REPAIR

Rapid Encapsulation of Pipelines Avoiding Intensive Replacement

PHMSA R&D Meeting December 1 2021
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ARPA·E Impact Indicators 2021

Since 2009 ARPA-E has provided **$2.93 billion** in R&D funding to more than **1,270 projects**

183 projects have attracted more than **$7.6 billion** in private-sector follow-on funding

109 companies formed by **ARPA-E projects**

17 exits market valuations worth **$19.4 billion** from mergers, acquisitions, and IPOs

266 projects have **partnered with other government agencies** for further development

4,871 peer-reviewed **journal articles** from ARPA-E projects

789 patents issued by U.S. Patent and Trademark Office

253 licenses reported from ARPA-E projects

As of September 2021

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What Problem Are We Trying to Solve?

- Replace quickly and cost-effectively >50,000 miles of legacy gas utility distribution pipes
  - Cast iron
  - Bare steel material
  - Current pace finish ~20 yrs
  - Current cost $1-10MM/mile, not including disruptions to public

- *Technologies address >500,000 miles of water/sewer pipes*

- *May provide insights for oil and gas transmission pipelines and legacy gathering systems*

REPAIR Deliverables/Advances

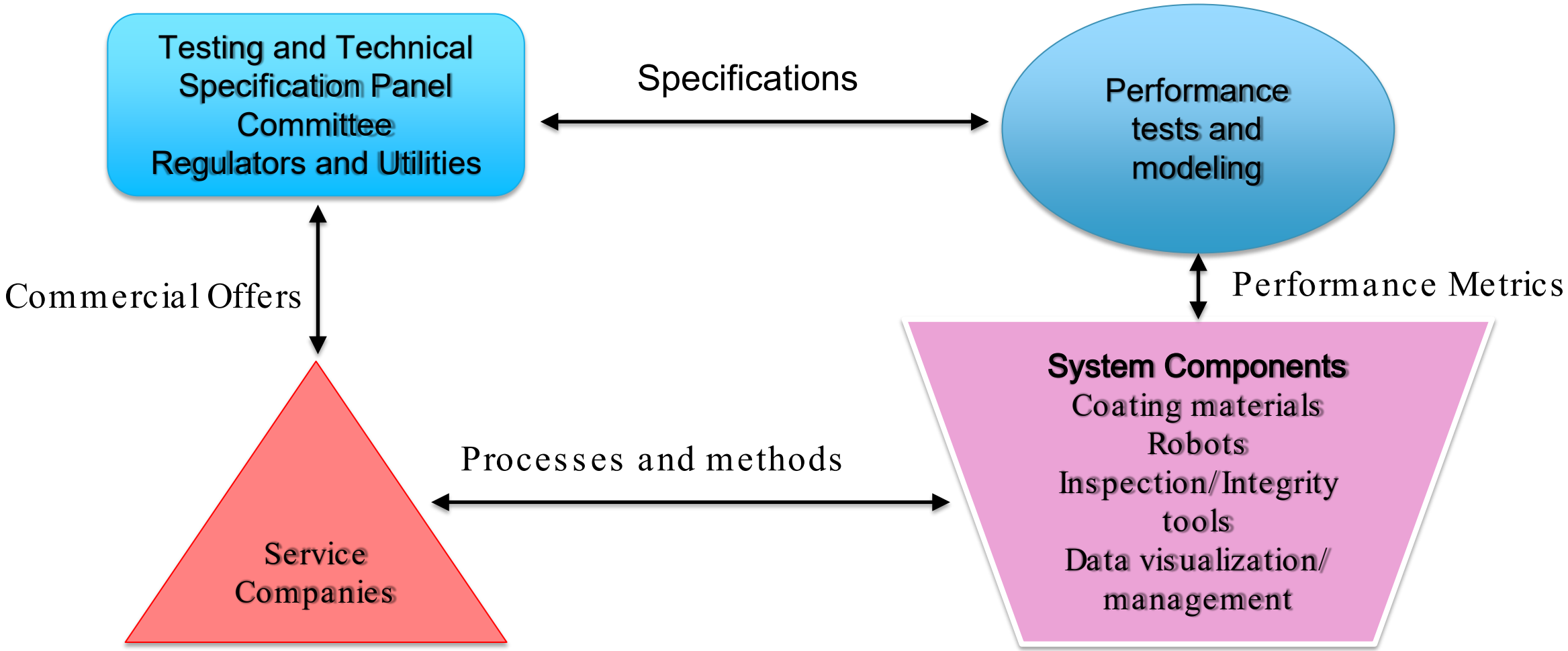
Work Categories

1. Testing
   - Codes and standards for techniques
   - Predictive models with latest Bayesian statistics for DIMP

2-5. Integrated coating, deposition tool, integrity inspection tools
   - Coating with 50 year life without reliance on legacy pipe
   - Stronger than steel, non-corroding, self-healing and self-reporting capability
   - In-Line Inspection tools that can be incorporated into DIMP

6. Mapping *(accelerated program)*
   - 3D maps of gas pipes and adjacent underground infrastructure
   - Real-time visualization tools for utilities, One-Call, and contractors
   - GIS-enabled database with locations, material certs, deposition conditions, inspection results to allow work planning and forecasting

Teamwork, Communication, and Coordination



Technical & Testing Specifications Panel (TTSP)

TTSP designed to provide input to ARPA-E on safety and regulatory issues related to REPAIR technology developments

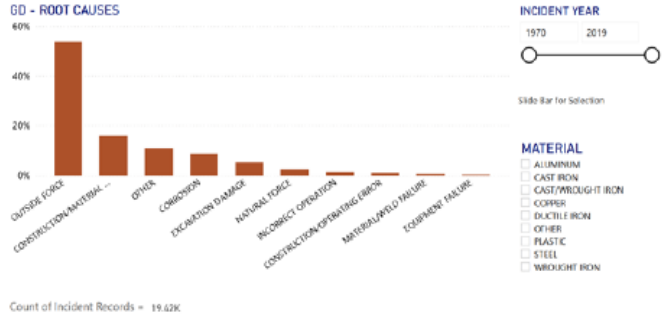
- Members include key REPAIR stakeholders
  - Regulators, PHMSA, NAPSR
  - Utilities
  - Codes and Standards organizations
  - DOE, DOT FHWSA, CEC
- Objective is to ensure REPAIR program testing protocols and metrics are consistent with the performance requirements for commercialization of REPAIR technologies, as required by regulators, gas utilities, and Codes and Standards organizations
- Quarterly meetings held to meet objectives
- ARPA-E has a budget for external consultants to support the TTSP
- Opportunities for synergies with DOT PHMSA, DOT FHWSA, CEC, and utility programs
- OTD facilitates the meetings

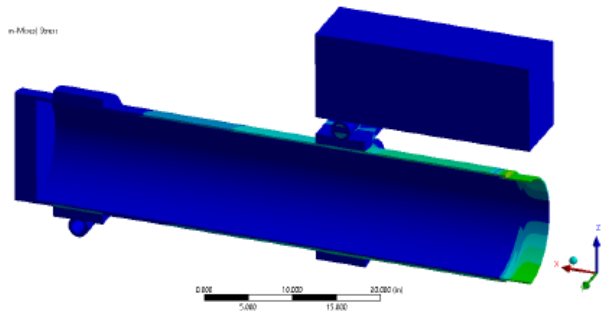
Colorado University Boulder testing team deliverables to date

- Project overview
  - "A State-of-the-art Review of Performance Criteria for Legacy Gas Pipes and Renewal Technologies" (draft journal paper)
  - "Development of a Testing and Analysis Framework for Validation of Rehabilitating Pipe-in-pipe Technologies" (NASTT 2022 No-Dig Show)

- Testing Guidelines:
  - Test Plan: External Loading
  - Test Plan: Hydrostatic Pressure Testing
  - Test Plan: Permeation

- Analysis and Modeling Documents:
  - "Analysis of failure modes in pipe-in-pipe repair systems for water and gas pipelines" (draft paper)
    - Modeling of PIP Failure Modes (6 individual reports on each primary POs)
    - Analytic hierarchy process (AHP) of failure modes
  - Modeling Circumferential (Hoop) stress – Guidance for Internal Testing
    - "End effects of the legacy pipe on the pipe-in-pipe liner under internal pressure" (draft paper)
  - Modeling Deflection (lateral deformation) – Guidance for External Testing
  - Analysis of thermal expansion of pipe-in-pipe with crack opening





Testing Team: Performance Objectives

T&A Team Focus: Mechanical performance of PIP Repairs
~80% Performance Objectives:

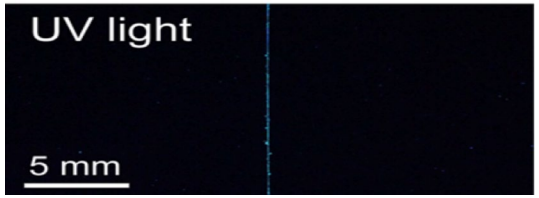
- PO1. Cyclic overhead loads, due to overhead traffic, etc.
- PO2. Deflection (lateral deformation), due to adjacent excavation, undermining/subsidence, frost heave, etc.
- PO3. Cross-section ovalization
- PO4. Axial deformation (displacement), due to thermal expansion/contraction (seasonal), *Termination point competency.*
- PO5. Circumferential (Hoop) stress due to internal pressure
- PO6. Puncture/impact due to drop weight or external force (improper excavation, host pipe fracture)
- PO7. Compatibility with current and future gas compositions
- PO8. Debonding between PIP and host pipe, to cause gas back-tracking or detachment at termination points.
- PO9. Service connections: pipe fixtures and service connections must be accommodated (abandoned or in-service)

Additional Important Considerations:
~20% Performance Considerations

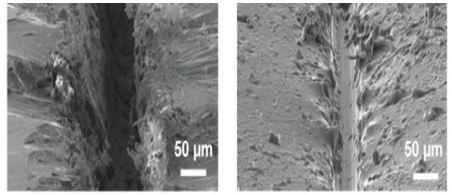
- Tapping for new service connections (PE, ST) or other similar sized components (e.g., drips, plugs)
- Existing tees, valves, threaded taps along pipe (e.g., blow offs, bag deployment, larger connections >3 in. diameter)
- PIP installation impact on:
  - elastomers, plastic pipe, seamed pipe
  - Various CI joint materials (e.g., jute/yarn/lead caulked, gasketed, mechanical)
  - Existing service connection taps of various materials (PE, ST, CI)
- Extreme temperatures
  - E.g., welding, exposed pipe at bridge crossing, proximity to buried steam line
- Seismic Considerations
- Impact of high-water table
- Others ?

Autonomic – Smart, self-healing, tough polymer coating

- Extruded-in-Place Pipe-in-Pipe (ExiPiP™) solution will allow for the installation of a new structurally independent pipe without the need for excavation
- The pipe material will be highly resistant to damage but will incorporate self-healing and self reporting functionality in the event of damage



Self-Reporting Functionality



Self-Healing Functionality

UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

Autonomic Materials™

Carnegie Mellon University

REDION

gti®

- Follow-on phase/program:
  - Extensive field testing and refinement; broad scope of application development engagements to develop ExiPiP™ platform tunability to various pipe sizes

GE PLUTO Epoxy and polyurethane coatings

PipeLine Underground Trenchless Overhaul (PLUTO)

Team: GE Research, WARREN ENVIRONMENTAL, GARVER

Project Vision:

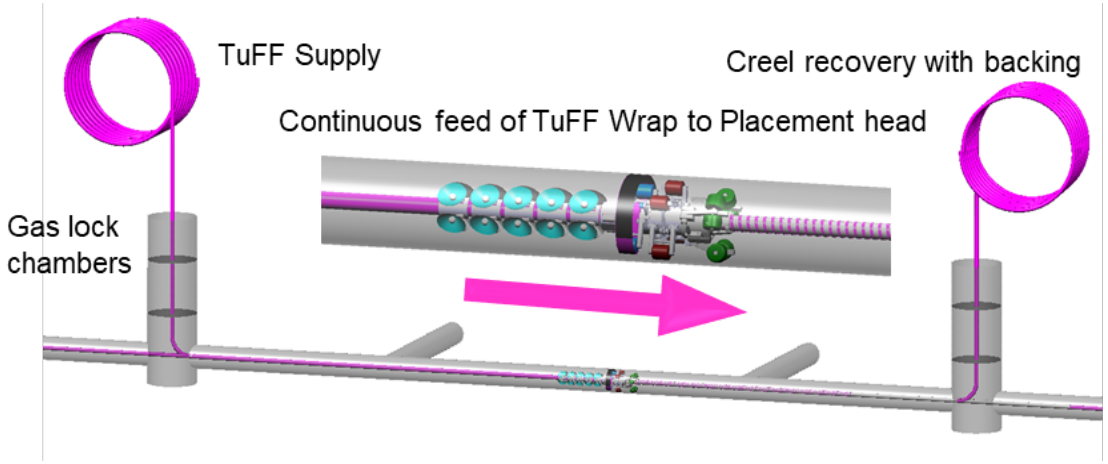
- Improve pipeline longevity and maintenance efficiency by developing a minimally invasive, long-range, structural pipeline rehabilitation system
- Build a commercial pipe maintenance system for gas transmission and adjacent domains

University of Delaware, Plitzie – TuFF Composite Coating

TuFF composite material feedstock and a robotic placement process to fabricate stand-alone structural pipe within the existing pipelines without disruption of gas delivery

- Two-step repair strategy where straight and slightly curved pipe sections will be internally wrapped followed by repair of complex geometry pipe transitions (e.g. T-joints, diameter reductions and steep bends)

TuFF material developed in previous DARPA program and the iWRAP concept relying on placement technology developed over the last three decades at UD-CCM.



Oak Ridge National Lab – Glass, aramid, carbon fiber composites

Technology Summary

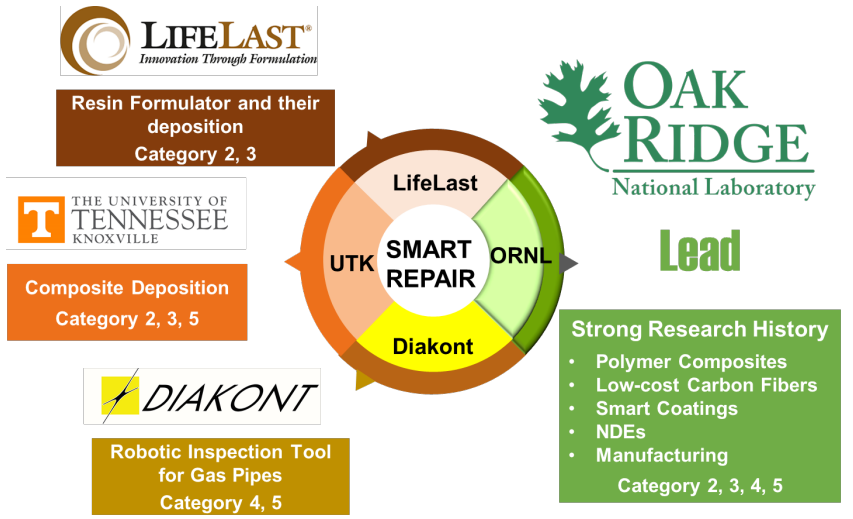
- *Develop "smart" structural polymer composite coatings*
- *Deploy methods on their deposition and NDE inspection with robotic technologies for structural renewal of gas distribution pipes*

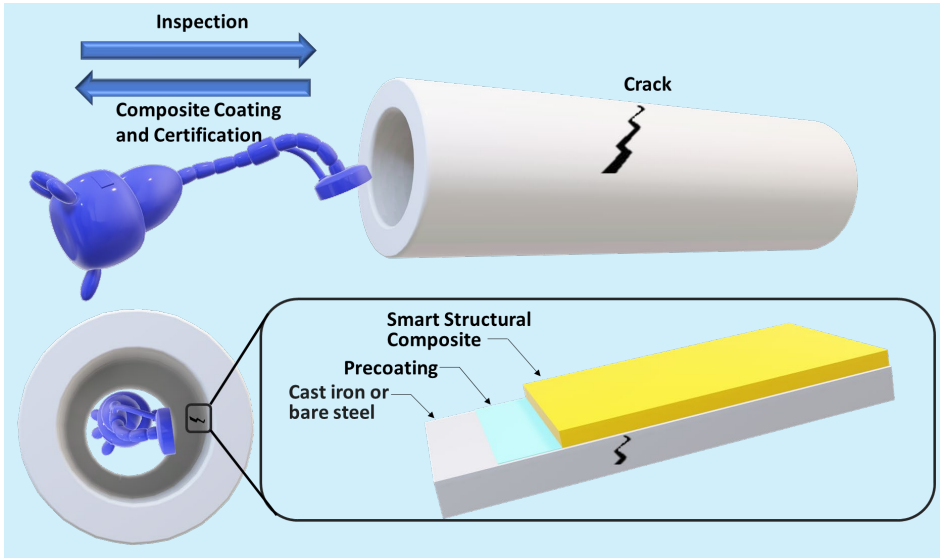
Technology Impact

- *Provide cost-effective ($1M/mile) and advanced solution for renewal of 60,000 mile gas pipelines*
- *Smart composite development will provide a strong leadership of U.S. in next generation advanced materials*

Targets

Metric	State of the Art	Target
Structural Composite's Tensile Strength	*Do not exist for gas pipelines*	*96 MPa*
Efficient Robotic Deposition and Inspection	*Do not exist for gas pipelines*	*> 15 m/hr*





Smart Complete Solution for Gas Pipeline Rehabilitation

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1-Year Exploratory Metal Coatings Concepts

- U Maryland/High-T Tech/Diakont/Exelon
  - Deposit slurry of powdered steel followed by rapid sintering
- ULC Technologies/Penn State/Brookhaven National Lab
  - Cold spray stainless steel coating and deposition robot
- U Pittsburgh/Pacific Northwest National Lab
  - Cold spray metal with imbedded fiber optic sensor
- Possibly suitable for oil and gas transmission?
  - Weld or spot repairs
  - Re-purposing for hydrogen

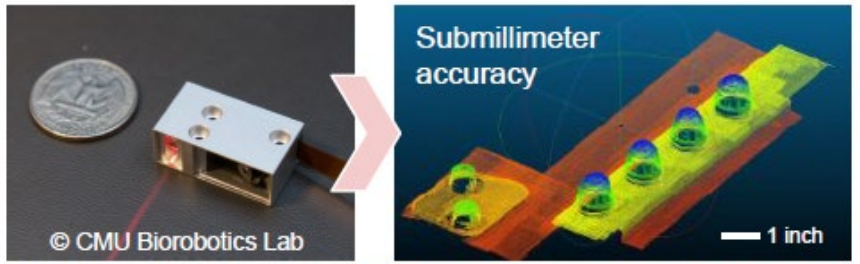
Carnegie Mellon University– In-pipe mapping sensor and 3D maps

Technology Summary

- *Compact Lidar and In-Pipe SLAM Module Design.*
- *Multimodal sensor fusion and feature registration.*
- *Ultra-large scale map manipulation and processing*

Status

- *10x map density, 0.5 mm accuracy to-date*
- *Works in small pipes*
- *In progress:*
  - *Real-time visualization of pipes from surface*
  - *Historical database for tracking changes with time*
  - *Artificial intelligence to identify defects and track changes*



Compact Lidar design for confined space inspection

White River – Real-time 3D locating and mapping from surface

- **3D Pipe Location, insensitive to soil conditions**
  - APEX; large-standoff, controlled-source 3D EM technology
  - 3D location of REPAIR pipes at 3m depth within 10cm (<10 cm @ 2.6m depth to-date)
- **In-pipe Transmitter**
  - Transmitting sonde attached to in-line tool maps pipe and REPAIR tools from surface
  - Easy-to-use technology, near realtime, in-the-field results
- **Seeking utility pre -excavation test sites for 2022**

white river technologies

CRREL

DARTMOUTH

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Closing Thoughts

- APRA-E welcomes pipeline stakeholders engagement
- All test methods and models from UCB testing team will be public documents
- All recommendations from the TTSP will be public documents
- Annual program review meeting scheduled for January 11, 2022. If interested in attending, send email to jack.lewnard@hq.doe.gov