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**HYDROGEN SYSTEMS ANALYSIS, EDUCATION,
AND OUTREACH**

Annual Report for the Period
August 1996 - September 1997

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**Annual Report for
Golden Field Office
DE-FC36-96G010170
Period of Performance:
August 16, 1996 - October 31, 1997**

**Introduction and Summary
Hydrogen Systems Analysis, Education, and Outreach Activities
Performed by SENTECH, Inc.
FY 1997**

Under cooperative agreement DE-FC36-96G010170, the set of activities performed by SENTECH, Inc. addressed the specific recommendations provided to the Department of Energy (DOE) by its advisors, including the Hydrogen Technical Advisory Panel and the review panel members of the DOE Annual Hydrogen Program Review. SENTECH's efforts were conducted under five tasks:

- Task 1: Technology & Process Analysis
- Task 2: Hydrogen Information Development & Transfer
- Task 3: Educational Products
- Task 4: Systems Analysis
- Task 5: Life Cycle Costs

SENTECH activities were executed in two broad areas -- analysis and technology transfer. The analytical tasks undertaken in FY97 were focused on two types of analysis - systems analysis and technical/economic assessments. These analytical activities benefit DOE by providing data that allow it to define the strategic goals of the hydrogen R&D program. By collecting analysis of the energy efficiency, environmental externality, and economic competitiveness factors of hydrogen energy systems, DOE is able to determine the potential impacts of these systems. The technical/economic assessments and process analyses looked at component technologies and their relative merits in different hydrogen energy system configurations. Together these analyses provide important information on factors affecting program direction.

The technology transfer activities conducted by SENTECH were aimed at disseminating technical information generated by the program to stakeholders in industry and the public. The tasks fall into two categories -- electronic/print media communications products and educational products. The first category focuses on getting information to industry while the second category of activities was targeted to middle and high school students and their teachers. The goal of both these efforts was to disseminate the appropriate technical information to different audiences in formats facilitating the understanding of the merits and potential of hydrogen. Many of these activities were implemented in close

collaboration with ongoing public awareness and educational activities performed by the DOE laboratories.

Detailed summaries of all deliverables, including significant findings under Tasks 1-5, are included in the sections that follow, which are organized by the subtasks listed below :

- Task 1: Technology & Process Analysis
 - Task 1.1: Assessment of Hydrogen Energy Technologies
 - 1.1a: Technical Evaluations
 - 1.1b: Process Studies
 - 1.1c: Technical Database
 - Task 1.2: Comparison of Hydrogen as an Energy Storage Medium for Electric Utility Applications

- Task 2: Hydrogen Information Development & Transfer
 - Task 2.1: Communications Products
 - Task 2.2: *Mission H₂* Interactive Multimedia Product

- Task 3: Educational Product

- Task 4: Systems Analysis

Task 1: Technology & Process Analysis

1.1(a): Technical Evaluation Reports

Hydrogen Storage in Carbon Nanofibers

Northeastern University - A review was conducted of the research being performed by Drs. Baker and Rodriguez at Northeastern University. They are working on a storage process that claims to retain 5.8 liters of hydrogen per gram of carbon. The recommendation of this evaluation is for the researchers to perform a proof-of-concept study that characterizes the cyclic sorbency of select fibers, demonstrates their reproducibility, and shows the operation of a small prototype system.

Hydrogen Storage in Carbon Nanotubes

National Renewable Energy Laboratory - A review was conducted of the research being performed by Dr. Mike Heben of the National Renewable Energy Laboratory (NREL). Dr. Heben is examining the development of carbon nanotubes for use in the on-board storage of hydrogen in vehicles. The goal of this research is to increase single walled nanotube (SWNT) production and concentration. Using a laser vaporization process, the research has made significant progress in increasing the production of nanotubes over the past year. The former production process, arc discharge, generated only .05 percent SWNTs and the current process, based on Dr. Smalley's method at Rice University, produces 60-90 percent SWNTs. Continued work is needed, however, to address the lack of hydrogen adsorption in the laser produced tubes.

1.1(b): Process Studies

Process Study: Analysis of the HBr-based Hydrogen Production Process

The SRT Group Inc. - The purpose of this analysis was to develop a cost model for water and hydrogen bromine (HBr) electrolysis systems. Compared to conventional water electrolysis, HBr electrolysis uses 25 percent less electricity per unit of hydrogen produced. However, equipment costs and operation and maintenance costs are higher for the HBr process. This analysis found that, in most cases, steam methane reforming would be preferred, if electricity costs are low.

The Dual-Bed Hydrogen Production Process

Florida Solar Energy Center - The purpose of this analysis was to evaluate and quantify the trade-offs presented by the dual bed process and determine if that process holds economic potential as a hydrogen production technology. Dual bed production of hydrogen was determined to have the potential of achieving solar efficiencies comparable to other

direct solar conversion approaches; however, further investigation into loss mechanisms is needed to confirm that potential.

1.1(c): Technical Database

First Interim Report: Status of the Development of the Methodology for a Technical Database - This report details the activities undertaken to develop a database maintaining information on the technologies being supported by the DOE Hydrogen Program. A series of meetings were held between June and July of 1997 to acquire feedback from the program analysts on ways to structure the system for enhanced value. However, those discussions led to consensus among the program analysts that such a system may have only limited value to them. Decision on further actions to be taken on the database was referred to the Program Management.

2nd Interim Report (Final FY97): Status of the Development of the Methodology for a Technical Database - This report states that the value of a static database was questioned by the program analysts. After consultations with the Program Management, it was decided that a technical database could be of value to the program, but that it was not a priority for FY98.

1.2: Hydrogen as an Energy Storage Medium for Electric Utility Applications

Electric Utility Applications of Hydrogen Energy Storage Systems - This report analyzes the various applications of energy storage systems for electric utility applications and appraises the suitability of different storage technologies to meet those needs. For the analyzed applications -- load leveling and "firming" of intermittent renewable resources -- battery energy storage is cited as the closest competitor to hydrogen energy storage systems out of those technologies examined in the study.

Task 2: Hydrogen Information Development and Transfer

2.1: Communications Products

Hydrogen Consensus Meeting Agenda Development - This meeting, conducted in February 1997, addressed programmatic strategies for expanding activities of the National Hydrogen Program for FY98.

Hydrogen Outreach Activities in FY97 - This summary document described the outreach objectives for FY97 in three categories;

communications, commercialization, and education. Key tasks in each area were recommended.

Hydrogen Websites - A summary of hydrogen websites was compiled as an adjunct to the maintenance and updating of the Hydrogen InfoNet website.

State Write-ups on EERE Funded Projects - In response to a request from Program Management (HQ), abstracts were compiled by State on activities carried out by the program. Approximately 43 abstracts were completed on projects funded by the program.

Secondary School Invitational - A high school program was organized to convey to students that science can be fun and fulfilling. The main feature of the program was the "Dr. Bob Show" where hands-on chemistry experiments using such objects as liquid nitrogen, dry ice, and neon lights were used to reinforce the chemical properties of hydrogen. A panel of speakers promoting careers in science and engineering called *Career Opportunity of a Lifetime (COOL)*, made up of practitioners, former students and current students in the field was assembled at the meeting.

A variety of materials was also produced in support of the second annual Secondary School Invitational at the National Hydrogen Association Annual Meeting, such as color brochures, stickers, presentations and awards. Student handouts containing hydrogen-related information were prepared and distributed in a folder together with the program agenda. Students also received a personal certificate of award, acknowledged by the US Department of Energy, to recognize their participation in the program. Specific deliverables for this activity include:

- *Certificate of Attendance for Students at the Dr. Bob Show*
- *Hydrogen for the Future. The Dr. Bob Show, March 12, 1997, Presentation*

Technology Validation Projects Fact Sheets - To publicize some of the newer technology validation projects, a series of one-page fact sheets were written and produced for each of the industry cost-shared partnerships within the DOE Hydrogen Program including a Hydrogen Program Overview fact sheet.

2.2: CD-ROM Multimedia Product

Mission H₂ CD-ROM Project Prospectus for Corporate Sponsorship - A prospectus was prepared that outlines expected plans for completing the CD-ROM for classroom use, publicizing it to target audiences, packaging

the final product with instructional materials, and distributing the final Mission H₂ package. The prospectus includes preliminary research into educational distribution channels, identifying related publications and media outlets for product promotion.

Mission H₂ CD-ROM Project Overview Presentation to HTAP - An overview of the CD-ROM Project was prepared and delivered at the September 1997 HTAP Meeting.

Mission H₂ Factsheet - A factsheet on *Mission H₂* was developed in a question and answer format to be used by the National Hydrogen Association at their display at the solar event held on Capitol Hill by the House Renewable Energy Caucus in the Spring of 1997.

Task 3: Educational Products

Hydrogen Education Outreach Progress Report, January - March 1997 - The primary focus of the Hydrogen Program Education Outreach activity is the development of a curriculum module for high school students. A significant support activity for the first calendar quarter of 1997 was the preparation and participation in the *Secondary School Invitational* at the National Hydrogen Association Annual Meeting. Plans for the next quarter included development of *Clean Corridor* hydrogen curriculum module. The curriculum module is based on a core of "need to know" hydrogen material. Units will provide information on hydrogen in transportation, utility power, industry, photoelectrochemistry, and photobiology.

Clean Corridor Hydrogen Curriculum Module - The core unit and 6 supporting units with mini-problems were preliminarily outlined for use in the Hydrogen Curriculum Module. Laboratory experiments and exercises were identified for the module.

Hydrogen Education Outreach Progress Report, April-June 1997 - Continued efforts at developing a high school curriculum module on hydrogen included the preparation of a proposed draft section and its submission to the American Chemical Society (ACS) for review, drafting of a memorandum of understanding between DOE and ACS for ongoing cooperation, and dialogs with ACS about including the hydrogen module in their *SciTeKs* series. In addition to these activities, discussions were also held with the National Science Foundation (NSF) to explore their possible involvement in the development of the module.

Hydrogen Education Outreach Progress Report, July-September 1997 - Redirection occurred in the hydrogen curriculum project during this

quarter. ACS could no longer commit to assisting in the development and inclusion of the module in the *SciTeKs* curriculum. As a result, the focus shifted toward pursuing NSF support through their grant solicitation process. In preparation of that process, a Hydrogen Technology Education Consortium (HyTEC) was formed to undertake the design and implementation of an expanded curriculum to be proposed to NSF.

Task 4: Systems Analysis/IEA Support

Interim Report: Status of the International Energy Agency Annex 11 Subtask B. April 1997 - The April 1997 Interim Report describes the status of efforts being carried out by Member Nations to support the International Energy Agency (IEA) Annex 11, Subtask B on Integrated Systems concerning Analytical Tools. The goal of the Annex is to identify, compile, and integrate models of hydrogen technology components into system models that will describe overall pathways. Completed component models that were delivered as of April under Subtask B include: coal gasification, biomass gasification, biomass pyrolysis, high pressure pipeline, and low pressure pyrolysis.

2nd Interim Report: Status of the International Energy Agency Annex 11 Subtask B. July 1997 - The July 1997 Interim Report describes the status of efforts being carried out by Member Nations to support the International Energy Agency (IEA) Annex 11 Subtask B on Integrated Systems concerning Analytical Tools. The goal of the Annex is to identify, compile, and integrate models of hydrogen technology components into system models that will describe overall pathways. Aspen Plus® was selected as the modeling software. Component models have been developed for 13 technologies (e.g., coal gasification, biomass gasification, chemical storage, and liquefaction).

3rd (and Final) Interim Report: Status of the International Energy Agency Annex 11 Subtask B - The report states that following the Stuttgart meeting, modeling of various components was assigned to teams. Component models have been developed for 13 technologies. Four additional technologies are detailed in this report, including the first utilization model (proton exchange membrane fuel cells).

Task 5: Life Cycle Costs

5.1(a) and (b): Literature Survey and Feasibility of Ion Transport Membranes for Partial Oxidation Reforming

Hydrogen Production Cost - A Survey - This report examines the processes and production economics of each of the commercially available hydrogen production systems. A model was created to compute various cost components in different hydrogen production technologies. The model also was used to establish a realistic price for hydrogen manufactured by each technology. A series of sensitivity analyses were performed to evaluate the effect of production cost to the variation in constituent costs. The analysis determined that production costs of hydrogen were the lowest for steam reformation of natural gas. The cost of production for technologies from least expensive to most expensive is as follows: partial oxidation of fuel oil, gasification of coal, gasification of biomass, and electrolysis, the most expensive production option.