

Breakthrough for Hydrogen Fuel Storage is like a “Liquid Battery”

Air Products has available for license a highly efficient method for storing hydrogen in a room-temperature organic liquid. This breakthrough invention solves the problem of hydrogen fuel storage, one of the major challenges facing the hydrogen economy.

How It Works

The unique technology incorporates hydrogen into a proprietary “carrier liquid,” capable of holding massive amounts of hydrogen. The liquid later releases the hydrogen on demand at the point of use, e.g., within a vehicle or power system. The depleted carrier liquid can then be reprocessed for reuse. One cubic centimeter of the liquid can store up to 700 cc of hydrogen gas (STP). A typical gas tank of carrier liquid can hold 5 kg of hydrogen, enough for the full range of a fuel cell vehicle.

When paired with a fuel cell, the liquid carrier technology has **three times the energy density of a lithium ion battery**. Unlike direct methanol fuel cell systems, the liquid carrier technology does not produce any CO₂ and is therefore safer for confined spaces.

The new technology eliminates problems inherent in other storage and dispensing systems, including the cost and time for pressurization, containment of a high-pressure gas, time to fill the tank, and temperature concerns during the tank fill. The liquid carrier can be contained in a conventional, atmospheric pressure tank. Most of the competing technologies require substantially longer tank fill times because of heat generated by the filling process.

Suitable for small-scale systems where energy-density is valuable.



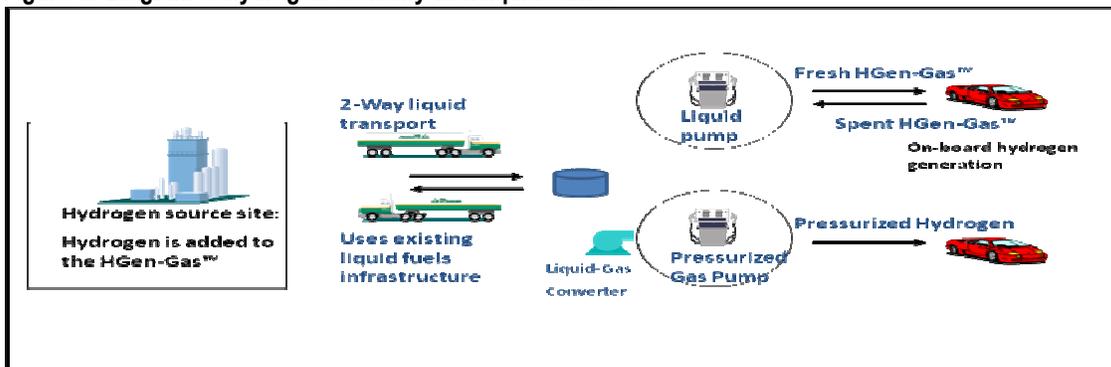
Advantages Over Other Storage Systems

This unique storage technology allows gaseous hydrogen to be stored and transported at room temperature as a liquid, mimicking conventional fuels (see Figure 1). Consider these advantages.

- **Great ‘Green story’** Liquid-carrier closes the loop from green hydrogen production to use with 100% re-used carrier and components. **For small or large scale applications, carrier replenishment can be local and distributed.**
- **Huge potential market as hydrogen begins to replace conventional fuels. Meets most of the strict DOE goals for vehicle hydrogen storage** (see Table 1).
- **Superior tank fill speed.** Tank fill speed is the “Achilles heel” of hydrogen technologies. Most systems require 10 minutes and compressed hydrogen needs 4 minutes (best in class). The liquid carrier technology requires an estimated 2 minutes.
- **Excellent volumetric hydrogen storage.** The liquid carrier technology has two to three times better storage density than compressed hydrogen. Unlike cryogenic storage, no special insulation or power is needed to sustain the storage indefinitely. **Liquid carrier tanks can be conformal or even flexible!**
- **Full suite of hydrogen economy patents are available:** Beyond broad patents for the fuel technology, Air Products has patents pending for various portions of the hydrogen economy infrastructure required to enable its use
- **Applications include all automotive, truck, bus, forklift, power tools, fuel cell, battery replacement, hydrogen storage, purge and transportation as well as power backup systems.** For in-building applications, this technology emits only water. The liquid carrier and a fuel-cell remain undiminished indefinitely.
- **Superior safety.** This material presents safety alternatives to conventional hydrogen systems, including minimization of hydrogen station setbacks ambient pressure operation and low-

This image shows hydrogen issuing from the catalyst in a glass of liquid-carrier.

Figure 1. Diagram of hydrogen economy with liquid carrier*



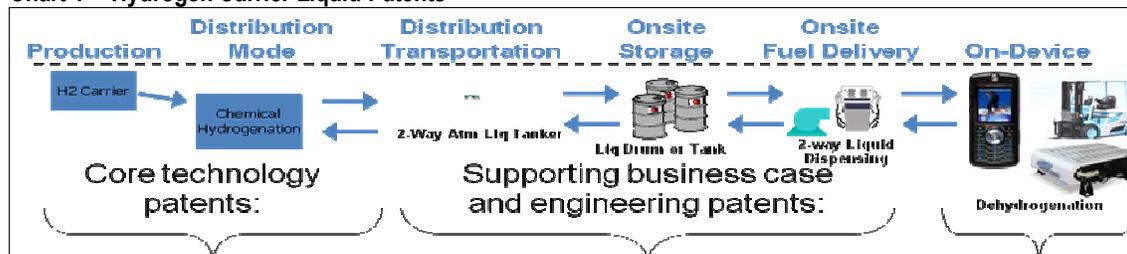
*This technology is similar to the current gasoline-based economy. Hydrogen sources exist at all refineries.

Table 1 Hydrogen Carrier Liquid Storage Vs. DOE Hydrogen Storage Goals*

DOE System-Level Goals	2010	2015	Carrier Liquid (material basis)	Pass/Fail
Gravimetric capacity (wt %)	4.5	5.5	4.9-7.2	Pass
Volumetric capacity (g of H ₂ /liter)	28	40	45-69	Pass
System fill time (5 kg H ₂ , min)	4.2	3.3	Est. 2.0	Pass
Fuel Purity	99.99%	99.99%	99.99+% ^a	Pass
Loss of usable H ₂ (g/h)/kg H ₂	0.1	0.05	0	Pass
System total cost				Needs Dev.

* No other hydrogen storage technology can pass these criteria. (Note that there are more DOE criteria.)

Chart 1 -- Hydrogen Carrier Liquid Patents



Title \ Filings	U.S. Patent *
Method and system of supply and delivery of product contained in a carrier	US2006/0226050
Secure loop system and method for supply and delivery of product contained in a carrier	US2007/0034532
Efficient system and method for delivery of product and return of carrier	US2006/0239905
Hydrogen storage by reversible hydrogenation of PI-conjugated substrates	US7101530
Hydrogen storage by reversible hydrogenation of PI-conjugated substrates	US7429372
Hydrogen storage by reversible hydrogenation of PI-conjugated substrates	US7351395
Methods for managing a product carrier	US2006/0259319
Auto thermal hydrogen storage and delivery systems	US2008/0260630
Dehydrogenation of liquid fuel in a microchannel catalytic reactor	US 7,485,161 US2006/0143981
Dehydrogenation of liquid fuel in a microchannel catalytic reactor	US2009/0019768

*Foreign equivalents exist for many of these patents. This broad patent estate covers a large range of possible molecules for hydrogen storage.

Find Out More

Air Products and Chemicals, Inc.
 7201 Hamilton Boulevard
 Allentown, PA 18195-1501
 Contact: Greg Wolf, Technical Licensing
 Tel 610 481-4241
 Email wolfrg@airproducts.com

tell me more
www.airproducts.com