International Energy Agency
Agreement on the Production and Utilization of Hydrogen

End-of-Term Report: 1999-2004
and
Plans: 2004-2009

INTRODUCTION

The current term for the International Energy Agency (IEA) Agreement on the Production and Utilization of Hydrogen ends in June 2004. The Hydrogen Agreement was initiated in 1977 to advance hydrogen production, storage and end-use technologies and to accelerate hydrogen's acceptance and widespread utilization. The most recent extension of the Agreement was approved in June 1999.

OBJECTIVES AND STRATEGY

Today, hydrogen is primarily used as a chemical feedstock in the petrochemical, food, electronics, and metallurgical processing industries, but is rapidly emerging as a major component of clean sustainable energy systems. It is relevant to all of the energy sectors - transportation, buildings, utilities, and industry. Hydrogen can provide storage options for intermittent renewable technologies such as solar and wind, and, when combined with emerging decarbonization technologies, can reduce the climate impacts of continued fossil fuel utilization. The members of the IEA Hydrogen Program agree that energy related hydrogen technologies, thus, merit serious attention. The following are the guiding principles on which the scope of the Agreement is based:

- Hydrogen--now mainly used as a chemical for up-grading fossil-based energy carriers--will in the future increasingly become an energy carrier itself. It is necessary to carry out the analysis, studies, research, development and dissemination that will facilitate a significant role for hydrogen in the future.

- Significant use of hydrogen will contribute to the reduction of energy-linked environmental impacts, including global warming due to anthropogenic carbon emissions, mobile source emissions such as CO, NOx, SOx, and NMHC (non-methane hydrocarbons), and particulates.

- Hydrogen can be used as a fuel for a wide variety of end-use applications including important uses in the transportation and utility sectors.

- Hydrogen is currently used to up-grade lower quality, solid and liquid fossil fuels, such as coal and heavy oils. The use of hydrogen in such applications reduces harmful emissions through more efficient end-use conversion processes and extends the range of applicability. Ultimately, with the addition of hydrogen, carbon dioxide emissions can be used to produce useful chemicals and fuels.

- Hydrogen has the potential for short, medium and long-term applications and the steps to realize the potential for applications in appropriate time frames must be understood and implemented.

- All sustainable energy sources require conversion from their original form. Conversion to electricity and/or hydrogen will constitute two prominent, complimentary options in the future.

- Hydrogen can assist in the development of renewable and sustainable energy sources by providing an effective means of storage, distribution and conversion; moreover, hydrogen can broaden the role of renewables in the supply of clean fuels for transportation and heating.

- Hydrogen can be produced as a storable, clean fuel from the world's sustainable non-fossil primary energy sources - solar, wind, hydro, biomass, geothermal, nuclear, or tidal. Hydrogen also has the unique feature that it can upgrade biomass to common liquid and gaseous hydrocarbons, thus providing a flexible, sustainable fuel.

- All countries possess some form of sustainable primary energy sources; hence, hydrogen energy technologies offer an important potential alternative to fossil fuel energy supply (in many instances to imported fuels). Utilization of hydrogen technologies can contribute to energy security, diversity and flexibility.

- Barriers, both technical and non-technical, to the introduction of hydrogen are being reduced through advances in renewable energy technologies and hydrogen systems including progress in addressing hydrogen storage and safety concerns.

- Hydrogen energy systems have potential value for locations where a conventional energy supply infrastructure does not exist. The development of hydrogen technologies in niche applications will result in improvements and cost reductions that will lead to broader application in the future.

The members of the IEA Hydrogen Agreement recognize that a long-term research and development effort is required to realize the significant technological potential of hydrogen energy. This effort can help create competitive hydrogen energy production and end-use technologies, and supports development of the infrastructure required for its use. Attention is to be given to the entire system, in particular all of the key elements should be covered either with new research or based on common knowledge.

If the technological potential of hydrogen is realized, it will contribute to the sustainable growth of the world economy by facilitating a stable supply of energy and by helping to reduce future emissions of carbon dioxide. Cooperative efforts among nations can help speed effective progress towards these goals. Inasmuch as hydrogen is in a pre-commercial phase, it is particularly suited to collaboration as there are fewer proprietary issues than in many energy technologies.

IEA Hydrogen Vision: Our vision for a hydrogen future is one based on clean sustainable energy supply of global proportions that plays a key role in all sectors of the economy.

IEA Hydrogen Mission: The mission of the IEA Hydrogen Program is to accelerate hydrogen implementation and widespread utilization.

IEA Hydrogen Strategy: Our strategy is to facilitate, coordinate and maintain innovative research, development and demonstration activities, through international cooperation and information exchange.

We will achieve this strategy by meeting the below listed objectives:

Technology Objective:

Promote acceptance of hydrogen as an energy carrier.

Actions:

- Conduct research and development activities to address important barriers to hydrogen's acceptance.
- Foster and maintain a balanced portfolio of hydrogen technologies.
- Develop safe, efficient, and cost-effective hydrogen storage systems.
- Demonstrate integrated hydrogen systems.
- Collect, disseminate, and analyze information on hydrogen technologies.
- Develop direct hydrogen production technologies.

Energy Security Objective:

Contribute to global energy security.

Actions:

- Facilitate the transition from fossil fuel energy systems to sustainable hydrogen-based energy systems.
- Provide resources for the conversion of intermittent and seasonal renewables to base-load, load-following or peak-load power supplies, and to transportation fuels.
- Assist developing countries in evaluating sustainable, indigenous resources for hydrogen production.

Deployment Objective:

Promote deployment of hydrogen technologies with important local and global energy benefits.

Actions:

- Provide design support for hydrogen demonstrations.
- Conduct cost-shared and task-shared deployment activities for hydrogen energy systems.
- Act as an information resource for on-going and proposed hydrogen demonstration activities, including performance analyses.
- Conduct case studies for hydrogen systems in developing countries.

Environmental Objective:

Exploit the environmental benefits of hydrogen.

Actions:

- Carry out research and development on renewable hydrogen production techniques.
- Promote hydrogen as a "clean" fuel.
- Perform life cycle assessments of hydrogen technologies and energy systems.
- Conduct research and development on technologies that lead to the decarbonization of fossil fuels.

Economic Objective:

Develop cost-effective hydrogen energy systems that can compete in global markets.

Actions:

- Encourage industry participation to obtain market-oriented input for the prioritization of research, development and demonstration activities.
- Develop and utilize analysis tools to evaluate and optimize hydrogen systems.
- Increase involvement of industry in the Agreement's activities.
- Foster clean system incentive policies.
- Identify secondary benefits of hydrogen energy systems, such as demilitarization.

Market Objective:

Identify and overcome barriers for hydrogen's penetration into the energy and fuel markets.

Actions:

- Contribute to the scientific and technical basis for approved codes and standards.
- Promote hydrogen infrastructure for supply, maintenance and operation.
- Pursue technologies that will lead to Increased market penetration for hydrogen.
- Initiate safety-related educational and technology assessment activities.

Outreach Objective:

Advertise the benefits of hydrogen.

Actions:

- Increase involvement of private and public organizations in the Hydrogen Program.
- Utilize media tools to promote hydrogen education.
- Establish collaborative research and development projects that promote international networks.
- Collaborate with other IEA Agreements to increase the effectiveness of crosscutting research and development activities.
- Increase cooperation to reach "critical mass" in research and development activities.

Concerns about global climate change and energy security create the forum for mainstream market penetration of hydrogen. Ultimately, hydrogen and electricity, our two major energy carriers, will come from sustainable energy sources, although, fossil fuel will likely remain a significant and transitional resource for many decades. Our vision for a hydrogen future is one of clean sustainable energy supply of global proportions that plays a key role in all sectors of the economy. We will implement our vision with advanced technologies including direct solar production systems and low-temperature metal hydrides and room-temperature carbon nanostructures for storage.

PARTICIPATION OF COUNTRIES, INDUSTRY AND UTILITIES

Table 1. Participating Countries in the IEA Hydrogen Agreement

Country	Contracting Party
Canada	Natural Resources Canada Stuart Energy Systems (formerly the Electrolyzer Corporation)
Denmark	*Danish Gas Technology Center*
European Commission	Joint Research Center
Iceland[1]	National Energy Authority
Italy	Ente per le Nouve Technologies, L'Energia E L'Ambiente (ENEA)

Country	Contracting Party
Japan	New Energy and Industrial Technology Development Organization (NEDO)
Lithuania[1]	Lithuanian Energy Institute
Netherlands	Netherlands Agency for Energy and the Environment (NOVEM)
Norway	Research Council of Norway
Spain	Ministry of Industry and Energy
Sweden	Swedish Energy Agency
Switzerland	Swiss Federal Office of Energy
United Kingdom	Department of Trade and Industry
United States	Department of Energy

[1] Indicates Non-Member Country Participants

During the term, Italy returned to active status. The United Kingdom rejoined the Agreement, this time with the Department of Trade and Industry as the Contracting Party. Denmark joined the Agreement in January 2004. Turkey remains a signatory to the Agreement, but is considered inactive. Non-member Country participants were Lithuania, who joined the Agreement in March 2002, and Iceland, who joined in [month] 2003.

Table 2. Task Participation

Country	Task 13	Task 14	Task 15	Task 16	Task 17	Task 18
Canada	X		X		X	X
European Commission	X					TBD
Iceland[1]						X
Italy					X	TBD
Japan	X	X	X	X	X	TBD
Lithuania[1]	X				X	TBD
Netherlands	X		X	X		TBD
Norway	X		X	X	X	X
Spain	X			X	X	TBD
Sweden	X	X	X	X	X	X
Switzerland	X	X		X	X	TBD
United Kingdom	X		X	X	X	TBD
United States	X	X	X	X	X	X

Industry Involvement

Stuart Energy Systems (formerly the Electrolyzer Corporation) remains a signatory to the Agreement and an active participant in the research tasks. Norsk Hydro served as Operating Agent for Task 16, Hydrogen from Carbon-Containing Materials. The Operating Agents for Tasks 15, 17 and 18, are from private consulting firms. Additionally, a number of industry representatives participated in the collaborative Tasks; these are shown in Table 2.

Table 3. Industry Participation

Company	Task 13, Design and Optimization of Integrated Systems	Task 14, Photoelectrolytic Production of Hydrogen	Task 15, Photobiological Hydrogen Production	Task 16, Hydrogen from Carbon-Containing Materials	Task 17, Solid and Liquid State Hydrogen Storage Materials	Task 18, Integrated Systems Evaluation
Biomass Technology Group (NL)				X		
BP				X		
Dynamotive				X		
ENI				X		
EniTechnology			X (unofficial)			
Ergenics (US)					X	
Gas Natural				X		
Gastec				X		
Gas Technology Institute				X		
Gaz de France				X		
Haldor Topsøe				X		
IGS Mahler				X		
Intelligent Energy				X		
Longitude 122 West (US)	X					X
Norsk Hydro				X		
Osaka Gas				X		
PanCanadian				X		
Repsol				X		
Shell				X		
Statoil				X		
Stuart Energy Systems	X					X
SunaTech, Inc. (US)					X	
Suncor				X		
Sycon	X					
Sydkraft	X					X
Texaco				X		
United Technologies					X	

Withdrawls

There were no withdrawls during the period. Germany withdrew from the Agreement just prior to the start of the period. Discussions continue with representatives from Germany to bring them back into the Agreement.

PROGRAM AND NATURE OF WORK

The use of hydrogen as an energy carrier is considered a mid- to long-term goal. Hydrogen production from renewables will likely not be cost-competitive with fossil-based production, at least in the near-term. Likewise, infrastructure barriers, particularly in the storage area, hinder near-term application of hydrogen for transportation applications. Additionally, safety issues, both real and perceived, are concerns for acceptance of hydrogen by the general population. Thus, the Hydrogen Agreement is focused on pursuing technologies that will help overcome some of the infrastructure barriers and/or result in the reduced cost of hydrogen systems.

- To achieve the advantages of a "hydrogen future," namely a reduction in carbon emissions, hydrogen must be able to be cost-effectively produced from renewables. Thus, the Hydrogen Agreement has been pursuing R&D in the solar production area, both biological and electrochemical. Much must still be learned about photobiological processes before we are able to understand the economic potential of this production technology. The electrochemical approach is, of course, hindered by the fact that photovoltaic technology is not yet cost competitive. However, advances with lower-cost materials, dye-sensitization, catalysts and novel system configurations are bringing this technology much closer to commercial practicality.

- On-board storage in vehicles is one of the major barriers to the acceptance of hydrogen-powered vehicles. Metal hydrides and similar storage medium, such as carbon, are thought to have the greatest potential for the safe, on-board storage of hydrogen. However, work-to-date has not proven cost effective due to the inability of current technology to meet the hydrogen storage percentages required for maintaining vehicle weights within a reasonable range.

- The use of hydrogen in the metals, chemicals, glass, food, electronics, fertilizer, petroleum and space industries is well established. The range of uses has been increasing, as has the consumption by specific application. Historically, hydrogen has had an excellent safety record. The many studies, R&D efforts, and experience base have contributed to the publication of regulations, standards, industrial data sheets and technical reports. Hydrogen safety is an issue of every aspect from production to utilization and continues to be of the utmost importance; not only to those researching, designing and working with it; but to the general public, local authorities, insurance agents, etc., as well.

- Achieving the vast potential benefits of a hydrogen system requires careful integration of production, storage and end-use components with minimized cost and maximized efficiency, and a strong understanding of environmental impacts and opportunities. System models combined with detailed life cycle assessments provide the platform for standardized comparisons of energy systems for specific applications. Individual component models form the framework by which these system designs can be formulated and evaluated.

The Hydrogen Agreement has developed a broad portfolio of collaborative research activities to address the aforementioned challenges for hydrogen penetration into the world energy marketplace. The portfolio of work includes task-shared basic and applied research; information exchange; and task-shared and cost-shared analysis of research, development and demonstration projects. The following Tasks were undertaken during the five-year period (note – participation in each Task is indicated in Table 2 above):

Task 13: Design and Optimization of Integrated Systems (January 1999 – June 2002)

Hydrogen energy systems have been proposed as a means to increase energy independence, improve domestic economies, and reduce greenhouse gas and other harmful emissions from stationary and mobile sources. These systems, however, face technical and economic barriers that must be overcome before hydrogen can become a competitive energy carrier for the 21st century.

Comparison of different system configurations for a particular application requires a set of criteria on which the comparison can be made. This can include efficiency, environmental impacts, economic impact, capital and operating costs, and other measures of importance to the analyst. In all cases, these parameters can be reduced to a comparison of costs, when an appropriate value is assigned to these criteria. It is important to develop consistent cost models for the various hydrogen components so that fair assessments can be made of alternative designs. This is particularly important when comparing dissimilar systems at very different levels of development and commercialization.

The objective of Task 13 was to provide a means by which hydrogen energy systems can be compared to conventional energy systems. In order to meet this objective, existing, planned, and conceptual hydrogen demonstration systems were designed, optimized, and evaluated using the tools developed under a previous effort. Emphasis was placed on comparative analysis of these integrated systems. The activities focused on near- and mid-term applications (3-10 years), with consideration of the transition to sustainable hydrogen energy systems.

A Cost Model was developed based on standard engineering procedures while allowing variations specific to each application. It uses multiple data sheets such as Components, Local Conditions, Investments, Operations, Cost Model and Cash Flows. The User is guided through each sheet and is asked to provide data where appropriate. Default values are included in the Cost Model. The "Components" section of the Cost Model provides information on the required system hardware. The "Local Conditions" sheet compiles data relative to the costs of various inputs in each country as well as prevailing economic conditions characterizing local business acceptability. The "Investment" section of the model details the required initial investment in each system as well as the future investment at the end of the life of the project. The "Operations" section compiles data relative to operating conditions of the system while the "Scaling" section adjusts the data to the size of the component for the project selected. Finally, the cash flow section determines the project's business acceptability in the selected country.

Experts canvassed potential hydrogen demonstration project leaders to identify candidate configurations for analysis. This activity included designs for conceptual hydrogen demonstrations. Potential demonstrations were evaluated and recommendations made as to optimum design and operation of the facility to meet the needs of the project. Three studies were conducted: Residential Systems; Remote Applications; and Infrastructure.

The value of hydrogen energy systems is often linked to environmental improvements (greenhouse gas reductions, and CO, NO_x, and SO_x reductions, etc.) or other intangible benefits (job creation, energy independence, etc). Quantification of some of these benefits can be made using life cycle assessment (LCA) comparisons. In this activity, the scope of an LCA for hydrogen systems was defined, based on established (published) LCA methodologies. The measures considered include comparison of CO_2 and other gaseous emissions, and determination of net energy ratio (amount of energy produced per unit of fossil fuel input). Assessments of the Residential Systems and Remote Applications were completed. A number of studies covering aspects of the Infrastructure case were also completed.

Results from these studies were presented at several international meetings and published in both annual and technical reports.

Task 14: Photoelectrolytic Production of Hydrogen (July 1999 – present)

Photoelectrolysis of water is the process whereby light is used to directly split water into hydrogen and oxygen. This can be achieved by illuminating a wet semiconductor device either directly or via dye sensitization. Such systems eliminate the need for two separate systems regarding power generation and electrolysis, and hence offer great potential for cost reduction of electrolytically produced hydrogen compared with conventional two-step technologies. The direct production of hydrogen via water splitting by sunlight requires a light-harvesting device in conjunction with water-splitting catalysts. The necessary semiconductor-based light-sensitive device is similar to a PV solar cell, with or without dye sensitization.

Research and development (R&D) programs on photoelectrolysis of water are in place in IEA member countries such as the United States, Japan, Sweden, and Switzerland. But despite encouraging early scientific, technical, and economic results (for example, a 14% solar-to-hydrogen conversion efficiency and hydrogen production costs of approximately US$ 3.00 per kilogram), the development of practical demonstration systems requires significant scientific and engineering efforts through a medium-term, well-structured R&D program.

The overall objective of this activity was to significantly advance the fundamental and applied science in the area of photoelectrolysis of water.

Specific target areas include:

- Practical System Efficiency
- Device Lifetime and Cost
- Semiconductor Materials and Structures
- Photosensitive Dyes
- Integrated PV/Electrolysis Systems
- Novel Single- and Dual-Bed Reactor Arrangements

[Andreas to insert major accomplishments.]

Task 15: Photobiological Production of Hydrogen (June 1999 – present)

Biological hydrogen production, the production of hydrogen by microorganisms, has been an active field of basic and applied research for many years. The governments of Japan and the United States, for example, support significant applied R&D programs. These and a number of other countries also support related basic research. Realization of practical processes for photobiological hydrogen production from water using solar energy would result in a major, novel source of sustainable and renewable energy, without greenhouse gas emissions or environmental pollution.

Collaborative research activities have been carried out on "biophotolysis" (the biological production of hydrogen from water and sunlight using microalgae photosynthesis). Specific research areas include:

- Light-driven Hydrogen Production by Microalgae
- Maximizing Photosynthetic Efficiencies
- Hydrogen Fermentations
- Improve Photobioreactor Systems for Hydrogen Production

Sustainable hydrogen production by microorganisms has been achieved. Additionally, improvements have been made to efficiencies. BioHydrogen 2002, co-sponsored Task 15 and EU COST 8.41 Biological and Biochemical Diversity of Hydrogen Metabolism, was held in Ede, the Netherlands April 21-24, 2002. About 150 scientists participated in this meeting. The scientific advancements made over the first three years of work under Task 15, the state of the art of biological hydrogen production, the current progress on early-stage applied science in this area, and promising research directions for the future were featured.

Task 16: Hydrogen from Carbon-Containing Materials (April 2002 – March 2005)

Approximately 95% of the hydrogen produced today comes from carbon-containing raw material, primarily fossil in origin. Most of the conventional processes convert the carbon to carbon dioxide, which is discharged to the atmosphere. The growing awareness of the impact of greenhouse gas emissions on global climate change has necessitated a reassessment of the conventional approach. Integrating carbon dioxide sequestration with conventional steam reforming will go a long way toward achieving "clean" hydrogen production from fossil fuels. Likewise, improving the robustness of pyrolytic cracking technologies for converting hydrocarbons to hydrogen and solid carbon should not only improve the process economics, but also its applicability to a variety of feeds. Furthermore, the thermal processing of biomass can yield an economic and carbon-neutral source of hydrogen. This effort is conducted with strong industry involvement and in collaboration with the IEA Greenhouse Gases and Bioenergy Agreements. The research and development areas include:

- Efficient Carbon Dioxide Separation and Sequestration
- Advanced Thermal Processing of Biomass
- Small-Scale, Distributed Systems for Hydrogen Production

Reports have been published on the state of the art of biomass to hydrogen technologies and on distributed technologies for hydrogen from natural gas. Technology options have been evaluated for the decarbonization of natural gas.

Task 17: Solid and Liquid State Hydrogen Storage Materials (June 2001 – present)

On-board hydrogen storage remains an undisputed challenge for hydrogen-fueled vehicles. Although recent progress in metal hydride batteries has been significant, little progress has been made in advancing the room-temperature hydrogen storage capacity of traditional hydrides. This is particularly true for PEM fuel-cell vehicle applications, where high gravimetric hydrogen storage density is required and where hydrogen must be liberated at temperatures compatible with the waste heat of the fuel-cell (<100°C). Alternatives to solid-state vehicular hydrogen storage exist, such as high-pressure gas, cryogenic liquids and on-board reforming of conventional liquid hydrocarbon fuels, but well-known disadvantages can be cited for each. Thus, the development of non-traditional hydrides and carbon materials (nanotubes, graphite fibers, etc) has received a great deal of attention and support.

Task 17 is a follow on to the very successful Task 12, Hydrogen Storage in Metal Hydrides and Carbon. Under Task 12, a material capable of 5 weight percent reversible hydrogen storage at 120°C was developed. Under Task 17 emphasis has been placed on fundamental material formulation and treatment techniques, understanding the mechanisms of hydrogen storage, reproducibility of results and on engineering aspects of using some of the more promising materials in a realistic on-board storage scenario. The specific targets of the task are to:

- Develop a reversible hydrogen storage medium with at least 5 wt.% H2 recoverable at < 80°C and 1 atm absolute pressure.
- Develop the fundamental and engineering understanding of hydrogen storage by various hydrogen storage media that have the capability of meeting the above storage target.

Task 18: Evaluation of Integrated Systems (TBD – present)

Hydrogen energy systems have been proposed as a means to increase energy independence, improve domestic economies, and reduce greenhouse gas and other harmful emissions from stationary and mobile sources. Hydrogen is now a high priority around the world. Many Roadmaps are being developed and high-level groups are being formed in many countries. Demonstration systems are being implemented in all the participating countries. Commercial systems, however, face technical and economic barriers that must be overcome before hydrogen can become a competitive energy carrier for the 21st century.

Tools were developed and used, under previous Hydrogen Agreement Tasks, to design and optimize integrated hydrogen energy systems. In order to facilitate the comparison of different system configurations for a particular application, criteria were developed on which the comparison could be made, including efficiency, environmental impacts, economic impact, capital and operating costs, and other measures of importance to the analyst. In all cases, these parameters can be reduced to a comparison of costs, when an appropriate value is assigned to these criteria.

With these tools, it is now possible to evaluate existing and planned demonstration projects and to provide alternative configurations and operating conditions to optimize efficiency and cost. Non-proprietary information will be provided to participating countries and parties to improve future demonstration project designs and operation. The overall goal of Annex 18 is to provide information about hydrogen integration into society around the world. Two specific objectives are: 1) to provide data and analysis to the hydrogen community in the form of inventory databases or compiled summaries, and 2) to use modeling and analysis tools to evaluate hydrogen demonstration projects, or to guide their design and assessment, and to validate models and assumptions.

The Task is addressing the growing need for a collection of information about issues related to the technology, policy, and regulation barriers to implementation of hydrogen energy systems and include, including:

- Lists of hydrogen component manufacturers and developers
- Listing of existing or potential infrastructure and hydrogen resources, optionally including maps and Geographic Information System (GIS) data layers
- Assessment / characterization of current hydrogen support programs (levels of investments, commitments, and activities in hydrogen) by country or region
- Review and/or summary of previous analyses, such as well-to-wheels studies
- Commercialization roadmaps by country for comparison of end-uses

The Task is also gathering data on hydrogen projects and exercising modeling and analysis capabilities to evaluate demonstration projects, and/or guide the design of them, in collaboration with industry.

ACHIEVEMENTS, BENEFITS AND ISSUES

Accomplishments Towards Objectives

Objectives/Actions	Accomplishments Towards Objectives
Promote acceptance of hydrogen as an energy carrier.	
• Conduct research and development activities to address important barriers to hydrogen's acceptance. • Foster and maintain a balanced portfolio of hydrogen technologies. • Develop safe, efficient, and cost-effective hydrogen storage systems. • Demonstrate integrated hydrogen systems. • Collect, disseminate, and analyze information on hydrogen technologies. • Develop direct hydrogen production technologies.	• Collaborative Tasks were carried out on longer-term hydrogen production technologies to improve the efficiency and lower the cost of direct hydrogen production technologies. ➢ Solar-to-hydrogen conversion efficiencies have topped 16% with the gallium-based photoelectrochemical cells. ➢ Sustainable photobiological production of molecular hydrogen using the green alga Chlamydomonas reinhardtii has been demonstrated. • A collaborative task is underway to develop efficient, low-emission technologies for producing hydrogen from natural gas. ➢ Technology options have been evaluated for pre-combustion decarbonization of natural gas. ➢ A report was published on technologies for distributed hydrogen production from natural gas. • A metal hydride material has been developed that surpasses 5 weight % reversible hydrogen storage at 150°C. • Information on a number of international hydrogen demonstration projects has been collected and published. • Through the integrated systems modeling efforts, a number of conceptual hydrogen energy systems have been evaluated. ➢ Planning evaluation for Utsira Wind-Electrolysis Project.

Objectives/Actions	Accomplishments Towards Objectives
Contribute to global energy security.	
• Facilitate the transition from fossil fuel energy systems to sustainable hydrogen-based energy systems. • Provide resources for the conversion of intermittent and seasonal renewables to base-load, load-following or peak-load power supplies, and to transportation fuels. • Assist developing countries in evaluating sustainable, indigenous resources for hydrogen production.	• A research effort was launched on converting carbon-containing resources (fossil and biomass) to hydrogen. Successful implementation of these nearer-term options will establish necessary infrastructure. • The modeling tools developed under the Agreement have been and can be used to design and optimize renewable hydrogen systems.
Promote deployment of hydrogen technologies with important local and global energy benefits.	
• Provide design support for hydrogen demonstrations. • Conduct cost-shared and task-shared deployment activities for hydrogen energy systems. • Act as an information resource for on-going and proposed hydrogen demonstration activities, including performance analyses. • Conduct case studies for hydrogen systems in developing countries.	• The integrated system modeling tools have been used to design and optimize conceptual energy systems, including the Utsira wind-electrolysis project. ➢ Under the new Task 18, Evaluation of Integrated Systems, the tools will be used to evaluate existing demonstrations. • Twenty detailed case studies of existing/completed hydrogen demonstration projects have been completed. ➢ Lessons learned from these projects can be applied to future demonstrations.

Objectives/Actions	Accomplishments Towards Objectives
Exploit the environmental benefits of hydrogen.	
• Carry out research and development on renewable hydrogen production techniques. • Promote hydrogen as a "clean" fuel. • Perform life cycle assessments of hydrogen technologies and energy systems. • Conduct research and development on technologies that lead to the decarbonization of fossil fuels.	• Collaborative research and development has been carried out on photobiological and photoelectrolytic water-splitting, and on biological and thermal routes to hydrogen. • Life cycle assessments were conducted on renewable (wind and biomass) and fossil-based systems (coal gasification and steam methane reforming). ➢ The results of these studies have been presented at international meetings. • A front-end engineering design is being developed for the precombustion decarbonization of natural gas under Task 16.
Develop cost-effective hydrogen energy systems that can compete in global markets.	
• Encourage industry participation to obtain market-oriented input for the prioritization of research, development and demonstration activities. • Develop and utilize analysis tools to evaluate and optimize hydrogen systems. • Increase involvement of industry in the Agreement’s activities. • Foster clean system incentive policies. • Identify secondary benefits of hydrogen energy systems, such as demilitarization.	• There has been significant industry involvement is several of the collaborative Tasks. • The modeling tools developed under the previous integrated systems Tasks are now being validated based on real-world demonstration projects.

Objectives/Actions	Accomplishments Towards Objectives
Identify and overcome barriers for hydrogen's penetration into the energy and fuel markets.	
• Contribute to the scientific and technical basis for approved codes and standards. • Promote hydrogen infrastructure for supply, maintenance and operation. • Pursue technologies that will lead to Increased market penetration for hydrogen. • Initiate safety-related educational and technology assessment activities.	• The Case Studies of international hydrogen demonstration projects highlights safety and permitting. ➢ Reports published to the web to increase impact. ➢ Operational and maintenance issues also highlighted. • Task 13, Design and Optimization of Integrated Systems, included an assessment of various cases for hydrogen supply to a fueling station. ➢ Results presented at multiple international meetings. ➢ Included infrastructure costs, supply issues, and environmental impacts of various technologies.
Advertise the benefits of hydrogen.	
• Increase involvement of private and public organizations in the Hydrogen Program. • Utilize media tools to promote hydrogen education. • Establish collaborative research and development projects that promote international networks. • Collaborate with other IEA Agreements to increase the effectiveness of crosscutting research and development activities. • Increase cooperation to reach "critical mass" in research and development activities.	• Presentations on the IEA Hydrogen Agreement and its activities were made at multiple international meetings, including the World Hydrogen Energy Conference, Hyforum, International Gas Conference and the World Energy Congress. • Web site redesigned to improve content and increase hits (from search engines). • Sponsored international meetings featuring the IEA efforts, including IEA Hydrogen Day at Hyforum and BioHydrogen 2002. • Task collaboration with other international networks: ➢ Task 14 with IEA SolarPACES Task 2, Solar Chemistry ➢ Task 15 with COST 8.41 Program ➢ Task 16 with IEA Greenhouse Gases and Bioenergy

SCALE OF ACTIVITIES AND MANAGEMENT

The national programs of the IEA Hydrogen Program Member Countries represent a diverse set of philosophies, policies, projects and budgets, brought together under the auspices of the IEA to accelerate hydrogen's acceptance and widespread utilization. These programs range from the hydrogen-dedicated North American and Japanese programs to those where hydrogen is but a player in various renewable and fossil programs. Budgets ranged from a few hundred thousand to forty million U.S. dollars (USD). Some large government programs were reduced and transitioned to industry while others have continually grown and become more focused on hydrogen technologies. The increase emphasis given to hydrogen technologies throughout the world has had significant impacts on these programs and on the representatives to the IEA Hydrogen Agreement.

The Agreement was managed through a part-time Secretary. With the increasing demands on the Agreement and increased opportunities for bringing in new members, the Agreement has decided to make the Secretariat a full-time position. The Agreement will pursue further expansion of this role, into a permanent office with multiple staff, if demands continue to increase and financial support is available from the Member Countries.

FUTURE STRATEGY

The Objectives and Actions outlined in the Agreement's Strategic Plan remain valid. Increased emphasis will be place on public and private outreach and on coordination with those organizations that are leading codes and standards development efforts. Currently, there are a multitude of views on how the different energy technology solutions will develop - when the Hydrogen Economy will be realized, which technologies are important, the appropriate paths to follow, areas to emphasize, etc. These views are all strongly influenced by political and commercial goals, which vary throughout the world. The Agreement will seek to serve as a neutral organization, with focused activities that address common areas of concern and on longer-term, pre-competitive research. The Agreement will continue to seek additional Members and industry Sponsors.

Many advances have been made in the longer-term photoproduction area. However, this work is still at the early development stage. A variety of materials and organisms remain under investigation. System design is also an area that requires a great deal of effort. This area of research will remain a priority for collaborative task-shared efforts.

Hydrogen use in non-energy processes, such as the chemical, metallurgical, and ceramics industries was identified as an area where a concentrated research effort could facilitate the increased utilization of hydrogen. Annually, these industries account for nearly 50 percent of the world's 500 billion Nm^3 hydrogen consumption. Process improvements and novel synthesis approaches could lead to overall efficiency improvements and reduced environmental impacts. Likewise, increased market share for hydrogen in these arenas should lead to expedited infrastructure development, a necessity for facilitating the advancement of the energy-related and renewable-based applications.

Hydrogen energy system demonstrations continue to be undertaken throughout the world. The experiences gained from these projects need to be compiled and made available to future demonstrators. Public response must be captured and considered when planning any hydrogen demonstration. System efficiency and cost optimization will also remain paramount issues for developing competitive hydrogen-based systems. Thus, utilizing all available information and international expertise and continually refining and expanding modeling tools will be imperative.

Hydrogen and renewables have a unique synergy. The success of the hydrogen economy will facilitate the success of renewables. Through hydrogen, intermittent resources like wind and solar can make significant and sustainable contributions to both the transportation and utility markets. Likewise, the true benefits of the hydrogen economy, where hydrogen is a clean and sustainable energy carrier, can only be realized if hydrogen is produced from renewables. We cannot continue to think of renewables and hydrogen as separate areas of research. We must think of them as intertwined and consider multi-product scenarios for renewables, where they are used from combined electricity, heat, fuel and/or chemicals production. Integrated renewable/hydrogen systems must be developed and must take advantage of near term market opportunities where the hydrogen can be produced and used in early fuel cell vehicle demonstrations or as a commodity chemical in industrial applications. Identifying these early market opportunities will be important and will facilitate an increased share for renewables in the world market. Hydrogen must team with Renewables to employ a multi-product approach, much like that employed by the petroleum industry. A refinery produces not just gasoline for passenger vehicles; it produces a range of fuel grades, high-value chemicals, heat and power; renewables, with hydrogen and electricity as key products, must take a similar approach.

Example: Wind is currently one of the most cost-competitive renewable electricity production technologies, particularly in areas with strong wind resources. However, the intermittent nature of wind prevents significant penetration of wind into the power grid and also adds to the cost of construction. By producing hydrogen during times where the wind resources are high and demand is low, hydrogen can either be sold as a transportation fuel or used to base-load the wind power. For this approach to be successful though, costs of wind turbines and electrolyzers must be lowered. Careful integration of components must be done based on accurate resource estimates and demand profiles. Opportunities:

- Lower-cost, higher-efficiency electrolyzers
- Low-cost, high-purity water
- Shared power electronics
- Resource assessment
- Market assessment

In all of its activities, the Agreement will continue and expand its partnerships with other Implementing Agreements, networks and organizations to prioritize activities and to establish collaborations of mutual interest.

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