VI.8 Inexpensive Pressure Vessel Production Through Fast Dry Winding Manufacture

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Objectives

- Demonstrate novel pressure vessel production process.
- Project cost advantages of new process.

Technical Barriers

This project addresses the following technical barrier from the Manufacturing R&D section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

(H) Lack of Carbon Fiber Fabrication Techniques

TABLE 1. Progress toward Meeting DOE On-Board Hydrogen Storage Technical Targets

Lawrence Livermore Tape-Fabricated Vessels					
Storage Parameter	**Units**	**2010 Target**	**2015 Target**	**2009 Proof of Concept[1]**	**2011 Projected Best Cost[2]**
Storage System Cost	$/kWh	4	2	~10	~5

[1] Using graphite prototype tape, estimate based on mass production rates (if proven)
[2] Estimate based on most favored fiber and mass production capital

Accomplishments

- Designed experiment capable of proving mass production rate.
- Coordinated planning with other members of the Tank Manufacturing team.
- Protected intellectual property through patent application.

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Introduction

As a universal transportation fuel that can be generated from water and any energy source, hydrogen (H_2) is a leading candidate to supplant petroleum with the potential to ultimately eliminate petroleum dependence, associated air pollutants and greenhouse gases. The predominant technical barrier limiting widespread use of hydrogen automobiles is storing enough hydrogen fuel onboard to achieve sufficient (500+ kilometers) driving range in a compact, lightweight, rapidly refuelable, and cost-effective system. Pressure vessels provide a necessary contribution to solving this challenge in the near term, but also contribute most of the cost and weight of a hydrogen storage subsystem. In collaboration with industrial partners on a DOE funded manufacturing technologies team, we are addressing the remaining cost efficiency hurdles to enable a rapid transition to hydrogen-fueled automobiles. Our contribution is a novel manufacturing process that may offer substantial manufacturing cost savings independent of the choice of fiber material.

Approach

The novel composite manufacturing process being researched and developed at LLNL has the potential for considerable savings in pressure vessel cost. Although this process has details that remain proprietary, it has numerous resemblances to proven composites manufacturing processes. Figure 1 outlines the composite manufacturing process choices, with LLNL's novel tape technology on its rightmost edge. Other efficient approaches to vessel manufacture (wet wound, fiber placement) are being researched by team members (Quantum Technologies and Boeing). Alternatives at the left of the figure lead to undesirable characteristics.

LLNL's novel process combines many of the features of proven high-strength processes, except that it seeks to perform them at high speed to drastically reduce manufacturing cost. Other features and drawbacks of the tape process could affect materials costs and vessel performance, but the effects are likely to be slight and positive. Until the reality of significant manufacturing cost improvements is proven, the investigation of vessel performance effects and potential restrictions on fiber choices would be inconsequential. Therefore LLNL is

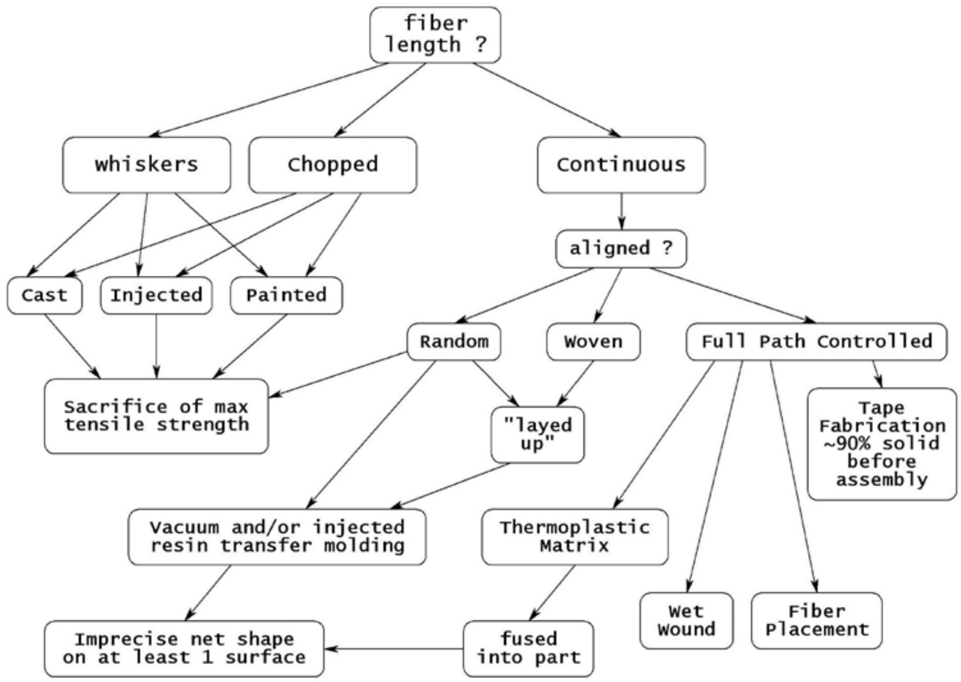

FIGURE 1. Bubble diagram dissects the various options for manufacturing composite vessels, starting from choices of the geometry of the individual composite fibers. Two undesirable characteristics of the final composite part are shown at the left of this diagram. The team of pressure vessel innovation partners (Quantum Technologies, Boeing, and Pacific Northwest National Laboratory) seeks to combine characteristics of wet winding and fiber placement, both of which avoid the undesirable consequences. LLNL's proposed novel tape technology, also on the right of this diagram, avoids the negative consequences and combines features of two proven processes being improved by team members.

proceeding to rapidly determine how much our novel process might save in just the manufacturing (capital and labor) cost. Figures 2 and 3 break that cost down in a fundamental way, first into what the process equipment adds to manufacturing cost as a function of how much material goes through a costly piece of production equipment how fast (the 'throughput'), and then how much 'throughput' that equipment can achieve when laying down a tape of a particular cross section at a particular speed. Attempts are made in these figures to roughly characterize our process with the conventional competing process – wet winding – while protecting proprietary process specifications.

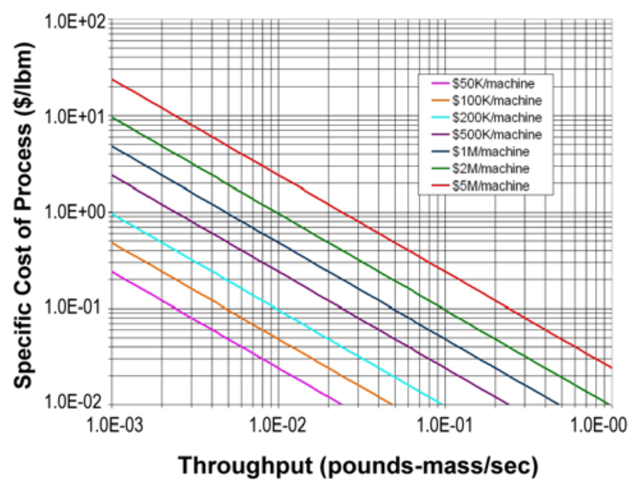

FIGURE 2. Cost to perform a composite manufacturing process versus the composite material processing rate ('throughput' in units of mass-per-unit-time), at various levels of production capital cost (presuming a three year return on investment). This graph applies to all composite manufacturing processes, with conventional wet winding processes occurring in roughly the middle of its left hand edge. LLNL's novel dry tape process projects operation in the middle of the bottom edge of this graph, but actual specifications are deliberately not exact (by >1 order of magnitude) to protect proprietary process technology.

Results

Our results to date from six months of funded research include various collaborations and plans for future collaborations with other team members. These provide a potential adoption path from LLNL to the most expert and incentivized pressure vessel manufacturers. Other results that are harder to report include intellectual property protection, which will only be complete when the patent office acts on LLNL's patent application. The central activity that has occupied LLNL researchers is the preparation of safety

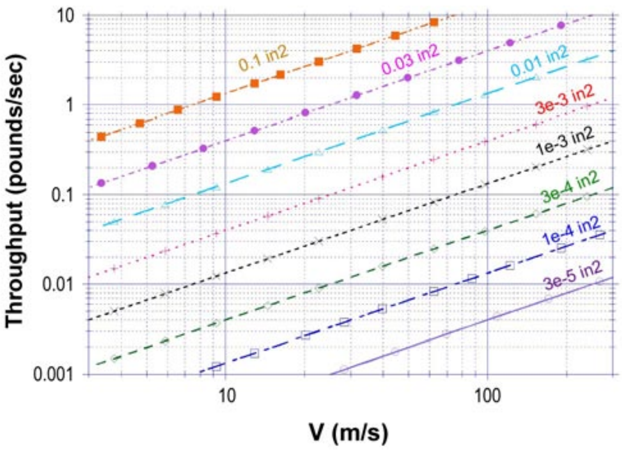

FIGURE 3. Tape material processing rate ('throughput' in units of mass-per-unit-time) as a function of tape velocity, at various levels of tape cross sectional area. This graph applies to all continuous filament fiber production processes, and current wet winding processes occupy the lower left corner. LLNL's novel dry tape process projects operation in the upper right corner of this range, but actual specifications are deliberately not exact (by >1 order of magnitude) to protect proprietary process technology.

and cleanliness arrangement sufficient for the proof of concept experiment we intend to perform over the next few months.

Although many fiber and matrix material choices should be compatible with LLNL's tape innovation, very few provide the confidence to quickly perform our proof of concept experiments. In particular, the repeatability of (rapidly testable) bonding is at risk from airborne contamination and perhaps from humidity. Low material sensitivity to environmental conditions is therefore important. Facilities have been approved to meet these challenges, and plans to procure proprietary tape and (slightly hazardous) bonding materials have been approved that are compatible with our laboratory.

Our proof of concept experiment is focused on determining bonding speed – the key parameter limiting winding velocity. Figure 4 shows a block diagram schematic of the calorimeter designed for a proof of concept test apparatus. This design is not arbitrary; it is the simplest way to make measurements of a high-speed process without the measuring instrument limiting how fast the process can occur. Its approach relies

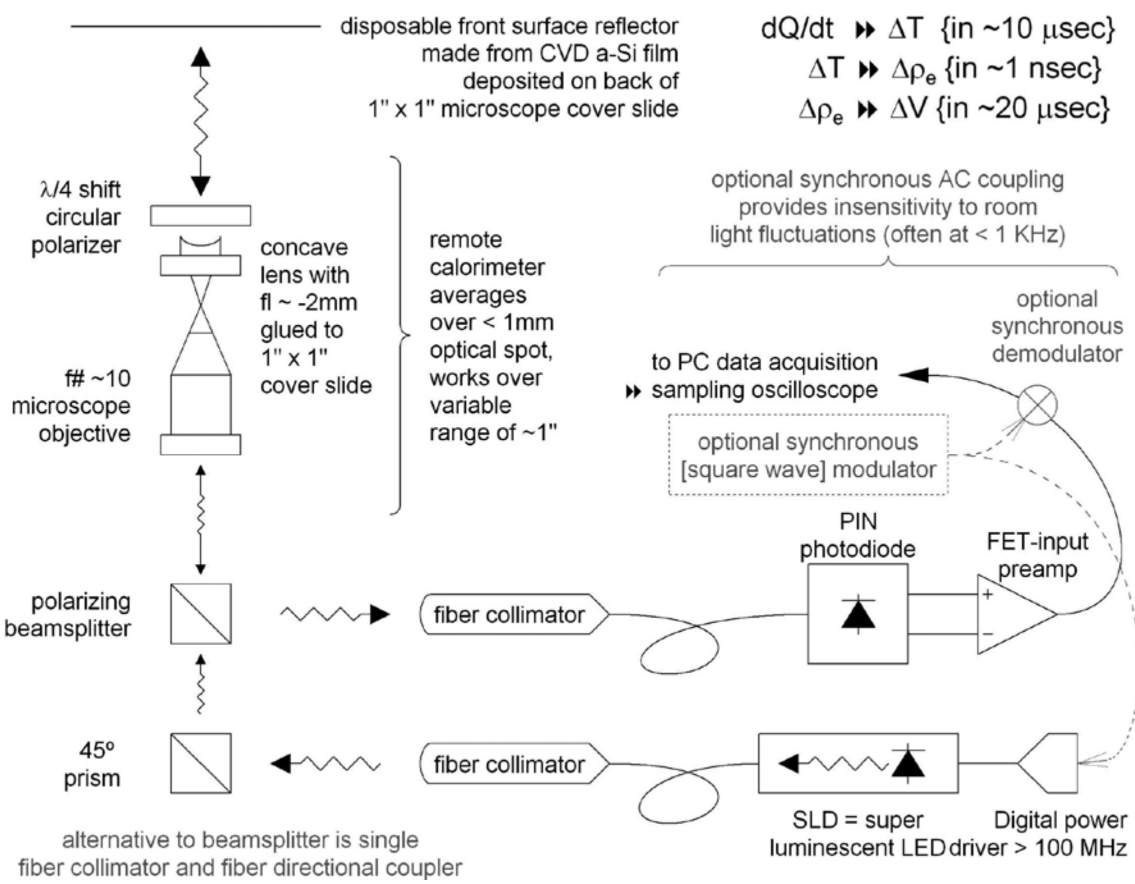

FIGURE 4. Schematic diagram of calorimeter to determine tape bonding speed by capturing temperature rise due to bonding with a digital oscilloscope. This hardware diagram mixes physical components, optical beam paths including captured photons in fibers, and electronics.

on the heat being evolved by a tape bonding process to find out how fast that process is occurring, without interfering with the mechanical phenomena that ought to be changing as a bond is forming (as might be the case with speed of sound, ultrasonic impedance, or opacity measurements), or further restricting the choice of experimental gas environment. Figure 5 shows the key components of the high-speed calorimeter now under construction, which are thermal isolation trusses that retain their dynamic calibration as stuck-together tape test specimens are bonded and taken out of the instrument.

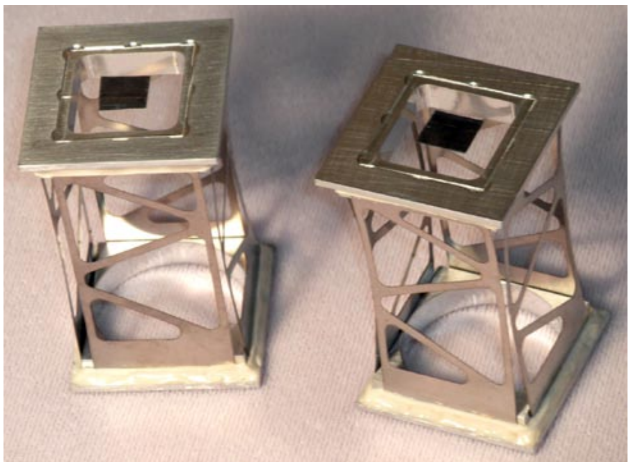

FIGURE 5. Thermal isolation truss components of apparatus under construction. These truss stages mount tape specimens (black squares in the center of clear microscope cover slides, glued atop these trusses). One of these trusses is inverted and its tape specimen placed in abrupt contact with the other tape specimen to determine bonding speed with the calorimeter apparatus of Figure 4.

Conclusions and Future Directions

- We are conducting experiments to prove the processing rates of a novel composite manufacturing process. If these experiments are successful at showing rates capable of high-speed mass production, they will be extended to prove lack of detrimental effects when applied to pressure vessel manufacture.
- In collaboration with industrial partners on a manufacturing technology team, we are addressing the cost advantages of major improvements in pressure vessel manufacturing processes.

FY 2009 Publications/Presentations

1. Poster Presentation, Hydrogen, Fuel Cells and Infrastructure Technologies Program Annual Merit Review, Arlington, VA, May 20, 2009.