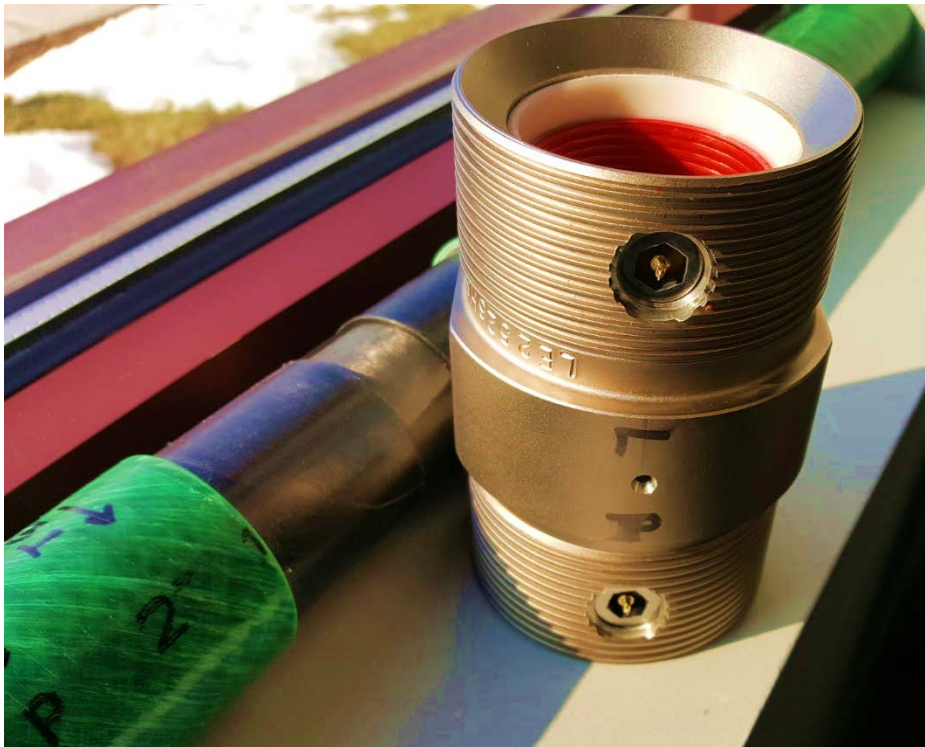


Continuous Fiber Composite Electrofusion Coupler

Project ID # MN015



P. I. – Dave Hauber
Presenter – Brett Kimball
Automated Dynamics
2017

Overview

Goal

To advance the state of the art for hydrogen transmission and distribution by improving the pipes' joining method.

Timeline and Budget

- Project Start Date: 12/31/15
- Project End Date: 12/31/18
- Total Project Budget: \$1,876,865.00
 - Total Recipient Share: \$376,865.00
 - Total Federal Share: \$1,500,000.00
 - Total DOE Funds Spent*: \$721,244.38

* As of 3/31/17 by ADC

Barriers

- D: High As-Installed Cost of Pipelines

Technical Targets

Transmission Pressure (bar)	100
H ₂ Leakage	< 0.5%
Lifetime (years)	50

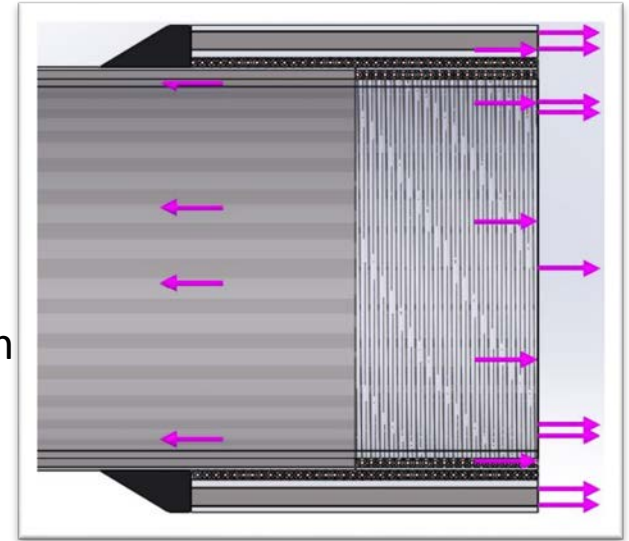
Partners

- DOE: Project Sponsor
- SRNL: Project Partner
- NOV: Project Partner
- Automated Dynamics: Project Lead



Relevance

- 3-Year Project Objective
 - Design and test a composite-based coupler to be used in the field during pipeline installation
 - 100 bar, <0.5% flow leak rate, 50 year life



Fundamental Problem:

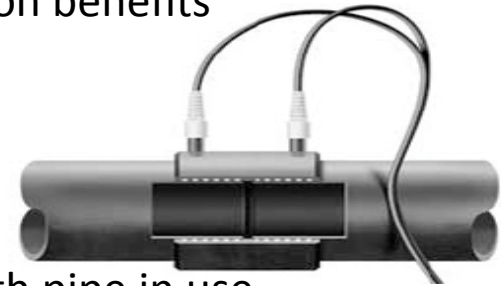
ASME B31.12 Code Committee concern that existing seal components will require maintenance in underground service.

- April 2016 – April 2017 Objective:
 - Improve coupler design from original intent to now apply to either thermoset or thermoplastic based composite pipes, drastically **enabling the commercialization of H₂ line coupling technology.**

Past year's Impact: Lowered predicted cost of H₂ pipelines by maximizing number of components from pre-existing coupler technology from NOV Fiber Glass Systems.

Approach

- Continuation of 2013 DOE Program: SNRL & NOV Developing FRP for H₂
- 2016-2017 research swung from All Non-Metal Solution to Multi-material Solution
 - No-Metal Design is Attractive for perceived Zero anti-corrosion benefits
 - Metal & Composite Design addresses low-cost Barrier AND accomplishes corrosion/embrittlement goals.



Metal Components

- Not in contact with H₂ to avoid hydrogen embrittlement
- Pre-existing Technology, proven mechanical performance with pipe in use.

Composite Components

- Electrofusion of thermoplastic components (thermoplastic coated wire, neat Polyethylene (PE), Fiberglass reinforced PE
- In contact with H₂, and internal to metal components

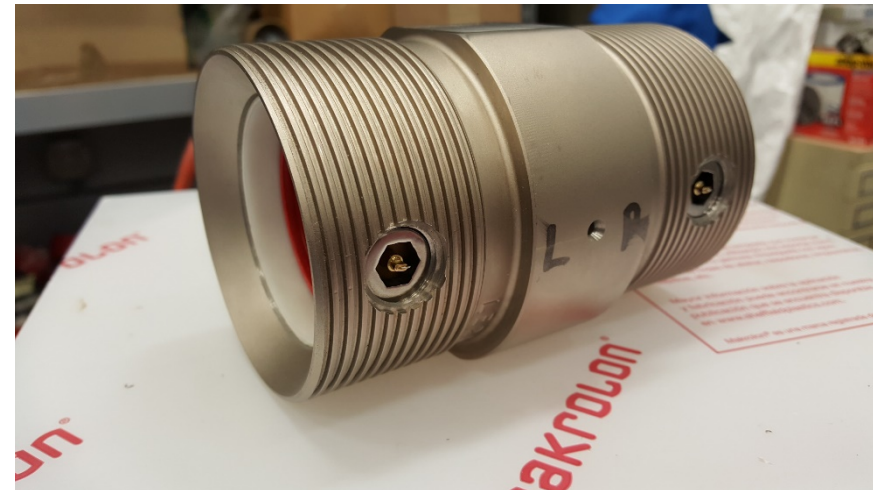
Go/No-Go Criteria 2016	Result 2016
Tensile Load >10,000lb	PASSED: 11,000lb
Burst Pressure >100 bar	PASSED: 369BAR (5,356psi)
Leak Rate <10x10e-4 cm ³ He/s	PASSED: 10e-6 cm ³ He/s

Approach

- 3 independent challenges in joining pipes (table below)
 - 3 distinct features address challenges separately.
 - Each feature works cohesively with others
 - Each feature robust for field installation.
- **For each challenge, the relevant MYRDD barrier (low pipe cost) was primarily considered.**

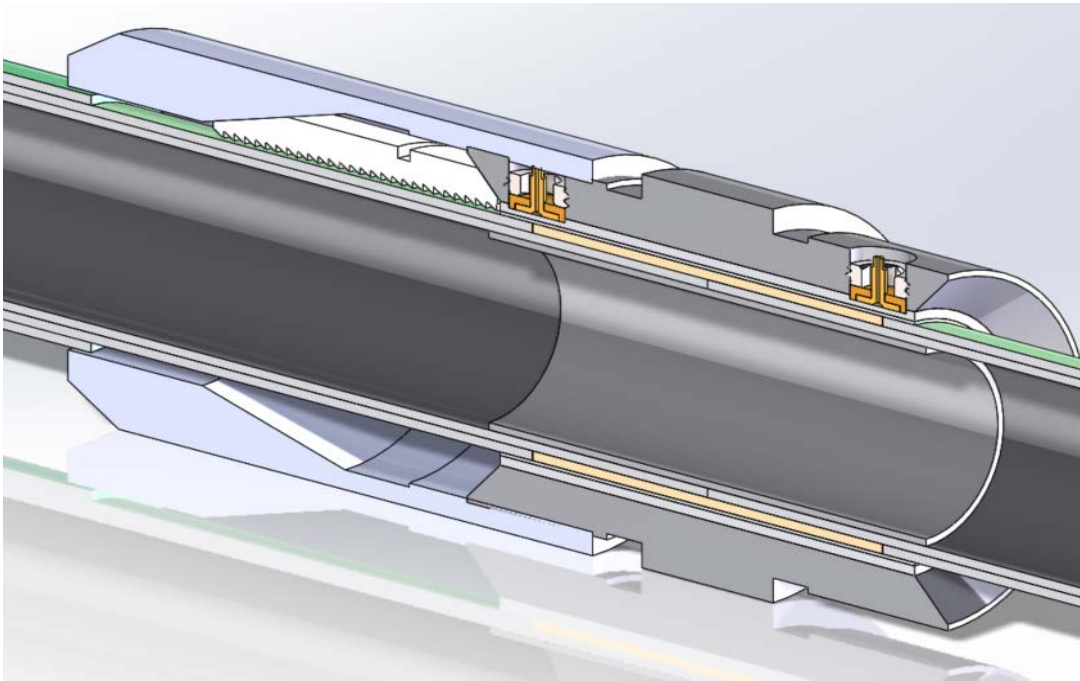


Challenge	Approach/Solution
Tensile Load thru coupler	Metal teeth bite into composite pipe (Employing pre-existing technology)
Burst Pressure	External metal housing (Employing pre-existing technology)
Seal H ₂ in pipe	Electrofusion (Custom wire/PE/Composite)



Approach

- Attempted from-scratch version of Grip Design
- Quickly went to NOV to use available components



Manufacturing Approach for Design allows for variable diameter pipe, with minimal re-design.

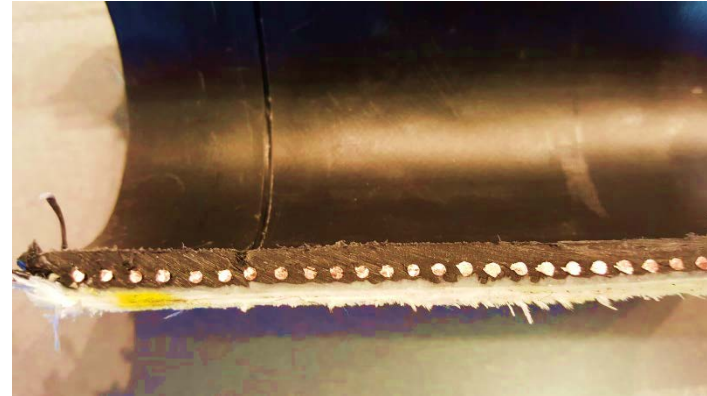


Approach

Date	Milestone/Gate	Status 3/31/17
March '17	Burst Pressure Test with Higher Requirement (3.5x Safety Factor over 100bar)	Achieved / 100% Complete
June '17	Test 3 couplers for Burst Strength.	On Track
	Perform Finite Element Fatigue Analysis	
Sept '17	Manufacture 5 couplers for fatigue testing +1 coupler for leak rate	
Dec '17	Fatigue Testing 5 couplers	
	Leak rate test 1 coupler	
	Go/No-Go: Leak Rate, Fatigue, Burst Pressure	
March '18	Final Design Review	
June '18	Creep Rupture Test	
Sept '18	Fatigue to Failure Test	
Dec '18 [End of Project]	Create Manufacturing and Quality Plan	
	Final Design Report	

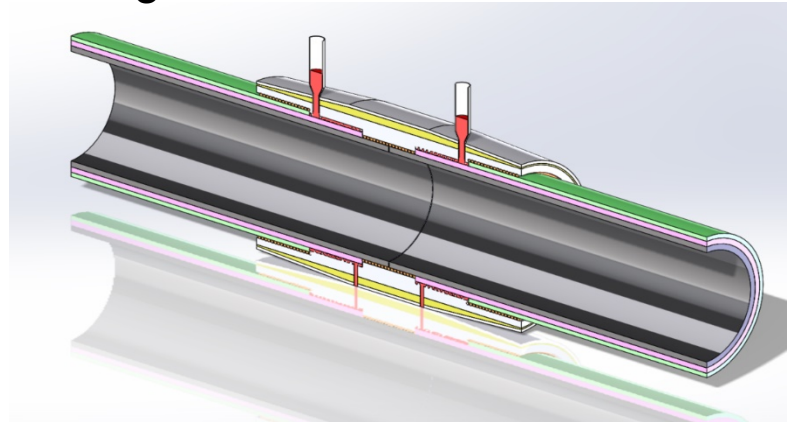
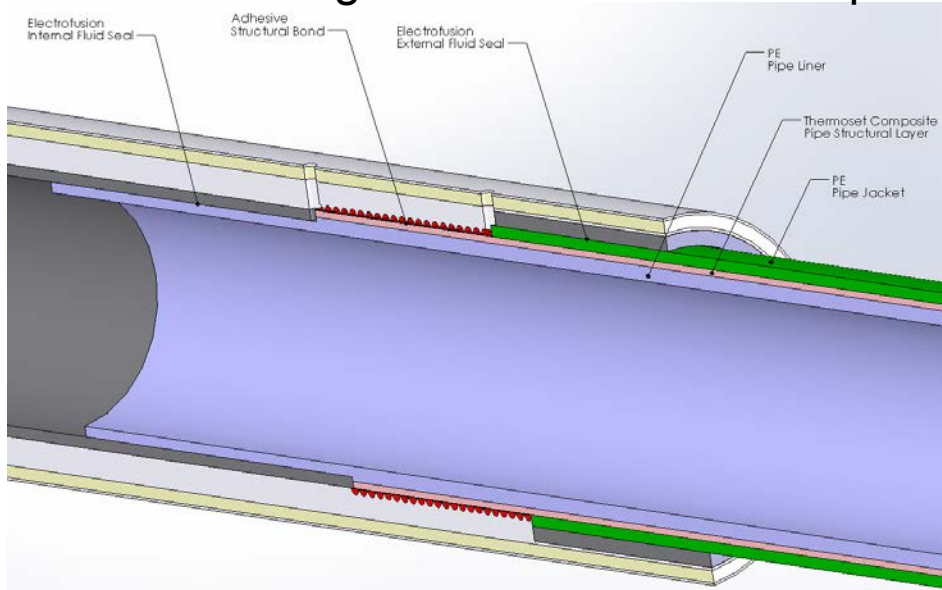
Accomplishments and Progress

- Passing Go/No Go gate is most notable achievement: 11 kip Tensile load, 300 bar Burst, $10e-5$ He cm^3/sec Leak Rate.
- Design and Manufacturing Challenges were also critical in project's opportunity for success
 - Choosing Mechanical Grip Design over non-metal/adhesive-based Design
 - Routing Wire to Electrodes repeatedly & reliably
 - Refining Electrofusion Process (Volts/Current/Time Recipe)



Accomplishments and Progress

- Adhesive Design would allow “All-Composite” Design



- But this showed poor bonding at PE surfaces
 - Tests gave 1/3 bond strength needed (>1,100psi needed).
 - Multiple adhesives tested
 - Multiple surface preps tested
 - Consistent inadequate results

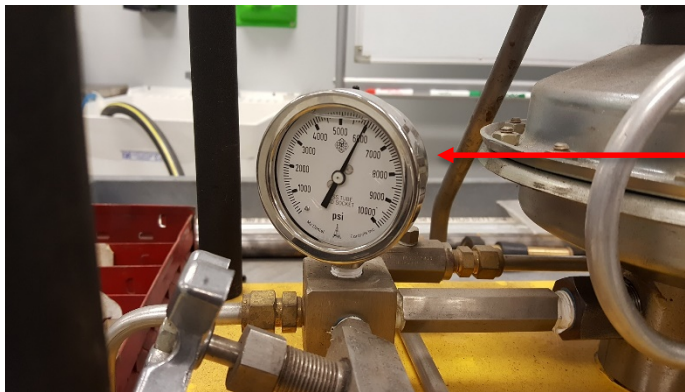


Accomplishments and Progress

- Choosing Mechanical Grip Design over non-metal/ adhesive-based Design
 - Higher probability of Commercialization with existing componentry from NOV
 - Eliminates adhesive application/cure errors in field
- Routing Wire to Electrodes repeatedly & reliably
 - Field Installation is Reliable; compatible with off the shelf Electrofusion equipment
 - Coupler design is poised for further cost reductions: able to use more off the shelf components (Slightly Modified EF Couplers)
- Refining Electrofusion Process (Volts/Current/Time Recipe)
 - Finalized on wire material and electrical resistivity most commonly used in off the shelf electrofusion couplers.

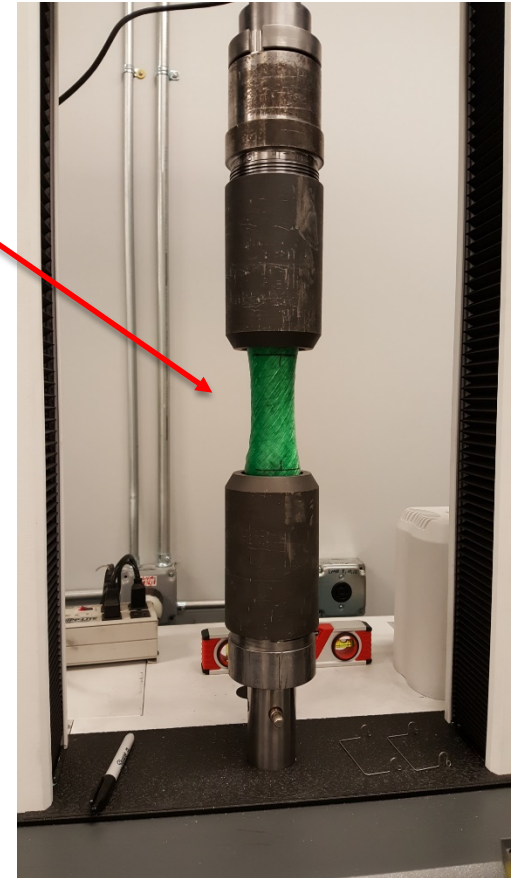
Accomplishments and Progress

- Achieving Leak Rate Target
 - Significant challenge in obtaining adequate seal.
- Achieving Tensile Load Target
 - Multiple iterations to arrive on current design.
- Achieving Burst Pressure Target
 - Burst pressure strength was not a big concern
 - Could not originally achieve Burst test due to leaking.



6,000 psi

11,000 lb



Most of the year was spent tackling simultaneous leak and tensile load challenges. Burst pressure goal was achieved upon resolving leaking challenge.

Pipe Technical Specification

- **Dimensions**

- Pipe Name: FS LP 2" 1,500 (E)
- Pipe ID: 1.89 inches nominal
- Pipe OD: 2.43 inches nominal
- Coupler OD: TBD
- Coupler Length: TBD

- **Nominal Ultimate Specifications (@26°C)**

- Burst Pressure: 406.8 bar (5,900 psi)
- Tensile Load: 10,000 lbs.
- Collapse Pressure: 48.3 bar (700 psi)
- Fatigue Life: 91,250 cycles with a 0.5R ratio for 100 bar

- **Service Specification**

- Fluid: Hydrogen gas
- Pressure: 103.4 bar (1450 psi)
- Maximum Leak Rate: $5 \times 10^{-4} \text{ cm}^3 \text{ H}_2/\text{sec}$
- Service Life: 50 years
- Tensile Load: 4,000 lbs.
- Fatigue Life: 36,500 cycles with a 0.5R ratio

- **Environmental Specifications**

- Operating Temperature: -34°C (-29°F) to 60°C (140°F)

- **Installation Specifications:**

- *Electrofusion Power Supply*
- Voltage: 110 to 120 VAC 60 Hz
- Current: 20 A maximum
- Electrofusion cycle time: TBD

Responses to Previous Year Reviewers' Comments

Project not reviewed last year.

Collaborations

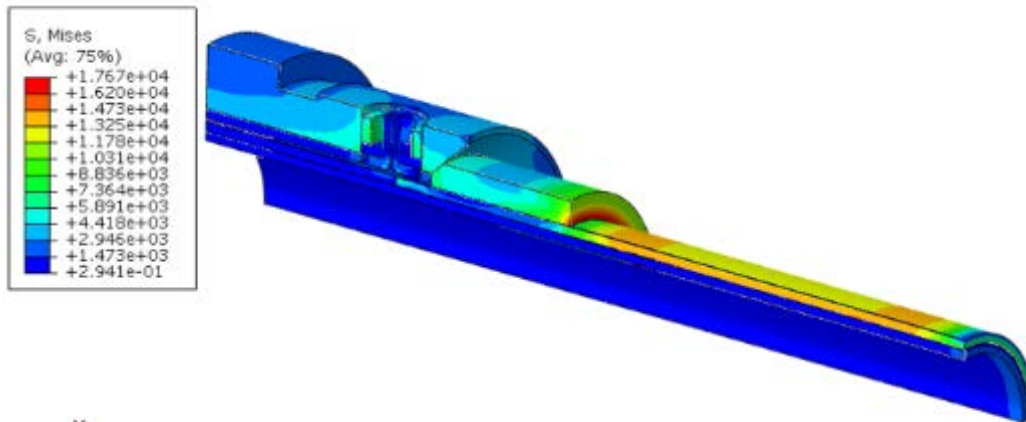
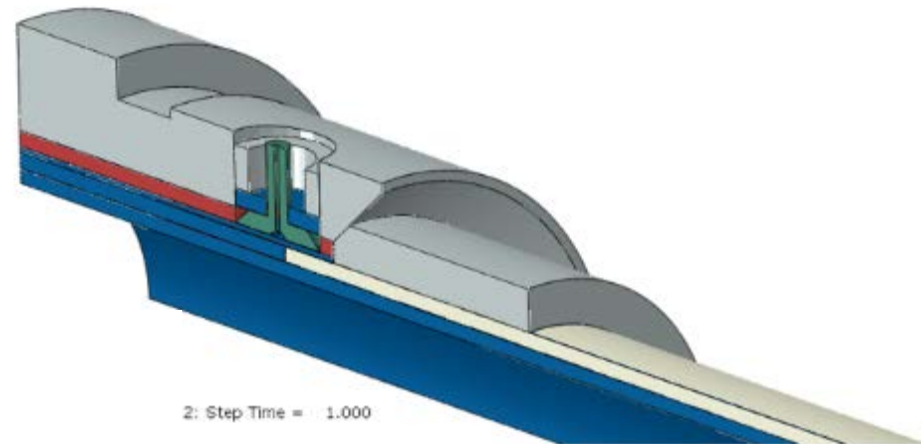
Partner	Relationship	Type	Extent of collaboration
SRNL	Sub – Design Support and Testing	Federal Laboratory	High
NOV	Sub – Pipe Supplier and End User	Industry	High

- SNRL & NOV have both been integrally involved partners in the design since the project's beginning. They have both participated in periodic group telecons and have been at disposal on a daily basis when needed.
- SRNL has been an invaluable influence on the program and design. Their support has identified technical and programmatic risks we may have likely missed. Communication is easy and their test results are thorough.
- NOV has also been invaluable with supply of coupler components for modification and pipe sections for testing. Furthermore, they offer insight into practical and effective means of field installation. Without this perspective, the design would not be robust or ready for use in the field. Communication has been easy.

Collaborations

Partner	Relationship	Type	Extent of collaboration
Materials Research & Design	Sub – Finite Element Analysis	Industry	Medium

- MR&D is a recent addition to the project to mitigate perceived high risk of fatigue failure.
- Status: Started March 2017.
- **FEA will focus on fatigue performance.**



Remaining Challenges and Barriers

- Complete the design of the electrofusion coupler
 - (90+% Complete)
- Prototypes must meet the requirements outlined in the Milestone table. Fatigue Testing is biggest risk currently.
 - FEA undertaken this quarter to mitigate Fatigue risk.
- Progress coupler from a TRL 3 to TRL 5.

Proposed Future Work 2017 & 2018

- 2017: Manufacture & Test parts for repeatability and to pass Milestones outlined.
 - Test prototypes as design progresses (Burst, Fatigue, Leak per previous Approach Milestone Table)
 - 2017 Q3 Fatigue and Leak Rate tests are “key” Milestones
- 2018: Finalized Design Review, Creep & Fatigue to Failure Tests.
 - Proof-test prototypes (creep & fatigue to failure) will further prove design.
 - Finalize in-field machining design and process

Any proposed future work is subject to change based on funding levels.

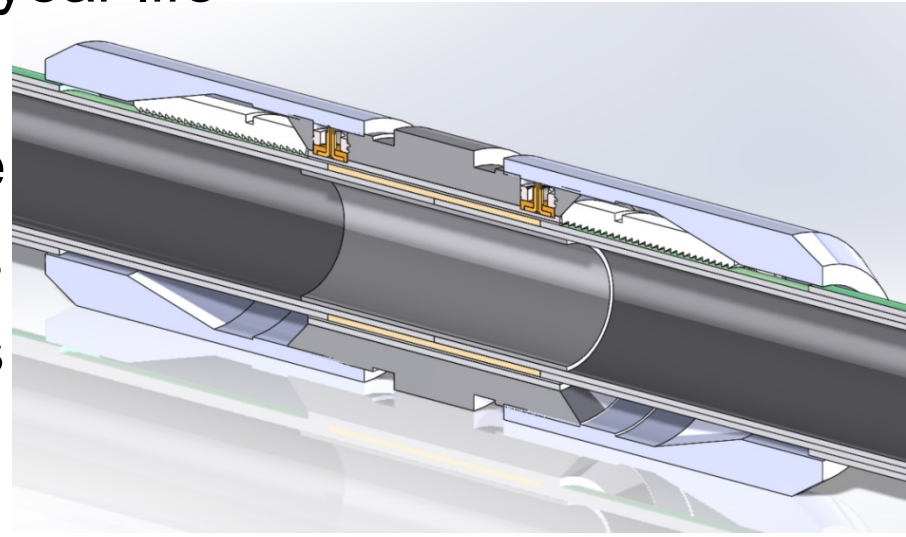
Ongoing Risk Analysis and periodic meetings with subs will mitigate risk of project failure. The overarching theme in face of critical decisions is: ensure a robust design that can be commercialized (low cost critical).

Technology Transfer Activities

- Automated Dynamics will further develop relationships for commercialization by the end of Year 2. In Year 3 of the project, the team envisions engaging the partners as advisors for the commercialization of the coupler.
- Partners include material suppliers, end-users, and of course, pipe manufacturers who will help qualify the couplers and associated pipe.
- The strategy for protecting the developed IP will begin with all investigators agreeing to monitor the research and contact the appropriate office when such property has been discovered.

Summary

- EF coupler designed for 50 year life
- Service rating of 100 bar
- Leak rate $<0.5\%$ of flow rate
- On track to meet Milestones
- Scalable to larger diameters



**Individual technical challenges (Go/No-Go's) have been achieved:
Tensile Load, Burst Pressure, Leak Rate.
Remaining challenge: Pass individual tests in series and after
dynamically loaded in fatigue.**