Inline Robot for Inspecting and Repairing Leaks in Pipeline and Preventing Methane Emissions

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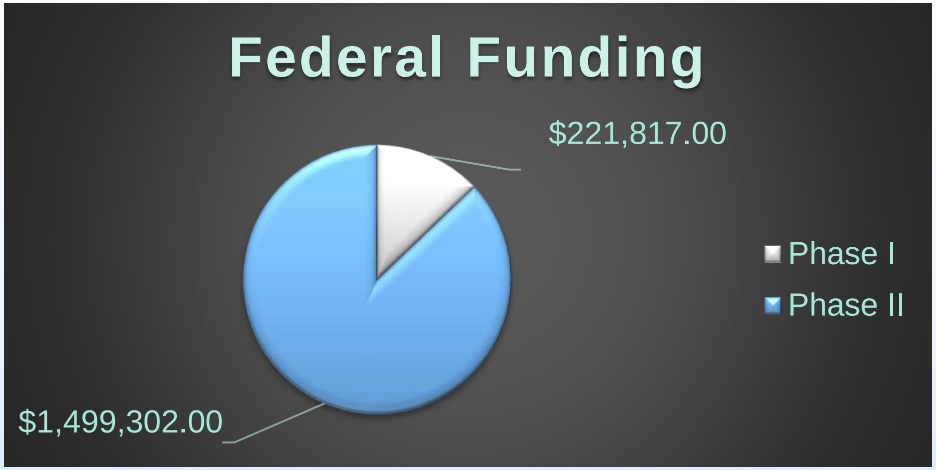
U.S. Department of Energy
National Energy Technology Laboratory
Oil & Natural Gas
2020 Integrated Review Webinar

Program Overview



Phase I Start
July 2018

Phase I End
May 2019

Phase II Start
Aug 2019

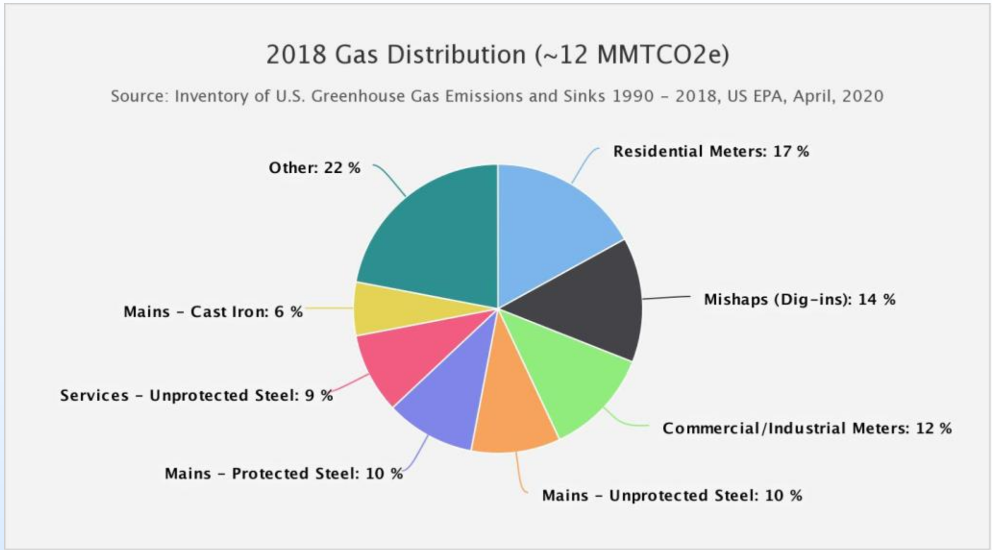
Phase II End
Aug 2021

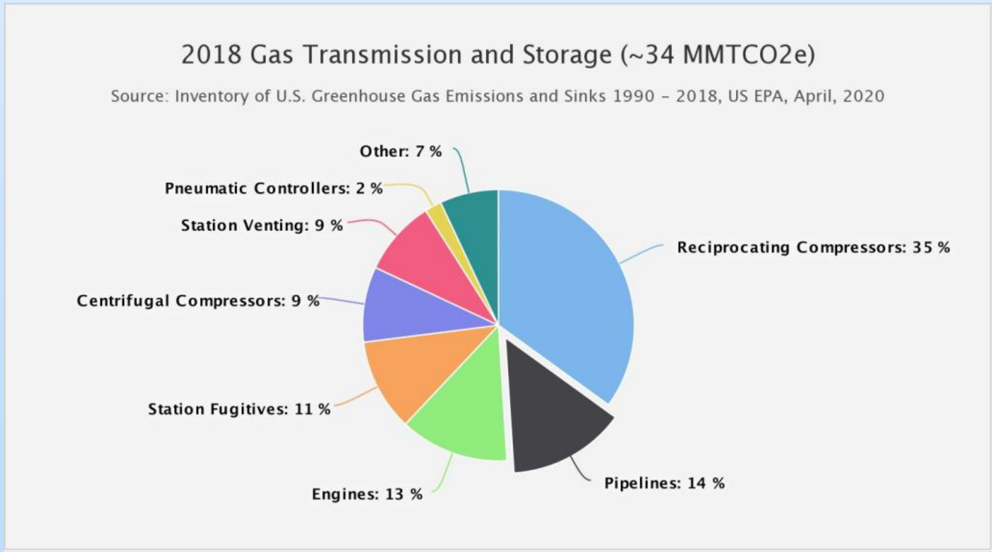
Overall Project Objective:

Develop a prototype robot for detecting and repairing leaks in live, natural gas pipelines

Program Overview

Pitting Corrosion - Leaks





In the United States:

> 400,000 miles of transmission pipeline

> 1 million miles of distribution pipeline

Technology Background

Launch robot into live natural gas mains

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Perform coarse leak detection scanning

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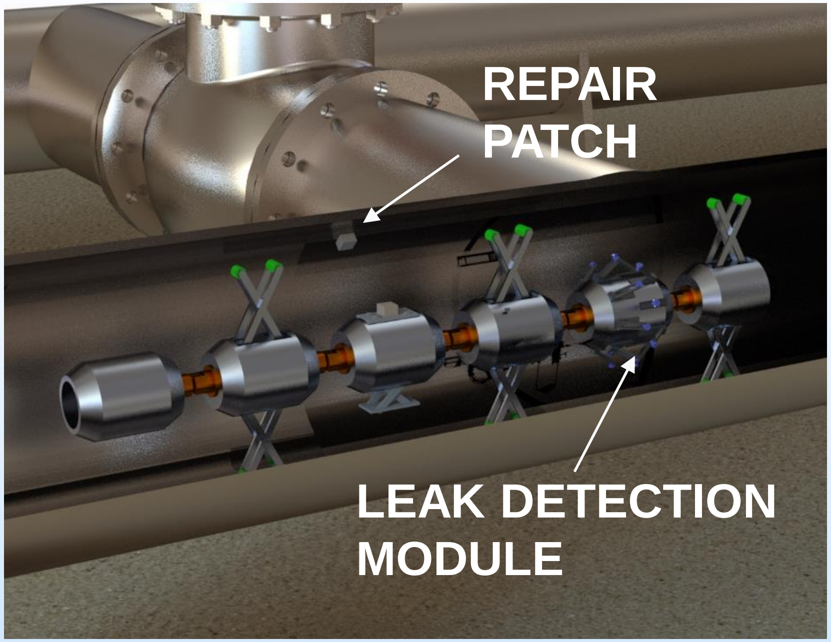
Perform fine scanning in region of interest

↓

Install repair patch(es)

↓

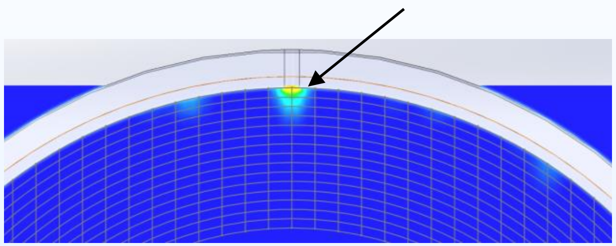
Robot returns to entry point



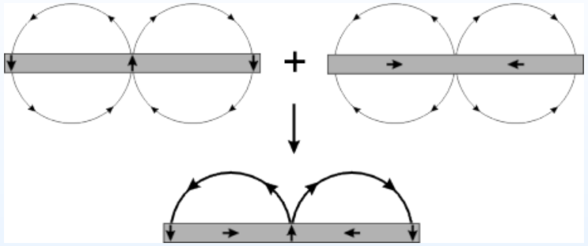
Key Requirements

- Operation in up to 1000 psig pressure
- Operating temperature: 40 to 140 ºF
- Travels 0.5 mile in either direction
- Battery Operated
- Distribution and Transmission Mains
- Gas Flow: Up to 100 feet/sec

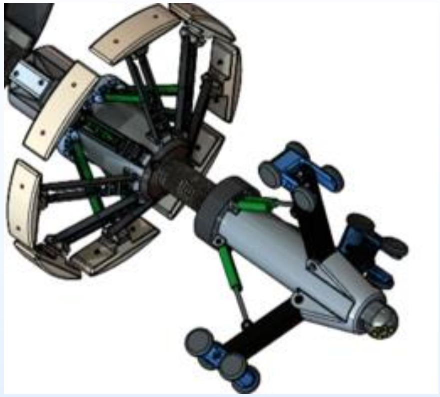
Technology Background



- Leaking gas produces pressure fluctuations that result in acoustic wave propagation
- Acoustic noise can be detected by a dynamic pressure sensor
- Highly localized phenomenon
- Sensing accuracy depends upon rate of change from peak amplitude – indicating leak position



- The repair patch must seal up to 1000 psi and withstand pressure cycling, unclean surfaces, thermal pipe expansion
- Halbach Magnetic arrays augments the magnetic field on one side of the array while cancelling the field on the other side to near zero
- Gaskets provide the sealing surface



- Robot navigating through varying pipe geometry (bends, valves, etc.) must possess sufficient degrees-of-freedom
- Precise leak locating and patch installation must be designed into the patch and control system using motors, precise encoders, and inertial measurement units

Technology Background

Technical Advantages

- Minimal Excavation
- Improved Leak Detection – Smaller Leaks
- No disruption to customer
- Reduced time for repair – permitting and excavation
- Access to difficult to reach location - water, railway, roadway crossings, and bridges

Economical Advantages

- Average costs associated with damage were $249,000 for distribution leaks
- Pipeline operators pay approximately $125,000 to prevent damage by performing immediate excavation and repairs of detected leaks[1]
- Robot service is a fraction of the cost

Technical Challenges

- Negotiating bends in pipes
- Traveling long distances
- Size constraints imposed by pipe
- Operation in natural gas and high pressure
- Installing a repair patch at the precise leak location

Economical Challenges

- High initial investment
- Temporary repairs limit market size
- Cost of service is not always justified in easy to reach locations
- Working with regulatory bodies and obtaining approval for use

1. https://www.phmsa.dot.gov/data-and-statistics/pipeline/pipeline-incident-flagged-files)

Technical Approach/Project Scope

Aug 2018	Aug 2019	Nov 2020	May 2021	Aug 2021
Leak detection and localization study	Finalize leak detection sensor selection; study sensor placement and coverage	Develop/select support electronics for leak detection sensor		
Repair patch design, fab, and test	Repair patch design optimization	Repair patch testing		
Robot Conceptual Design	Robot Detailed Design	Robot Fabrication and Assembly	Robot System Testing	

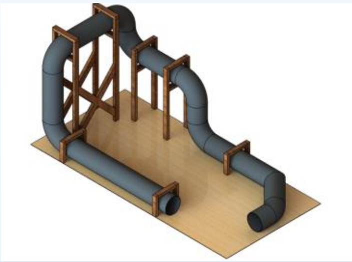
Technical Approach/Project Scope

Successful Prototype Robot Testing

High Pressure Test

- Survive and Operate
- Leak Detection, Localization and Repair

Pipe Test Loop



- Navigation through Bends and Joints
- Adequate Drive Power

Risks and Mitigation

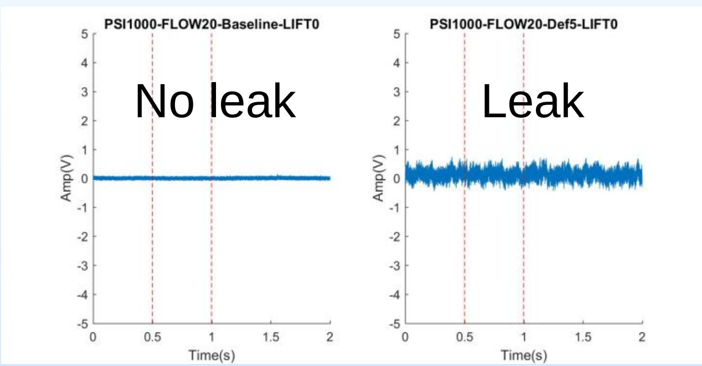
Risks A: Incorrect repair patch installation due to locating and positioning inaccuracies
Mitigation: Develop leak testing method for in-pipe measurements

Risk B: Higher than expected loads or failure of driving assembly in unconstrained environment
Mitigation: Redundancy will allow for recovery

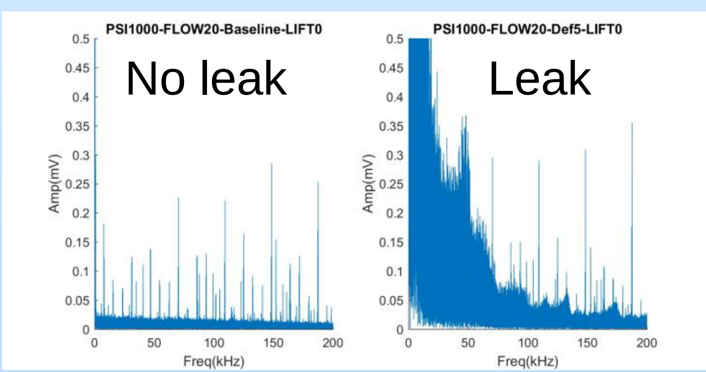
Risks C: High pressure can damage components
Mitigation: Perform shop pressure testing; select components, employ custom enclosure for sensitive parts incl. batteries

Progress and Current Status of Project

Built test pipe and tested leak detection in up to 1000 psi, flowing natural gas

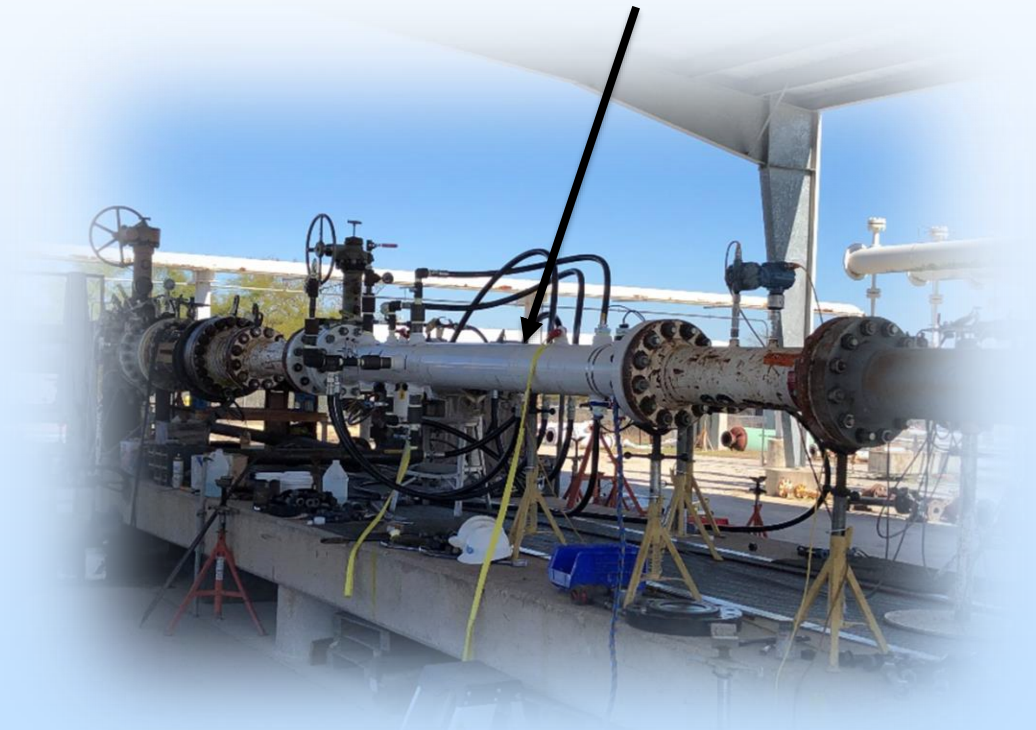


Example Time domain signal



Example Frequency domain signal

Test Pipe



Progress and Current Status of Project

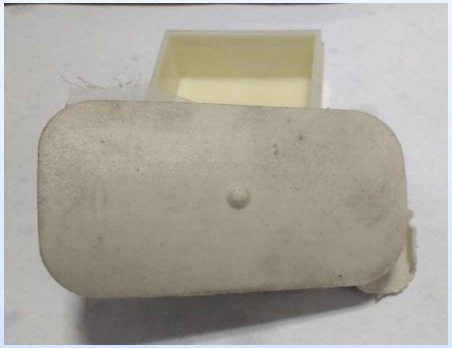
Completed leak detection sensitivity and classification studies

- Sensor selection is complete
- Sensor mounting options have been studied and its impacts on measured noise
- Sensor coverage was evaluated
  - Currently studying how to reduce number of sensors
- Data Acquisition system is being developed
- The code for acoustic signal processing will be refined for multi-channel processing

Detecting pitting corrosion leaks was successful in both high- and low-pressure mains

Progress and Current Status of Project

- Developed 4” diameter test bench for testing repair patch sealing capabilities
- Created and tested different types of patches to provide a large sealing surface, strength, and adhesion

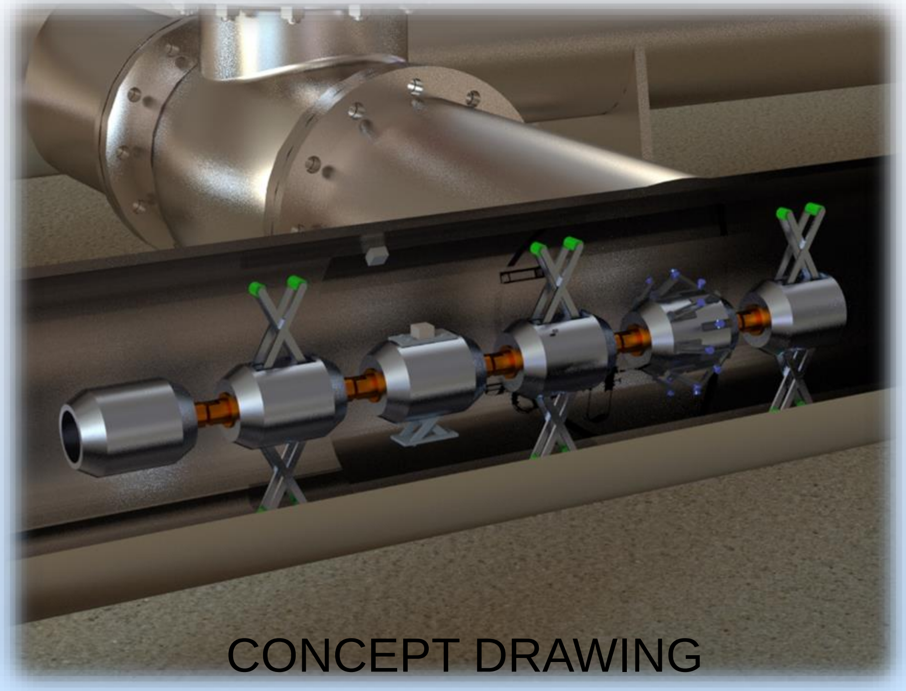




- Final candidate selected was the magnetic patch
- Tested between 0 to 1000 psi and pressure cycled
    - Sealed at very low pressures and highest pressure
    - Strong adhesion
    - Does not require surface preparation
    - Easily installable
- Patch is currently being redesigned for robotic installation

Progress and Current Status of Project

The robot system design was completed:

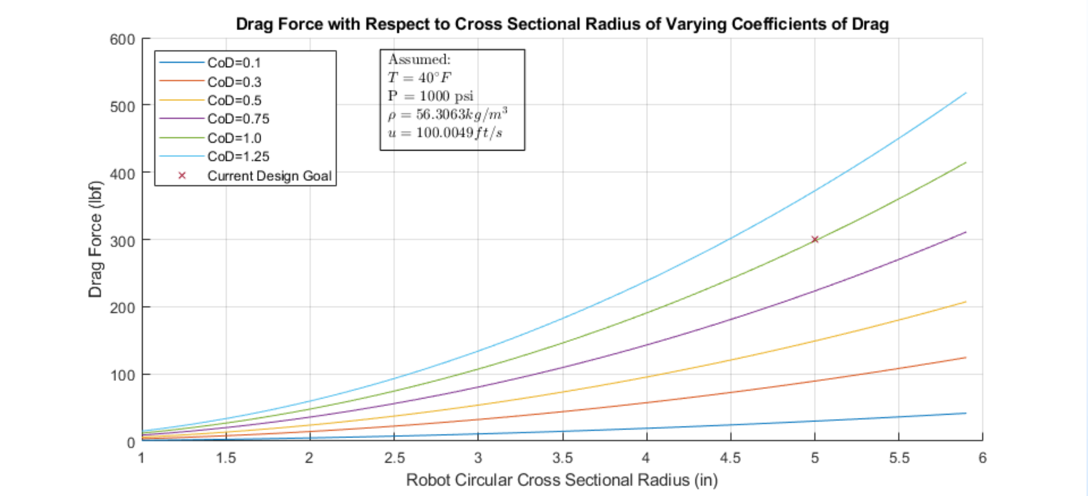
- Modular robot - common size and architecture allows for scalability
- Vertically launchable into a 12” to 20” diameter pipe
- Travel distance can cover most riverbeds, roadway and railway crossings
- Multiple degrees of freedom for each module
    - Bend negotiation
    - Avoidance of debris at pipe bottom
    - Challenging valve openings

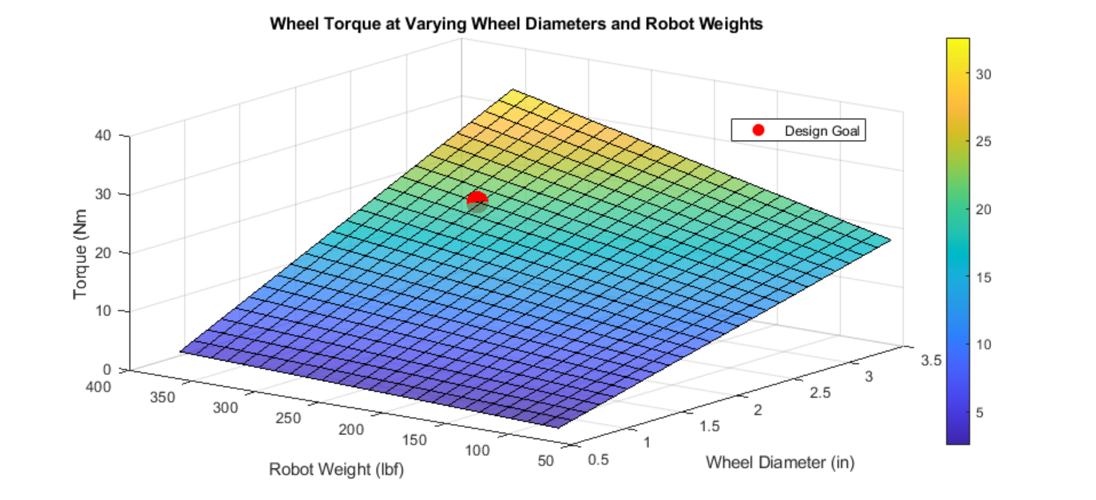


Progress and Current Status of Project

Drive Module Design

- Generated driving torque and wall press requirements
- Developed a custom telescoping mechanism for wheels to reach pipe wall
- Designed a custom gear box – 2” diameter
- Incorporated redundancy considering various failure scenarios
- Tiny module will block less than 50% of pipe cross-sectional area





Progress and Current Status of Project

LEAK DETECTION MODULE

- Designed leak detection sensor housing
- Designed method for collapse and extension of sensors

COMMUNICATIONS MODULE

- Designed for communication between operator outside pipe and robot inside pipe
- Selected communications hardware
- Developed methods for extending travel distance

REPAIR MODULE

Designs developed for:

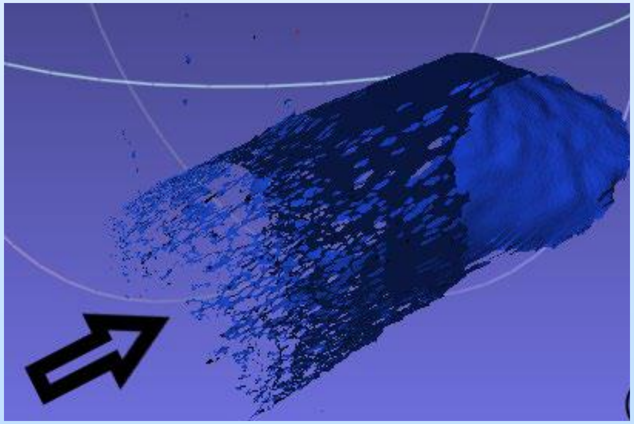
- Repair patch cartridge
- Actuation of patch towards pipe wall
- Positioning of patch, pressure test, and removal

INTERMODULAR JOINTS

- Designed for providing sufficient degrees of freedom
- Developed techniques for routing cables between modules
- Developed approach for future repair robot to easily recover and remove failed robot

Progress and Current Status of Project

- Selected and tested sensors for generating point cloud of pipe
- Algorithms were developed to estimate bend angles during robot travel
- These algorithms needs to be refined through repeated testing in different angled bends
- Inverse kinematics will allow for coordinate frame translation and rotations for manipulation of each joint



Automated bend detection and negotiation is important to reduce time and complexity of using multiple modules and joints in a pipe

Plans for future testing/development/ commercialization

End of Phase II Aug 2021	Sept 2023	Sept 2024	Mid 2025
Prototype Robot	Enhanced Prototype	Final Product	
• Perform demonstration to pipeline operators • Obtain approval for repair method	• Develop full circumferential repair method/module • Update design for manufacturing	• Build First Product • Perform Pilot Inspections	Start Service
DOE Funding	3rd Party Funding	ULC Funding	

Summary Slide

PROJECT SUMMARY: ULC Technologies is completing the design and starting fabrication of the world's first leak detection and repair robot that will provide technical, societal, and economical advantages:

Reduce the cost of repairs	Lower repair time	Compliance to regulations
Reduce methane emissions	Improve safety	No service disruption

KEY FINDINGS:

- Leak Detection can be performed in both transmission and distribution mains up to very low pressures, but detection is easier in higher pressures
- Magnetic repair patch works well in an unconstrained environment
- Robot negotiation through bends requires automation

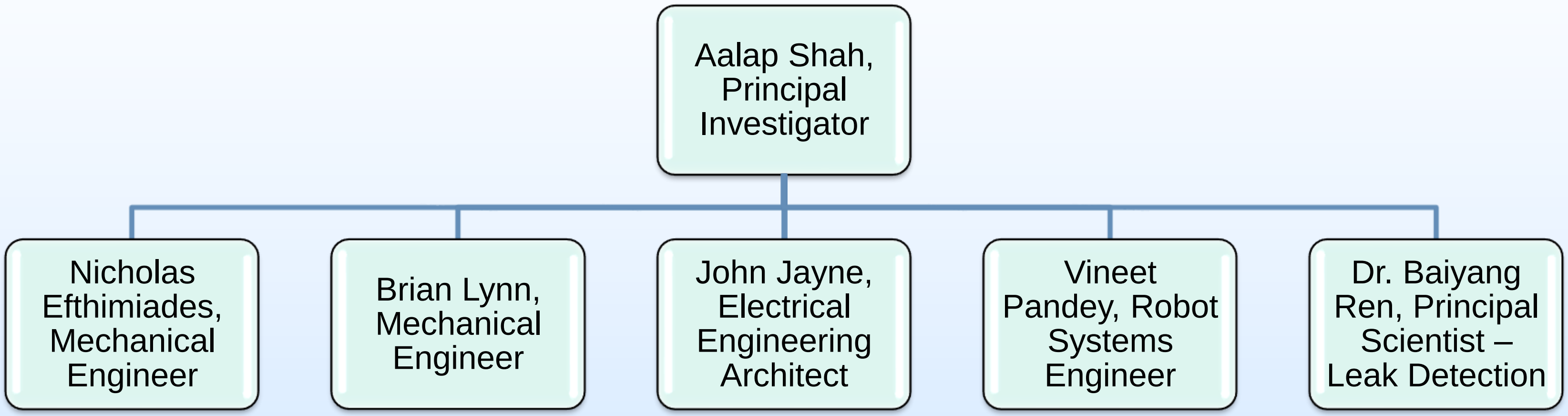
LESSONS LEARNED:

- Leak detection sensor sensitivity depends upon operating pressures – select sensor accordingly
- Intermodular joint design affects the design of all modules
- Repair patch may be considered as a temporary seal and offers a smaller market size

FUTURE PLANS: Develop additional repair capabilities; design and build launch tube, and obtain regulatory and customer approval

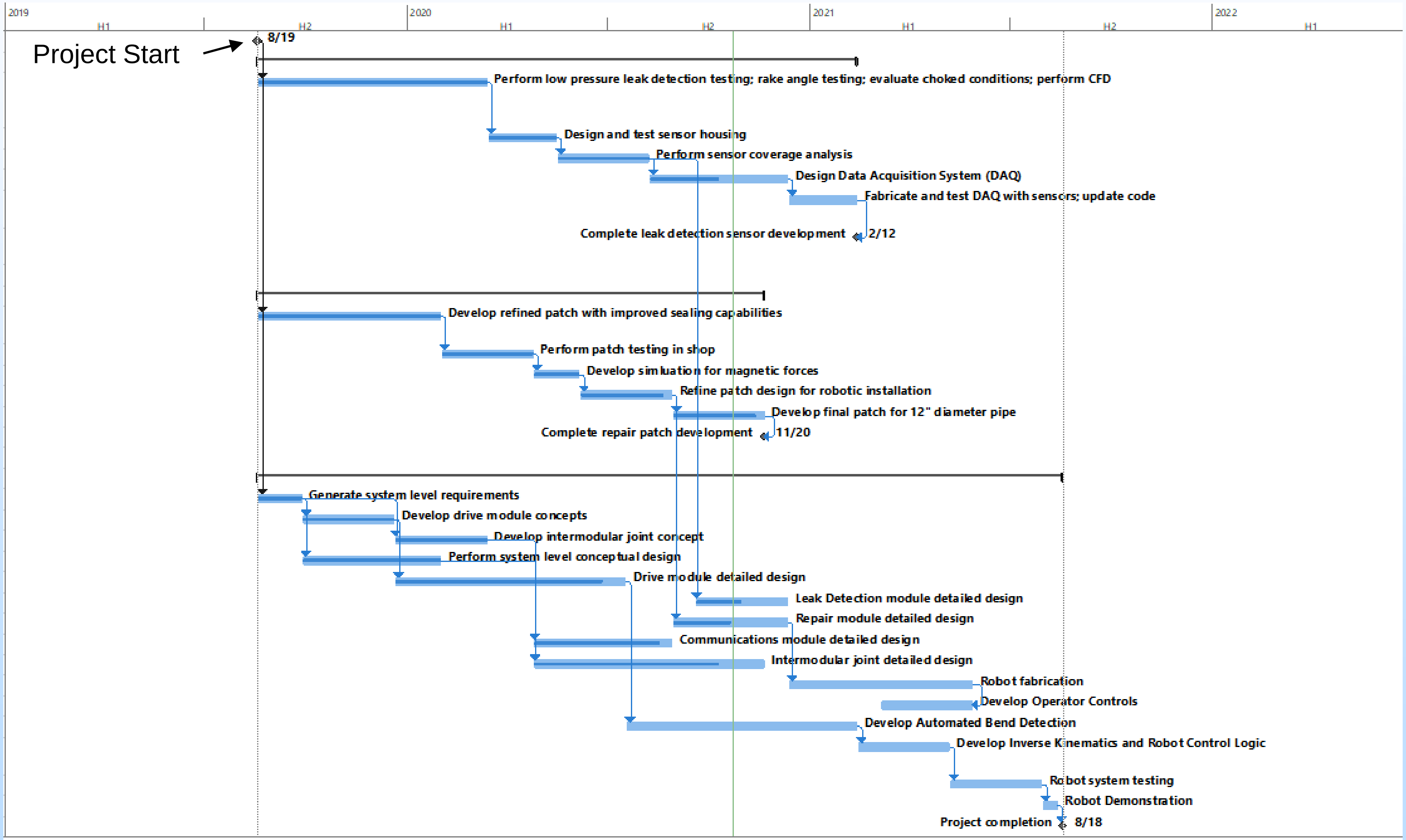
Appendix

Organization Chart



ULC Technologies has been developing, integrating, testing, and commercially deploying in-pipe robotic technology services in the US and UK for over nineteen years. Our technical teams have patented multiple specialized in-pipe robotic systems that perform repair and non-destructive testing in live gas mains. This includes technologies that perform services inside pipelines, but also vital support systems like launch and recovery equipment, tethers and cable reel systems, procedures, and purpose-built on-site vehicles that enable and support operations and maintenance functions. The support systems include highly specialized tethers, feeder mechanisms for pushing or pulling robot tethers through pressure glands on pipe entry equipment, protection mechanisms to prevent damage to robot tethers during operation, docking mechanisms to rigidly capture a robotic tool inside a launch vessel and many others.

Gantt Chart


2019
H1
H2
2020
H1
H2
2021
H1
H2
2022
H1
Project Start
8/19
Perform low pressure leak detection testing; rake angle testing; evaluate choked conditions; perform CFD
Design and test sensor housing
Perform sensor coverage analysis
Design Data Acquisition System (DAQ)
Fabricate and test DAQ with sensors; update code
Complete leak detection sensor development
2/12
Develop refined patch with improved sealing capabilities
Perform patch testing in shop
Develop simluation for magnetic forces
Refine patch design for robotic installation
Develop final patch for 12" diameter pipe
Complete repair patch development
11/20
Generate system level requirements
Develop drive module concepts
Develop intermodular joint concept
Perform system level conceptual design
Drive module detailed design
Leak Detection module detailed design
Repair module detailed design
Communications module detailed design
Intermodular joint detailed design
Robot fabrication
Develop Operator Controls
Develop Automated Bend Detection
Develop Inverse Kinematics and Robot Control Logic
Robot system testing
Robot Demonstration
Project completion
8/18