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Durable Low-Cost Pressure Vessels for Bulk Hydrogen Storage

DE-FE-0032002

Project Duration: 3/1/2021-2/28/2023
Project Budget: DOE $500,000, Cost Share $193,176; **Total $693,176**

WIRETOUGH CYLINDERS, LLC
AND
SIEMENS CORPORATION
CORPORATE TECHNOLOGY CENTER

Ashok Saxena, PhD
(asaxena@wiretough.com)

and

Santosh Narasimhachary, PhD

Project Review:
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Presentation Outline

- Project Objectives
- Background
- Technical Approach
- Potential Project Benefits
- Results to-date
- Tasks, Deliverables and Status
- Conclusions
- Acknowledgements

PROJECT OBJECTIVES

- To develop and build a prototype of a Type-IIs, low-cost and durable pressure vessel with a capacity between 1,500 to 2,000 liters to safely store 50 to 60 KG hydrogen at 450 to 500 bar pressure for use in fossil-fuel power plants.
- The design will fully comply with ASME-BPVC Section VIII-Division 3 requirements including Article KD-10 for service in hydrogen.
- The vessel will be capable of withstanding one full pressure cycle per day ranging from the maximum operating pressure of 450 to 500 bar to ambient pressure for 20+ years of service.
- The design life will be determined as per ASME Section VIII-Division 3 code.
- The vessel will be modular in design and can be configured based on the capacity needs of the power generating station.

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BACKGROUND

- Capital intensive equipment in fossil-fuel electricity generating plants are required to shut-down frequently and ramp-up rapidly to manage variable energy demands within a single day.
- Damage to plant equipment/components due to such thermal cycling causes unplanned outages that can be expensive and results in inefficient energy conversion.
- Economical, effective, and safe solutions for energy storage are needed but pose several technological challenges.
- The solution pursued in this project is to store energy in the form of high-pressure hydrogen
- One KG of hydrogen contains the heat equivalent of 39 kWh of electricity and assuming an efficiency of 60% for fuel cells, it will yield back an estimated 23.4 kWh of electricity.
- Alternatively, hydrogen can be mixed with other gaseous combustible fuels in gas turbines for cleaner burning.

TECHNICAL APPROACH

- WireTough's approach lowers energy storage costs by addressing the need for bulk, economical and safe ground storage of hydrogen
- A 1720-liter cylinder with an OD 610 mm (24") and a length of 7.6 m (24.7') operating at a hydrogen pressure of 50 MPa can store approximately 52 KG of hydrogen and potentially deliver 1.2 MWh of electricity via fuel-cells.

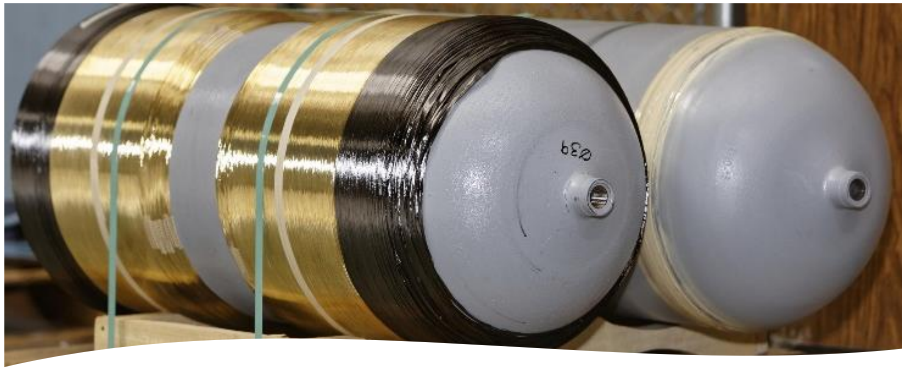
Technical Approach

- WireTough's technology uses a layered, very high strength steel-wire wrap under tension to significantly lower wall-thickness requirements of a Type 1 cylinder.

- The pressure vessel can withstand deep pressure cycles and is built to account for hydrogen assisted crack growth and can be certified for 20+ years of safe-design life

- An *optional* manufacturing process that uses high-pressure hydrostatic pressurization, or autofrettage, after winding will be used to enhance fatigue life.

- Steel-wire wraps utilize readily-available, less-expensive, ultra-high strength steel wires compared to materials such as E-glass and carbon fibers, used commonly in Type 2 composite cylinders



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WireTough Cylinders for CNG have been on the market and used for over 10 years

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Potential Project Benefits

A new product for bulk storage of hydrogen will be developed and will be ready for commercialization. The solution will be suitable for excess energy storage during peak-production/low-demand periods in

- Fossil-fuel power plants
- Nuclear energy generation plants
- Renewable solar/wind energy generation plants
- Ground storage of hydrogen in fueling stations

Potential Project Benefits (contd.)

The pressure vessel will have the following key *differentiating characteristics*:

- Ability to withstand deep pressure cycles daily ranging from the maximum operating pressure to ambient with a design life of 20+ years or longer,
- better safety and durability against fire hazards and ballistic projectile strikes,
- better scalability in terms of numbers due to use of low-cost commercially available materials in the construction of the vessel,
- versatility in operation due to its modular construction with a small foot-print,
- low cost and a capacity that can be tailored to the needs of the power station.

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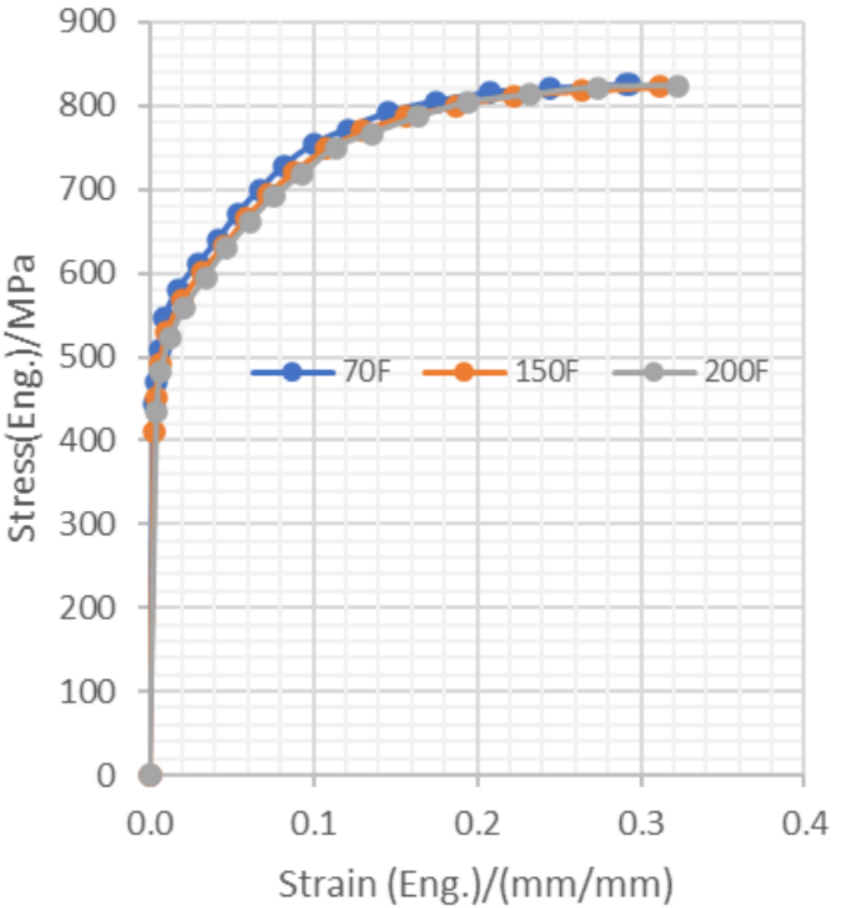
Results to-date

- Liner Diameter: 610 mm (24 in)
- Liner wall thickness: 22.9 mm (0.9 in)
- Liner Weight: 2960 KG (6,512 lbs.)
- Water capacity of the vessel 1715 L
- Number of wire layers in the wrap: 48 (wrap thickness = 18 mm (0.708 in)
- Weight of the wire wrap: 1552 KG (3414 lbs.)
- Total vessel weight: 4512 KG (9,926 lbs.)
- Vessel weight per KG of hydrogen stored: 86.7 KG
- Maximum Operating Pressure: 50 MPa (7,250 psi)
- Estimated autofrettage pressure: 97 MPa (14,070 psi)
- Weight of H_2 stored at 50 MPa pressure: 52 KG (114.4 lbs.)
- Maximum Allowable working pressure: 55 MPa (8,000 psi)
- Estimated ASME design Life: > 20 years based on an initial flaw that is 1 mm deep and 5 mm long on the inside surface of the vessel.

Liner Finite Element Analysis Results

- Liner OD = 610 mm; Wall thickness =22.9 mm, Length = 7.6 m

Internal Pressure MPa	Max Von Mises Stress, MPa	Von Mises Strain
50	629	0.0459
60	754	0.118
66	755	0.120
At yield: 35.8	482.6	0.00432
At Burst: 71.8	827	



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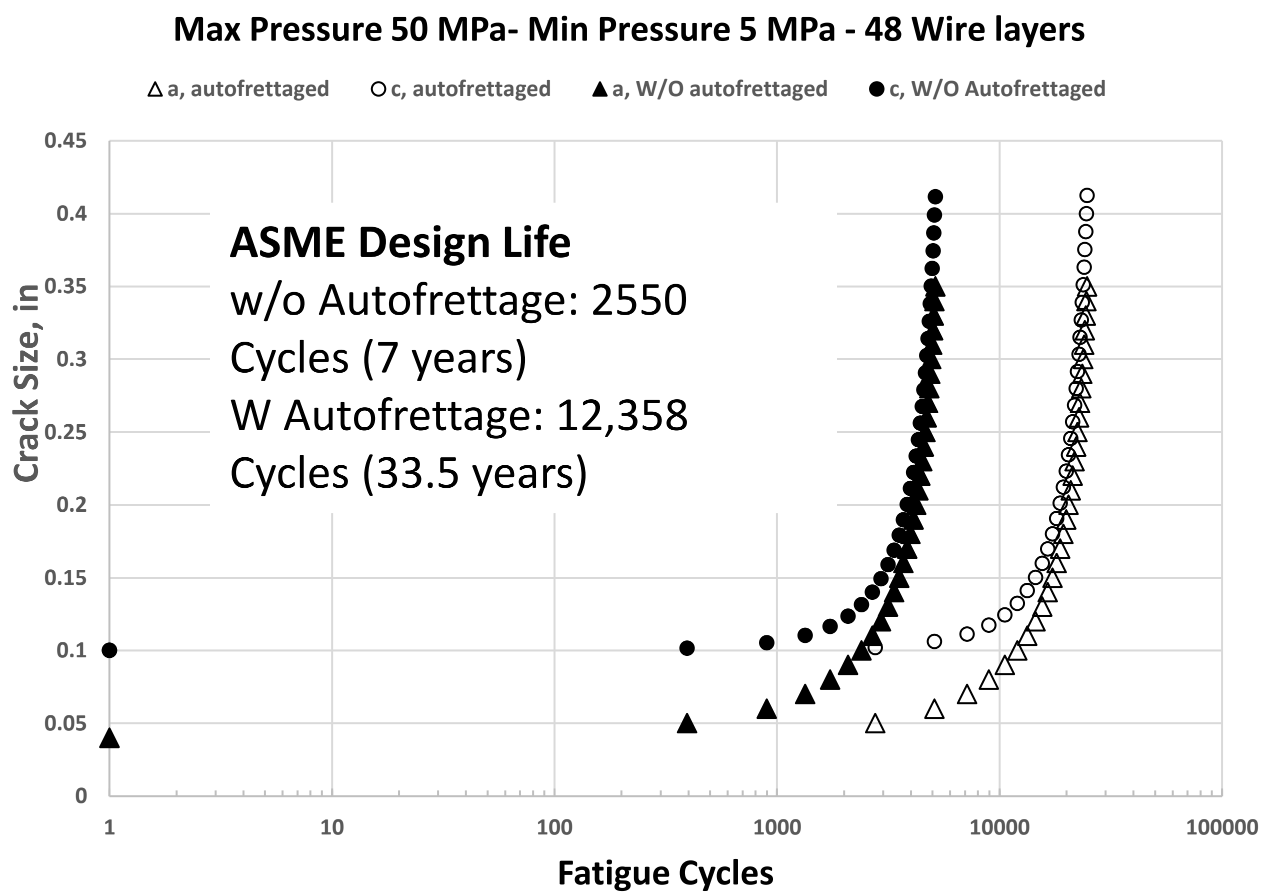
Preliminary Fatigue Crack Growth Analysis



TASKS , DELIVERABLES & STATUS

Task Description	Schedule
Task 1.0 – Project Management and Planning (WTC)	
• Project management plan	Continuing
• Technology maturation plan	Completed
Task 2- Design Optimization and Selection of Preliminary Design (WTC)	
• Prepare user design specification	Completed
• Preliminary cylinder design	Completed
Task 3 –Design Analyses (Siemens/WTC/3rd Party Consulting Company)	
• Analysis of the liner	Completed
• Analysis and assessment of the wire wrapped vessel	5th Q
• Fatigue crack growth analysis during service loading	6th Q
Task 4 – Liner Selection and Manufacture (WTC/Vendor)	6th Q
Task 5 – Building a Prototype of the Cylinder (WTC)	
• Wire wrapping and inspection	7th Q
• Autofrettage and final finishing	7th Q
• Cylinder cost analysis	7th Q
Task 6. 0 – Manufacturing Design Report and ASME Certification (3rd Party Consulting Company)	6th Q
Task 7.0 – Task 7.0 – Technoeconomic Assessment (TEA)	8th Q
Contract Final Report	8th Q

CONCLUSIONS

- WireTough Cylinders with help from Siemens Technology Center is engaged in developing a cost-effective and safe solution for storing hydrogen at high pressures

- Onsite storage of gaseous hydrogen at high pressures is a ubiquitous need for a hydrogen economy:
  - Fossil energy, nuclear energy, and renewable energy power plants
  - Fueling stations on ground
  - In the form of fuel tanks for hydrogen powered vehicles.
- In the first year of the program, WireTough has completed a preliminary design of the vessel that meets the identified design targets and is poised to conduct design verification
- In the second year, prototypes of the vessel will be produced and will be subject to certification by ASME under Section VIII Division 3 design Codes
- We expect that at the end of the program, we will have product ready to be launched commercially

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THANK YOU

Q & A