REPAIR Workshop Overview

Rapid Encapsulation of Pipelines Avoiding Intensive Replacement (REPAIR)

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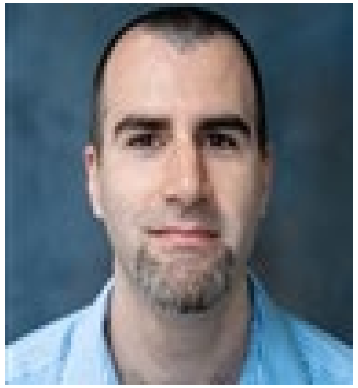

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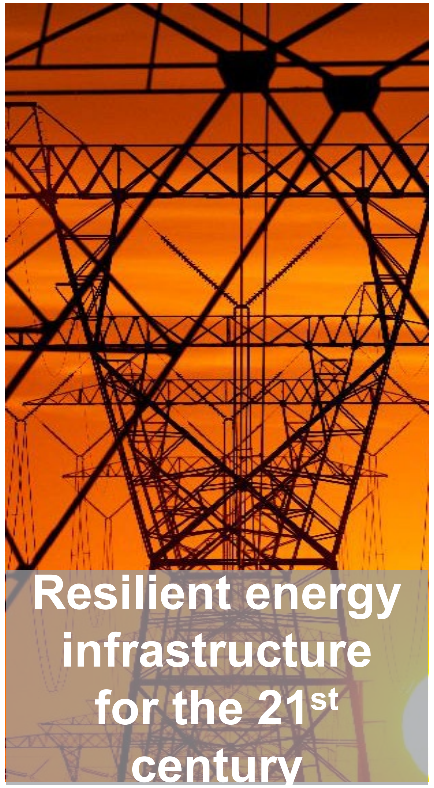
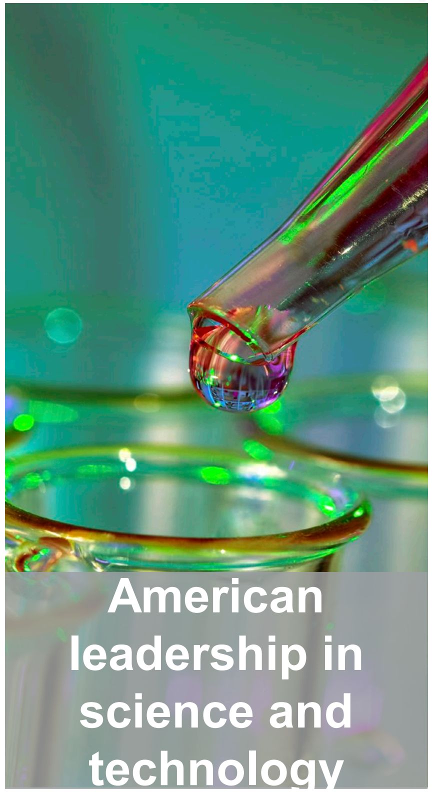
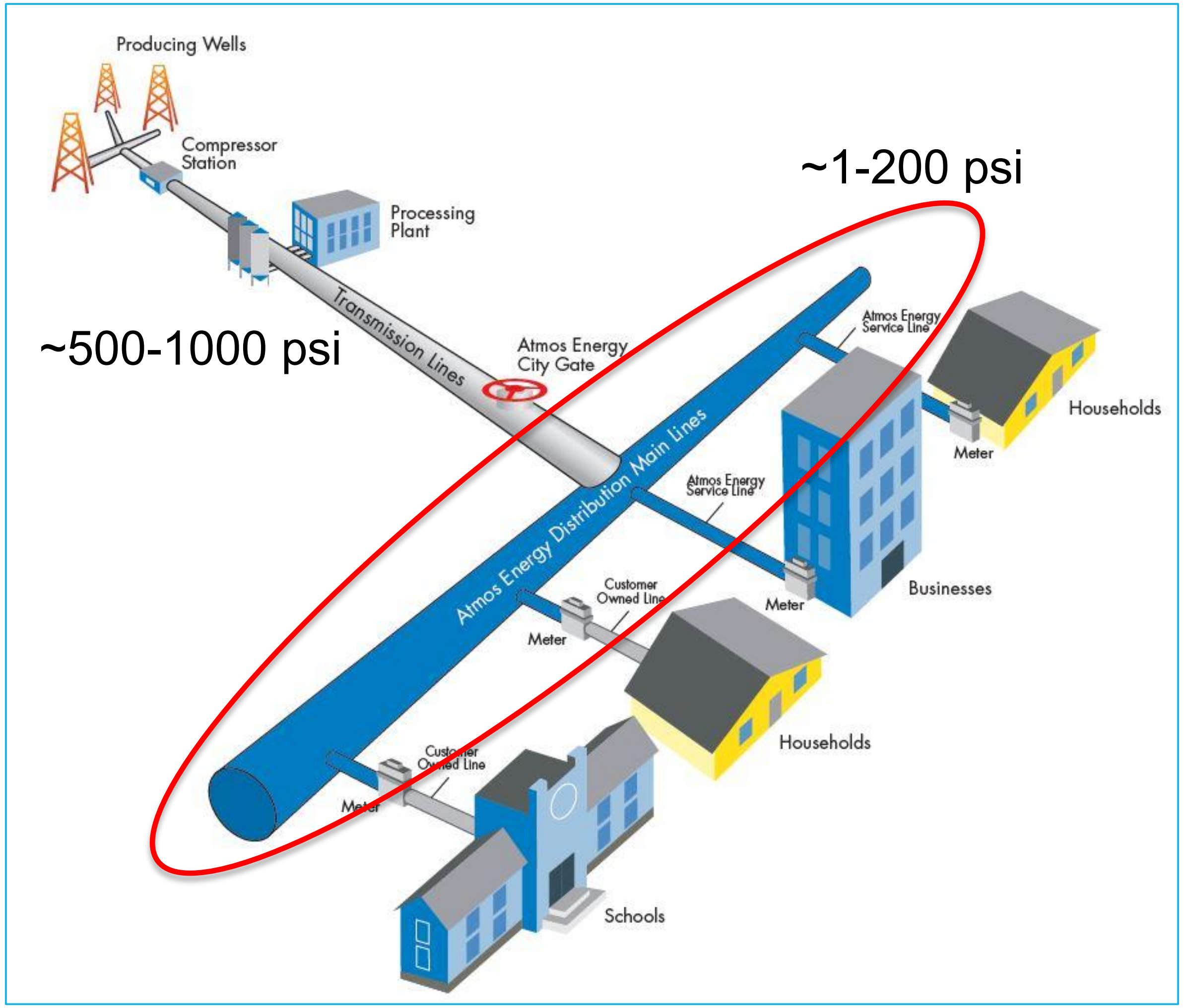
REPAIR Fit With ARPA-E Mission





- Natural gas provides 31% of US primary energy, serves 70 MM homes, 5 MM commercial customers
- Abundant and affordable domestic energy resource
- Pipeline infrastructure repair/rehabilitation spending >$3B/year across all sectors
- Novel rehabilitation technologies touch material science, chemistry, physics, robotics, data analytics, etc.

Gas Distribution 101



- Gas utilities start ~mid-1800's
- Low-pressure "Town gas" from coal
- Wrought iron pipe, joined by couplings, through early 1900's
- Cast iron pipes joined with bell/spigot and packing, through 1950's
- Transition to natural gas in 1940's and (bare) steel in 1950's
- Transition to plastic pipe in 1960's
- Continuous investment to upgrade infrastructure; more than 60,000 miles of cast iron and bare steel have already been replaced

Issues and Options

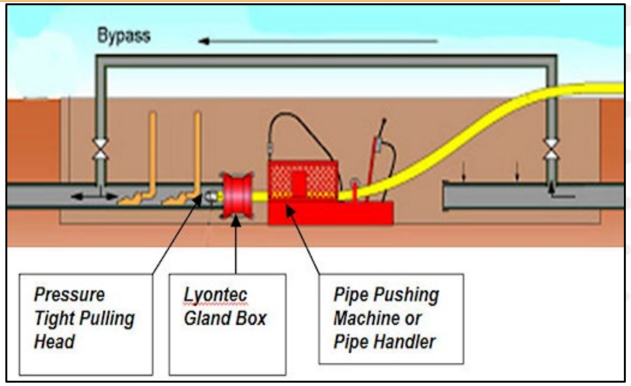
- Cast Iron (<2 bar, 35 psi pressure)
  - Leaks at joint
  - Brittle; small-diameter pipe subject to cracking from frost-heaves or displacement
  - Graphitization (corrosion)
- Bare Steel (generally <15 bar, 200 psi)
  - General corrosion
  - Pitting
- Replacement costs
  - $1MM to >$8MM, depending on location
  - Extended pipe replacement schedules
- Current Options
  - Excavation
    - Replace with plastic (remove old pipe or abandon in place)
    - External wraps
    - Couplings
  - "Trenchless Technologies"
    - Keyhole repair (can be on-line)
    - Plastic pipe bursting
    - Plastic pipe insertion
    - CIPP Liners
    - MICP
    - CISBOT (on-line)

Example Commercially Available Technologies

Clamps

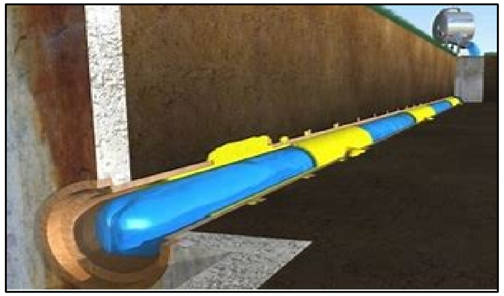
Wraps

Pipe Bursting

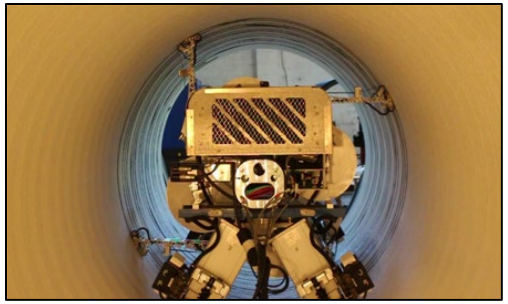


Slip-lining

Keyhole encap-sulaiton



CIPP liner



MICP

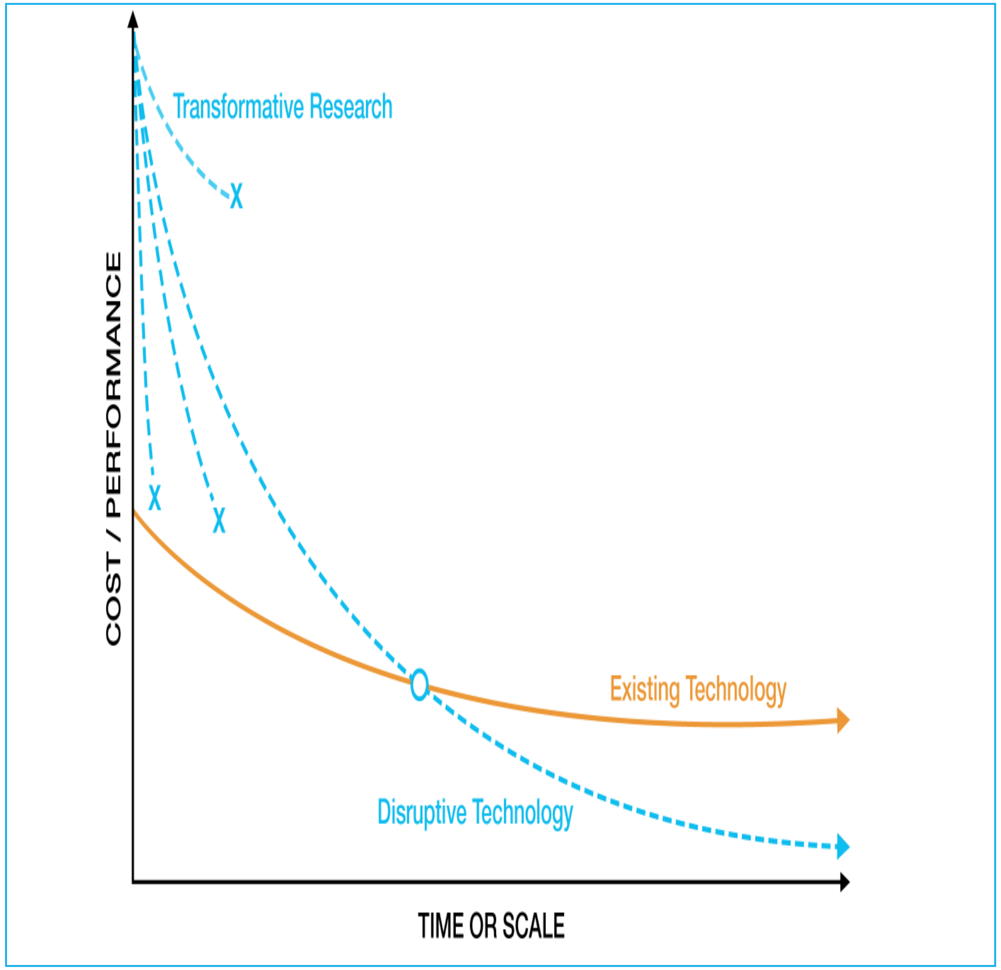
CISBOT

Potential TRL 5 Deliverables

- Composite “Pipe-in-Pipe”
  - Live pipe, 15 m/hr rate, 800 m reach,
- Inspection tools
  - Original pipe, minimal cleaning
  - Integrity tests for composite layer
  - Future testing for composite and outer pipe
  - Real-time data with visualization to support field operations
  - 3D map with integrity data to support LDC engineering
- Test protocols
  - Link mechanical properties, test methods, models, and inspection tools to validate 50+ years life
- Path to rate-base authorization for costs

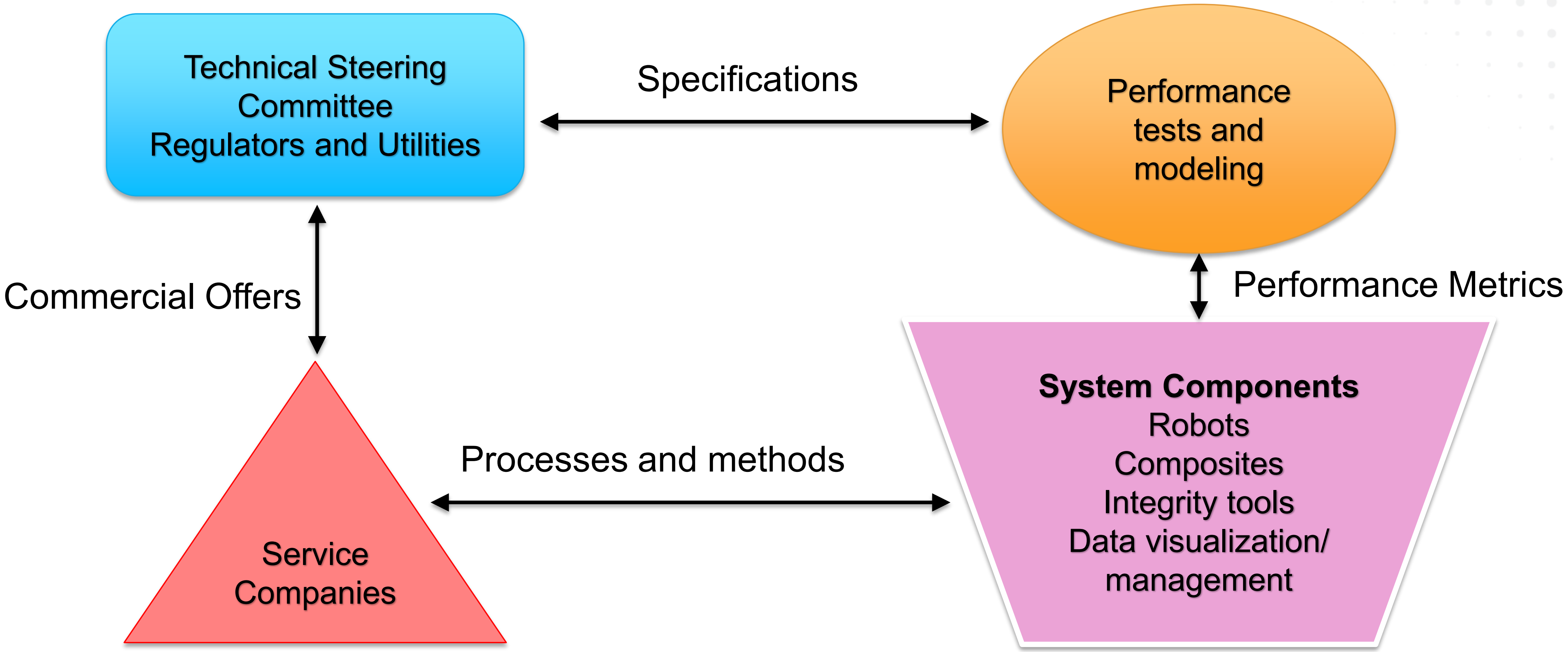
TRL	1	2	3	4	5	6	7	8	9
Phase	Research & development						Demo. Small	Demo Large	Commercialization
Output	Paper	Pieces	Prototype				Product		
Scale		Concept	Lab Scale	Bench Scale	Engineering Scale		Full Scale		

What Puts REPAIR on a Disruptive Technology Curve?



- Repair while pipe in service
- Speed
- Distance
- New robotic functionality
- Smart composite coating
- Orthogonal integrity tools
- Testing protocols
- Integrate pipeline mapping, coating data, integrity measurements
- Cost and Performance

Who Do We Need



Workshop Goals

- Level-set on current state of art
- Introduce developments outside pipe domain
- Identify technical and regulatory hurdles
- Stimulate new concepts, approaches
- Address your questions
- Provide input to refine Funding Opportunity Announcement
- Foster networking among participants

Critical Questions To Answer

- **Breakout Session #1: Success Metrics and Component Capabilities**
  - What will be the toughest technical challenges for the system components – robots, composite materials, integrity inspection?
  - What are various options for component testing? Integrated system testing? Please comment on accessibility, cost, capabilities, and any gaps?
  - What is the most important criteria for the technology to be deemed successful?
  - “The envisioned program has assumed a system solution involving a robot and composite material. Are there other high-risk, high-reward system solutions or components that we would miss with this construct?

Critical Questions To Answer

- **Breakout Session #2: Data Management/System Level Solutions**
  - What data will be needed from each of the system components - robots, inspection tools, coating equipment – to ensure:
    - Lowest-cost alternative technology
    - Minimum life >50 years
    - Regulatory approval
  - What are the challenges for making integrity testing and coating QA/QC data available real-time?
  - How can component developers and system providers collaborate to expedite commercialization of the best innovations?