Why Ohio?

Ohio ranks #2 in the US in automotive-related employment.

60% of compressed gas-fueled vehicle manufacturers within half-day drive from IACMI centers.
Ohio Technology Area

- >40 years’ experience in applied, advanced composites RD&D
- 200,000 ft², fully equipped and industrially focused US composites manufacturing research center and business incubator
  - 1,000 ton, 10 x 8 ft press
  - 3-station robotic preformer
  - Long-fiber thermoplastics molder
  - Sheet mold compounding
  - Thermoplastic tow infusion line
  - 440 ton co-injection molder
  - 10 x 5 ft, 800 °F, 200 psi autoclave

Site Director
Brian P. Rice
UDRI—Division Head
937-229-2519
brian.rice@udri.udayton.edu

UDRI—UNIVERSITY of DAYTON RESEARCH INSTITUTE

Automation processes
- In situ thermoplastic infusion

Models for
- Preforming
  - Infusion
- Cure kinetics
- Performance

Develop automated manufacturing cell

High-Pressure Resin Transfer Modeling (HP-RTM)
- Preforming
  - Joining

Low cost carbon fiber
- Lab-scale intermediates and composites fabrication
  - Nondestructive evaluation
- Recycling

Institute for Advanced Composites Manufacturing Innovation
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

**Type IV:** An all-composite construction featuring a polymer (typically high-density polyethylene, or HDPE) liner with carbon fiber or hybrid carbon/glass fiber composite. The composite materials carry all of the structural loads.

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

**The markets: Pressure vessels (2015)**

High-pressure gas storage vessels represent one of the biggest and fastest-growing markets for advanced composites, as transportation markets demand alternative fuels (Compressed natural gas [CNG] and hydrogen) for motive power systems.

*Composites World January 12, 2015*
DOE EERE CNG Investments Fact

Clean Cities

VICE 2.0 Helps Fleets Evaluate CNG Investments

The Vehicle and Infrastructure Cash-Flow Evaluation (VICE) Model helps you estimate the financial and emissions benefits you can expect by transitioning to compressed natural gas.

Using your fleet-specific data:

- Number of vehicles
- Vehicle types
- Fuel use
- Planned vehicle-acquisition schedules

VICE calculates and displays:

- Return on investment
- Payback period
- Annual greenhouse gas savings
- Fuel availability and usage
Reduced Cost of CGS Tanks Enables Greater Use of Domestic Fuels Such As Natural Gas

KCF = 1000 cubic feet

http://www.calstart.org/Libraries/CalHEAT_Documents/Heavy-Duty_NGV_Roadmap_2014.sflb.ashx
CNG Market Projections

Payback period for CNG fuel system is 3–5 years. 70% of cost. IACMI seeks to reduce cost by 25% to drive faster growth.

Figure 2. Percent Cost Breakdown of a 700-bar Type IV Hydrogen Storage System (Strategic Analysis 2012)

<table>
<thead>
<tr>
<th>Change in Pressure Vessel Demand by Vessel Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>-----------------</td>
</tr>
<tr>
<td>Type I</td>
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<tr>
<td>Type II</td>
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<tr>
<td>Type III</td>
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<tr>
<td>Type IV</td>
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<td>Type V</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Estimated Pressure Vessel Unit Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>CNG Vehicles</td>
</tr>
<tr>
<td>H₂ Vehicles</td>
</tr>
<tr>
<td>Gas Transport</td>
</tr>
</tbody>
</table>
Natural Gas Vehicle Cylinder Safety Standards

There are approximately 15 million road vehicles, worldwide, using CNG for fuel. That number is increasing every year (but only 150,000 in the US) (1).


Cylinder designs that meet the requirements of these standards:

- will have a fatigue life that exceeds the specified service life
- when pressure-cycled to failure, will leak but not rupture
- when subject to hydrostatic burst tests, will have stress ratio factors that exceed the values specified for the cylinder type and the materials used
- must meet damage tolerance criteria for drop impact, bonfire, penetration, and environment

Service pressure of 245 bar (3600 psi), safety factor of 2.35 for carbon fiber

IACMI to foster improved safety as well as cost reduction

(1) http://www.afdc.energy.gov/vehicles/natural_gas.html
(2) overview_of_ngv_cylinder_safety_standards.pdf (Mark Trudgeon, July 2005)
CGS Potential Project Areas

- **High technology readiness level (TRL)**: Increase efficiency of filament winding and foster integration of low-cost carbon fiber as it emerges.

- **Mid TRL**: Dramatically decrease fiber placement time/cost by wrapping with custom braid. Also expected to increase safety and damage tolerance while reducing mass. Application area focus is for Class 6–8 trucks.

- **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.
CGS Manufacture SOA

*Courtesy of Xperion*
CGS Tank Manufacturing Innovation

Carbon Fiber Supply Roll

Tank Tension Wrap Position

Molds Alternate to Allow for Cleaning Between Mold Cycles

Mold 1

Mold 2

Robot Transfer To Injection & Cure

Robot Transfer To De-Flash

Robotic De-Flash

Completed Tanks

Modular Concept Allows for Line Layout Flexibility

Incoming Liners

Robot Transfer To Wrapping Station
Braid Offers Potential for Enhanced Safety and Reduced Mass

Braided Tank After Burst Test

Filament Wound Tank After Burst Test
Safety is Critical
Conformable Core Gas Tank

REL

Fully and Intricately Conformable, Single-Piece, Mass-Manufacturable High-Pressure Gas Storage Tanks

Program: MOVE
ARPA-E Award: $5,000,000
Location: Calumet, MI
Project Term: 09/01/2012 to 08/31/2015
Project Status: ACTIVE
Website: www.relinc.net
Technical Categories:
Transportation Storage: Natural Gas
Intestinal Natural Gas Storage

Otherlab

Safe, Dense, Conformal, Gas Intestine Storage

Program: MOVE
ARPA-E Award: $3,450,000
Location: San Francisco, CA
Project Term: 09/03/2012 to 09/25/2015
Project Status: ACTIVE
Website: www.otherlab.com
Technical Categories:
Transportation Storage: Natural Gas
Ohio–IACMI CNG Ecosystem for Alternative Fuels

Material Suppliers

<table>
<thead>
<tr>
<th>Company</th>
<th>City</th>
<th>State</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Worthington Cylinders</td>
<td>Columbus</td>
<td>OH</td>
<td>Tank</td>
</tr>
<tr>
<td>Xperion Energy &amp; Environment</td>
<td>Heath</td>
<td>OH</td>
<td>Tank</td>
</tr>
<tr>
<td>Trilogy Engineered Systems</td>
<td>Stow</td>
<td>OH</td>
<td>Fuel System</td>
</tr>
<tr>
<td>OPW Fueling Components</td>
<td>Hamilton</td>
<td>OH</td>
<td>Fuel System</td>
</tr>
<tr>
<td>Ariel Corp</td>
<td>Mt Vernon</td>
<td>OH</td>
<td>compressors</td>
</tr>
<tr>
<td>IGS Energy</td>
<td>Dublin</td>
<td>OH</td>
<td>Nat gas retailer</td>
</tr>
<tr>
<td>WW Williams</td>
<td>Columbus</td>
<td>OH</td>
<td>Heavy Duty trucks</td>
</tr>
<tr>
<td>Parker</td>
<td>Cleveland</td>
<td>OH</td>
<td>parts and fueling systems</td>
</tr>
</tbody>
</table>

fleet operators (Kroger, Walmart, municipal transit, UPS)
vehicle manufacturers (specialty commercial vehicles - Kidron Trucks, Sutphen, etc.)
UDRI Overview

• Established in 1956 in Dayton, OH
• Performs basic and applied research, engineering services, and testing
• Fully supported by external sponsors
• Third in the US in funded materials research
• More than 450 professional research staff
• 218,000 ft² of facilities
• Average annual revenues (last 3 years): $90 million
• Currently under contract for more than $550 million of research
Ohio Partners

Ohio is ranked third nationally in polymers and composites market size, boasting nearly 300 companies and 24,000 employees in the market segment.

Business and Workforce Development Partners

Institute for Advanced Composites Manufacturing Innovation
Ohio IACMI Automotive Work Cell

1000 ton press for HP-RTM and prepreg compression molding
Process Simulation for Compression Molding of Stretch Broken Carbon Fiber (SBCF) Bead Stiffened Laminate

Strain model for SBCF prepreg during compression molding

\[ \sigma = A e^{\alpha \epsilon + b \epsilon^2} \]

Typical Overall Model

Rigid male tool face
Deformable plies
Rigid female tool face

Mesh Detail
Integrated Computational Materials Engineering (ICME)

Demonstrate linking of engineering disciplines and tools to design and manufacture key feature articles

FEP integration activity

Institute for Advanced Composites Manufacturing Innovation
Thermoplastic Injection Overmolding

“One of a kind” all-electric Cincinnati Milacron injection molding machine. Ability to use 440 tons of clamping force and two barrels, our machine is ideal to conduct developmental work and short production runs for automotive insert/overmolding applications.

Injection Molding Specifications

- Cincinnati Milacron NT440 S Powerline model
- Horizontal injection shot capacity: 40 oz (1135 g)
- Vertical injection shot capacity: 10 oz (284 g)
- Maximum injection rate (horizontal): 20.8 oz/s (590 g/sec)
- Peak injection pressure: 30,000 psi (206 MPa)

Mold and Clamp Unit

- Daylight: 56.1 in. (1425 mm)
- Minimum mold height: 9.8 in. (250 mm)
- Maximum mold height: 29.5 in. (750 mm)
Custom Polymer Compounding

Devolatilizing Twin Screw Extruder

- **Model:** Coperion ZSK 26
- **Drive:** 30 HP Allen Bradley AC induction motor, 1800 RPM base speed, oil-lubricated reduction and distribution gear assembly with torque limiting coupling
- **Screw:** co-rotating shafts, 12–1200 RPM screw speed, 82 N-m available torque per shaft, configurable screw designs
- **Barrel:** 25mm diameter barrels, 1300 mm length, nitrided steel, 7 independent controlled heating zones, 15.6 kW total heating power, 400°C maximum temperature, pressure transducer at barrel exit
- **Venting:** 3 vent ports for devolatilization, each with vacuum/pressure gauge, sight glass, throttling nitrogen valve, and insert block (when venting is not used). All vents connect to vacuum manifold pipe system
Structures and Material Evaluation

- Proficient with a large variety of standardized tests (e.g., ASTM, SAE)
  - ISO-9000 certification
- Wide variety of materials:
  - Metals (e.g., aluminum, titanium, steel, nickel-based, magnesium)
  - Composite systems
    - polymeric (PMCs)
    - metallic (MMCs)
    - ceramic (CMCs)
  - Elastomers
  - Polymers
  - Components
  - Structures/substructures

Truck spring fatigue

Fatigue testing of composite spring
High-Rate Test Capabilities

- National/international expertise
- Rates up to ~1000 in./s [25.2 m/s] (800 s⁻¹)
- Standard specimens as well as structures/components
- Non contact digital image correlation (DIC) system for strain measurement

LGFPP* tensile strength

*Long glass fiber–filled polypropylene

Vinyl ester/epoxy weave
Gaged and DIC
At the University of Dayton Research Institute, we combine (un)common sense with creativity to deliver innovative, practical science and engineering solutions.

- 50+ year track record in advanced composites
- Trusted partner of Air Force and aerospace community
- Technical breadth and depth of a prime contractor without the cost and conflicting business interests
- Proven track record for assisting to move technologies forward from TRL1 to TRL9

On Budget
On Time

Shaping the technology of tomorrow
Contact UDRI personnel to network and discuss potential IACMI projects:

Jared Stonecash  
937-229-4361  
jared.stonecash@udri.udayton.edu

Brian Rice  
937-229-2519  
brian.rice@udri.udayton.edu

Kevin Cunningham  
937-229-4383  
kevin.cunningham@udri.udayton.edu