ARPA-E REPAIR PROGRAM BRIEFING

Introductory Remarks:

Commissioner Diane Burman, New York Public Service Commission

Moderators:

Commissioner Ethan Kimbrel, Illinois Commerce Commission

Commissioner Julie Fedorchak, North Dakota Public Service Commission

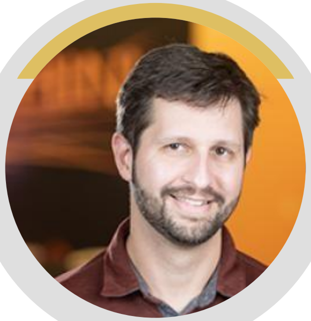
ARPA-E REPAIR PROGRAM BRIEFING FOR NARUC

Panelist

DR. JACK LEWNARD
Program Director

ARPA-E

Panelist



DR. TODD DANKO
Principal Roboticist

GE Global Research

Panelist

DR. FARAH SINGER
Associate Project Manager

ULC Robotics

Panelist

DR. GERALD WILSON
President & CEO

Autonomic Materials, Inc.

CHANGING WHAT'S POSSIBLE

REPAIR

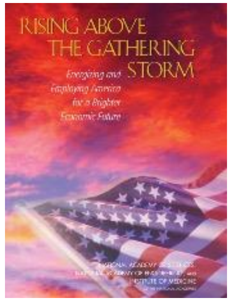
Rapid Encapsulation of Pipelines Avoiding Intensive Replacement (REPAIR)

NARUC Gas Committee
September 18, 2020
Washington, D.C.

Jack Lewnard, Program Director ARPA-E
jack.lewnard@hq.doe.gov

ARPA-E History

In 2007, The National Academies recommended Congress establish an Advanced Research Projects Agency within the U.S. Department of Energy to fund advanced energy R&D.



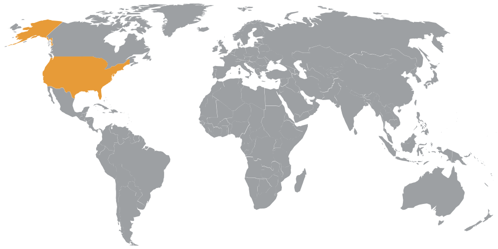
2007

Rising Above the Gathering Storm **Published** – warns policymakers that U.S. advantages in science and technology had begun to erode

America COMPETES Act **Signed** – authorizes the creation of ARPA-E

2009

American Recovery & Reinvestment Act **Signed** – Provides ARPA-E its first appropriations of $400 million, which funded ARPA-E's first projects



2020

850+ Awards
54 Programs

Current Funding:
$425M
(FY20)

CHANGING WHAT'S POSSIBLE

What is ARPA-E?

The Advanced Research Projects Agency-Energy (ARPA-E) is an agency within the U.S. Department of Energy that:

- Provides **Research and Development** funding for high-risk, high-reward, transformational ideas. FY 2020 budget $366MM

- Focuses on technologies that could **fundamentally change** the way we get, use, and store energy

- Accelerates energy innovations that will create a more secure, affordable, and sustainable **American energy future**

CHANGING WHAT'S POSSIBLE

U.S. DEPARTMENT OF ENERGY

ARPA-E Mission

Goal 1: To overcome long-term and high-risk technological barriers in the development of energy technologies that…

Goal 2: To ensure that the United States maintains a technological lead in developing and deploying advanced energy technologies.

Means:

- Identify and promote revolutionary advances in fundamental and applied sciences;
- Translate scientific discoveries and cutting-edge inventions into technological innovations; and
- Accelerate transformational technological advances in areas that industry by itself is not likely to undertake because of technical and financial uncertainty.

ARPA-E Impact Indicators

Since 2009 ARPA-E has provided **$2.4 billion** in R&D funding to more than **950 projects**

166 Projects have attracted more than **$3.3 billion** in private-sector follow-on funding

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

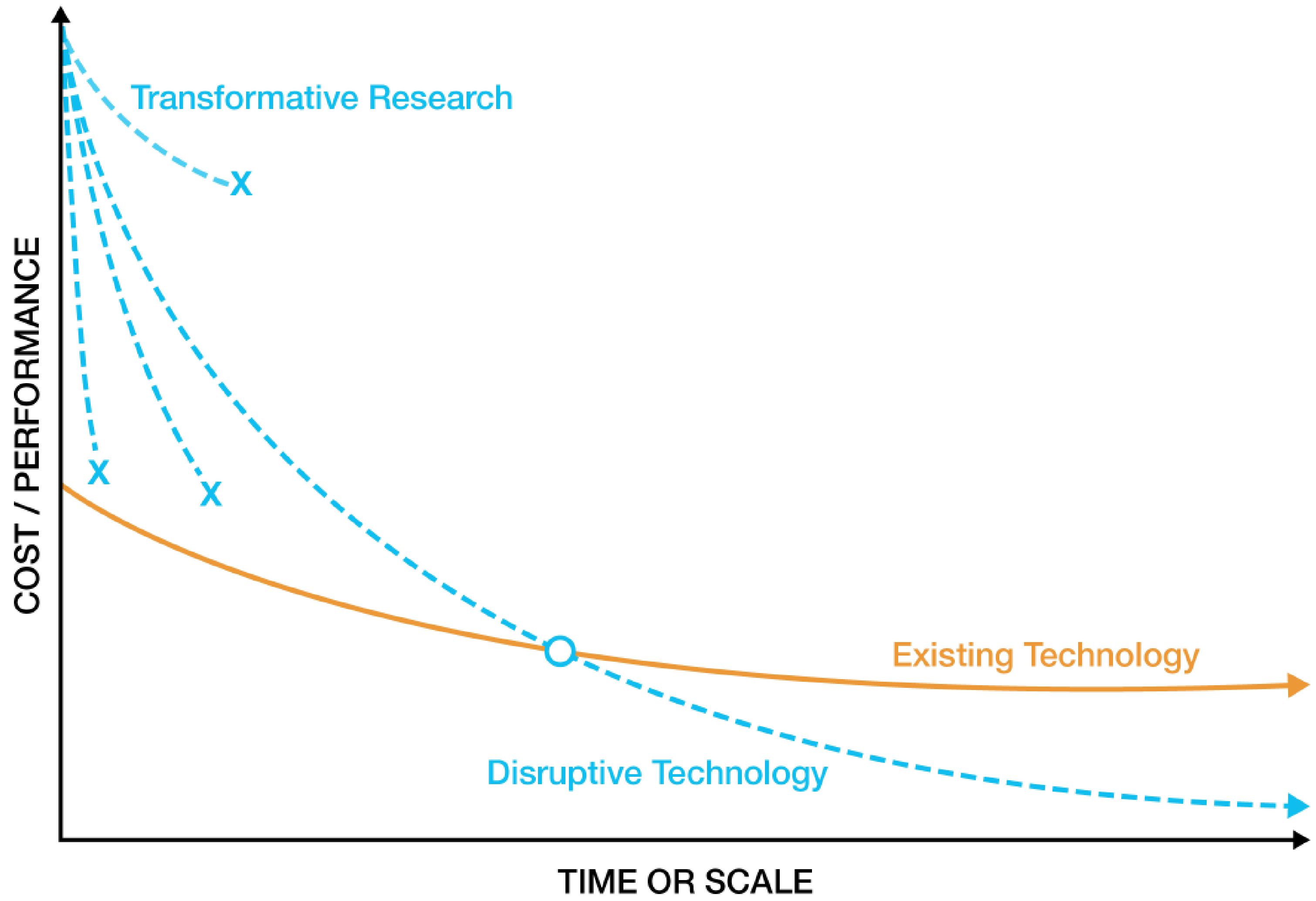
229 projects have **partnered with other government agencies** for further development

4,021 peer-reviewed **journal articles** from ARPA-E projects

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

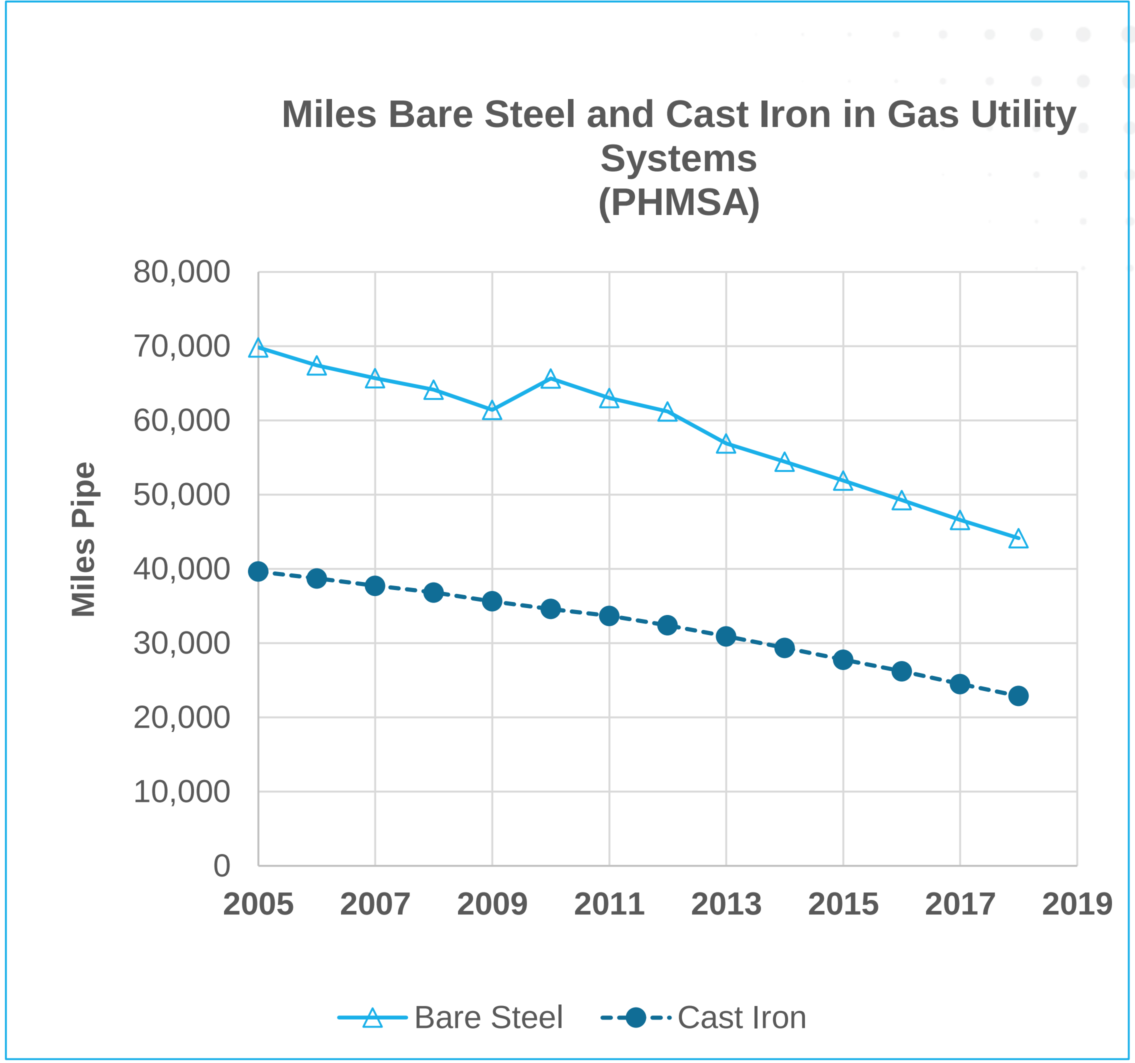
As of September 2020

Creating New Learning Curves, Disruptive Technologies



REPAIR Goals

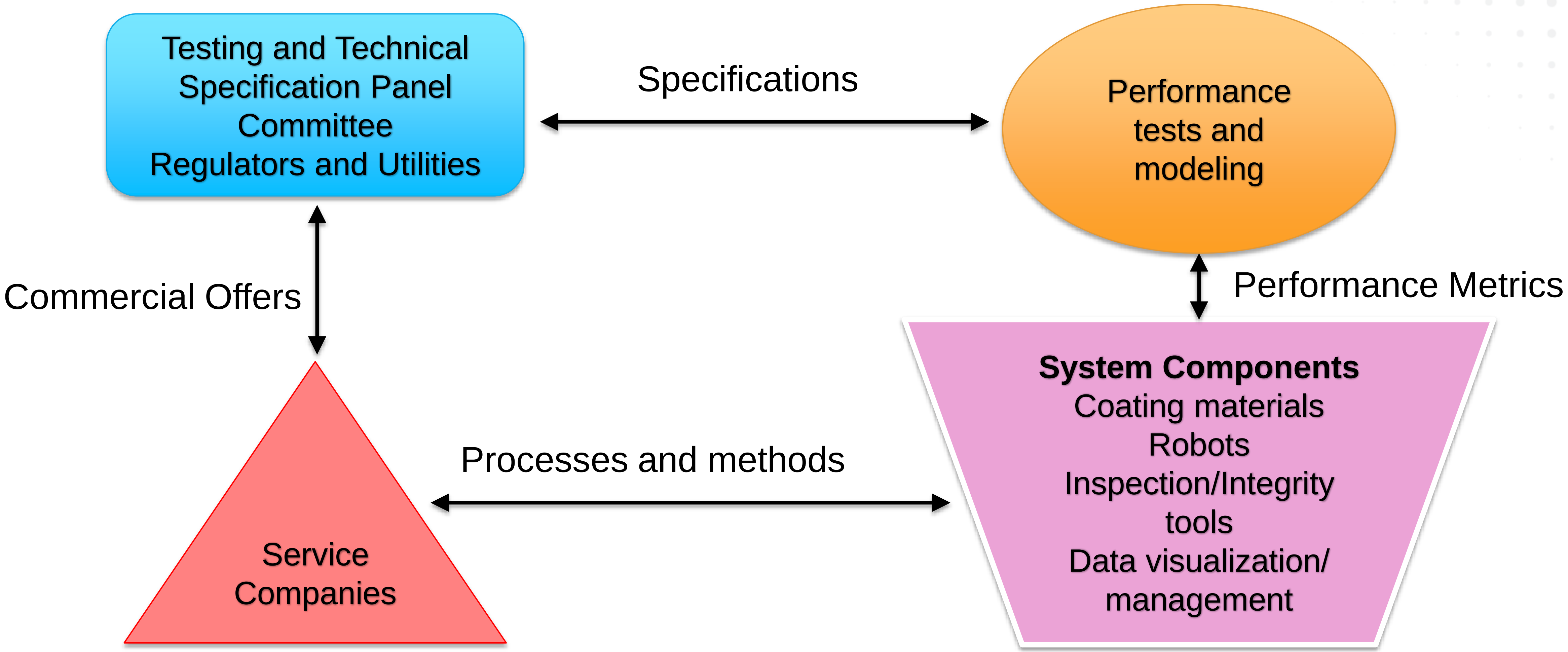
- Turn-key solutions for gas utilities and pipeline owners
  - <u>Rehabilitate</u> cast iron and bare steel pipes > 10-inch diameter
    - 50-year life
    - $1MM/mile cost
    - Accepted by regulators as equal to pipeline replacement
    - Costs allowed in rate base
  - <u>3D maps</u>
    - Visualize gas pipes and adjacent underground infrastructure
    - Integrate data from coating tool, inspection tool(s), leak reports
- 3 year, $38.5MM budget



Benefits

- Minimize excavation
  - Lower cost: excavation is the largest cost component
  - Less disruption
- Enhance assets
  - Rehabilitated pipe should be stronger, smarter than new polyethylene
  - 3-D system map with detailed inspection record including materials certifications
- Same technology can be adapted for other pipelines
  - Gas gathering, water, sewer, and higher-pressure transmission lines
  - $500B-$1T infrastructure replacement costs

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

- TTSP kicked-off meeting first week of September
- Members include key REPAIR stakeholders
  - Regulators, PHMSA, NAPSR
  - Utilities
  - Codes and Standards organizations
  - DOE, DOT, 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
- Opportunities for synergies with DOT PHMSA, DOT FHWSA, CEC, and utility programs
- OTD will facilitate the meetings

TTSP Needs You!

- Contact: Jack Lewnard

  Jack.Lewnard@hq.doe.gov

  202-507-0003

  Commercialization requires regulatory approval. Let's get it right from the start.

  Virtual meeting 1st week of October

REPAIR Deliverables/Advances

Work Categories

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

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

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

REPAIR Awards

Testing: UC Boulder, GTI, Cornell, U South Wales (Australia)

- Levering experience from testing CIPP liners, qualifying plastic and steel distribution pipes, and repairs for high-pressure oil and gas lines

Coatings, deposition tools, and inspection tools

- General Electric and Autonomic: polymer-based coating technology
- University of Delaware and Oak Ridge National Lab: composite fiber coating technology
- University of Maryland: sintered-metal coating
- University of Pittsburgh and ULC Robotics: cold-spray metal coating

3D Mapping

- White River Technologies: above ground 3D mapping technology, data management/data visualization
- Carnegie Mellon University: in-pipe 3D mapping technology

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

Questions

Back-up

Task 1 – Testing and Analysis

- **Scope**
  - **1.1** Define failure mechanisms
    - Precedents: ASTM test standards for polyethylene and steel pipes; CIPP test protocols
    - Identify failure modes for cast iron and bare steel pipes
    - Collaborate with TTSC for consensus to validate 50 year lifespan
  - **1.2** Model failure modes to identify critical physical properties and develop test methods
    - Communicate properties to coating material development teams
    - Critical properties are function of material, pressure, and legacy pipe dimensions
    - ISO 17025 practices, reviewing existing/available protocols
  - 1.3 Pipe testing and failure analysis
    - Samples fabricated by system integrators from Task 5

Potential tests, based on liners

- Deflection (lateral deformation), due to undermining, frost heave, ground subsidence, possibly earthquakes (i.e., liquefaction, lateral spreading).
- Axial deformation (axial displacement), due to thermal expansion/contraction, adjacent construction activity, and possibly earthquakes (i.e., transient wave propagation, permanent deformation from lateral spreading or landsliding)
- Vibrational loads, due to overhead traffic, which may cause fatigue failure
- Bonding/de-bonding at coating/pipe interface, due to differences in the thermal expansion of metal and coating or mechanical loads. Debonding could result in gas pockets at the composite/pipe interface, which may cause damage to the coating if the pipe is rapidly depressurized. Note that debonding may be advantageous in responding to some mechanical loads.
- Compatibility with current and future gas compositions with regard to corrosion and permeability, especially for hydrogen
- Cross-section ovalisation – this maybe critical for low modulus coatings
- Bends, tees, valves, and service connections - The presence of pipe fixtures and service connections may create stress concentrations and localized failures, in conjunction with the above failure mechanisms.

Comments on Testing

- Carved out as separate task
  - Requires expensive, specialized equipment. Can ‘t afford to have each team build their own pipe testing equipment
- Team working on Tasks 2-5 are expected to
  - conduct their own “coupon” scale testing
  - Include testing requirements in their proposals
  - Need stay within their testing request
- Budget for pipe testing will be set with Task 1 performers
- ARPA-E will coordinate access to testing
- Testing teams will have access to results from teams working on Tasks 2-5. Therefore they cannot also work on Tasks 2-5 to avoid any conflict of interest

Task 2 – Smart Coating Materials

- **Scope**
  - Develop smart coating materials consistent with:
    - Performance requirements per TTSC (i.e. 50 year life)
    - Requirements for deposition tool(s) forming coating pipes (i.e. viscosity, cure time)
  - Incorporate Smart features
    - Self healing
    - Self reporting Enhanced adhesion (as required)

Getting started

- Physical properties defined per failure modeling and performance testing (e.g tensile strength)

Task 3 – Coating Deposition Tool

- **Scope**
  - Develop coating deposition tool
  - Design and test robotic crawler integrated with deposition tool:
    - Operate 500 m in each direction from pipe launch point
    - Deposit coating at 15 m/hr or greater
    - Capable of operating 10-inch diameter pipe and larger
    - Capable of operating in pipe with minimal cleaning
    - On-board diagnostics for coating deposition QA/QC
    - Preference for ability to operate with pipe on-line

Task 4 – Pipe Integrity/Testing Tool

- **Scope**
  - **4.1** Pre-coating integrity/inspection
    - Identify any gross features that could hinder pipe rehabilitation (e.g. obstruction such as debris, liquids, pipe joints, tight bends, reducers, valves, etc.)
    - Identify pipe defects that would limit the operation of the coating deposition tool (e.g. cracks, excessive corrosion, dents, etc.)
    - Provide real-time information with data visualization for operators.
  - **4.2** Post-coating integrity/inspection
    - Above requirements in addition to testing the integrity of the newly deposited coating

Task 5 – Integrated Task 2,3,4 Pipe Test

- Scope
  - Commercial success requires system integrators to develop “turnkey” offerings for gas utilities
  - Responsible for selecting and integrating system components
  - Final tests will be run on a 10- to 20-inch diameter segment of field pipe removed from service
  - Applicants will demonstrate pre-coating inspection, coating deposition, and post-coating inspection to verify coating integrity

Task 6 – Pipeline Mapping/Inspection Data Integration

- **Scope**
  - **6.1** In-pipe mapping
    - In-pipe mapping tools deployed on the coating robot and/or inspection robot preferred
    - Tools deployed independently require Applicants to provide the target operating ranges
  - **6.2** Surface mapping
    - Develop 3D sub-surface imaging tool
      - Real-time data visualization
      - Capable of identifying sub-surface infrastructure
      - Ideally capable of measuring pipe properties (i.e. materials, diameter, and wall thickness)
  - **6.3** Data integration and data management/visualization
    - Create unified data management tool to integrate all REPAIR information into 3D pipeline maps
    - Provide an interface that allows users to manage and visualize the data in real time.

GE Research

WARREN ENVIRONMENTAL

GARVER

arpa·e awardee

PipeLine Underground Trenchless Overhaul (PLUTO)

Todd Danko, *PhD* todd.danko@ge.com
GE Research
September 18, 2020

PipeLine Underground Trenchless Overhaul (PLUTO)

Goals, Approach, and Impact

Project Goals

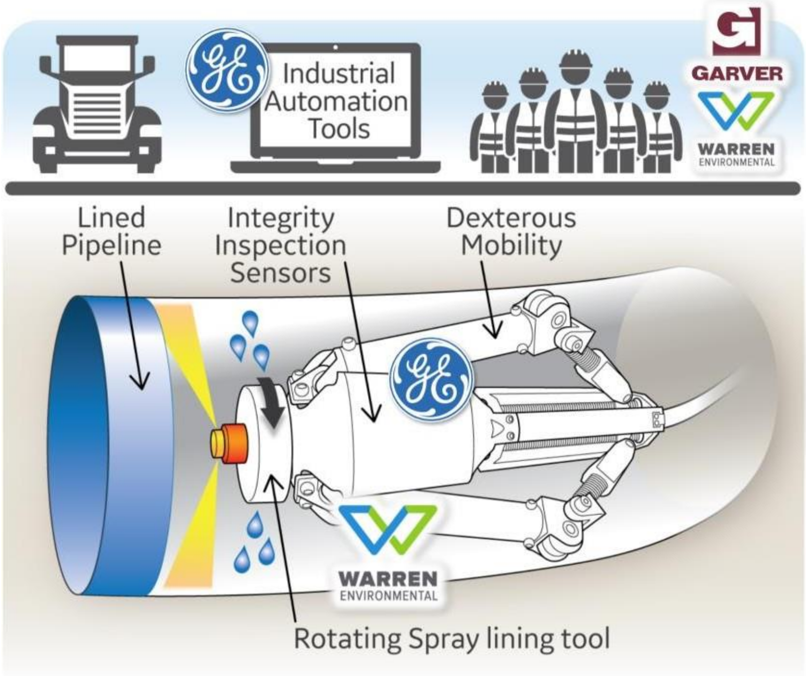
- **Minimally Invasive Structural Pipeline Rehabilitation:** Apply structurally independent liner to leaking iron and steel pipelines, reducing gas pipeline transmission loss
- **Economical Infrastructure Maintenance:** Rehabilitate existing pipe infrastructure through sparse access points rather than replacement through continuous pipeline excavations ❼ ½ to 1/20th of the cost of full pipe replacement

Approach

- **Access:** Dexterous pipe crawler system with tether managing features for scalable range extension
- **Prepare:** Selective surface preparation for high speed deployment, and structural liner independence from host with intimate bonding to service connections
- **Material and Process:** Water, wastewater and fuel sector proven epoxy for long-life, structurally independent pipe linings
- **Inspect:** Advanced inspection technologies paired with deep learning analytics for detecting life limiting defects

Technology Impact

- **Long-Range:** Up to 1000 m one-way travel, minimizing excavations & reducing interruptions
- **Fast:** 1000 m pipeline inspection coating and validation ~36 hours
- **Longevity:** 75+ year service life is as good or better than new pipe installation



PLUTO: Minimally Invasive, Long-Range, Structural Pipeline Rehabilitation

Timeline – Core Component Development to Scaled Field Adoption

Pipeline Owner and Regulator Outreach / Acceptance Activities

Access System Development

Coating Material Development

Material Applicator Development

Pre-and-Post-Coating Inspection System Development

ARPA-E Funded PLUTO Pipe Rehabilitation Demonstrator System Development

Maturation

Commercial PLUTO Pipe Rehabilitation System

Domain Extension
Water, Wastewater, Nuclear, Petroleum, Industrial Site Infrastructure, …

Today → 2021 → 2022 → 2023 → 2024+

ARPA-E Funded Team PLUTO Effort

TEAM PLUTO Independent Effort

Challenges and Path to Economic Viability

Risk: Regulatory Adoption - A successful technical solution is valueless if it is not trusted for deployment by pipeline owners and regulators

- **Mitigation:** Early and frequent interaction with regulators and pipeline owners through ARPA-E REPAIR program. Cooperatively shape requirements for acceptance.

Risk: Performance - Each system component is unproven in target environment: Access, Materials, Inspection

- **Mitigation:** Design philosophy and risk reduction activities shape solution that is as simple as possible to achieve goals. Test often with regular critical evaluations of system and approach

COLD SPRAY ADDITIVE MANUFACTURING FOR NEW PIPELINE FABRICATION IN LIVE, NATURAL GAS DISTRIBUTION MAINS

ARPA-E REPAIR Program: DE-FOA-0002289
Prime Recipient: ULC Technologies, LLC
Period of Performance: 12 months

Principal Investigator: Dr. Farah Singer
Co-Principal Investigator: Dr. Baiyang Ren

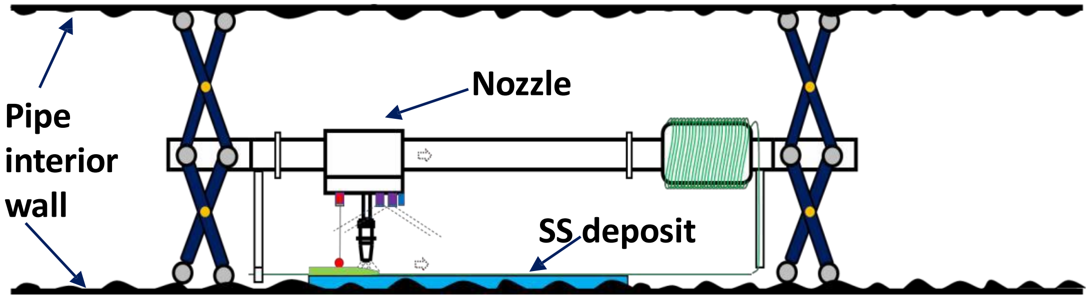
September 18th, 2020

ULC | ROBOTICS

Innovation

PROJECT OBJECTIVES

- **Cold spray structural Stainless Steel coatings**
  - ✓ Minimal reliance on aging host pipe substrate
  - ✓ Excellent corrosion-resistance
  - ✓ Anticipated >50 years life expectancy
  - ✓ Standard for Hydrogen transport and storage
- **Next-generation process for rehabilitating aging gas distribution pipelines**
  - ✓ Operates in live natural gas pipes
  - ✓ Does not require pipe pre-cleaning
  - ✓ Cold spray has years of proven performance in various industries
  - ✓ Safe for operators: remote robotics operation
  - ✓ Faster than conventional 3D printing processes



Simplified Robotic Concept for Material Deposition

IMPACT

IMPACT

- **Markets**
  - ✓ Gas distribution and transmission pipelines
  - ✓ Water and sewer pipelines
  - ✓ Crude oil and petroleum product pipelines
  - ✓ Steam distribution pipes
- **Economics**
  - ✓ Cost-effective process: < $1 million per mile
  - ✓ Drastically-reduced excavation costs
- **U.S. Economy**
  - ✓ New U.S. manufacturing jobs
- **Energy**
  - ✓ Enhanced reliability of energy delivery
- **Environment & Safety**
  - ✓ Eliminate need for pipes cleaning/eliminate need for hazardous waste disposal
  - ✓ Significant reduction in number of leaks/reduced methane (greenhouse gas) emissions into atmosphere
- **Social**
  - ✓ No disruption of gas service to customers

Minimal Excavation Site For Employing A ULC Technology

TEAM

- **ULC Technologies, LLC: Prime Recipient**
  - Process development/Testbench development
  - Experimental testing
- **Pennsylvania State University (PSU)**
  - Process parameters development
  - SS material selection and characterization
- **Brookhaven National Laboratory (BNL)**
  - Deposited material characterization
  - Physical/mechanical properties testing

Challenges

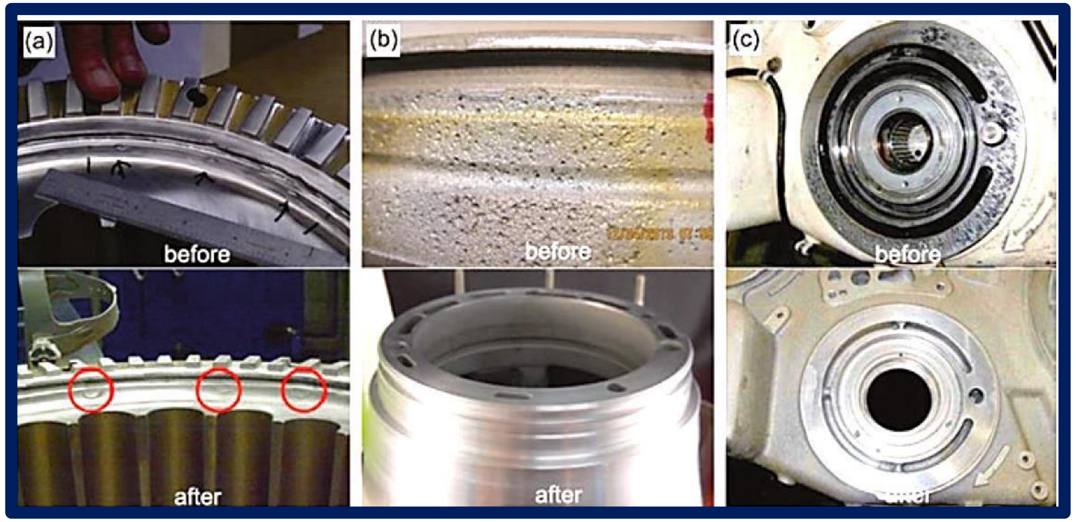
BACKGROUND

- Cold spray process: particles of metal powder are propelled through a nozzle using heated, pressurized gas to accelerate them to supersonic speeds
- He or N2 gas: typical carrier gases
- Applications: repairs, deposit metals on sensitive or difficult-to-weld surfaces, etc.

CHALLENGES

- Use Methane as carrier gas
- Successfully scale down the system dimensions
- Achieve targeted physical/mechanical properties
- Undeposited SS powder: carryover in live pipes
- Achieve targeted process costs: impact of SS (feedstock) powder price and process speed

Restored B737 nose wheel steering actuator barrel via Cold Spray Remanufacturing (Ref: Cold Spray Coatings, Pasquale Cavaliere)



Comparison between damaged and cold sprayed components: (a) AH-64 helicopter mast support, (b) F18-AMAD gearbox, and (c) front frame of T-700 engine (Ref: Cold Spray Coatings, Pasquale Cavaliere)

Timeline and Future Prospects

TIMELINE

- **2020-2021**
  - ✓ Develop cold spray process for rehabilitating gas distribution steel pipelines
  - ✓ Explore market requirements and commercialization potential
- **2021-2023**
  - ✓ Adapt the process equipment for compact robotic applications
  - ✓ Develop a complementary structural health monitoring system
  - ✓ Demonstrate early robotics prototype
  - ✓ Facilitate technology adoption by regulators and operators
- **2023-2026**
  - ✓ Develop commercial cold spray robotic system; launch service for natural gas pipelines
  - ✓ Conduct field tests and demonstrations
  - ✓ Target other markets: crude oil and petroleum product pipes, and steam distribution pipes

Thank you!

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Autonomic Materials™
NARUC REPAIR WEBINAR

REPAIR GOALS AND CONTRIBUTORS

Structurally Independent

Pipe Replacement (Costs Allowed in Rate Base)

$1MM/Mile

Minimize Excavation

50-Year Life

Self-Healing/Self Reporting

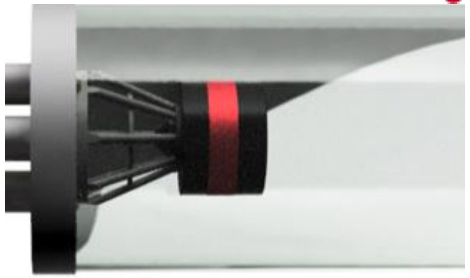
UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

Carnegie Mellon University

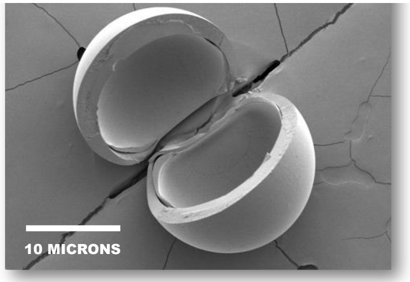
Autonomic Materials™

Extruded Pipe POC

Extrusion



Robotic Extrusion of New Pipe

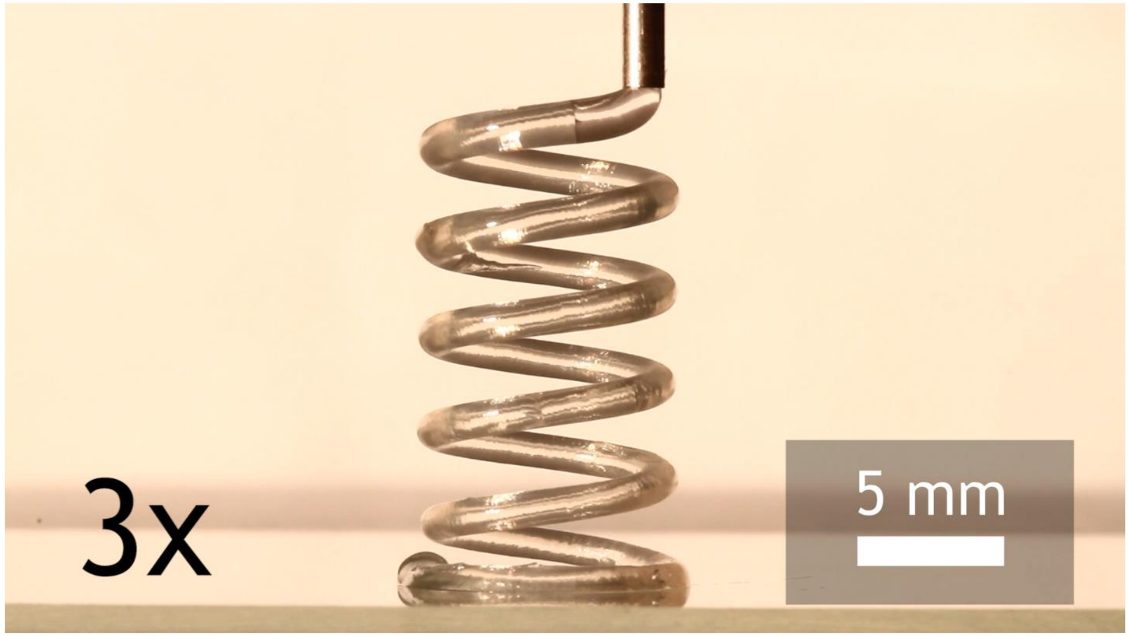


Ruptured Microcapsule

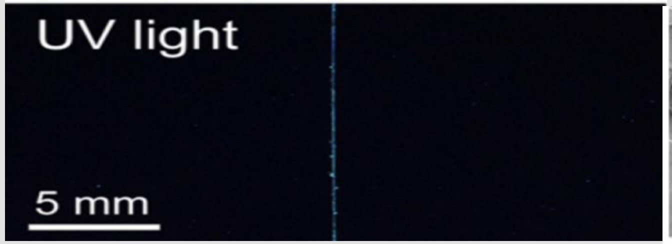
3

PROPOSED SOLUTION

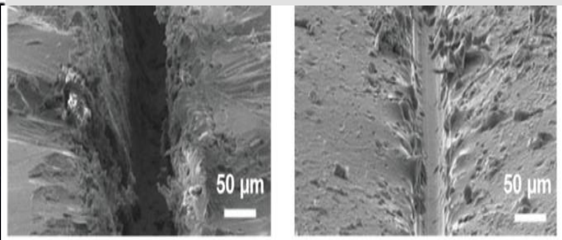
- Robotic platform with sensor payloads assess the pipe condition prior to rehabilitation, pulls along a deposition tool that extrudes out and cures new pipe, performs post-inspection of the pipe
- Extruded material rapidly converts from a gel to a structurally independent material in a matter of seconds (pipe acts as mold)
- New pipe will have the capability of identifying and arresting crack propagation extending fatigue lifetime of the pipe
- Robotic platform and self-reporting capability allows for ongoing inspection at size scales as low as a few microns and modeling of lifetime



Frontally-Cured Polymeric Rehabilitation Material



Self-Reporting Functionality



Self-Healing Functionality

FEATURES AND TIMING

Autonomic Materials

FEATURES

- Rehabilitation method will meet target cost of less than $1MM/mile and up to a 94% decrease in cost relative to new pipe installation
- Extruded pipe will be structurally independent from the host pipe and will be deployable in live pipe conditions
- Poly(DCOD) will exhibit improved mechanical properties relative to incumbent polymeric pipe materials and commonly used CIPP materials but will also incorporate self-healing functionality to arrest cracks that form and extend the lifetime of the pipe and self-reporting functionality to assess damage on an ongoing basis
- Modular robotic platform will perform pre- and post-inspections as well as post-deployment inspections leveraging self-reporting capability of the pipe to assess health of the pipe

TIMING

- Project timeline: Q4, 2020 to Q4, 2023 followed by transition into field deployment

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