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TECHNICAL EVALUATIONS AND ANALYSIS OF CURRENTLY FUNDED PROJECTS AND DATABASE DEVELOPMENT

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Abstract

This paper discusses the methodology and results of a series of twelve site-visit based evaluations performed by Energetics during the time period May 2001 – April 2002. These site-visit-based analyses of hydrogen technology projects are the latest in a series of some forty evaluations performed under contract to the DOE Hydrogen Program over the past six 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 summarizes two feasibility analyses that Energetics performed during the Fiscal Year, and also discusses the development and updating of databases of or associated with hydrogen storage projects. The databases include descriptions of over 100 storage projects, including publications associated with the projects. In addition, a stakeholder database now includes information on some 800 stakeholders. These databases have been uploaded to the Internet.

Introduction

The work being described here was performed under three different contracts. One, under the Golden Field Office, involves site-visit evaluations of currently funded DOE/H_2 projects as well as some in-depth analyses The second under contract to the National Energy Technology Laboratory involves analyses and feasibility studies on certain niche markets and special topics as well as development and updating of databases. The third, under contract to Sandia National Laboratories (CA) is an economic feasibility analysis on the addition of hydrogen to mid-sized natural gas turbines, with an emphasis on lowering NO_x emissions. For the sake of better organization, rather than being divided on a contract basis, this paper will be divided into sections on Site-visit Evaluations, Analyses, and Databases.

Site-Visit Evaluations

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, <u>independent</u> 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 2001, Energetics had performed a total of 28 site visits/technical evaluations of hydrogen R&D projects. These projects are shown in Exhibit 1. During the period between the FY 2001 and FY 2002 Annual Peer Review, Energetics performed a total of twelve technical evaluations based on site visits. These are listed in Exhibit 2.

Results/Conclusions

The "official" site-visit reports are sent to the Golden Field Office, and any request for individual reports must be processed through them. However, we are in the process of compiling all site-visit reports through July 2001 (a total of 32 site-visits) into one volume, which we plan to post in pdf form on the Internet at the eren website. We plan for this to be available by the end of the summer of 2002. As in the past, we are not publishing the results of the individual site-visits in this present report. We will, however, make some general observations:

- There has been a large increase in the past couple of years in the number of well-designed projects aimed at small-scale (distributed) hydrogen production. Most, but not all, of these are based on reforming of natural gas. Most of these are proceeding very nicely. This is addressing an important option in the building of a hydrogen infrastructure.

- Some hydrogen production projects are focusing on system optimization rather than on maximization of hydrogen production. While maximization of hydrogen production should be paramount for many of the long-term high-risk hydrogen from water projects, this is not the case for the reforming projects. Here, focusing on system optimization is a good thing.

- We still have some issues with laboratory measurements of material properties. Proprietary issues are important, but affirmation of whether a material has certain desired properties or not can reflect on the entire direction of the overall Program. Independent laboratory measurements are a necessity. The originating research organization can and should be part of the measuring team, and should be on site for the measurement, but the independent measurement must take place.

- Separation and purification issues are extremely important for many production technologies. They are, however, not currently the focus of many projects – even when they should be. In all cases where the hydrogen product is being fed to a fuel cell, CO and sulfur removal prior to use is essential. There are also many projects being undertaken in the Program where the production of hydrogen itself, its compression and/or its storage is highly dependent on the purity of its feedstock. These purification issues are being, if not completely ignored, at least pushed aside in several cases. Purification could become the showstopper for some of these projects, and it's something that should be learned sooner rather than later.

- Some PIs are still having difficulty with understanding the programmatic workings of the overall Program. As a result, they may be remiss in properly adhering to schedule in progress and deliverables as well as other miscommunications. This problem seems as ongoing today as it was in other years (Reference 1) when it was commented upon in our reports.

- On the other hand, knowledge of other projects and even collaborations seem to be on the upswing.

Exhibit 1. Technical Assessments Performed Prior to April 2001

Project	Performing Laboratory	Date of Visit
Enzymatic Conversion: Biomass-Derived Glucose to Hydrogen	Oak Ridge National Laboratory	February 1996
Hydrogen from Catalytic Cracking of Natural Gas	Florida Solar Energy Center	February 1996
Hydrogen Manufacture by Plasma Reforming	Massachusetts Institute of Technology	April 1996
Photovoltaic Hydrogen Production	University of Miami	May 1996
Hydrogen Storage in Carbon Nanofibers	Northeastern University	December 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)	September 1998
Biomass to Hydrogen via Fast Pyrolysis and Catalytic Steam Reforming	National Renewable Energy Laboratory	December 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
Hydrogen Storage in Metal Hydride Slurries	Thermo Technologies	August 2000
Conformable Tanks for Hydrogen Storage	Thiokol	September 2000
Solar Photocatalytic Hydrogen Production From Water Using A Dual Bed Photosystem	Florida Solar Energy Center	September 2000
Production of Hydrogen Through Electrolysis	Proton Energy	December 2000
Plasma Reforming	Massachusetts Institute of Technology	December 2000
Carbon Nanotube Materials for Hydrogen Storage	National Renewable Energy Laboratory	February 2001
Hydrogen Composite Tank Program	Quantum (IMPCO)	February 2001
Maximize Photosynthetic Efficiencies and H2 Production In Microalgal Cultures	University of California, Berkeley	February 2001
Low-cost Reversible Fuel Cell System	Technology Management, Inc.	March 2001

Exhibit 2. Technical Assessments Performed May 2001 – April 2002

Project	Performing Laboratory	Date of Visit
Vehicular Hydrogen Storage Using Cryogenic Hydrogen	Lawrence Livermore National Laboratory	May 2001
Hydrogen Internal Combustion Engine Research	Sandia (CA) National Laboratory	May 2001
Thermal Dissociation of Methane Using Solar Coupled Reactor	University of Colorado/National Renewable Energy Laboratory	June 2001
Biological H_2 From Fuel Gases and Water	National Renewable Energy Laboratory	July 2001
Gallium Nitride Integrated Gas/Temperature Sensors for Fuel Cell System Monitoring for Hydrogen and Carbon Monoxide	Peterson Ridge LLC/ Fluence	September 2001
Supercritical Water Partial Oxidation	General Atomics	November 2001
Hydrogen Commercialization for the 21st Century	SunLine Services Group	November 2001
Thermocatalytic CO_2-Free Production of Hydrogen From Hydrocarbon Fuels	Florida Solar Energy Center	February 2002
High-Efficiency Steam Electrolyzer	Lawrence Livermore National Laboratory	February 2002
Thermal Hydrogen Compression	Ergenics, Inc.	March 2002
Microchannel Reforming	InnovaTek	April 2002
Superadiabatic Decomposition of Hydrogen Sulfide	Gas Technology Institute	April 2002

Analyses

As stated above, Energetics has been conducting techno-economic analyses on a number of processes. Two of these have been completed and will be summarized here; three others are in progress.

Non-Recycling Hydride Systems for Powered Wheelchairs

Over the past few years there have been many hydrogen projects based on the use of hydrolysis hydrides to store and/or produce hydrogen. These are materials (e.g., LiH, NaH, MgH_2, CaH_2, $NaBH_4$, etc.) which upon addition to water will release hydrogen either in a controlled manner, or in one that can be made controlled by limiting the amount of contact between the hydride and the water. The production of hydrogen from these hydrolysis hydrides is generally considered to be irreversible. At the very least, the regeneration of the hydride from the byproduct hydroxide is highly endothermic, inefficient, and expensive. If the use of these hydrolysis hydrides occurred in a large market (e.g., passenger automobiles) disposing of the byproduct (potentially incurring toxic disposal fees), or trying to sell it (flooding small markets) in lieu of recycling it would likely also be untenable. Energetics therefore considered identifying scenarios where a niche market may exist where the byproduct would be produced in lesser amounts and may indeed be salable.

We thus performed an analysis on the use of an hydrolysis hydride, namely sodium hydride, as a hydrogen source for a fuel-cell for a power wheelchair. Results of this analysis are summarized in Exhibit 3. The cost of the hydride/fuel cell wheelchair power system is considerably higher than the battery system at today's costs, and would likely project to still be somewhat more expensive than batteries in the future (unless sodium hydride costs come way down). However, considerable benefit could be realized by the hydride/fuel cell wheelchair user in a system that was much lighter weight, took up less space, and was more flexible in how it could be used. The flexibility issue is most important for users whose daily routine was more varied – users who might use the wheelchair to travel widely diverse distances from day to day. Such diversity is difficult for battery-powered wheelchair users who have to deal with the problems of keeping the battery optimally charged, not to mention the charging time and the need to keep back-up batteries.

Exhibit 3. Comparison of Sodium Hydride/Fuel Cell Systems with Lead-Acid Batteries for Use in Power Wheelchairs

Parameter	Battery System	Hydride (Very Active User)	Hydride (Less Active User)
Volume	954 in2	129 in2	122 in2
Weight	34.1 kg	2.2 kg	2.0 kg
Yearly Cost	$284	$1891 (now) $507 (future)	$1025 (now) $334 (future)

Details of this analysis are found in Reference 2.

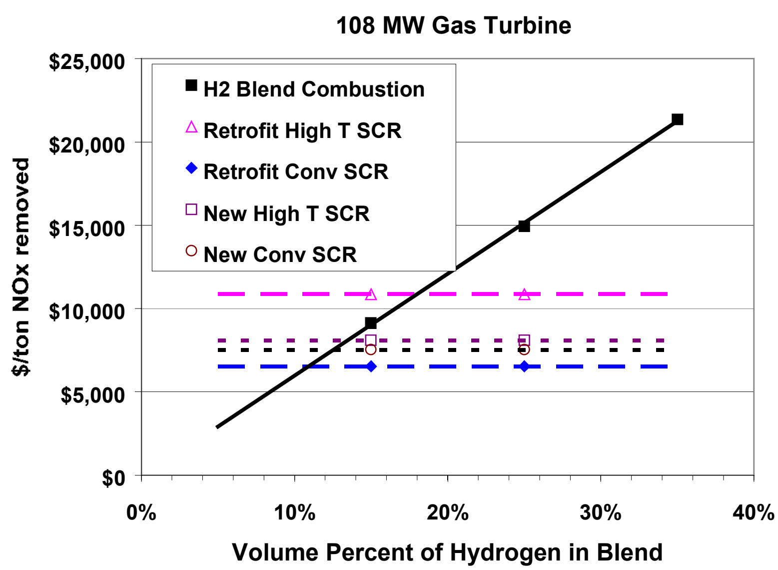
Hydrogen Addition to Mid-sized Gas Turbines

Researchers at Sandia (CA) National Laboratories have been addressing the issue of increasing flame stability and decreasing emissions from mid-sized turbines (nominally 30-150 MW) by blending hydrogen into natural gas, and burning the mixture in a lean, premixed mode (Reference 3). Energetics in conjunction with this has conducted a techno-economic analysis on the feasibility of using this process commercially in lieu of standard processes for reducing NO_x emissions.

In this analysis, the use of hydrogen in blends of 10-40% with natural gas is compared as a reducer of NO_x to a state-of-the-art process involving pre-mixing the air and fuel (dry-low NO_x or DLN process) with post combustion reduction of NO_x using ammonia and a catalyst (Selective Catalytic Reduction or SCR). The comparison involves results for both new and retrofitted turbines, and includes both high temperature, simple cycle units and combined cycle units. DLN/SCR can reduce NO_x to about 3 ppm for combined cycle units and to 5 ppm for the high temperature units.

The comparison between DLN/SCR in new and retrofit, simple and combined cycle units and the use of hydrogen blend for 108 MW turbines (about in the middle of the range being studied) is shown in Exhibit 4. The results are shown in terms of the cost of removing NO_x. Estimates from Sandia indicate that about 3 ppm NO_x can be achieved with a 15/85 hydrogen/natural gas blend. The cost of NO_x reduction is therefore comparable for DLN/SCR and hydrogen blending. Details can be found in Reference 4.

Exhibit 4. The Cost of NO_x Removal in a Mid-size Turbine, Comparing Hydrogen Blending with DLN/SCR



Other Analyses

Energetics is currently completing a feasibility study of the use of a combination of a solar thermal reactor and a steam reformer to optimize the production of hydrogen at refueling stations. The solar thermal system, developed by the University of Colorado and NREL (Reference 5), generates hydrogen and carbon black from natural gas. The premise for the feasibility study is to show whether overall cost reductions could be realized from combining the two systems in certain climates. Preliminary results are indicating that if heliostats can be purchased for less than $\$75/m^2$, and carbon black can be sold for at least $1.25/kg, the combined system appears to be feasible in a locale like Phoenix. If the heliostat cost were lowered to $\$50/m^2$, Miami could be a feasible location as well. Work on this analysis is continuing.

Energetics is also performing comparative evaluations on:

- Solid oxide vs. high temperature PEM fuel cells, and
- Three different compressed hydrogen storage system concepts.

Databases

During FY 2001, Energetics developed a database of the research that has been or is being conducted on hydrogen storage technologies. This database was 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 (Reference 1).

During the current reporting period, Energetics updated the two databases, added a third database on storage publications, and linked all three databases. We are currently developing an analogous hydrogen utilization database, and are continuously updating all of the others. There are currently some 800 entries in the stakeholder database, and over 100 each in the storage projects and publications databases.

We have uploaded pdf versions of the databases to the eren hydrogen website. (We chose pdf versions to avoid inadvertent changes to the data that might occur with an open database.) The Storage Database can be found at http://www.eren.doe.gov/hydrogen/infra.html, the Publications Database can be found at http://www.eren.doe.gov/hydrogen/publications.html, and the Stakeholder database can be found at http://www.eren.doe.gov/hydrogen/program.html.

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