TECHNICAL EVALUATIONS OF DOE PROJECTS AND STORAGE DATABASE

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Abstract

This paper discusses the methodology and results of a series of nine technical analyses performed by Energetics during the time period April 2000 – April 2001. These site-visit-based analyses of hydrogen technology projects are the latest in a series of over thirty evaluations performed under contract to the DOE Hydrogen Program over the past five years. The results presented in this paper are general in nature; specifics are left to the individual reports on each project.

In addition, this paper discusses the development of a database of hydrogen storage projects. This database is meant to put in one place, information on all hydrogen storage projects, past and present, domestic and international, public and private. In addition, a second database was assembled that identified individuals who would find the storage database of use and interest – hydrogen stakeholders. A total of 112 hydrogen storage projects, and 493 stakeholders were identified in this ongoing process.

Introduction

The work being described here was performed under two different contracts. One involves technical analysis of currently funded DOE/H_2 projects. The second focuses specifically on hydrogen storage technologies. Both of them involve performing on-site technical analyses for the benefit of hydrogen stakeholders. The first contract called for ten site-visit analyses to be performed during the first year of the contract (July 2000-July 2001). The second called for three site visits to storage-related projects, plus the additional development of two databases: one to identify hydrogen stakeholders and a second to identify hydrogen storage projects that have been performed over the last several years in the U.S. and abroad. This paper first discusses the total of nine site visits (six on one contract, three storage visits on the other) completed prior to the Annual Review, and then discusses the databases.

Technical Analyses

Background/Approach

For the past several years, Energetics has been performing site-visit-based technical analyses. The reports based on these analyses have provided hydrogen stakeholders with an in-depth view of research conducted at national laboratories, universities, and industry in support of the U.S. Department of Energy (DOE) Hydrogen Program. The reports have an extra benefit of providing to the Hydrogen Annual Peer Review Panels the type of in-depth, impartial, independent information that cannot be obtained in a 20-30 minute presentation at the Annual Peer Review.

Once a project is chosen for technical assessment, a literature review is performed on the subject. This includes a review of the last two or three years of Annual Operating Plan submittals, monthly reports, the Annual Review paper, reviewers' consensus comments from the past few years, publications in journals by the research group, and journal publications on the same or similar topics by other researchers. The Principal Investigator (PI) is then contacted, and an on-site visit is arranged. A set of topic questions or discussion points is then drawn up and sent to the PI one to two weeks prior to the visit. These questions form the basis for a major part of the discussion during the site visit.

During the site visit a tour is requested, preferably with a demonstration of the experimental process(es) as well as a presentation by the PI on the project and its status. The visit also includes discussions based on the topic questions and any other issues that may result from the tour, demonstration, and presentation. The on-site visit may last from a half-day to over a full day. Following this, Energetics prepares a detailed report, which is made available to the public.

Assessments Performed

By April 2000, Energetics had performed a total of 19 site visits/technical evaluations of hydrogen R&D projects. These projects are shown in Table 1.

Table 1. Technical Assessments Performed Prior to April 2000

Project	Performing Laboratory	Date of Visit
Enzymatic Conversion: Biomass-Derived Glucose to Hydrogen	Oak Ridge National Laboratory	Feb. 1996
Hydrogen from Catalytic Cracking of Natural Gas	Florida Solar Energy Center	Feb. 1996
Hydrogen Manufacture by Plasma Reforming	Massachusetts Institute of Technology	April 1996
Photovoltaic Hydrogen Production	U of Miami	May 1996
Hydrogen Storage in Carbon Nanofibers	Northeastern U	Dec. 1996
Carbon Nanotubes for Hydrogen Storage	National Renewable Energy Laboratory	June 1997
Storage and Purification of Hydrogen Using Ni-coated Mg	Arthur D. Little, Inc.	June 1998
Hydrogen Transmission and Storage with a Metal Hydride Organic Slurry	Thermo Power, Inc.	June 1998
Thermal Management Technology for Hydrogen Storage	Oak Ridge National Laboratory & Materials and Environmental Research, Inc.	August 1998
Improved Metal Hydride Technology	Energy Conversion Devices, Inc.	August 1998
Hydride Development for Hydrogen Storage	Sandia National Laboratories (CA)	Sept. 1998
Biomass to Hydrogen via Fast Pyrolysis and Catalytic Steam Reforming	National Renewable Energy Laboratory	Dec. 1998
Hydrogen Separation Membrane Development	Savannah River Technology Center	March 1999
Hydrogen Production by Photosynthetic Water Splitting	Oak Ridge National Laboratory	March 1999
Bioreactor Project	University of Hawaii	July 1999
Insulated Pressure Vessels for Cryogenic Hydrogen Storage	Lawrence Livermore National Laboratory	September 1999
PEM Fuel Cell Stacks for Power Generation	Los Alamos National Laboratory	January 2000
Hydrogen from Biomass in Supercritical Water	University of Hawaii	March 2000
Hydrogen Storage Tank Liners	Lawrence Livermore National Laboratory	March 2000

During the period between the FY 2000 and FY 2001 Annual Peer Review, Energetics performed a total of nine technical evaluations based on site visits. These are listed in Table 2.

Table 2. Technical Assessments Performed April 2000 – April 2001

Project	Performing Laboratory	Date of Visit	
Hydrogen Storage in Metal Hydride Slurries	Thermo Technologies	August, 2000	S
Conformable Tanks for Hydrogen Storage	Thiokol	September, 2000	S
Solar Photocatalytic Hydrogen Production From Water Using A Dual Bed Photosystem	FSEC	September, 2000	T
Production of Hydrogen Through Electrolysis	Proton Energy	December, 2000	T
Plasma Reforming	MIT	December, 2000	T
Carbon Nanotube Materials for Hydrogen Storage	NREL	February, 2001	T
Hydrogen Composite Tank Program	Quantum (IMPCO)	February, 2001	S
Maximize Photosynthetic Efficiencies and H_2 Production In Microalgal Cultures	University of California, Berkeley	February, 2001	T
Low-cost Reversible Fuel Cell System	TMI	March, 2001	T

T = Performed under contract DE-FC36-00GO10602 (Technical Analysis of Funded Projects)
S= Performed under contract DE-FG03-00SF22103 (Comprehensive Summary of Hydrogen R&D Technologies—Storage)

Results/Conclusions

A compilation of the individual reports will shortly be made available. For the purpose of this paper, we will make some general observations:

- Many of the laboratory-scale projects are in great need of independent laboratory measurements. This has been true for a long time, especially in cases where product is limited and claims are great. Researchers are sometimes reluctant to provide material to others, citing, among other things, a potential loss of competitive edge to the tester, skepticism in the tester's ability to handle the material properly to get accurate results, or the lack of sufficient material to spare.

Based on what we've seen and heard during the site visits, we believe that we need to overcome these objections and perform independent testing. Lack of sufficient material should not be an excuse. If there is only enough material for one measurement, it should be done by the independent laboratory. If the PI has issues with the independent laboratory, then the PI should be on-site for the test. The mechanism has to be satisfactory to all – but a mechanism is needed.

- Several of the PIs are concerned by what they feel to be inequalities with how their work is viewed. At more than half of the site visits, PIs expressed concern with matters such as: other organizations taking over their projects, being peer reviewed by competitors, and having tests and measurements being run by competitors. The disruption of research due to on-again, off-again funding is another complaint.

- The average researcher in the laboratory still (as last year) does not have a clear concept of: what the DOE Hydrogen Program direction is, who's who in the program and related DOE programs, where the overall hydrogen community stands, etc. (Example: one PI was unaware that the old DOE Office of Utility Technologies (OUT) had become the Office of Power Technologies (OPT) over a year earlier).

  This year the researchers were given a rare opportunity. Due to an earlier cancellation, the Hydrogen Technical Advisory Panel (HTAP) Spring Meeting was held immediately before the Hydrogen Annual Peer Review Meeting. As a result, Peer Review attendees who came a day earlier were able to attend the HTAP meeting and get a better understanding of what the hydrogen community is thinking (in last year's Annual Review presentation we had recommended that PIs attend HTAP whenever possible). The HTAP meeting was better attended than ever, but a number of PIs had not gotten the message about the schedule change.

- Pressurized hydrogen storage tanks are a reality. Many of the questions about safety, cycling, and aging – areas that have been of great concern – are being answered. It appears that these pressurized tanks will fulfill at least the near-term requirements for on-board hydrogen storage.

- Progress, albeit slow, is being made on many of the long-term technologies being researched by the Program – the "pure hydrogen" aspect. These are, basically, the photobiological and photoelectrochemical hydrogen production technologies and the carbon nanotube hydrogen production technology (hydride storage is likely in a shorter timeframe).

  During the year Energetics had a chance to investigate some of these projects. Put simply, without dwelling on the individual projects, to maximize the chances of success, more needs to be done. There is now a second nanotube project; perhaps there needs to be even more. We are learning that there is much in this area that we did not (and do not) know. In the photobiology area, three laboratories are collaborating (to a degree) on different aspects of using mutants of the alga *Chlamydomonas reinhardtii* to develop water-splitting, hydrogen-producing (on a commercial scale) organisms. Perhaps, a second group could be identified that could go down a different research path.

Regardless, one thing is known. The goal of the hydrogen production from water research must be to make hydrogen; the goal of the hydrogen in nanotubes research must be to store hydrogen. The rest of us must have patience.

- Many of the projects are encouraged to (or obligated to) engage in agreements with non-Federal partners. This has the very positive results of leveraging money, building the technical knowledge base through collaboration, and increasing the overall hydrogen stakeholder base. However, PIs point out the negative aspects as well. It is hard to work for two masters. Partnering often results in a redirection (or even a misdirection) of the intended research.

Databases

Background

DOE has been funding research on various hydrogen storage technologies for many years. The U.S. government, however, is just one of the many entities interested in pursuing these technologies. Many domestic and international corporations, universities, and governments are interested in the advantages hydrogen storage can provide. During FY 2001, Energetics developed a database of the research that has been or is being conducted on hydrogen storage technologies. This database is meant to gather together, all hydrogen storage projects, past and present, domestic and international, public and private. In an effort to identify the hydrogen community to whom this information should be imparted, Energetics also put together a database of hydrogen stakeholders.

Methodology

Two linked Microsoft Access databases were created to store the stakeholder and storage information. The stakeholder database includes the information on hydrogen stakeholders from academia, industry, utilities, project developers, and state and local officials. The information was obtained from attendee lists at such meetings as the Annual Hydrogen Peer Review Meeting, the Annual National Hydrogen Association Meeting, and the semi-annual Hydrogen Technology Advisory Panel Meeting. These were augmented by mailing lists from meetings on related topics such as fuel cells, wind, biomass energy, and photovoltaics as well as Internet searches.

The storage database was created to store the information on hydrogen storage technologies. This database is linked to the stakeholder database to allow for the easy connection of a stakeholder's contact information with details of their research project. The hydrogen storage projects were separated into three types of technologies: carbon structures, hydrides, and physical storage. Information on the storage technologies came from:

- U.S. DOE Hydrogen Program
- Activities from other government agencies
- University and private research (where available)

- International activities as determined from the International Energy Agency (IEA) Hydrogen Implementing Agreement Annexes on storage and on integrated systems
- Internet resources

The stakeholder database contains contact information for 493 domestic and international members of the hydrogen community. These stakeholders can be sorted according to the type of research they are or have been involved in (e.g., production, storage, utilization, validation, analysis and outreach). Each stakeholder has been designated as industry, academia, or government. Other information such as whether the stakeholder is an HTAP member, or former HTAP member is also included. These designations allow for additional sorting options.

A total of 72 research institutions have been identified as conducting studies on hydrogen storage. These institutions are located in 16 different countries (see Table 3) and are responsible for 112 hydrogen storage projects. Just under half of all the hydrogen storage projects that we have identified have been conducted within the U.S. Germany represents the next highest country, accounting for 22% of all research on hydrogen storage technologies. The storage medium being studied the most is hydrides (47%), followed by physical storage devices (30%).

Table 3. Hydrogen Storage Projects by Country and Storage Medium

Country	Carbon Structures	Hydrides	Physical Storage	Total
Australia		1		1
Belgium			1	1
Bulgaria		1		1
Canada		3		3
China	1			1
Denmark			1	1
Finland		2		2
France			2	2
Germany	1	14	10	25
India		1		1
Japan	1	3	2	6
Russia		1		1
Switzerland	1	4		5
UK		1		1
Ukraine		1		1
USA	19	19	11	49
Unknown	2	2	7	11
Total	25	53	34	112

Research on hydrides as a hydrogen storage medium dates back to 1974 when the Public Service Electric Gas Company in Newark, NJ, investigated the possibilities of using hydrogen during peak demand periods. From then on, research was conducted on hydrides to serve in both stationary and vehicular applications. The stationary applications considered are for utility primary power and peak-shaving applications as well as stand-alone solar and wind power applications. The vehicles range from mining vehicles to buses.

The database includes 25 research projects on carbon structures. The majority of these are directed towards hydrogen adsorption onto carbon nanofibers (see Table 4). For the purposes of this database, fullerene hydrides have been considered as a carbon structure. These projects could also be classified as hydrides, but due to inherent differences between typical hydrides (using metals) and these studies (using carbon) we choose to identify them as carbon structures.

Table 4. Hydrogen Storage Research by Storage Medium and DOE Funding

Storage Type	Total	DOE Funded
Activated carbon	2	1
Fullerene	3	1
Fullerene hydride	2	2
Nanofiber	4	3
Nanotube	12	2
Nanotube & carbon slit pores	1	
Undefined	1	
Metal hydride	52	8
Metal hydride for hydrolysis	1	1
Compressed gas	21	7
Compressed gas – liquid compressed cryogenic.	1	1
Liquid compressed cryogenic	12	
Total	112	26

Physical storage technologies are by far the most developed form of hydrogen storage. As with all types of hydrogen storage, research is currently being done to increase the percent weight and/or volume of hydrogen while lowering the total weight of the system.

Fifteen different organizations, shown in Table 5, have been identified as funding research on hydrogen storage technologies. The U.S. DOE is recognized as supporting just less than one quarter of all the storage projects included in the database. The majority of the funding agencies are international organizations and governments.

The stakeholder and storage databases will shortly be available for stakeholder use.

Table 5. Agencies Funding Hydrogen Storage Research

Domestic	International
Army Research Office	Aventi Res. & Technol
Augusta-Richmond County Public Transportation	AVL LIST GmbH
Honda R&D Americas, Inc	Bavarian State Ministry for Economic Affairs, Transport and Technology (BstMWVT)
National Science Foundation	BRUKER Analytischer Messyechnik GmbG
Petroleum Research Fund of the American Chemical Society	European Commission (EC)
U.S. Department of Energy and its National Laboratories	Free State of Bavaria public funds
	German Federal Ministry for Research and Technology
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