Project ID: **mn015**

Continuous Fiber Composite Electrofusion Coupler

David Hauber – P.I. **Brett Kimball** - Presenter

Automated Dynamics, Part of Trelleborg Group

June 14, 2018

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Overview

- **Timeline and Budget**
  - Project Start Date: 12/1/15
  - Project End Date: 4/1/19
  - Total Project Budget: $1,876,865
    - Total Recipient Share: $376,865
    - Total Federal Share: $1,500,000
    - SRNL Share: $525,000
    - Total DOE Funds Spent*: $885,369
      - *As of 03/31/2018

- **Barriers addressed**
  - D: High As-Installed Cost of Pipelines

- **Partners**
  - *DOE*: Project Sponsor
  - *SRNL*: Project Partner
  - *NOV*: Project Partner
  - *Automated Dynamics, part of Trelleborg Group*: Project Lead

Technical Targets	
Transmission Pressure (bar)	100
H_2 Leakage	< 5x10e-4 cm3 H_2/s
Lifetime (years)	50

Relevance

- **3-Year Project Objective**: Design and Validate pipe coupler for FRP Hydrogen Delivery for **yet to be installed pipes**, without use of elastomeric seals

  ASME B31.12 Code Committee (Hydrogen Piping and Pipelines) concerned that existing seal [PROBLEM THAT NEEDS IMPROVEMENT ON NEXT DESIGN] components (i.e. o-rings or other elastomeric seals) will require maintenance in underground service.

  - 350bar Burst, <0.5% flow leak rate, 50 year life

- **Current Year Objective, April 2017 – April 2018**
  - Pass Milestone for Fatigue Failure Criteria (fail pipe before coupler)

- **Past Year's Impact**
  - Advanced Technology to allow low-maintenance composite H_2 pipelines.

Approach

Enable FRP for Hydrogen Delivery

- Problem with existing steel pipe solution is corrosion
- Problem with existing o-ring based seals on FRP is o-ring maintenance
- **Develop Pipe Coupling Technology through unique combination of existing market solutions**
  - Metal end fittings for FRP ~~with o-rings~~
  - Electrofusion Couplers for ~~low-pressure~~ pipe
  - Thermoset FRP with HDPE liner
- Non-standard pipe for EF requires custom EF couplers
- Builds from past DOE funded Project to Savanah River National Lab, 2013

Go/No-Go Criteria 2017	Result 2017
Leak Rate < 5x10e-4 cm^3 He/s	**PASSED**: 10e-6 cm^3 He/s
Burst Pressure > 350bar	**PASSED:**
Fatigue: Pipe bursts before coupler bursts	Not Passed, revisiting in 2018

Approach

Milestones and Percent Completion

Go/No-Go (Dec 2017)	**12/31/17**	**Prototype must show 1) leakage rate less than 5 x 10^{-4} cm^3 He/s, 2) hydrostatic standards set by ASTM D2992 at 1,500psi (~100bar), an R ratio of 0.1 and pipe must burst before joint bursts.**	**Fatigue Criteria Not Yet Complete (50%)**
Interim Design Review	3/31/18	Continue Manufacturing Prototypes and Conduct Interim design review	50%
Conduct Fatigue Test	6/30/18	Test Coupler by hydrostatic standards set by ASTM D2992 at 1,500psi (~100bar), an R ratio of 0.1. Pipe must burst before joint bursts.	50%
Fatigue to Failure, Burst, Leak, Tests	9/30/18	Fatigue test at R=0.1, 1,500psi, run on coupler and pipe. Pipe must fail before coupler. Burst Test must pass 350bar (5,076psi). Leakage rate less than 5 x 10-4 cm3 H_2/s,	50%
Create Manufacturing and Quality Plan	9/30/18	Complete Manufacturing and Quality Plan.	50%
Final Design Report	12/30/18	Write final report	25%

Accomplishments: Redesign Underway

- Fundamental Problem
  - Weakening of small amount of plastic acting as leak barrier, during fatigue test.
- Solution
  - Increase volume (cylinder thickness) of plastic acting as sealing mechanism.
  - Increase redundant sealing area.
  - Remove non-essential materials from design that cause potential failures.

Accomplishments: Redesign Underway

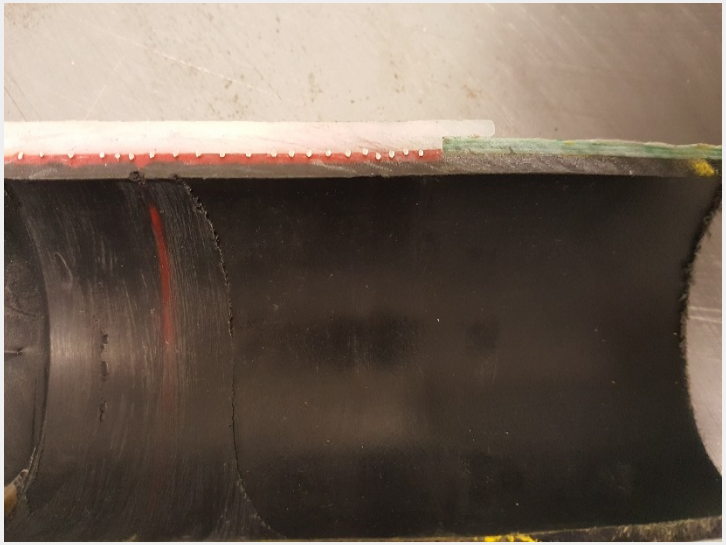
- Previous design did not pass fatigue test
  - 2 Bond Areas: outside and inside of wire
  - Leak path through porous media
  - Crack in centerline allows leak path potential through porous media
- New Design
  - 1 Bond Area: Centerline may crack; monolithic plastic is redundant sealing mechanism

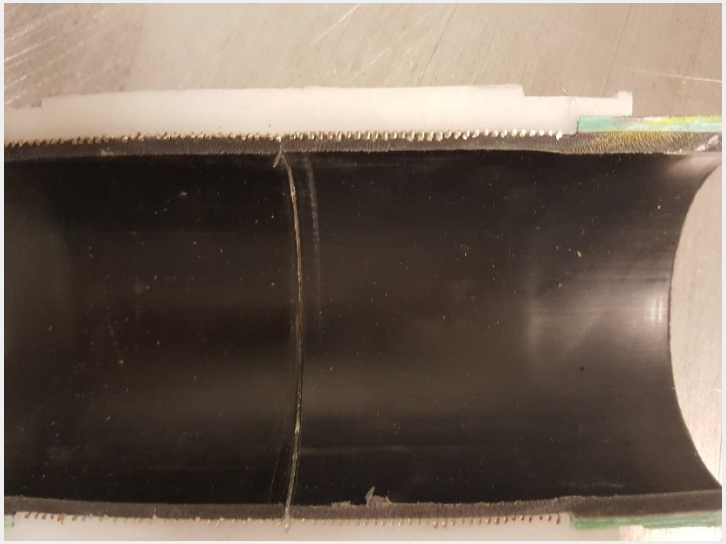
Accomplishments: Redesign Underway

Previous Design	Current Design	Improvements
2 bond zones	1 bond zone	• ½ the area for potential leaks • ½ the area to need heat transfer
4 materials: Pipe Liner, Metal Wire, **wire coating,** outer plastic	3 materials: Pipe Liner, Wire, Outer Plastic	• No need for intermediate layers (wire coating above and below wire) to bond • More consistent through fewer manufacturing steps • Fewer voids due to fewer dissimilar material joining
"Thick" bond zone: Wire Ø+ 2x PE Coating thickness	"Thinner" bond zone: Wire Ø only	• Less shear strain • Less thru-thickness variation

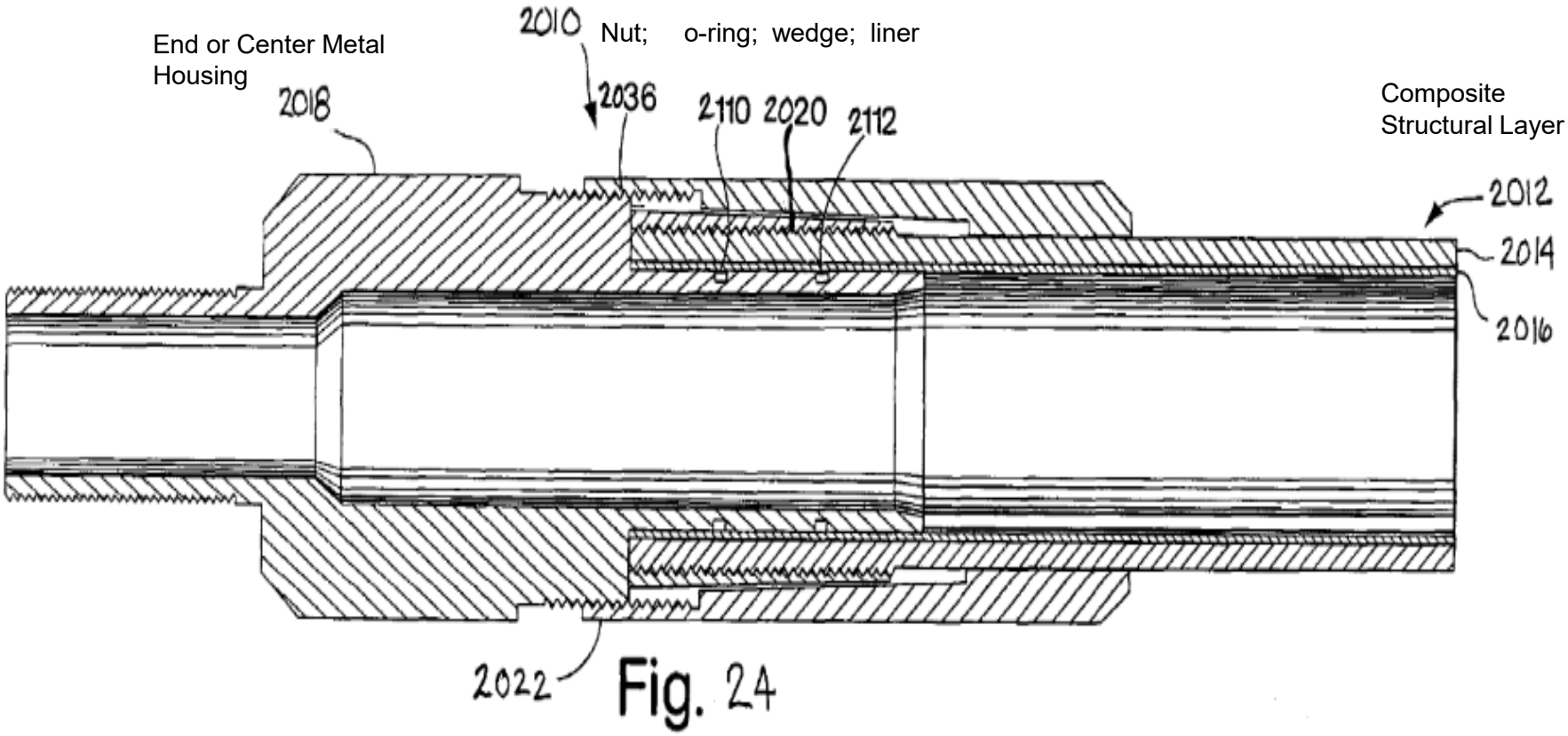
Accomplishments: Redesign Sealing Mechanism

Previous Design	Current Design

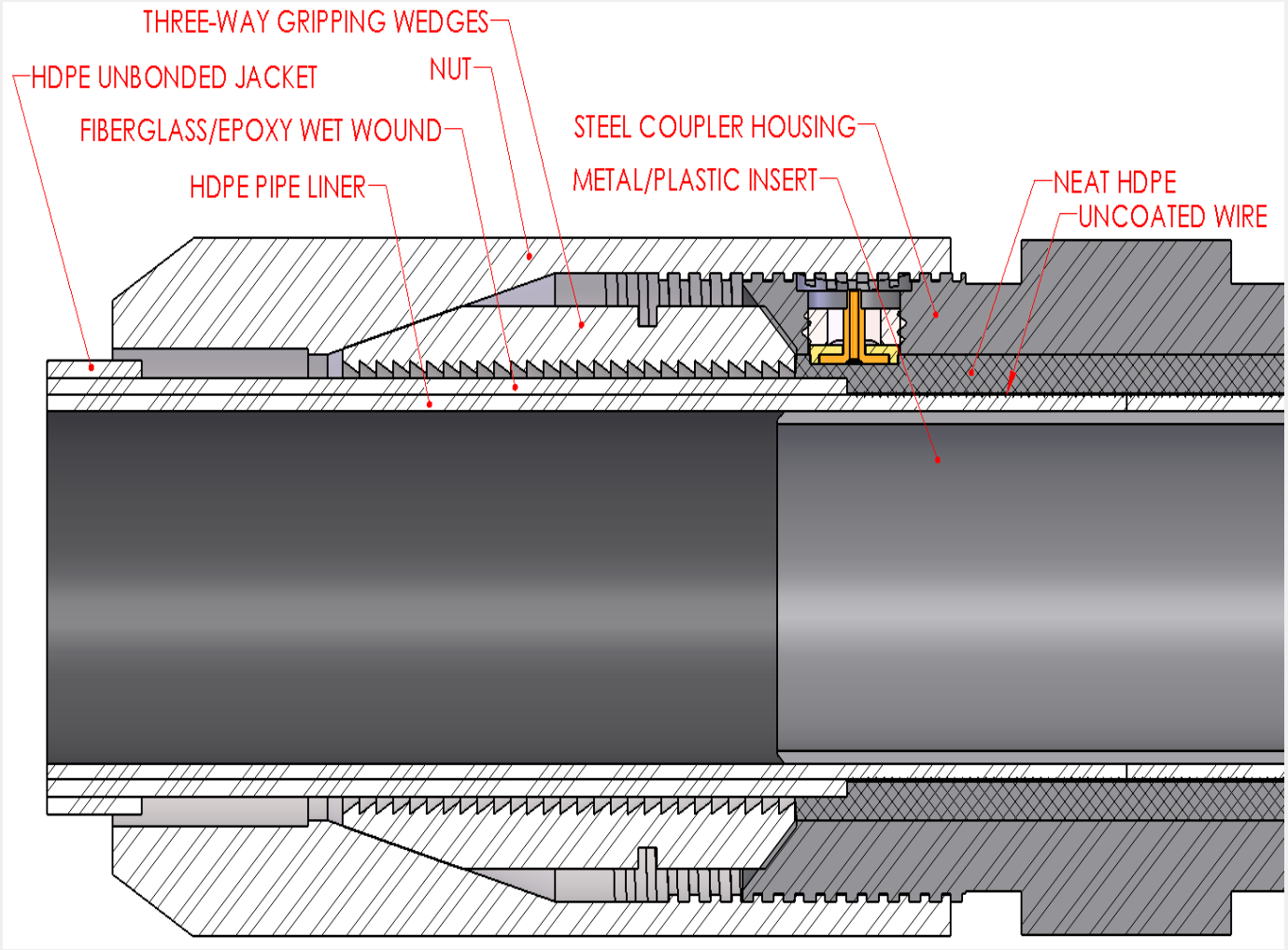




Accomplishments: O-Ring Based Design for Reference



Accomplishments: New Design



Progress: Response to last year's comments

- **How does this address previously installed pipe?**
  - The goal of this project is for future pipe installs. But for already installed pipe, each coupler is cut out and a section with two EF couplers is installed.
- **How does this work in the field? Not at all clear how coupler will be installed.**
  - In field, pipe is cut and machined with automated equipment designed specifically for this. This is well established technology. Install coupler components on each end of pipe; join; electrofuse; assemble mechanical components; wait to cool; finish.
- **How can you prove 50 year lifespan?**
  - Fatigue stress values correlate with # of cycles (Life prediction)

Credit: NOV

Credit: H&S Tools

Progress: Testing

Fatigue Test

- ASTM D2992
- Prototype Fatigue Criteria: < 5x10e-4 cm^3 **He**/s
- Fatigue to Failure Criteria: < 5x10e-4 cm^3 $\mathbf{H_2}$/s
- Room Temperature
- Min/Max pressure 150 / 1,500psi (R Value = 0.1)
- Varying R and testing produces fatigue data for extrapolation info Millions+ cycles

Collaborations

SRNL™ SAVANNAH RIVER NATIONAL LABORATORY	Project Partner Test Expertise Past Coupler Expertise ASME Code Expertise
NOV Fiber Glass Systems	Project Partner Commercialization Value In-field Expertise
AUTOMATED DYNAMICS® PART OF TRELLEBORG GROUP	Project Lead Composite Design and Automated Manufacturing

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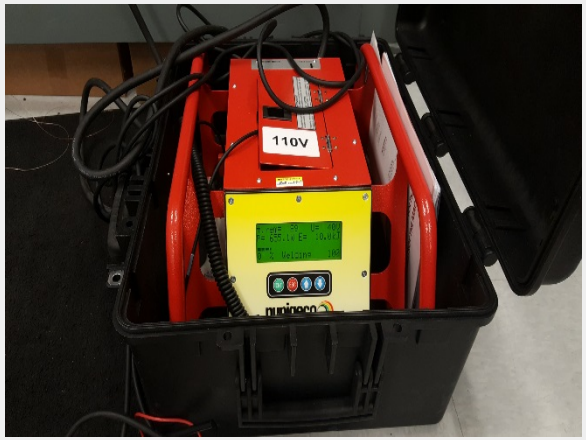
Challenges & Barriers: Pass Fatigue Test Criteria

- Failure criteria in test: pipe fails before coupler. Expected >10K cycles.
  - Pipe failure means any leak causing steady state pressure drop
  - Evidence in test is stepwise change in pressure driven into system

- Passing this test is critical in achieving 50 year service life

Challenges & Barriers: Pass Fatigue Test Milestone

- Design Refinements
- Optimize wire spacing
  - Larger spacing between wires is better for more plastic bond area; worse for consistent heat transfer and fusion.
- Electrofusion cycle
  - Use off the shelf electrofusion machine; spec wire (i.e. resistivity) as needed
  - Melt surface, not entire liner
- Manufacturing
- Consistency in wire embedment into HDPE
- Long-term
  - EF plastic/wire portion is molded as typical EF couplers are



Proposed Future Work: FY 2018

- **April**
  - Refine process, measure and record fusion data, analyze cross sections
- **May**
  - Send first prototype for fatigue test
- **Q2 Remainder**
  - Successful Fatigue tests take several weeks
  - Adapt design if needed
- **Q3/Q4**
  - Validate new design for Burst and Leak Rate
  - Test as many samples possible for statistical confidence

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

Proposed Future Work: Past FY18

- **Commercialization**
  - Current Project: TRL 3 to TRL 5
  - Future: TRL 5 to TRL 9
    - Buy-in from fueling station(s) and pipe supplier(s)
    - Requires detailed cost analysis of FRP compared to steel (outside project scope)
- **Cost Evaluation**
  - Overall cost of FRP solution is driven by cost of pipe, proprietary to NOV. Outside scope of this project.
  - Cost of coupler, in volume, is negligible compared to pipe, given lengths at hand.
  - Coupler will cost <$300 Total: <$20 for custom molded EF Coupler component, <$250 for machined components.
  - Equipment needed for pipe prep and electrofusion: $20K

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

Technology Transfer Activities

- Patent Application on Coupler submitted 2017
- Future commercialization plans include proposing idea to pipe suppliers and re-fueling stations.

Summary

- Challenge is rigorous to seal against fatigue stress.
- Remaining goal: pass sequential fatigue and leak rate tests. (Achieved Targets on Leak rate in isolation).
- Commercialization and cost of FRP H2 lines is largely a function of FRP cost. Coupler is a necessary detail.