INTESTINE-STRUCTURED GAS STORAGE

UPDATED: OCTOBER 7, 2016

PROJECT TITLE: Safe, Dense, Conformal, Gas Intestine Storage
PROGRAM: Methane Opportunities for Vehicular Energy (MOVE)
AWARD: $3,450,000
PROJECT TEAM: Otherlab, Inc. (Lead)
PROJECT TERM: September 2012 – March 2016
PRINCIPAL INVESTIGATOR (PI): Dr. Saul Griffith

TECHNICAL CHALLENGE

Natural gas vehicles (NGVs) provide an opportunity to increase U.S. energy security by diversifying the resources we rely on for transportation, enabled by the substantial increases in U.S. natural gas reserves and annual production over the past ten years. However, the large, cumbersome, and expensive on-board fuel tanks presently used in NGVs create a major barrier to increased utilization of natural gas as a transportation fuel. Additionally, the low volumetric density of compressed natural gas – 26.9% of the volumetric energy density of gasoline – limits the driving range of NGVs and makes cost-effective storage solutions an even more important challenge. Significant improvements must be made to the capacity, conformability, and cost of on-board storage to accelerate NGV adoption.

TECHNICAL OPPORTUNITY

Currently NGVs are outfitted with bulky and expensive cylindrical pressure vessels that can be difficult to fit within the vehicle without compromising passenger or cargo utility. Traditional natural gas storage tanks are cylinders with hemisphere caps. These cylindrical tanks do not always make the best use of space within a vehicle, especially when placed in spaces with square or rectangular cross-sections, such as a trunk or truck bed. The technical potential of a conformable gas tank based on innovative geometries, lighter materials and a new overall design presents an opportunity to overcome key market barriers that NGVs currently face. Such a tank could potentially be conformed to a variety of shapes providing higher storage capacity than current cylindrical tanks.

INNOVATION DEMONSTRATION

To enable low cost, low-weight fuel storage that conforms to the available space on a vehicle, Otherlab proposed a new natural gas tank design that comprises a single tube with a series of bends that allow the tube to occupy more of a space, much like the bends in an intestine allow it to occupy the space in the abdominal cavity.

Figure 1. Otherlab's compressed natural gas tank is a folded tube that conforms to the available space, allowing more efficient fuel storage in irregularly-shaped spaces than in a traditional compressed gas cylinder.

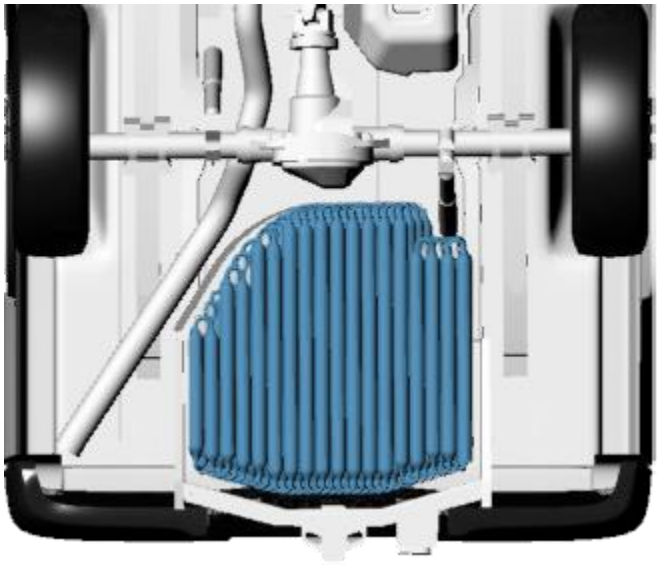
Commercial composite tanks for compressed gas storage are made from a plastic liner wound with a carbon fiber and epoxy exterior. However, a wound exterior is not compatible with Otherlab's proposed bent design. To maintain the required structural integrity needed to safely confine compressed natural gas in a tube with bends, Otherlab developed two innovations: first, fabricating a liner with periodic narrow sections that allow the tank to bend into its final shape, and second, by braiding the exterior of the tank so that the fiber can reinforce both the wide and narrow portions of the tank, as well as the bends.

Otherlab's space-filling, intestine-inspired design has key advantages over traditional carbon fiber composite cylinders. The conformable tank is well-suited to highly automated continuous manufacturing processes, whereas traditional carbon fiber composite cylinders are wound one at a time. Otherlab's

design results in a 20% improvement in fuel capacity and driving range when replacing a single, large gas cylinder in a truck bed with a conformable tank that fits into the same rectangular prism storage space. Conformable tanks fit into smaller, more complicated spaces such as a spare tire well, which cannot reasonably accommodate a traditional compressed gas cylinder for fuel storage. By taking advantage of smaller spaces on the vehicle, Otherlab's conformable tank design allows natural gas fuel storage to be moved out of cargo and passenger space, even for a pickup truck with 20 gasoline gallon equivalent (GGE) of natural gas capacity.

Thus far, the team has fabricated 4 GGE tanks that exceed the target 8100 pounds per square inch (psi) burst pressure target for 3600 psi compressed gas tanks. Otherlab's tanks have a gravimetric energy density similar to other composite tanks, 15 MJ/kg. Otherlab tanks have a volumetric energy density of approximately 5.9 MJ per liter of vehicle space compared to 4.75 MJ/L for a cylinder; however, volumetric energy density for both a conformable tank and a cylinder is dependent on the size and shape of the tank enclosure.

Figure 2. A compressed natural gas tank that conforms to the spare tire compartment



PATHWAY TO ECONOMIC IMPACT

Otherlab formed a new company, Volute, supported by a strategic partnership with Westport Innovations Inc. (now Westport Fuel Systems Inc.), which engineers, manufactures, and supplies alternative fuel systems and components. Volute's initial target application is natural gas pickup trucks and passenger vehicles, which typically carry cylindrical natural gas tanks in the truck bed or trunk, respectively.

Any storage tank technology must be certified to confirm safe performance in automotive conditions before it enters the market. Volute will address this regulatory barrier to market entry for novel tank technologies by contributing to the development and validation of standards applicable to cylindrical and conformable tanks. To that end, Volute has become a member of the CSA Natural Gas Vehicle 2/HGV 2 Technical Advisory Group (TAG) for compressed natural gas and compressed hydrogen vehicle fuel containers. They have joined this group to address technical issues and draft proposed standards text for industry review, comment, and final approval as an American National Standard. The goal is to develop and approve a new edition of NGV2 that paves a path for the certification of conformable fuel storage tank technologies. The new standards are expected in 2018.

After completing their ARPA-E project, Volute licensed their technology for conformable compressed natural gas storage to Westport. Volute is refining and scaling up their manufacturing process, and has begun a hydrogen storage project.

LONG-TERM IMPACTS

About 27% of oil consumed in the United States is imported, and about 71% of U.S. oil consumption goes to transportation. The U.S. Energy Information Administration (EIA)[1] projects that natural gas use for transportation will reach 710 trillion BTUs by 2040 based on present-day technical factors, compared with the 50 trillion BTUs consumed by natural gas vehicles in 2013. This increase would displace about 300,000 barrels of oil equivalent per day out of the present 12 million barrels of oil equivalent per day of petroleum-based motor fuels.

Consumer willingness to adopt NGVs, particularly for light-duty applications, will be increased by technology innovations such as Otherlab's conformable gas tank, which frees up vehicle cargo space and allows vehicles to carry more fuel, and improves range between refueling. Such improved performance may enable further reduction of U.S. dependence on imported oil for transportation needs.

INTELLECTUAL PROPERTY

[1] U.S. Department of Energy, Energy Information Administration, *Annual Energy Outlook 2015*. May, 2015. http://www.eia.gov/forecasts/archive/aeo15/

As of August 2016, the Otherlab team's project has generated five invention disclosures to ARPA-E and five U.S. Patent and Trademark Office (PTO) patent applications.