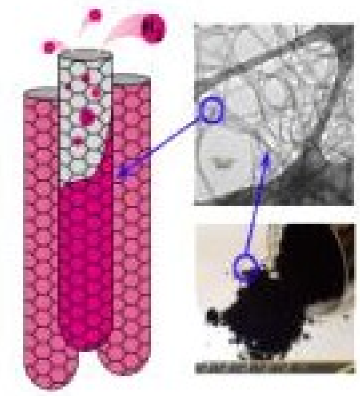
2.2.4 HYDROGEN STORAGE

Technology Description

Unlike electricity, hydrogen can be stored for long periods of time without significant losses. Today, hydrogen is stored as a cryogenic liquid or compressed gas, and transported by cryogenic liquid or high-pressure trucks; and, to a limited extent, by gaseous pipelines. In the future, it could be stored and possibly transported in chemical and metal hydrides, carbon nanostructured materials, and high surface area adsorbents. In such forms, hydrogen would be more amenable to safe and efficient distribution and storage. In the meantime, current technologies can be adapted to store and distribute hydrogen to the emerging transportation and stationary markets for hydrogen.



Carbon nanotube structure and micrographs.

System Concepts and Representative Technologies

- There are four broad hydrogen storage approaches currently under development: (1) composite pressure vessels, which will contain the hydrogen as a compressed gas or cryogenic vapor; (2) physical absorption on high-surface-area lightweight carbon structures; (3) reversible metal hydrides; and (4) chemical hydrides. Improving hydrogen compression and/or liquefaction equipment – as well as evaluating the compatibility of the existing natural gas pipeline infrastructure for hydrogen distribution – are also planned.
- Materials-based approaches such as solid-state materials or liquids may offer increased safety for onboard vehicular storage of hydrogen, because tank punctures or ruptures would not result in large energy releases. These approaches also require less volume than pressurized or liquid systems. Stationary applications would also benefit from the successful development of such systems.

High-pressure, all-composite gaseous hydrogen storage cylinders encourage commercialization of hydrogen gas-powered vehicles.

Technology Status/Applications

- Most prototype vehicles store hydrogen in composite tanks at high pressures (5,000 or 10,000 psi), while some store liquid hydrogen at 20 K. There are limited demonstrations of vehicles with metal hydrides and chemical hydrides, such as sodium borohydride. Metal hydrides are used in limited stationary applications where weight is not a critical factor, and where waste heat is available at the appropriate temperature for hydrogen release.
- Current R&D efforts are focused on improving performance (i.e., weight, volume, charging/discharging rates, cycle life, safety, etc.) and lowering cost.
- Particularly notable are recent advances in storage energy densities, primarily focused on mobile applications. The composite tank development is a prime example of a successful technology partnership among the national labs, DOE, and industry.
- Industrial investment in chemical hydride development has recently been initiated

- Continued improvements are still required to meet perceived customer demands in vehicular applications, in particular with respect to convenience, safety, and cost.

Current Research, Development, and Demonstration

RD&D Goals

- By 2010, develop and verify hydrogen storage systems with 6 weight-percent, 1,500 watt-hrs/liter energy density, and at a cost of $4/kWh of stored energy.
- By 2015, develop and verify hydrogen storage systems with 9 weight-percent, 2,700 watt-hrs/liter energy density, and a cost of $2/kWh of stored energy – and develop the associated technology.

RD&D Challenges

- Onboard hydrogen storage for transportation applications requires increased storage density, so that the volume and weight of storage systems can be reduced while providing range equal to that of a conventionally fueled vehicle, without compromising vehicle weight and performance. Technologies that meet performance (capacity, cycle life, charging/discharging kinetics, efficiency, etc.), safety and cost are required.
- Fundamental understanding of chemical and metal hydrides and carbon nanostructured materials as hydrogen storage media is needed to enable the efficient and timely development of storage systems that are inherently safe and more efficient and convenient than current systems.
- Research and development of advanced materials-based hydrogen storage systems – including chemical hydrides, metal hydrides, such as amides and complex metal hydrides, and carbon materials – needs to be broadened, with deployment of the resultant systems in prototype vehicles and/or at user sites.
- Thermal management, particularly for metal hydride systems, is critical to meet required refueling times. Efficiency and energy requirements to release hydrogen from storage systems must also be addressed.
- Production processes for materials-based technologies need to be developed and scaled-up with industry.
- Off-board regeneration efficiency for chemical hydrogen storage needs to be improved and life-cycle energy and environmental impact needs to be assessed.
- For the interim approach of physical storage, low-cost tanks that meet safety and performance requirements for high-pressure or cryocompressed storage – as well as improved hydrogen compressors – are needed.
- Improved liquefaction equipment that uses less energy to liquefy hydrogen compared to conventional processes (where 30%-35% of the energy contained in the hydrogen is required) could provide additional storage options for stationary applications and more energy-efficient and lower-cost transport of hydrogen by cryogenic liquid trucks.
- New hydrogen compression technology to improve reliability and reduce cost.

RD&D Activities

- The overall strategy of DOE's Hydrogen Program is to conduct a comprehensive and balanced program that includes mid- and long-term research and development of hydrogen production, storage, and utilization technologies; integrated systems and technology validation with close industry collaboration that develops, demonstrates, and deploys critical technologies emerging from research and development; and an analysis element that helps determine the performance and cost targets that technologies must meet to achieve the overall goals of the Hydrogen Program, as well as the specific project objectives determined by peer review.
- RD&D for DOE's Hydrogen Program is carried out by national laboratories, universities, and the private sector, including CRADA collaborations between industry and labs, and cost-shared industry-led efforts.

Recent Progress

- "Centers of Excellence" were established in FY 2005 with multiple Federal laboratory, industry, and university partners, focusing collaborative research in the three key areas of metal hydrides, chemical hydrogen storage, and carbon-based materials.
- High-pressure, composite storage tanks have been developed through the combined efforts of industry, national labs, and universities. Building on DOE-funded industry research, these tanks have been tested and certified, and are now being used in prototype hydrogen vehicles.

• A prototype complex metal hydride system for 1 kg of hydrogen was developed using sodium alanate ($NaAlH_4$) and provides a basis to investigate critical issues such as performance and thermal management. Sodium borohydride ($NaBH_4$) was demonstrated in a prototype vehicle, and efforts are underway to investigate regeneration efficiency of the spent fuel. • A novel thermal hydrogen compressor is being developed in an industry-led project. This compressor operates in conjunction with advanced hydrogen production technologies and improves the efficiency and economics of the compression and hydrogen utilization process. The thermal compressor is an absorption-based system that uses the properties of reversible metal hydride alloys to silently and cleanly compress hydrogen; hydrogen is absorbed into an alloy bed at ambient temperature; and, subsequently, is released at elevated pressure when the bed is heated with hot water. Compression energy can be supplied by waste heat or solar hot water.
Commercialization and Deployment Activities
• High-pressure tanks (up to 10,000 psi) have been demonstrated in prototype vehicles, and more than 1,500 have been built and tested. • Through a national laboratory and industry effort, a prototype cryocompressed tank was constructed and is being tested onboard a pickup. • An industry-led project is developing metal-hydride storage containers for use on scooters, wheelchairs, and other personal mobility products.