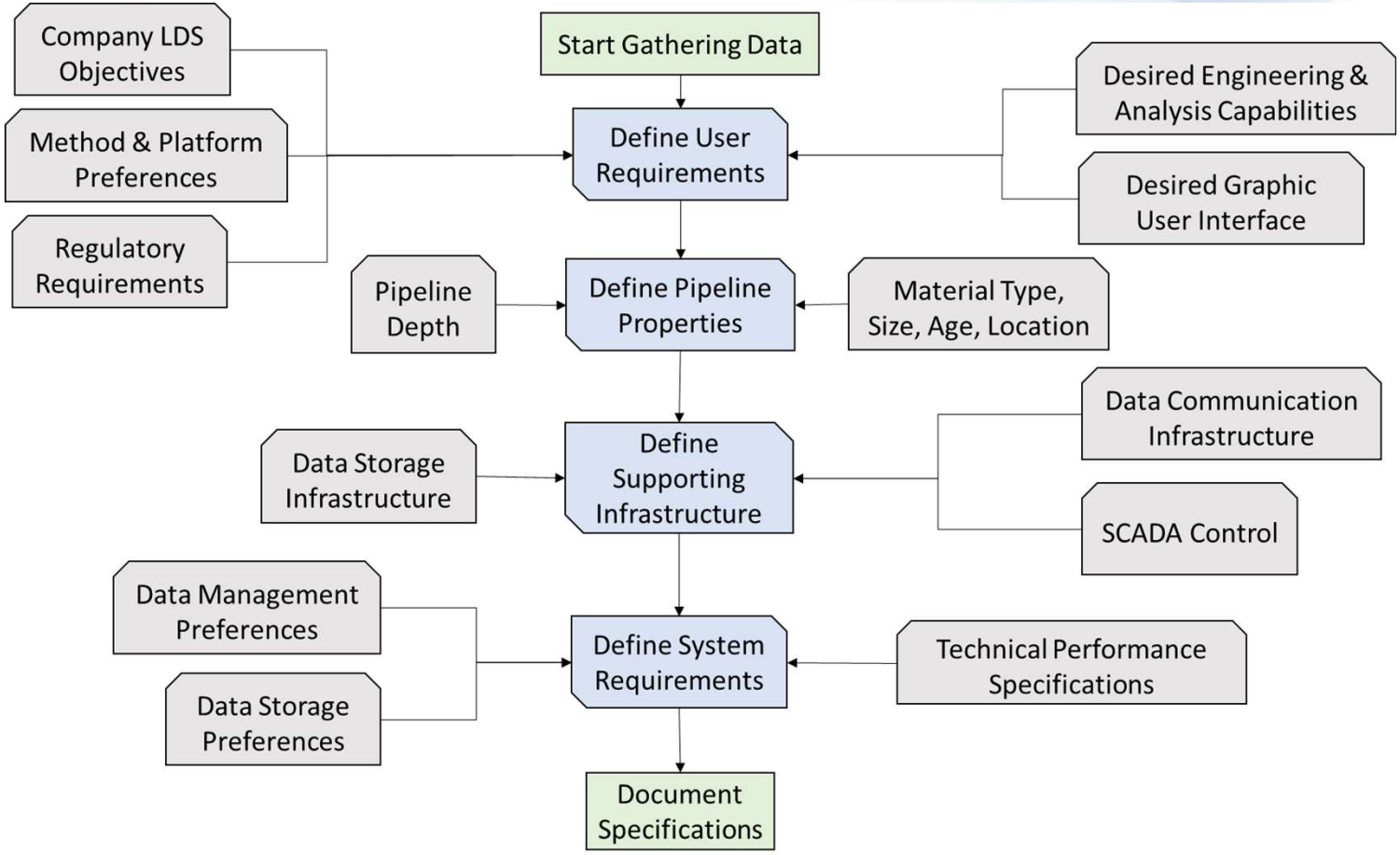
Establishing a Leak Detection System (LDS)

- Companies have many factors to consider when establishing a leak detection system
- At the highest level there are 3 basic objectives all leak detection systems must accomplish

- *Objective 1* – Should contain one or more methane sensors to detect above a defined threshold
- *Objective 2* – Capable of locating leaks across a variety of terrains
- *Objective 3* – Achieve compliance with both local, state, and national regulations

Selection Methodology

- Companies must also align the LDS with internal company procedures and infrastructure
- One option could be to rely on an external independent certification organization for info



Evaluation of Leak Detection Systems Has Also Had to Evolve

Traditional Validation

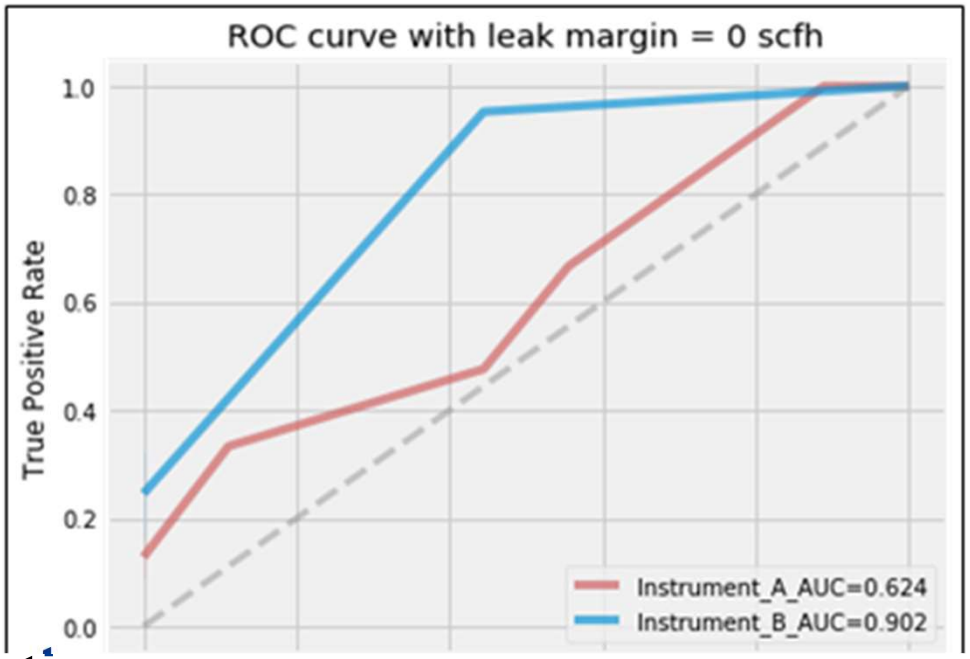
- Focused on individual performance abilities of sensor
- This simplistic approach is becoming outdated
- Instrument complexity increasing – same sensor yields different results based on method used due to:
  - Integrated sub-sensors
  - Real-time analytics
  - Modeling algorithms
  - Advanced data logging and management

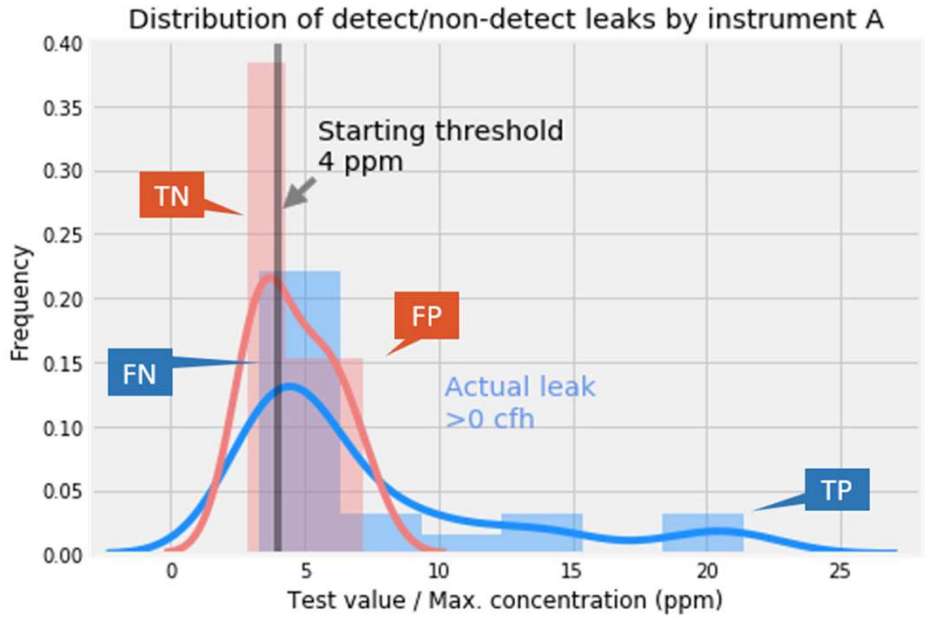
Method Based Validation

- Focus certification based on methods used
- Test the process of detection and not the individual sensors
- Go beyond pass/fail to more probabilistic approach for validation of performance
- Categories of methods can be grouped – such as
  - Component-Level Survey & Measurement
  - Aggregate-Level Survey & Measurement
  - Continuous Emission Monitoring Systems

Certification Organization – Suggested Evaluation Methods

- Receiver Operating Characteristics (ROC) curves
- Area Under the Curve (AUC) statistics
- Standardized comparison of different full systems ability to locate leaks





Note: TN = True Negative, FP = False Positive, FN = False Negative, TP = True Positive

Certification Considerations

Various types of instruments could be used on each deployment platform and method class

Each method class and deployment platform has different methods of detection and performance evaluation needs

Method Class	Deployment Platform	Technology Class	Example Instrument Types
Component-Level Survey and Measurement	Handheld and Vehicle-Mounted	Ranged Laser	TDLAS
		In-Plume Laser	Miniature OPLAS
		Etalons	CIPS
		Nondispersive IR	NDIR
		Flame Ionization (FI)	FID
		Photo Ionization	PID
		Thermal Conductivity	Thermal Conductivity
		IR Imaging	OGI
		Catalytic Combustion/Pellistor	Catalytic Pellistor
Aggregate-Level Survey and Measurement	Vehicle-Mounted	Ranged Laser	TDLAS
		In-Plume Laser	WMS, CRDS, OA-ICOS
		IR Imaging	OGI
	Unmanned Rotary (Drone) Mounted	Ranged Laser	TDLAS, LiDAR
		In-Plume Laser	Miniature OPLAS
	Manned Rotary (Helicopter) Mounted	Ranged Laser	TDLAS, DIAL
	Unmanned Fixed-Wing (Drone) Mounted	In-Plume Laser	TDLAS, OA-ICOS, WMS, Miniature OPLAS
	Manned Fixed-Wing (Airplane) Mounted	Ranged Laser	DIAL
		In-Plume Laser	CRDS, OA-ICOS, WMS
		IR Imaging	Imaging Spectrometer (i.e., Hyperspectral)
	Satellite Mounted	IR Imaging	Imaging Spectrometer (i.e., Hyperspectral)
Stationary Continuous Monitoring Systems	Semi-Permanent (Tripod or Truck) or Permanent (Tower)	Ranged Laser	OPFTIR, TDLAS
		In-Plume Laser	WMS, CRDS, ICOS, TDLAS, MCS
		In-Plume Point Sensor	CNT
		Catalytic Combustion/Pellistor	Catalytic Pellistor
		Metal Oxide Senor	MOS
		Nondispersive IR	NDIR
		IR Imaging	Imaging Spectrometer (i.e., Hyperspectral)

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Instrument Performance: Component - Level

- Two main types of deployment platforms
  - Handheld
  - Vehicle-Mounted
- Key evaluation parameters
  - ROC/AUC
  - Battery life
  - Human error

Method Class	Deployment Platform
Component-Level Survey and Measurement	Handheld and Vehicle Mounted Sensors

Technology Class	Commonly Used Instrument Types
Ranged Laser	TDLAS
In-Plume Laser	Miniature OPLAS
Etalons	CIPS (ex. DPIR, OMD)
Nondispersive IR	NDIR
Flame Ionization (FI)	FID
Photo Ionization	PID
Thermal Conductivity	Thermal Conductivity
IR Imaging	OGI
Catalytic Combustion/Pellistor	Catalytic Pellistor

KPIs	Evaluation Metrics
Detection	ROC Performance Curve
Power	Battery life span
Human-Based Uncertainty	Assessing Training Requiremnts
	Acceptable size and weight
	Appropriate design for weather conditions
	Data retrieval, aggregation,
	Sensor configuration and complexity
	False postive rate

Instrument Performance: Aggregate – Level

- Most diverse set of deployment platforms
- Leak location determination becomes key for usefulness
- Very promising aerial platforms
- Key evaluation parameters
  - ROC/AUC
  - Power systems
  - Location determination
  - Human error

Method Class	Deployment Platform
Aggregate-Level Survey and Measurement	Vehicle Mounted Sensors
	Unmanned Rotary (Drone) Mounted Sensors
	Manned Rotary (Helicopter) Mounted Sensors
	Unmanned Fixed Wing (Drone) Mounted Sensors
	Manned Fixed Wing (Airplane) Mounted Sensors
	Satellite Mounted Sensors

Technology Class	Commonly Used Instrument Types
Ranged Laser	TDLAS
In-Plume Laser	WMS, CRDS, OA-ICOS
Etalons	CIPS (ex. DPIR, OMD)
IR Imaging	OGI
Ranged Laser	TDLAS, LiDAR
In-Plume Laser	Miniature OPLAS
Ranged Laser	TDLAS, DIAL
In-Plume Laser	TDLAS, OA-ICOS, WMS, Miniature OPLAS
Ranged Laser	DIAL
In-Plume Laser	CRDS, OA-ICOS, WMS
IR Imaging	Imaging Spectrometer (Hyperspectral)
IR Imaging	Imaging Spectrometer (Hyperspectral)

KPIs	Evaluation Metrics
Detection	ROC Performance Curve
	Time required to define a detection
Power Systems	Voltage requirements, battery life
Meterological Stations	Accuracy of wind speed/direction capture
GPS Systems	Effectiveness/speed of spatial data capture
Communication Systems	Effectiveness/security of wireless data transfer
Human-Based Uncertainty	Assessing Training Requiremnts
	Ease of use, system complexity and maintenance
	Data retrieval, aggregation, communication
	False positive rate

Instrument Performance: Continuous Monitoring

- Promising new technologies
- Leak location determination involves complex analytics
- Key evaluation parameters
  - ROC/AUC
  - Durability
  - Human error

Method Class	Deployment Platform
Stationary Continuous Monitoring Systems	Semi-Permanent (Tripod or Truck) or Permant Mounted (Tower)

Technology Class	Commonly Used Instrument Types
Ranged Laser	OPFTIR, TDLAS
In-Plume Laser	WMS, CRDS, ICOS, TDLAS, MCS
In-Plume Point Sensor	CNT
Catalytic Combustion/Pellistor	Catalytic Pellistor
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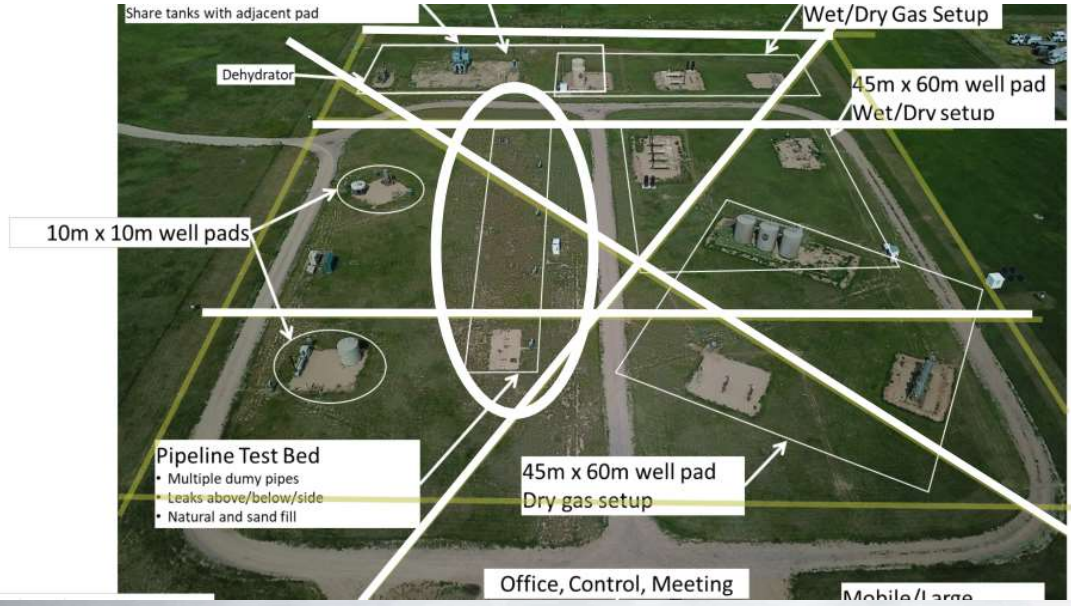
KPIs	Evaluation Metrics
Detection	ROC Performance Curve
Power Systems	Battery Performance
Meterological Systems	Accuracy of wind speed/direction capture
GPS Systems	Effectiveness/speed of spatial data capture
Human-Based Uncertainty	Assessing Training Requiremnts
	Data retrieval, aggregation, communication
	Sensor configuration and complexity

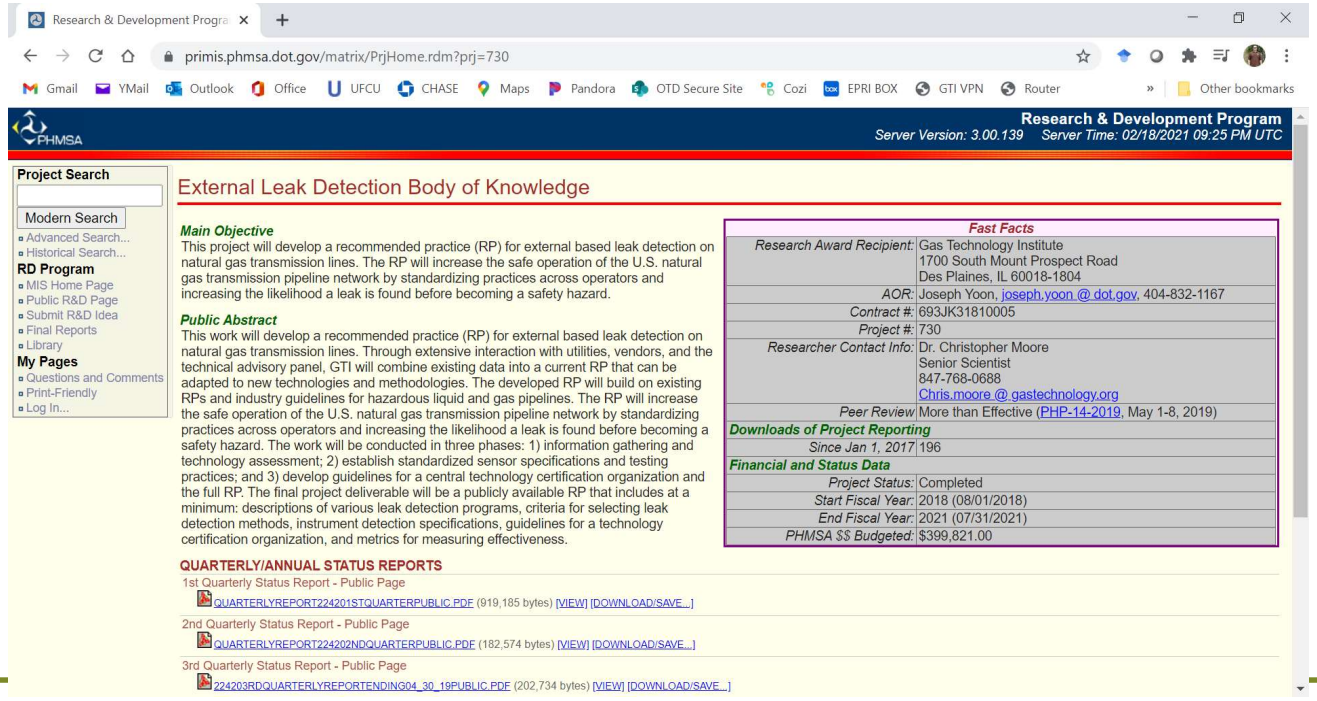
Next Steps – Certification Methods Use

- Current DOT PHMSA project
- DOT PHMSA 693JK31910006: Validation of Remote Sensing and Leak Detection Technologies
- Apply methods to evaluate performance of drone mounted leak detection and integrity threat monitoring



Project Public Page

https://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=730



Research Team and Technical Advisory Panel

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  - Gerry Bong, GTI
  - Kristine Wiley GTI
- Technical Advisory Panel
  - Colorado State University
  - Harrisburg University
  - Atmos
  - National Grid
  - Pacific Gas & Electric
  - SoCal Gas

Thank you!!

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