U.S. Department of Energy
Office Energy Efficiency and Renewable Energy

Solar Hydrogen Workshop

Final Report (May 5, 2005)

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Introduction

As the United States moves toward a hydrogen energy future, methods are being sought for large-scale production of hydrogen with renewable energy. The purpose of the Solar-Hydrogen Workshop was to bring together a group of experts from both the solar and hydrogen communities to examine potential pathways for cost-effectively producing hydrogen from solar energy, in both the mid- (i.e., by 2015) and long-term (i.e., by 2030) time horizons. While the emphasis of the workshop was on solar-hydrogen production via electrolysis pathways, several other pathways were also discussed, including solar-thermal and direct-conversion technologies.

The Solar Hydrogen Workshop was held on November 9-10, 2004 at the University of Maryland University College Inn and Conference Center in Adelphi, Maryland. It was hosted by the U.S. Department of Energy (DOE) Solar Energy Technologies (SET) Program in collaboration with the DOE Hydrogen, Fuel Cells & Infrastructure Technologies (HFCIT) Program. The primary goal of the workshop was to foster a more collaborative approach between these two DOE programs, as well as the broader solar and hydrogen communities. Through improved collaboration we hope to gain a better understanding of the technical and market potential of solar-hydrogen technologies, and to identify critical R&D pathways that will enable solar-produced hydrogen to play a significant role in the U.S. energy economy in the future.

For information, workshop presentations, and a record of the workshop's proceedings, please visit http://www.eere.energy.gov/solar/systems_driven_workshops.html. In addition, a CD has been included with this version of this report and will include all presentations and workshop materials.

Meeting Process

The Solar Hydrogen Workshop was composed of three sessions, conducted over two days, to explore the vision, current (analytical) thinking, and R&D pathways toward feasible and cost-effective solar-hydrogen production. The first session included overview presentations regarding the current state of analysis and technology development for solar hydrogen pathways. Presentations at the first session included basic technology status reviews for solar photovoltaics (flat-plate and concentrator), concentrating solar power, and direct photoelectrochemical hydrogen production. In addition, presentations on the technology status of hydrogen production included low- and high-temperature electrolysis, as well as a review of past and current analytic work in this area.

The second session involved small group discussions focused on particular market sectors (residential, commercial and distributed). During these breakout sessions, participants were led through facilitated discussion that focused upon solar-hydrogen in the mid-term (10-15years) and in the longer-term (20-30 years). Key topics addressed in the breakout sessions included:

1. Identification of potential solar-hydrogen systems
2. Definitions of key technologies for given markets/applications
3. Technological barriers and challenges
4. Identification of critical R&D pathways

The final session was devoted to summarizing the outcomes of the small group discussions, and to producing a set of recommendations for how the solar and hydrogen communities can work together to contribute to our future energy needs. Participants were also given the opportunity to comment on the proceedings and make suggestions for future meetings.

Workshop Findings

Workshop Objective: To convene a panel of experts and determine the principal pathways that offer the greatest technical and economic feasibility to produce significant quantities of hydrogen from solar energy, and determine the key research and development areas that need focus to make this a reality.

Session 1: Solar and Hydrogen Technology Status, Opportunities, and Analysis

The workshop began with welcome and opening remarks from Ray Sutula (SET Program Manager), Pete Devlin (HFCIT Hydrogen Production Tech Team Leader), and Jonathan Hurwitch (SENTECH, Inc.) who gave an overview of the purpose and objectives of the workshop. This was followed by technical presentations on the current status of the U.S. Department of Energy Solar and Hydrogen Programs, and industry-funded research, development, and deployment activities. Presentations were made covering current R&D pathways, market development requirements, infrastructure issues, and materials consumption requirements related to using solar energy for the production, distribution and use of hydrogen. Brief presentation abstracts are included below for each presentation. Compete versions of the presentations are included on the accompanying CD and at: http://www.eere.energy.gov/solar/systems_driven_workshops.html

Welcome and Opening Remarks

Dr. Raymond A. Sutula, Program Manger DOE Solar Energy Technologies Program
In his remarks, Dr. Sutula introduced the DOE Solar Program's mission, vision and high-level cost and technology goals. Dr. Sutula explained the way the DOE Solar program has organized itself through market-oriented, systems-analysis methodology, or the Systems-Driven Approach (SDA). In addition, the presentation covered the purpose and vision behind the Solar–Hydrogen Workshop in the context of the SDA and DOE cross-program activities.

Peter Devlin, Production Team Leader, DOE Hydrogen, Fuel Cells, and Infrastructure Technologies Program
As the Hydrogen Production Team leader, Mr. Devlin's presentation focused on the Hydrogen, Fuel Cell and Infrastructure Technologies (HFCIT) Program's perspective on solar-produced hydrogen. Details on HFCIT budgets, cost and technology goals, as well as challenges of the hydrogen economy were presented and discussed in context of Presidential Initiatives and national needs. The presentation ended with a review of current and out-year HFCIT activities and the posing of questions about the feasibility of solar-produced hydrogen.

Jonathan Hurwitch, (Meeting Facilitator) Senior Vice President, SENTECH, Inc.
Mr. Hurwitch presented a review of meeting objectives and purpose, and facilitated the introduction of workshop participants. In addition, he reviewed the structure and agenda

of the workshop. Finally, he introduced the breakout session questions and reviewed the process for: 1) Identifying potential solar hydrogen systems; 2) Defining key technologies for given markets/applications; 3) Defining technological barriers and challenges; and 4) Identifying critical R&D pathways.

Solar Technology Status and Opportunities

Solar Photovoltaics: Dr. James Loman, GE Energy- Solar Technologies

This presentation served as general overview for the status of photovoltaic technologies and current industry trends. Dr. Loman's presentation also provided an industry perspective on current and future R&D and market opportunities. The presentation covered the world energy landscape including PV and renewable technologies, the current state of the PV industry, General Electric's PV activities, and the long-term vision of the future for solar-hydrogen. In addition, the presentation provided real-world data on the status of PV markets and technology. Major points included a discussion of current shortages in supply for solar wafers and cells (which is causing prices to rise in the short-term), the trend toward thinner silicon wafers, the push for higher efficiencies, and movement towards advanced manufacturing and R&D concepts.

Concentrating Solar Power: Mr. Greg Kolb, Sandia National Laboratory

The presentation covered the current state of concentrating solar power (CSP) technologies. It began with a review of the three main CSP technologies: parabolic troughs, Stirling dish-engines, and solar power towers. Mr. Kolb described the major elements of trough systems (including the parabolic mirror dish collector, the receiver and the power block), Stirling dish-engines (consisting of a mirrored dish collector and Stirling engine), and power towers (consisting of a field of heliostat mirrors and a tower-mounted power block). The presentation continued to discuss the current application of CSP technologies throughout the U.S.A. and the world. Particular attention was paid to the potential for hydrogen produced via CSP electricity as well as a cursory mention of direct thermochemical processes. The potential for the technology was also discussed in the context of predicted energy use. Issues related to recent DOE programmatic budget cuts wee also presented. In conclusion, an overview of a detailed external analysis conducted by Sargent and Lundy of CSP cost-competitiveness was presented as evidence of the expanding potential for CSP technologies.

Hybrid Solar Concentrator for the Electrolytic Production of Hydrogen: Dr. Robert McConnell, National Renewable Energy Laboratory

This presentation summarized a DOE-funded university research project on the electrolytic production of hydrogen using hybrid solar concentrators. The process involves the use of heat and PV electricity to drive electrolysis, requiring only solar energy and water. The various, patented hybrid solar concentrator systems were summarized in the presentation. In addition, energy conversion efficiencies of solar-driven water splitting were presented with detailed cost figures. The results of the analysis indicate that there is a great deal of uncertainty about both the technology and economics of such systems. The potential for hybrid solar concentrators, however, could offer a technologic leapfrog to lower the cost of hydrogen production due to increased cell efficiencies and the utilization of thermal energy from the system. In conclusion, a future vision was presented that included conceptual images of hydrogen production facilities utilizing hybrid solar concentrators.

Direct Photoelectrochemical Production of Hydrogen: Dr. John Turner, National Renewable Energy Laboratory

This presentation provided a technical overview of direct photoelectrochemical production of hydrogen. It began with a brief overview of various sustainable pathways to hydrogen production that utilize solar energy. The technical fundamentals of the photoelectrochemical conversion process were presented, as were the benefits of this method of hydrogen production as compared to electrolysis using photovoltaics. A discussion of the technical challenges associated with the photoelectrochemical production of hydrogen followed, focusing on materials, efficiency, and energetics. Current research efforts were discussed in the following five areas: metal oxides (mixed and single), novel and new materials, advanced structures/hybrid designs, characterization tools, and catalysts. In addition, a list of DOE contract recipients was provided. The presentation concluded with a discussion of future directions for photoelectrochemical hydrogen production at NREL and the approach being used at the Hawaii Natural Energy Institute.

Hydrogen Production Status, Opportunities and Analysis

Low Temperature Electrolysis: Dr. Tom Maloney, Proton Energy Systems

This presentation provided a technological overview of low temperature electrolysis and the solar-hydrogen pathway from a commercial proton exchange membrane (PEM) electrolysis manufacturer’s perspective. The presentation covered the basic configurations for PEM electrolysis units including grid connectivity, ancillary subsystems, power conversion, PEM cell units, and hydrogen purification. PEM electrolysis issues associated with cost, efficiency, and utilization characteristics were explored with emphasis placed upon the role of solar power and its own special characteristics. Details were provided on Proton Energy Systems HOGEN 40RE™ electrolysis unit that addresses solar-PEM electrolysis connectivity. Through propriety configuration, Proton Energy Systems directly supplies the AC part of the PEM electrolysis unit with grid electricity whereas the DC elements of the unit are power by photovoltaics. This configuration helps to address the power quality issues common in conventional solar-powered PEM electrolysis units. Examples of current PEM electrolyzers were provided covering the China Lake RFC Energy Storage Project and University of Nevada-Las Vegas (UNLV) Filler Station Project. The China Lake Project uses 10.8 kW PV panels to power two 1.2 kW electrolyzers for an output of 820 kWh of stored H_2 at 200 psi. The UNLV Project is a two-year DOE project to install a PV-powered PEM electrolyzer resulting in a 2,000 psig PEM electrolysis system.

High Temperature Electrolysis: Dr. Richard D. Doctor, Argonne National Laboratory

This presentation began with a discussion of the key drivers for high-temperature electrolysis; 1) oxygen as the charge carrier replaces the use of strategic metals, 2) low footprint allows for adaptable scalability, 3) high-temperature electrolysis represents the high efficiency form of electrolysis. The presentation summarized research being conducted at Argonne National laboratory (ANL), in conjunction with Idaho National

Laboratory (INL). This research includes efforts to demonstrate 1000^0 K electrolysis with accompanying process design data, long-term performance testing, production and handling of reagent–grade water, economic-feasibility analysis, and life-cycle emissions evaluations. The objective of the research is to optimize the production of hydrogen through the correct choice of process and materials. Additional objectives covered in the presentation included optimization of the overall plant systems through balance of plant analysis, heat-recuperation studies, as well as overall efficiency. The presentation included an overview of the computational fluid dynamics and electrochemical work associated with high-temperature electrolysis including work into overpotential, heat effects, Ohmic losses and systems integration. The presentation concluded with a cost comparison for high- and low- temperature electrolysis.

Overview of past analysis and status of current efforts: Johanna Ivy Levene, National Renewable Energy Laboratory, and Dr. Robert Margolis, National Renewable Energy Laboratory

This talk presented an overview of past and current analysis efforts on solar-hydrogen energy production. It began with a discussion of an analysis that examined various strategies for combining PV and grid electricity to drive hydrogen production via electrolysis. Some of the key assumptions used in this analysis included: continued movement towards a deregulated energy market, a typical system size of 10MW capacity, and electrolyzer and solar costs declining to $600/kW capital cost and $3000/kW DC respectively. This analysis included four scenarios, direct PV-electrolysis; grid electricity combined with PV to baseload the electrolyzer, hydrogen production from PV plus off-peak grid-electricity, and decoupled solar-electricity and hydrogen production. The results of this analysis indicated that there are cost advantages when the capacity factor of the electrolyzer is increased over the capacity factor of the solar system. Next, the results of a GIS solar-hydrogen resource analysis were discussed. This GIS analysis used basic data on U.S. population, solar resource availability, and exclusion zones to estimate the potential solar-hydrogen resource base, on a state-by-state basis, for the U.S. Finally, a recent analysis of distributed solar-hydrogen production was discussed. In this analysis, three potential cases for solar produced hydrogen were examined. These included the large forecourt (filling station) case, the small forecourt (filling station) case, and the small neighborhood system case. The presentation suggested that future analyses focus upon identifying the optimal solar/grid/electrolyzer configuration, non-PV solar options, scalability issues, and developing more detailed solar-hydrogen cost models.

Session 2: Small Group Discussions

After the opening session concluded, participants were divided into three breakout groups to facilitate discussion on the feasibility of solar-hydrogen for three different market sectors – residential (off-grid and grid-tied), commercial (large-scale power/hydrogen plants) and distributed (filling stations). Each group was responsible for identifying the system components, barriers and future R&D pathways as they applied to the particular market sector.

Key topic questions addressed in the breakout included:

1. What are the most likely solar-hydrogen production pathways that can achieve technical feasibility in both the mid- and long-term?
    a. Photovoltaics-electrolysis
    b. High-temperature electrolysis
    c. Direct photoelectrochemical
2. What key research and development breakthroughs on which technologies will be necessary to achieve technical feasibility?
3. Which of the technically feasible pathways show the most promising economics?
4. What type of commercialization (technology transfer) strategy can help accelerate the various solar-hydrogen pathways to market?

Following a market-based approach to the small group discussions aligned well with the broader Systems-Driven Approach that has been adopted by the Solar Energy Technologies Program. The key to this approach is the identification of applications and markets that can provide real-world data on performance and cost in addition to theoretical models.

The following summaries were complied from the breakout session notes. Although each group was provided with a topic guideline, each group was allowed flexibility to change topics and discussion length.

A. *Residential/rooftop Solar-Hydrogen Market*
Concept: Residential Systems/Interconnected Mini-Grids

The residential/rooftop group focused more on the "bigger picture" issues related to a solar-hydrogen residential/rooftop system. This group did not specifically identify barriers to a potential system, but rather focused on a simple, systems description and the R&D work needed for success. The system described by this group included a 1 MW PV array with a 1 MW fuel cell. These approximate sizes revealed the group's focus on economic feasibility. The issues related to economic feasibility extended to both the consumer and developer. The consumer for this group is assumed to be focused on the availability of inexpensive hydrogen and the ease of use of the given system. The developer in this case assumes some form of incentives and continued government funded R&D.

System Description

- Homes/rooftops produce electricity using PV to run a community-scale electrolyzer producing 100 kg hydrogen/day for transportation, emergency power and storage
- 1 MW PV distributed over 125 homes = $2.2 Million
- 1 MW fuel cell = $200,000 (based on 2015 goal of $200/kW for stationary fuel cell)
- Five refueling units to produce 100 kg per day x $100K each = $500K
- Total system cost = $2.9 Million

R&D Recommended by Participants (Fundamental and Applied Research, Systems Engineering, and Analysis)

- Business case study analysis
    - Risk analysis
    - Return on investment
    - Market analysis
- Conceptual engineering design addressing:
    - Interaction and potential of microgrids
    - Power electronics
    - Smart EMS, power electronics, controls
    - Effective use of energy
    - Computer control over power lines
    - Integrating future grid development
    - Other low cost electricity options (wind)
    - Options for real-time pricing
- Valuation
    - Determine value to homeowners, financiers, and utilities
    - Energy security
    - Grid reliability
- Detailed design/simplified installation
    - Plug and play
    - DFMA (Design for Manufacturing and Assembly)
    - Improve DC to AC module efficiency
- Reduce institutional barriers
    - Codes and standards
- Additional needs
    - Continued applied research to improve PV cell, fuel cell, and electrolyzer efficiency
    - Continued development of Zero Energy Homes (ZEH)
    - Individual home refueling system analysis

B. Distributed Systems Solar-Hydrogen Market Concept: Filling Station

The distributed systems group defined a potential system, market applications, barriers, and R&D priorities. The focus was a forecourt (filling station) that could serve over 500 automobiles per day and produce over 100,000 kg of hydrogen per year. The system was assumed to have either flat-plate PV or concentrating PV (CPV) located either on a forecourt roof or other structure located nearby. In terms of markets beyond a public forecourt, the group also envisioned a power park concept as well as military applications.

Potential barriers identified included the high costs of hydrogen storage and the problems with interconnection and integration into an overall hydrogen economy. Solar barriers included the high cost of solar technologies, the need for more efficient modules, high temperature materials issues, water availability issues for area with high solar insolation and policy barriers surrounding grid development. The distributed systems group identified the following R&D recommendations, lowering the cost of solar and electrolyzer technologies, increasing efficiency, systems analysis, and improved balance of systems/power conditioning equipment.

System Description

- Solar
    - Flat plate PV or concentrators – potentially on rooftops or in parking lots (covered parking)
    - High efficiency solar cells – Amonix 20% and SunPower 20% silicon PV
    - Highway filling station – PV on sound barrier
- Electrolyzers – low temp or high temp
- Storage and compressor
- Photoelectrochemical cells
- Develop an optimized system based on the cost of electricity and fuel
- Power with PV in the daytime and off-peak grid electricity at night
- Other markets
    - Power park
    - Military applications
    - Rural market
    - Zero-energy neighborhood

Barriers

- Hydrogen barriers
    - Cost
    - Storage – defining optimal size
    - Interconnection
    - Efficiency
- Solar Barriers
    - Cost
    - Increased efficiency
    - High temperature materials issues

    - Water availability in areas with high solar resource
- Electrolyzer
    - Reliability and efficiency
    - Availability of high temperature electrolyzers at suitable sizes
- Policy issues
    - kWh buyback programs
    - Federal and state tax incentives
    - Uniform state regulations
    - Increased R&D funding
    - Government carbon policy
    - Programmatic barriers (DOE stove piping)
- Business model
    - Cost
        - Materials
        - Components
        - Balance of Systems
        - Land cost
    - Changing business model for refueling
    - Development of on-site technical know-how
    - Financing for international rural projects
    - Sizing of stations – larger and further apart?
    - Breakdown of economic model as more systems are added (off-peak vs. on-peak rates)

Suggested R&D Activities

10-15 Years
- Increase efficiency of electrolyzers
- Increase membrane conductance
- Develop lower cost electrolyzer
- Thermal and electrical cycling in electrolyzers
- New catalysts
- Market development and demonstration
- Develop partnership with industry to determine what industry values
- Controls and systems
- DC to DC interface
- Improved manufacturing R&D (PV and electrolyzers)
- Distribution alternatives
- Analysis of local production vs. transport from central source
- Distribution of electricity vs. hydrogen
- Development of cost framework for innovative ideas – metrics to choose R&D paths
- Systems analysis
- Definition and integration
- Requirement for interdisciplinary approaches

20-30 Years

- Increased size of high temperature electrolyzers
- Develop mid to high temperature membranes
- Photoelectrochemical
- Material stability
- Engineer band gap to increase efficiency
- Development of practical system designs
- Lower PV system costs
- Higher efficiency to reduce sq. ft. required
- Get to where electricity needs are higher than electricity loads
- Systems analysis
- Commercial / large scale systems

C. Commercial Large Scale Systems Solar-Hydrogen Market
Concept: Solar Hydrogen Production Facility

The commercial large-scale group focused on the systems description, barriers and R&D suggestions. The group targeted the use of solar technologies capable of utility-size electricity production including, but not limited to, parabolic troughs, solar towers, plant-sized dishes, large PV fields, and MW-scale CPV arrays. The main feature would include modular designs, advanced power blocks, and reliable distributed electrolyzers.

Major barriers identified include the high costs for hydrogen (storage and production), the high cost for solar (systems and balance-of-systems), lack of consistent R&D efforts, lack of fuel volatility studies, high capital costs associated with power plant installation, transmission and distribution issues (interconnection and availability).

Identified R&D areas of interest include, reducing the cost of all associated technologies (solar and electrolysis), enhanced grid operation and interconnection, cyclic operations for hydrogen technologies, bulk energy storage, high-temperature electrolysis using CPV and CSP at 800^0C, and detailed systems analysis to match electricity and hydrogen need. The group also focused on the need for a demonstration. One example was to bring hydrogen production capability to the SEGS plants in Nevada.

System Description

- Size
    - Troughs and Towers >50 MW in Southwest U.S.A. ($0.02-0.05 per kWh)
    - Multi-MW plants utilizing 25 kW dishes
    - Large scale PV-based electricity plants ($0.03-0.05 per kWh DC)
    - Hybrid CSP/CPV concentrator units (MW-scale)
- Features
    - Extensive land area needed
    - Grid interconnection to “Advanced Grid of Future”
    - Bulk storage
    - Modularity
    - Electrolyzers could be located within plant gate, or plants could simply sell green power
    - Transform a solar plant (SEGS?) into a H_2 demo plant – possible sales to Department of Defense
- Components
    - Ten 2 MW distributed electrolyzers
    - High temperature electrolysis at 600^0 C to $1{,}000^0$ C

Barriers
- Policy
    - Siting issues
    - Consistent government funding levels and policy
    - Limited US electrolyzer manufacturers
    - No mandates for renewable portfolio standards or tax incentives

- Challenges to explosive growth
    - Siting issues
    - Land use/cost
- Technical
    - Impact of intermittency on electrolyzers
    - Materials availability
    - General component issues both for solar and hydrogen technologies
    - Bulk storage issues
    - Bus-bar issues
- Environmental
    - Water purity
    - Water availability for cooling
- Fuel volatility not quantified
- Future fossil fuel costs may be low
- Long distance transportation for hydrogen
- Electricity transmission and distribution issues
- Safety, codes and standards need update and revision
- Cost
    - Solar too expensive
    - H_2 too expensive
    - Cost of electricity is too high (for plant owner)
    - High capital costs
    - Calculus of energy pricing
    - Electrolysis costs too high
- Systems analysis is needed
- Reliability of all systems needs improvement
- No hydrogen infrastructure
- Fossil competition is difficult to overcome

R&D Suggestions in the Mid-term

- Systems analysis – matching electricity and hydrogen demand
- Smart grid R&D (tie to Office of Electricity and Energy Assurance formerly OETD)
- Use solar to displace natural gas demand
- Power conditioning for both PV systems and electrolyzers
- Higher-efficiency multi-junction CPV
- Better, modular, scalable dishes
- Thinner CIS & CdTe (1/4 micron, 15% efficiency)
- Cyclic operation of all hydrogen equipment
- Where is the hydrogen generation to be located – at the plant or distributed (transmit electrons)

R&D Suggestions Long-term

- High-temp electrolysis using CPV and CSP 800C capability
- Fossil/solar thermal hybrid – 15% for heat, 85% for electricity
- Superheated steam from Rankine cycle

- Site issues for bulk storage (both for distributed generation and on-site production)

Session 3: Small Group Summary Reports, Facilitated Discussion, and Closing Comments

During the final session, all workshop participants re-convened to discuss the outcomes of the small group discussions. Each group appointed a chairperson to present a summary of its findings and recommendations for moving forward within that particular market sector.

Following the breakout summary presentations, participants were led through a facilitated discussion regarding the workshop results. This discussion resulted in the following recommendations agreed upon by the group:

- Increased collaboration is needed both between the SET and the HFCIT programs, as well as between government and industry stakeholders
- Wherever possible, the use of common terminology should be implemented across SET and HFCIT
- DOE should increase R&D funding for both SET and HFCIT programs with the continued goal of reducing costs for both technologies
- SET and HFCIT should perform additional analyses (both technical and economic) of solar-produced hydrogen
- Government-industry supported solar-hydrogen demonstration projects should be proposed and built to gain real-world experience and collect real-world data
- Further analysis is needed on utility interconnection of solar for hydrogen production

To close the session, each participant was asked to verbally provide feedback on the workshop, including the following:

- Strengths and weaknesses of the workshop
- Views of consensus findings
- Next steps

By and large, participants agreed that the workshop's greatest strength was having solar and hydrogen stakeholders together in one room to commence dialogue on potential collaboration. Most participants also agreed that the breakout discussions were valuable, and were surprised to learn that all three groups agreed that a 1MW, or larger, solar-hydrogen system size was the most feasible scale for development. Some agreed that breaking the groups down by market, as was done, was an effective approach to initiate discussion; others felt that dividing the groups up according to technology would have been more useful for coming up with more clearly defined R&D pathways.

Suggestions included having DOE solar and hydrogen program goals and technology descriptions beforehand so that more time could have been spent during the workshop to discuss solar-hydrogen pathways and collaboration opportunities. It was also suggested that the international community be included in future meetings so that lessons might be learned from their experiences with hydrogen and solar. Some suggested including electrolyzer developers and more industry and utility involvement in future discussions.

The group was in agreement that a set of consistent terminology needed to be developed to allow for easier discussions between the hydrogen and solar communities, such as a solar-hydrogen translation dictionary. It was also agreed upon that conducting joint (solar and hydrogen) systems analysis was an important next step for moving forward. Several participants also suggested planning the development of solar-hydrogen demonstration projects (e.g. filling stations), which could prove quite valuable for learning lessons on the feasibility of such projects. Finally, it was agreed that an important next step is for the DOE solar and hydrogen programs to meet on a more regular basis to provide for better coordination and to build upon the initial discussions that resulted from this workshop.

Final Agenda

DAY ONE - November 9, 2004

7:30 - 8:00 a.m.	**Registration and Continental Breakfast**
8:00 - 8:30 a.m.	**Welcome and Opening Remarks:** *Review of Meeting Objectives and Purpose, and General Introductions* • Dr. Raymond A. Sutula, *Program Manger*, U.S. DOE - Solar Energy Technologies • Peter Devlin, *Hydrogen Production Tech Team Leader*, U.S. DOE - Hydrogen, Fuel Cells, and Infrastructure Technologies • Jonathan Hurwitch, *Senior Vice President*, SENTECH, Inc.
8:30 - 10:20 a.m.	**Solar Technology Status and Opportunities** • Solar Photovoltaics – Dr. James Loman, *Technology Leader*, GE Energy - Solar Technologies • Concentrating Solar Power - Greg Kolb, *Distinguished Member of Technical Staff*, Sandia National Laboratories • Hybrid Solar Concentrator for the Electrolytic Production of Hydrogen – Dr. Robert McConnell, *PV Exploratory Research Project Leader*, NREL • Direct Photoelectrochemical Production of Hydrogen – Dr. John A. Turner, *Principal Scientist*, NREL • Discussion (20 Minutes)
10:20 - 10:40 a.m.	**Break**
10:40 a.m. - 12:00 p.m.	**Hydrogen Production Status, Opportunities and Analysis** • Low-temperature Electrolysis – Dr. Tom Maloney, *Fueler Program Manager*, Proton Energy Systems • High-temperature Electrolysis - Richard D. Doctor, *Manager, Hydrogen & Greenhouse Gas Engineering Section*, Argonne National Laboratory • Overview of past analysis and status of current efforts - Johanna Ivy Levene, *Engineer II*, NREL, and Dr. Robert Margolis, *Senior Energy Analyst*, NREL • Discussion (20 Minutes)
12:00 - 1:00 p.m.	**Lunch** Real World Experiences with Solar Hydrogen Production - Ray Hobbs, Senior Consulting Engineer, Arizona Public Service
1:00 - 2:30 p.m.	**Solar Hydrogen Small Group Discussions:** • Residential Market Team • Distributed Generation Market Team • Commercial/Large Scale Team
2:30 - 3:00 p.m.	**Break**
3:00 - 5:00 p.m.	**Facilitated Discussion and Analysis Continues**

5:00 p.m.	**Adjourn**
6:00 - 8:00 p.m.	***Optional Group Dinner – Bus departs at 5:30 p.m. from lobby***

DAY TWO – November 10, 2004

7:30 - 8:30 a.m.	**Continental Breakfast**
8:30 - 10:00 a.m.	**Team Discussions Continue (Small Groups)**
10:00 - 11:00 a.m.	**Summary Reports from Small Group Chair(s)**
11:00 a.m. - 12:30 p.m.	**Facilitated Discussion: Workshop Results**
12:30 - 1:00 p.m.	**Final Thoughts and Comments**
1:00 p.m.	**Adjourn**

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Invitation Letter

Department of Energy
Washington, D.C.

Dear Colleagues,

You are cordially invited to attend the U.S. Department of Energy's (DOE) Solar Hydrogen Workshop, to be held at the UMUC Conference Center, in Adelphi, MD (just outside Washington, DC) on November 9-10, 2004. The purpose of this meeting is to bring together a group of experts from both the solar and hydrogen communities to examine potential pathways for cost-effectively producing hydrogen from solar energy, in both the mid- (i.e., by 2015) and long-term (i.e., by 2030) time horizons.

This workshop is being hosted by the DOE Solar Energy Technologies Program (SET) in collaboration with the DOE Hydrogen Fuel Cell and Infrastructure Technologies Program (HFCIT). The primary goal of this workshop is to foster a more collaborative approach among these two DOE programs, as well as the broader solar and hydrogen communities. Through improved collaboration we hope to gain a better understanding of the technical and market potential of solar hydrogen technologies, and to identify critical R&D pathways that will enable solar produced hydrogen to play a significant role in our energy future over the next couple of decades.

The meeting will include technical presentations on the current status of DOE and industry funded research, development, and deployment. It will examine R&D pathways, market development requirements, infrastructure issues, and materials consumption requirements related to using solar energy for the production, distribution and use of hydrogen.

The meeting will be held November 9-10, 2004 and is by invitation only. There will be no registration fee for this event; however, an attendance confirmation is requested prior to attending. A preliminary agenda and information regarding registration and hotel accommodations is posted at www.sentech.org/solarhydrogen.htm. Finally, in keeping with its working nature, participants should note that the workshop will be conducted with a business casual dress code.

If you have any questions regarding meeting logistics, please contact Krista Long at meetings@sentech.org. The registration deadline is October 22, 2004, but we would appreciate an early confirmation of your participation.

We hope that you will be able to participate and we look forward to both interesting and productive discussions.

Sincerely,

Raymond A. Sutula, Program Manger
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U.S. Department of Energy

Steven G. Chalk, Program Manager
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