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-reactivity chemistry that is not ‘exothermic’.

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

<table>
<thead>
<tr>
<th>DOE System-Level Goals</th>
<th>2010</th>
<th>2015</th>
<th>Carrier Liquid (material basis)</th>
<th>Pass/Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravimetric capacity (wt %)</td>
<td>4.5</td>
<td>5.5</td>
<td>4.9-7.2</td>
<td>Pass</td>
</tr>
<tr>
<td>Volumetric capacity (g of H₂/liter)</td>
<td>28</td>
<td>40</td>
<td>45-69</td>
<td>Pass</td>
</tr>
<tr>
<td>System fill time (5 kg H₂, min)</td>
<td>4.2</td>
<td>3.3</td>
<td>Est. 2.0</td>
<td>Pass</td>
</tr>
<tr>
<td>Loss of usable H₂ (g/h)/kg H₂</td>
<td>0.1</td>
<td>0.05</td>
<td>0</td>
<td>Pass</td>
</tr>
<tr>
<td>System total cost</td>
<td></td>
<td></td>
<td></td>
<td>Needs Dev.</td>
</tr>
</tbody>
</table>

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

Chart 1 -- Hydrogen Carrier Liquid Patents

- Title of Filings: Method and system of supply and delivery of product contained in a carrier
  - U.S. Patent: US2006/0226050
- Title of Filings: Secure loop system and method for supply and delivery of product contained in a carrier
- Title of Filings: Efficient system and method for delivery of product and return of carrier
  - U.S. Patent: US2006/0239905
- Title of Filings: Hydrogen storage by reversible hydrogenation of Pi-conjugated substrates
  - U.S. Patent: US7101530
- Title of Filings: Hydrogen storage by reversible hydrogenation of Pi-conjugated substrates
  - U.S. Patent: US742972
- Title of Filings: Hydrogen storage by reversible hydrogenation of Pi-conjugated substrates
  - U.S. Patent: US7351395
- Title of Filings: Methods for managing a product carrier
  - U.S. Patent: US2006/0259319
- Title of Filings: Auto thermal hydrogen storage and delivery systems
- Title of Filings: Dehydrogenation of liquid fuel in a microchannel catalytic reactor
  - U.S. Patent: US 7,485,161
- Title of Filings: Dehydrogenation of liquid fuel in a microchannel catalytic reactor
  - U.S. Patent: US2009/0019768

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

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