FLAT, MODULAR TANK TECHNOLOGY FOR NATURAL GAS VEHICLES

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PROJECT TITLE: Low Cost Hybrid Materials and Manufacturing for Conformable CNG Tanks
PROGRAM: Methane Opportunities for Vehicular Energy (MOVE)
AWARD: $4,299,964
PROJECT TEAM: *United Technologies Research Center (UTRC)*, Oak Ridge National Lab
PROJECT TERM: October 2012 – March 2016
PRINCIPAL INVESTIGATOR (PI): Dr. Ellen Sun

TECHNICAL CHALLENGE

The United States is the largest producer of natural gas in the world, increasing its output by more than 50% over the last 10 years, and prices are near historical lows. The potential environmental benefits of this hydrocarbon as a transportation fuel are significant in terms of lower pollutant emissions compared to other fossil fuels. Despite these attractive characteristics, the number of natural gas vehicles in the United States lags far behind other countries in Europe, Asia, and South America. Today, most natural gas vehicles in the U.S. are produced by retrofitting existing gasoline and diesel models, which results in a high purchase premium and the installation of bulky cylindrical compressed natural gas (CNG) tanks that take up essential cargo space. The low volumetric energy density of natural gas also makes it difficult to store sufficient fuel for adequate driving range. Consequently, solutions are needed to make on-board storage of natural gas practical and cost effective so that consumers and businesses can adopt this alternative fuel. Such an approach calls for tanks that can conform more closely to irregularly-shaped spaces available on production vehicles.

TECHNICAL OPPORTUNITY

Cylindrical tanks used today have a conformability factor (the inner tank volume divided by the enclosing outer rectangular cuboid volume) from 60 to 70% (depending on materials). Non-cylindrical designs are challenging due to non-uniform stress distributions, extremely high stress concentrations, and the need for thicker walls and internal supports to address these structural considerations. It is especially difficult to achieve a much higher conformability factor in a tank while also hitting energy density and cost targets acceptable to the market. Recent advances in computer modeling techniques have enabled rapid experimentation with new designs.

INNOVATION DEMONSTRATION

UTRC designed its tank through an integrated computational optimization, employing detailed topology optimization and structural analysis. The team explored a large design space and conducted trade-off studies to identify key value factors. The design was further simplified by taking inspiration from Plateau's Laws governing intersecting bubbles and considering manufacturing feasibility.

The final design is flat, multi-chambered, and modular, adaptable to the wide range of aspect ratios applicable to different vehicle platforms, as shown in Figure 1. The conformable UTRC design can provide 30% more gas storage in comparison to cylindrical tanks occupying the same space, at a manufacturing cost that is comparable to cylindrical tanks. An individual tank is composed of two D-shaped chambers on the outer edges, sandwiching a variable number of "stadium"-shaped

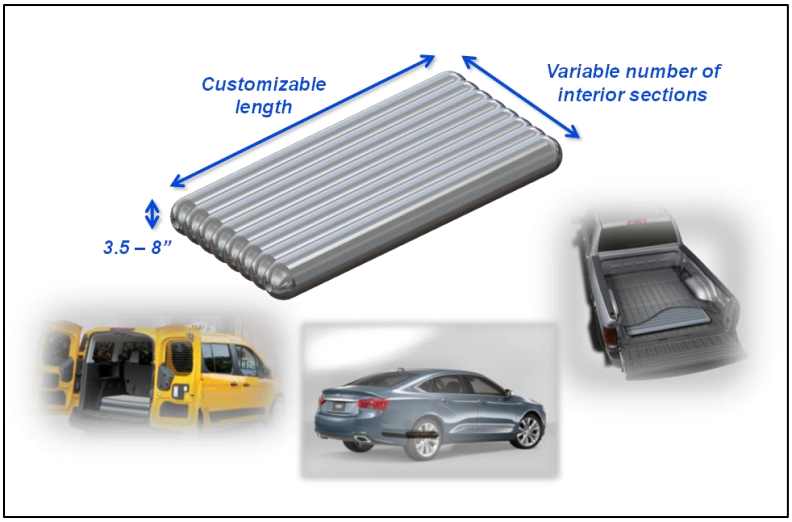

Figure 1: Rendering of full-scale tank and illustrations of tank configurations on a variety of vehicles.

interior chambers. Domed end caps complete the chambers, and adjacent chambers can be internally connected so that only one external valve is necessary.

UTRC validated the conformable tank design via subscale prototypes. During the course of the project, three parallel paths were taken to fabricate prototypes for design validation and manufacturing process development: (1) steel tank with conventional welding processes, (2) high strength aluminum using solid state welding processes, and (3) long chopped fiber composite using a molding process. The steel prototypes achieved 8,100 psi burst pressure, held for over 70 seconds, and 2,800 pressure cycles, surpassing both the burst and pressure cycle requirements specified by the ARPA-E MOVE program (8,100 psi for 5 seconds; 1,000 pressure cycles). A major achievement with the aluminum tank development was in the area of state-of-the-art solid state welding. High strength aluminum materials are known for difficulty in welding by conventional welding processes. Friction stir welding and linear friction weld processes were developed for aluminum alloy 7055. The chopped carbon fiber polymer matrix composite material and fabrication process were validated using a cylindrical tank, which survived the 8,100 psi burst test.

The team ensured that the manufacturing processes are viable for volume productions. A detailed cost analysis was carried out on the aluminum conformable tank, including raw materials, capital equipment, step-by-step labor and materials, and overhead cost. A $1,700 volume production cost was projected, well within the current natural gas tank market price range. This cost analysis was reviewed with one major cylinder manufacturer and one automotive OEM. For the composite conformable tank, UTRC collaborated with ORNL on automated manufacturing processes and utilizating low cost carbon fibers.

PATHWAY TO ECONOMIC IMPACT

Under the MOVE project, UTRC has advanced integrated design and optimization methods for complex structural components, and developed manufacturing strategies for lightweight alloys and carbon fiber composites. UTRC is executing a licensing strategy to commercialize its conformable tank technology.

In December 2015, UTRC signed an agreement to license the composite conformable tank technology to Adsorbed Natural Gas Products (ANGP) for composite, non-metal tanks containing activated carbon adsorbents at operating pressures up to 1,000 psi. UTRC is working with a consortium of partners assembled by ANGP to take the technology to commercialization, including a tank fabricator, the manufacturer of a patented activated carbon adsorbent material (enabling low-pressure storage), a supplier of a miniature rotary compressor fuel pump, and an automotive OEM. As of late 2016, UTRC is embarking on a joint development program funded by ANGP to support the certification of the conformable tank under ANSI NGV2-2007 standards for compressed natural gas vehicle fuel containers, a prerequisite to commercialization. This activity is targeted for completion in the second quarter of 2017.

UTRC is also pursuing parallel paths for licensing its technology for high pressure (3,600 psi) CNG applications, and continues to work with automotive OEMs to advance the technology for commercialization.

LONG-TERM IMPACTS

The advanced materials and manufacturing processes developed for the conformable tanks have additional potentially energy-saving applications in other areas such as building systems and aerospace.

The availability of CNG tanks that reduce the space penalty for fuel storage, at cost parity with existing tanks, lowers a significant barrier to adoption of natural gas-powered vehicles. Adoption in light-duty vehicles, which represent over 70% of highway transportation fuel consumption, may occur first for fleet vehicles where a centralized fueling infrastructure can be used. Wider adoption will likely depend on both policy and the relative prices of natural gas and oil.

INTELLECTUAL PROPERTY AND PUBLICATIONS

As of December 2016, the UTRC team's project has generated 21 invention disclosures to ARPA-E including 11 U.S. Patent and Trademark Office (PTO) patent applications.