Institute for ADVANCED
Composites Manufacturing
INNOVATION

700 Bar COPV Manufacturing - IACMI 24 August 2016

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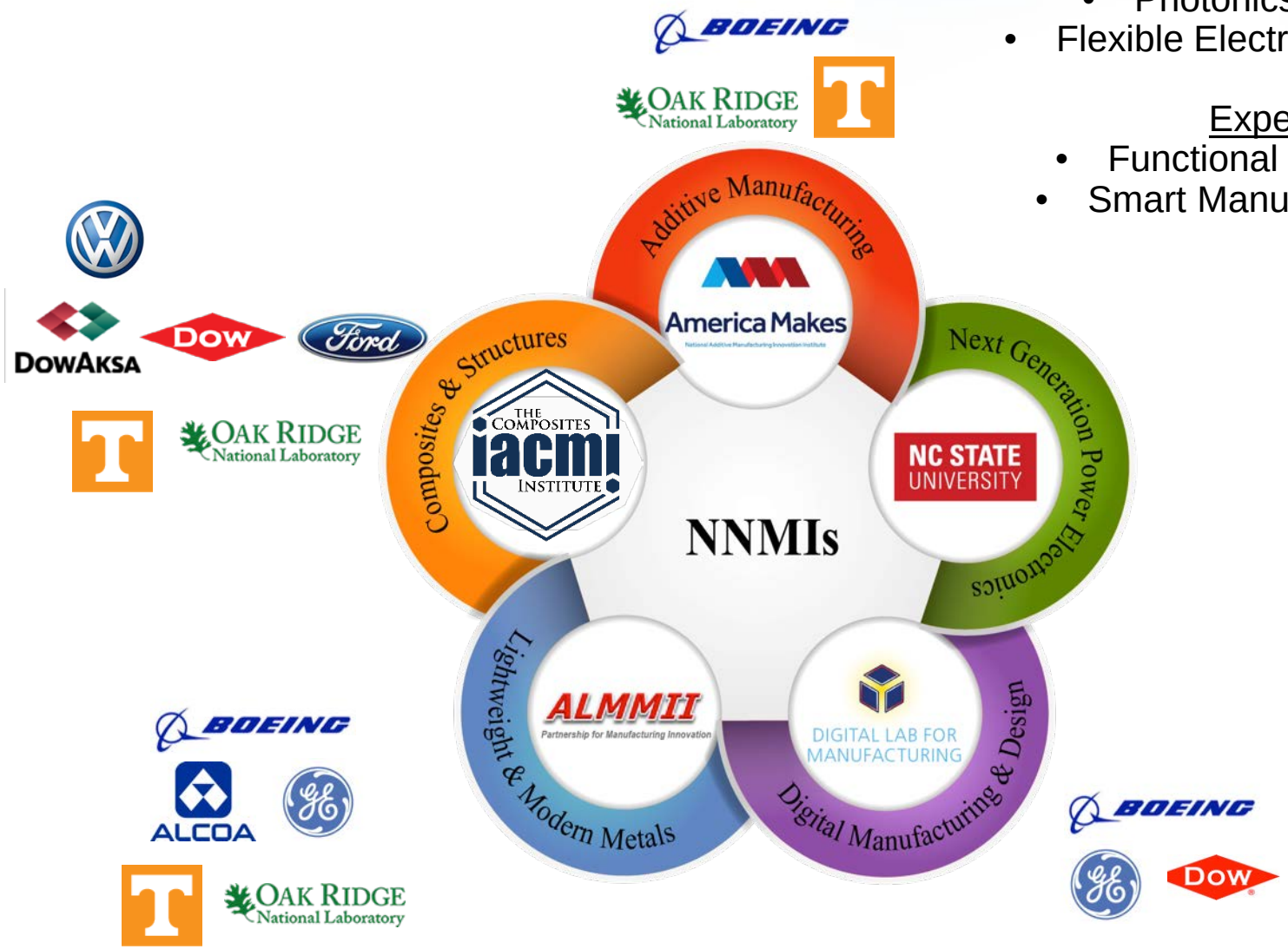
IACMI CGS Director

THE COMPOSITES iacmi INSTITUTE

NNMI Network



Plus:

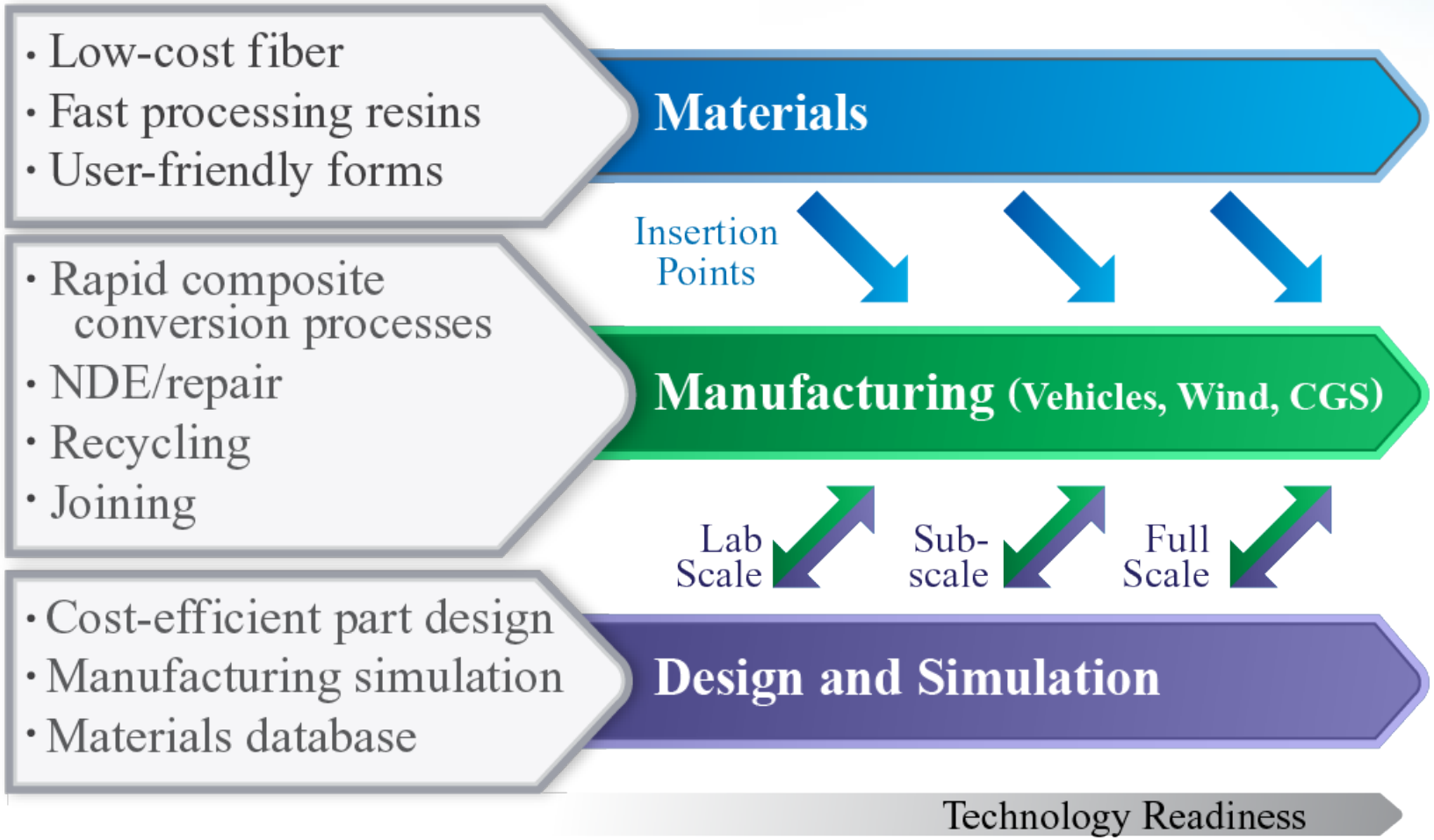
- Photonics (NY) (DOD)
- Flexible Electronics (CA) (DOD)

Expected:

- Functional Fabrics (DOD)
- Smart Manufacturing (DOE)

Shared RD&D facilities will support industry

An integrated approach is required



Economic Development Council
A Platform for State Economic Collaboration

Each state deploys **hundreds of millions of dollars annually** to create jobs and investment through:

- Business Services/ Incentives
- Venture Funds
- Workforce Training
- Innovation Incubation

DOE Compressed Gas Storage (CGS) Tank Targets

Reduce the cost of a type IV hydrogen storage tank by 30% (2018) and 50% (2024) with a capacity of 500,000 units/year

SOA

Fabrication method: Filament winding, a mature industry, 40+ years

IACMI - Possible Approaches

Lower cost materials

Faster, cheaper fabrication

Reduced factor of safety through SHM (maintain safety in service)

Novel designs, reduced certification costs

*Composites World January 12, 2015

Project Approach and Accomplishments

Approach: Improve individual constituents of **materials**, **design** and **operating conditions** to synergistically enhance tank performance and reduce cost.

700 bar compressed tanks can meet the DOE targets except:
cost, volumetric capacity, and weight

OPTIONS

Material Selection	***Tank Design and Manufacturing***	***Operating Conditions***
Reduce material cost	Better material use	Reduce pressure
Increase performance	Improve efficiency	Increase density

PROJECT SCOPE

Alternative low cost resin **Resin with nano-particles**	**Optimize fiber pattern** **Mix different fiber types**	**Cold gas storage concept**

Technical Gaps and Barriers
CGS IACMI Roadmap

- Designs and certification of conformable tanks
- Permeability of hydrogen molecules; need new liners
- Limited experience with thermoplastics; questionable energy savings in moving to TPs
- Method to screen and predict performance without testing full-scale tanks (reduce screen cost by 50%)
- Reduce fiber deposition cycle times (by 30%)
- High tensile strength fiber required; need for increased toughness
- Predictive models for design, scaling, and conformable geometries
- Cost model for high-volume manufacturing

R&D Activities
CGS IACMI Roadmap

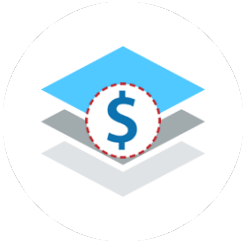
- Develop a toughened system and method to assess trade-offs between higher tensile-strength and higher of fibers
- Developing new fiber deposition technology which is cost-competitive with current methods
- Evaluate benefits of alternate fiber architecture designs (e.g., braided continuously wound TP UD tape)
- Develop alternate TP materials, screening and testing methods, and validate tank performance
- Develop standards and testing methods for non-standard tanks
- Assess energy savings pathways associated with thermoplastics versus thermosets
- Evaluate/develop open-source predictive models using new or developmental materials

Barriers to Entry

Manufacturing Volume

- Push for H2 economy
- Encourage H2 infrastructure
- Encourage competition

High Material Cost



- Tighten manufacturing variance
- Graded construction

Cost of Product Certification

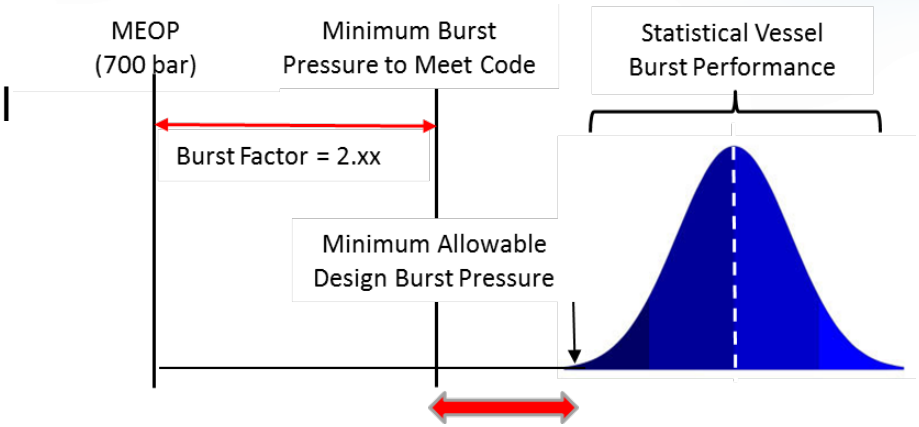
- Revise codes/standards without sacrificing safety
- Incentivize OEMs to share cost

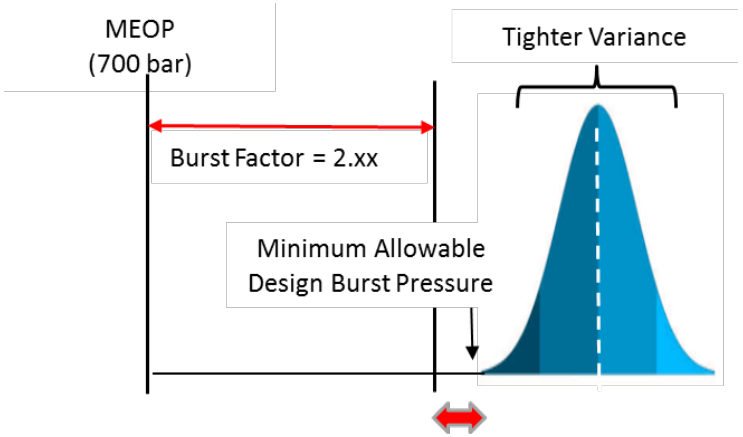
Unclear needs from the market/industry

- Harmonize interface requirements
- What size and volume?

Manufacturing Variance

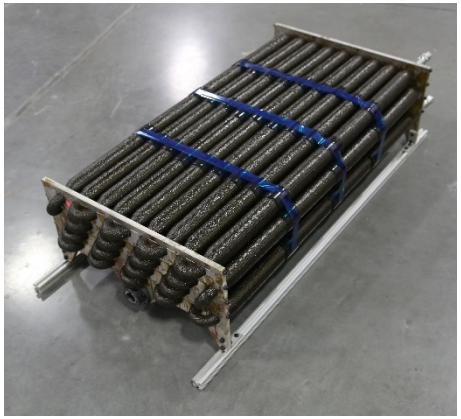
- Trial & error characterization of composite strength in pressure vessel application
- Composite material properties are inseparable from manufacturing variance
- Padded safety factors leads to material cost
- Design allowables need statistical consideration
- Fabrication methods can dictate tighter variance and lower material usage



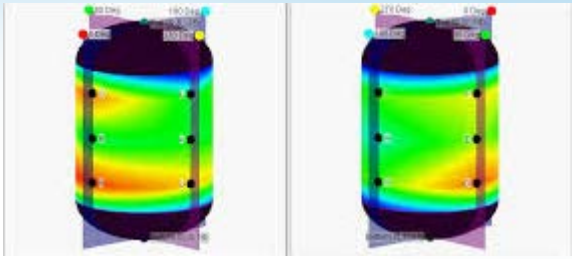


Conformable Tanks

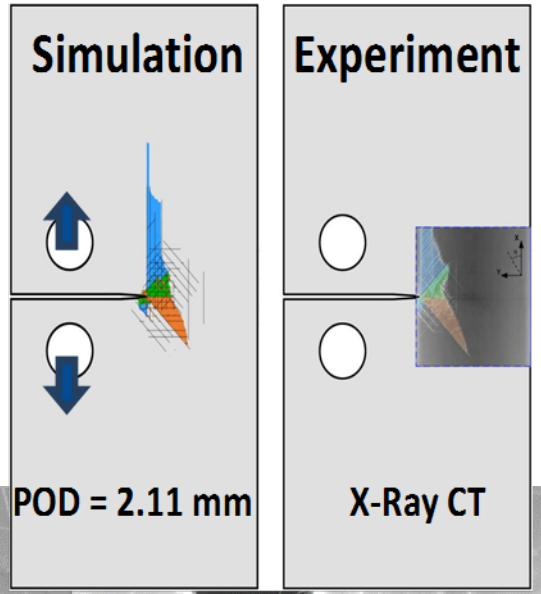
- Several great concepts have been proposed over time
- Challenge in maturing them beyond TRL 3
- Not trivial to realize in 700 bar production ready vessels
- Regulatory standards are not ready for new concepts other than cylindrical vessels

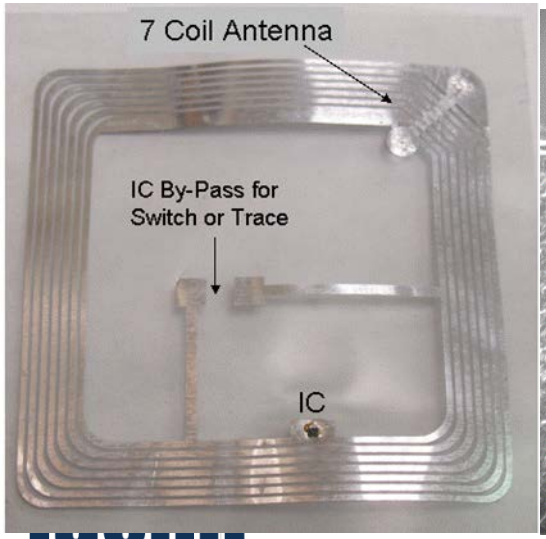


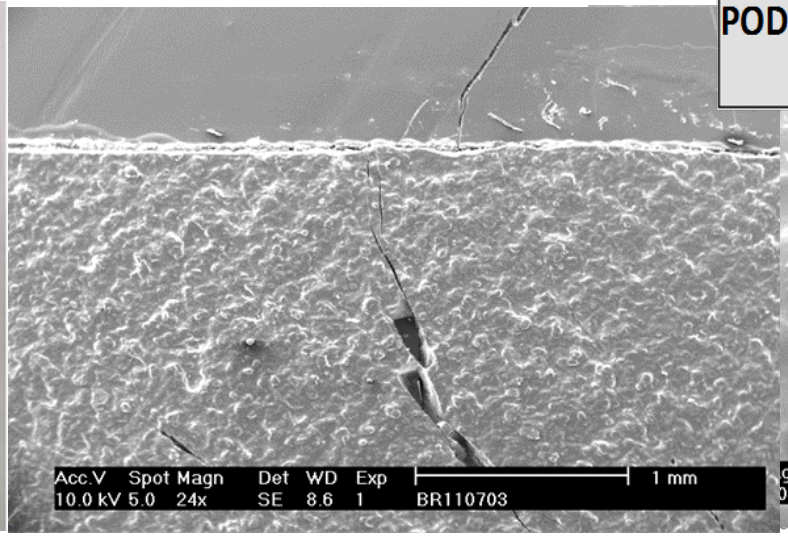
Structural Health Monitoring – Allow Reduced Factor of Safety?

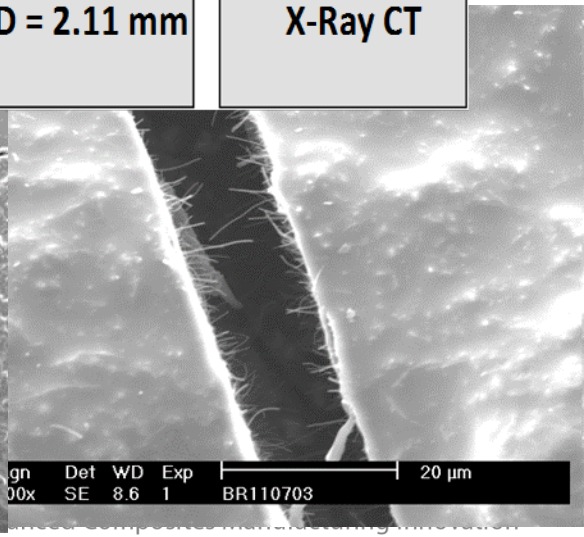


- Optimize design for improved fatigue life, stress rupture and damage tolerance
- Continuous health monitoring to encourage reduced burst factor
- Encourage adoption of cost-effective NDE techniques and life prediction for in-situ health monitoring
- Retire for cause rather than life



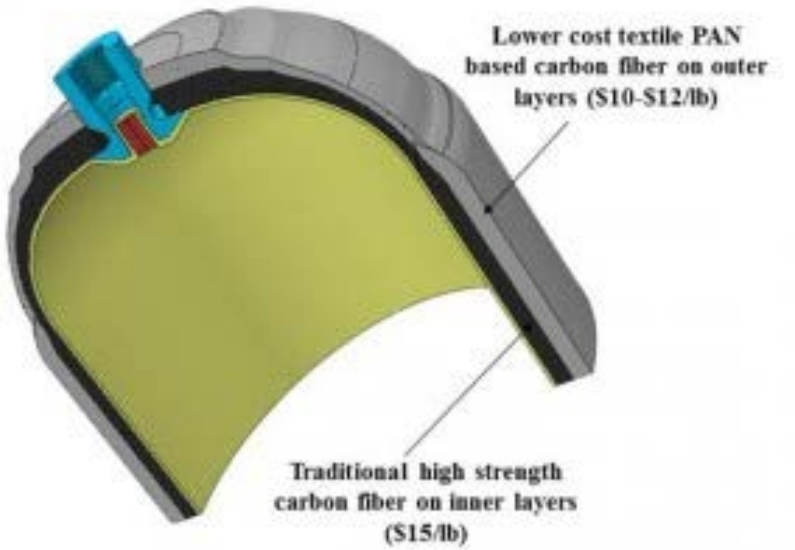






Low Cost Pressure Vessels for Hydrogen Storage Utilizing Low Cost Carbon Fiber

http://www.ctd-materials.com/wordpress/?page_id=101



Example design of 700 bar hydrogen storage vessel using a graded construction

CTD is developing **graded composite tanks** that utilize low-cost carbon fibers, such as those being developed at Oak Ridge National Laboratory (ORNL).

CGS Potential Project Areas

- **High technology readiness level (TRL):** Increase efficiency of filament winding and foster integration of hybrid reinforcements. Improve performance and reduce processing time with new matrix resins.

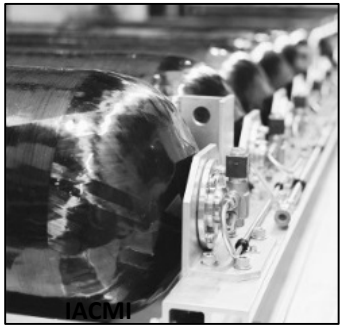
- **Mid TRL**: Dramatically decrease fiber placement time/cost by wrapping with (1) custom braid or (2) winding with thermoplastics. Expected to increase safety and damage tolerance while reducing mass. Application area focus is for CNG currently.

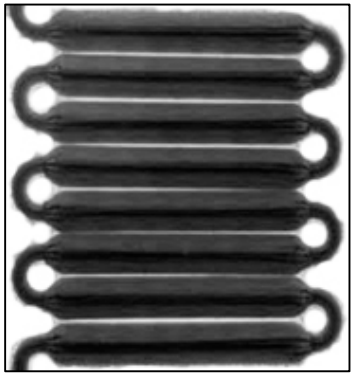
- **Low TRL:** Support manufacture of conformal/novel tank design for automotive market designed to preserve trunk space. Recognize absorption technology could significantly reduce pressure requirements and alter optimal tank design.

IACMI to foster improved safety as well as cost reduction

DuPont Thermoplastic Composite CGS Tank Proposal

- Develop a manufacturing process with IACMI partners to significantly reduce cycle time and increase safety performance and damage tolerance of compressed gas storage (CGS) tanks utilizing:
  - *Low cost heavy carbon fiber tows (>12k)*
  - *Novel fiber placement technologies, graded tension*
  - *Tough Thermoplastic*
- Demonstrate an integrated platform technology for manufacturing tanks for compressed gas and hydrogen storage in the forms of conventional tanks, conformable tanks, and adsorbed natural gas tanks
  - *Type IV tanks with a polymeric liner*
  - *Liner-less Type V*
- Departs significantly from epoxy-based conventional filament winding





Roles of the Integrated Project Team

Flame-retardant thermoplastic resins; impregnated continuous carbon fiber composites

Primary IACMI project partner; material characterization and testing

Prototyping and testing capabilities; scouting trials

Automated fiber placement technologies

CGS tank OEM; tank specifications and design

Advantages of Proposed Process

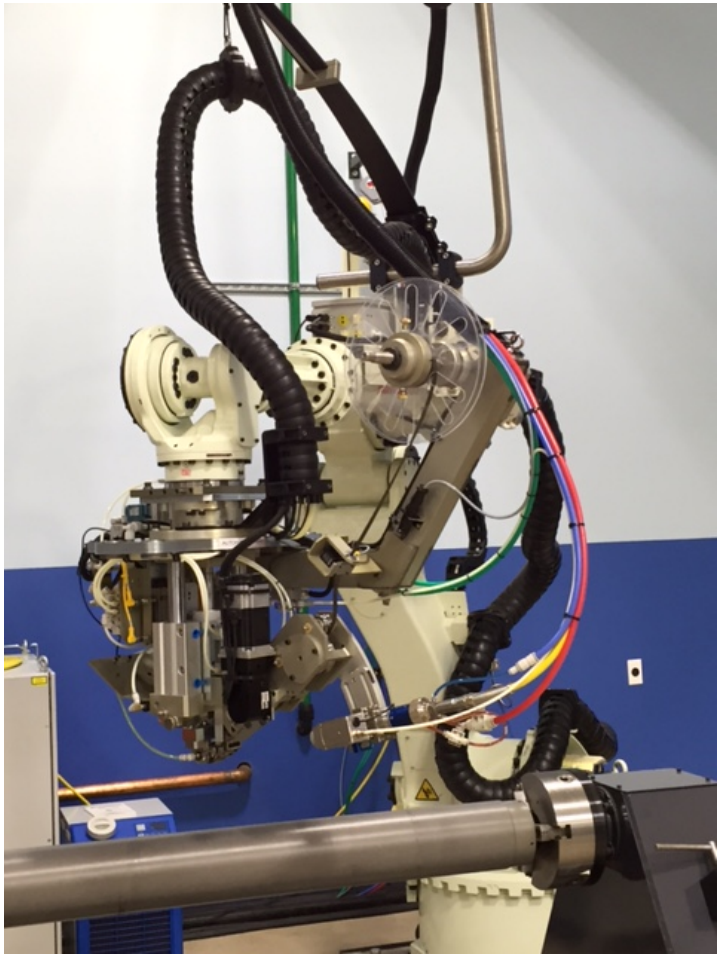
- Thermoplastic Resins
  - *Intrinsically tougher than thermosets*
- Cost Reduction
  - *Heavy carbon fiber tow offers comparable mechanical properties to the existing 12k material, but at about half the cost*
  - *Enhanced toughness of thermoplastics relative to thermosets suggests that less reinforcement layers and hence, less total mass will be needed*
- Embodied Energy Reduction
  - *Thermoplastics provide a cleaner, lower energy process with no curing or shelf-life issues compared to current wet-resin systems*
- Novel Manufacturing Processes
  - *Automated laydown processes potentially offer better tank performance.*
- Recyclability
  - *Thermoplastic resins in general are recyclable, while epoxy and any other thermoset resin systems are not*

ADC Filament Wind/Post Consolidate

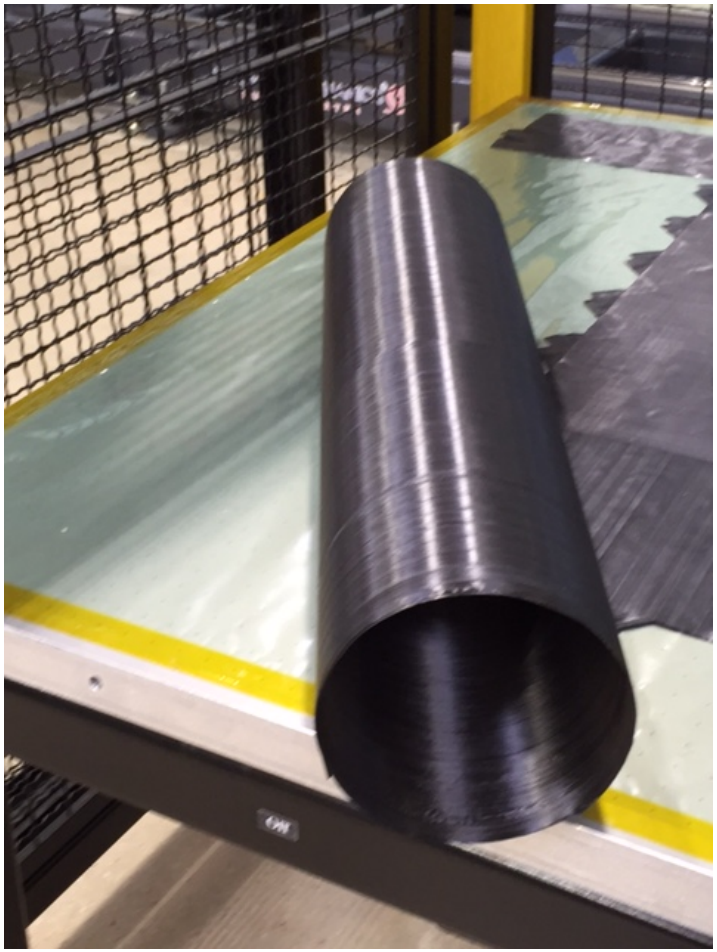
Results

- 37% less reinforcing fiber for equal burst pressure as existing thermoset tank
- Near perfect fiber load translation
- 20% weight savings overall
- 2 x faster winding time
- 90 second consolidation time
- Excellent fatigue life
- Burst pressure was exactly at calculated tensile load of prepreg.

Composite Prototyping Center



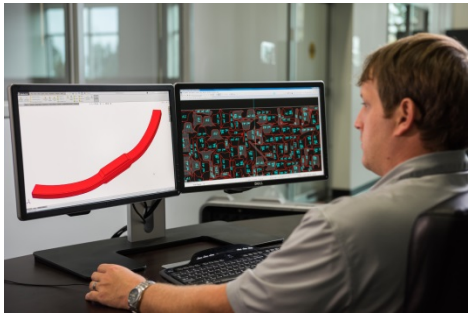
Automated Fiber Placement Laser Head



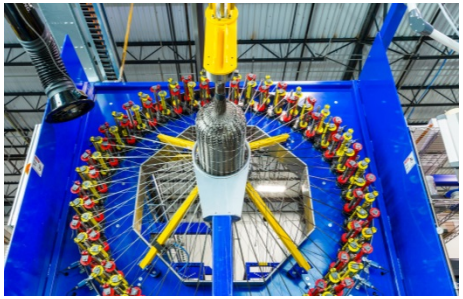
Prototype Pressurized Tank Proof of Concept

Highland's Overbraiding Offering

- Ability to deliver significant performance, cost, and waste benefits over other technologies
- Full-service "fiber-to-finished-part" composite structures manufacturing utilizing unique proprietary overbraiding technology
- Core knowledge in braided structures with product engineering capability and ability to collaborate with customer on design
- World-class equipment and processes that enable the manufacturing of a broad range of simple-to-complex part shapes.
- Key processes contained under one roof



Product Design



Preform Manufacture

Final Part

UDRI Overview

UDRI
UNIVERSITY of DAYTON RESEARCH INSTITUTE

- Established in 1956 in Dayton, OH
- Performs basic and applied research, engineering services, and testing
- Fully supported by external sponsors
- Third in the U.S. in funded materials research
- More than 460 professional research staff
- 218,000 ft^2 of facilities
- Average annual revenues (last 3 years): $90 million
- Currently under contract for more than $550 million of research

UDRI/IACMI Contact Information

Contact UDRI personnel to network and discuss potential IACMI projects:

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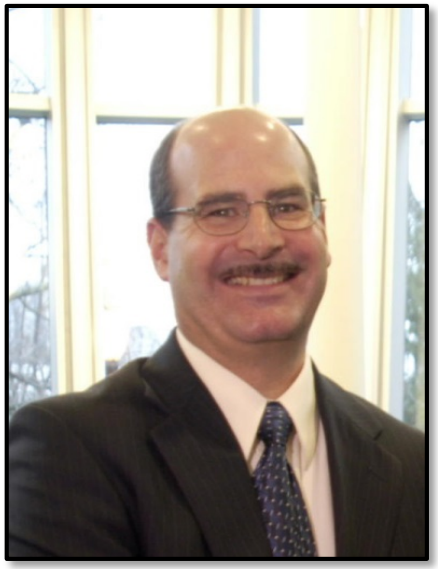

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