HYDROGEN IMPLEMENTING AGREEMENT
2008 ANNUAL REPORT

IEA AGREEMENT ON THE
PRODUCTION AND UTILIZATION
OF HYDROGEN
The International Energy Agency (IEA) is an autonomous body that was established in November 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme.

It carries out a comprehensive programme of energy co-operation among twenty-six* of the OECD’s thirty member countries. The basic aims of the IEA are:

• to maintain and improve systems for coping with oil supply disruptions;
• to promote rational energy policies in a global context through co-operative relations with non-member countries, industry, and international organisations;
• to operate a permanent information system on the international oil market;
• to improve the world’s energy supply and demand structure by developing alternative energy sources and increasing the efficiency of energy use; and
• to assist in the integration of environmental and energy policies.

• IEA member countries: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, the Republic of Korea, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States. The European Commission also takes part in the work of the IEA.

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Pursuant to Article 1 of the Convention signed in Paris on 14th December 1960 and came into force on 30th September 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

• to achieve the highest sustainable economic growth and employment and a rising standard of living in member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
• to contribute to sound economic expansion in member as well as non-member countries in the process of economic development; and
• to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

The original member countries of the OECD are Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The following countries became members subsequently through accession at the dates indicated hereafter: Japan (28th April 1964), Finland (28th January 1969), Australia (7th June 1971), New Zealand (29th May 1973), Mexico (18th May 1994), the Czech Republic (21st December 1995), Hungary (7th May 1996), Poland (22nd November 1996), the Republic of Korea (12th December 1996) and Slovakia (28th September 2000). The Commission of the European Communities takes part in the work of the OECD (Article 13 of the OECD Convention).
# Introduction

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<td>Institut of Energy Research, Forschungszentrum Jülich GmbH</td>
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<td>Centre for Renewable Energy Sources RES &amp; Hydrogen Technologies</td>
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## CHAIRMEN & MEETINGS RECORD

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<th>Chairman</th>
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<td><strong>Mr. J. P. Cotzen</strong> (CEC) 1977-1982</td>
<td>1. Paris, France 8 November 1977 2. Ispra, Italy 31 August - 1 September 1978</td>
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<td><strong>Dr. Gerhard Schriber</strong> (Switzerland) 1992-1995</td>
<td>9. Pasadena, California, USA 18 June 1982</td>
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<td><strong>Mr. Nick Beck</strong> (Canada) 2005-2008</td>
<td>32. Istanbul, Turkey 17-18 November 1994 33. Ottawa, Canada 4-5 May 1995</td>
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<td><strong>Mr. Antonio G. García-Conde</strong> (Spain) 2008-current</td>
<td>34. Seville, Spain 21-24 November 1995 35. Diamond Bar, California, USA 8-10 May 1996</td>
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<td><strong>Mr. Nick Beck</strong> (Canada) 2005-2008</td>
<td>42. Toronto, Ontario, Canada 26-29 October 1999 43. San Ramon, CA, USA 14-17 May 2000</td>
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<td><strong>Mr. Nick Beck</strong> (Canada) 2005-2008</td>
<td>52. Utsira, Norway 10-12 May 2005</td>
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<tr>
<td><strong>Mr. Antonio G. García-Conde</strong> (Spain) 2008-current</td>
<td>53. Singapore 6-7 October 2005 54. Lyon, France 16-18 June 2006</td>
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<td><strong>Mr. Antonio G. García-Conde</strong> (Spain) 2008-current</td>
<td>57. Montecatini, Italy 8-9 November 2007 58. Brisbane, Australia 15-19 June 2008</td>
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<tr>
<td><strong>Mr. Antonio G. García-Conde</strong> (Spain) 2008-current</td>
<td>59. Athens, Greece 4-6 November 2008</td>
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Mr. Nick Beck continued to serve as IEA HIA Chair for the first half of 2008. His successor, Mr. Antonio G. García-Conde, was elected at the 58th Executive Committee (ExCo) Meeting that took place in June 2008 in Brisbane, Australia. In this Chairmen’s Report, Mr. Beck reviews his last six months in office. Mr. García-Conde then maps out conditions during his first six months in office, previewing his three year term as IEA HIA Chair.

Mr. Nick Beck

As I reflect on the three years of my IEA HIA chairmanship, I am grateful for the opportunity to have served the Agreement in this capacity. My experience has been very rewarding, professionally and personally. My thanks go to the ExCo, Operating Agents and the Secretariat, who all helped to make my tenure a productive period for the IEA HIA.

R&D Portfolio Status

By the June ExCo meeting in Brisbane, Task 26–Photoelectrochemical Production of Hydrogen was well underway. Dr. Eric Miller, the Task 26 Operating Agent, made his first ExCo presentation at that meeting. The ExCo also gave preliminary approval in Brisbane to Task 27–Near-Term Market Routes to Hydrogen by Co-Utilization of Biomass as a Renewable Energy Source with Fossil Fuel. Final approval for this task is expected in the next few months when Operating Agent support has been finalized. Task 21-BioHydrogen received a two year extension at the 58th ExCo meeting.

The IEA HIA Analysis Committee met in March 2008 in Paris under the leadership of Committee Chair Mr. Jürgen-Friedrich Hake of Germany. The Committee’s key message to the ExCo is that the IEA HIA needs an analysis effort which makes the case for hydrogen.

Membership

The Secretariat, Ms. Mary-Rose de Valladares, made a presentation at the April meeting of the International Partnership for a Hydrogen Economy (IPHE) Steering Committee in Moscow. The presentation focused on IEA HIA collaboration with the IPHE and the opportunity for non-IEA HIA countries that are IPHE members to join the Agreement. I am pleased to report that the Russian Federation has sent the ExCo a Letter of Intent (LOI) to participate in both Task 22–Fundamental and Applied Hydrogen Storage Materials Development and Task 19–Hydrogen Safety. These tasks are, respectively, the subjects of Annexes I and II between the IEA HIA and the IPHE. Execution of the LOI permits the Russian Federation to participate in Tasks 19 and 22 with the understanding that its official application for IEA HIA membership will be completed within a defined timeframe. The LOI mechanism was created as a result of the November 2007 Memorandum of Understanding (MOU) between the IEA HIA and the IPHE.
Interest in joining the IEA HIA now extends beyond countries: the United Nations Industrial Development Organization International Centre for Hydrogen Energy Technologies (UNIDO ICHET) has sent a letter to the IEA HIA expressing interest in membership.

ORGANIZATIONS

The lifeblood of IEA HIA collaboration is, quite simply, people – ExCo members, Operating Agents, Experts and Secretariat. I would like to acknowledge the outstanding contributions of two individuals who left IEA HIA service mid-year 2008: Dr. Andreas Luzzi, former Task 20 Operating Agent and Task 26 Organizer; and Ms. Elisabet Fjermestad-Hagen, former Task 16 Operating Agent, Task 27 Organizer, and Norwegian ExCo member.

PUBLICATIONS


OUTREACH AND COMMUNICATION

The IEA Networks of Expertise in Energy Technology (NEET) initiative held an event entitled “Workshop on Sustainable Rural Energisation in Major Emerging Economies” in May at the IEA Secretariat in Paris. While considerable progress has been made internationally in rural energisation, significant technical and institutional barriers still exist and innovation is welcome. Our Secretariat, Ms. de Valladares, presented on behalf of the Agreement. This presentation made extensive use of information from Task 18–Integrated Hydrogen Systems, and Task 24–Wind Energy and Hydrogen Integration. The information was furnished by Task 18 and Task 24 Operating Agents, Dr. Susan Schoenung and Dr. Luis Correas, respectively.

On June 10, I had the privilege of presenting the inaugural IEA HIA Individual Prize to Dr. Gary Sandrock, former Task 17 Operating Agent, in a ceremony at the annual U.S. Department of Energy (DOE) Hydrogen Program Review. The Individual Prize was awarded for technical excellence and leadership in international cooperation that advances basic and applied hydrogen science.

While the IEA HIA Individual Prize was conceived as a single award, special circumstances warrant special consideration. The late Dr. Tapan Kumar Bose, former Director of the Hydrogen Research Institute at the Université du Québec à Trois-Rivières (UQTR) in Canada, was also honored with the IEA HIA Memorial Individual Prize for lifetime achievements in hydrogen R&D. Dr. Richard Chahine of UQTR accepted the award on his behalf.

The month of June 2008 marked another first with delivery of an all IEA HIA track at World Hydrogen Energy Conference (WHEC) in Brisbane. Task 22 Operating Agent Dr. Bjorn C. Hauback presented a plenary talk on storage, “Novel Materials for Hydrogen Storage–Status and Challenge” that was co-authored by Dr. Gary Sandrock. The IEA HIA track included seven additional presentations, including my overview entitled “IEA HIA R,D&D to Supply Hydrogen Energy for a Changing World.”

I look forward to continued affiliation with the IEA HIA ExCo in my longstanding role as the Canadian Representative.
INTRODUCTION

The hydrogen domain continues to expand and this is, for sure, a welcome trend. As Chairman I look forward to collaborating with all my IEA HIA colleagues toward the Agreement’s continued growth in substance, size and stature in support of the advancement of hydrogen.

I would like to begin by acknowledging my predecessor, Mr. Nick Beck, for leading the Agreement through a period of unprecedented growth. It is an honor for me to be elected to serve as the IEA HIA Chairman for the next three years. The leadership team will also include Vice Co-Chairs Mr. Jan Jensen of Denmark and Dr. Steven Pearce of New Zealand. Having represented Spain since 1995, I am – as Nick was when he became Chair – no stranger to the IEA HIA. When I assumed the Chairmanship after the ExCo meeting in Brisbane, things were in full swing for the year and the pace has not slowed down. I will touch on just a few key events and activities in the second half of the year.

R,D&D PORTFOLIO STATUS

Task 27–Near Term Market Routes to Hydrogen by Co-Utilization of Biomass as a Renewable Energy Source with Fossil Fuels received final approval at the 59th ExCo meeting in Athens, Greece. This approval followed resolution of the funding approach for Co-Operating Agents Dr. Jan-Erik Hanssen and Ms. Elif Caglayan.

MEMBERSHIP

Brazil executed a Letter of Intent (LOI) to join the IEA HIA in order to expedite participation in Task 22. Under the terms of Annex I of the MOU, Brazil will then be required to seek IEA HIA membership within a defined timeframe. UNIDO-ICHET Representatives attended our 59th ExCo meeting in Athens, Greece. This international organization is now a serious candidate for IEA HIA accession and membership discussions are underway.

ORGANIZATION

The IEA HIA’s current 2004-2009 term of operation is scheduled to end 30 June, 2009. In order to renew the term, the IEA requires an End of Term (EOT) Report for 2004-2009 and a Strategic Plan for the next five years, 2009-2014. The EOT and Strategic Plan must be submitted to both the IEA
Renewable Energy Working Party (REWP) and the IEA Committee for Energy Research and Technology (CERT) for approval. The Secretariat will prepare the written plan under the direction of the Strategic Planning Committee, which the ExCo established to guide the five-year strategic planning process. The Committee functions under the chairmanship of Dr. Carole Read of the U.S. The members are IEA HIA Co-Chairs, Mr. Jensen and Dr. Pearce, as well as Mr. Jürgen-Friedrich Hake, Secretariat Manager Ms. de Valladares, and me in my capacity as IEA HIA Chairman. The Committee laid the groundwork for conducting a successful day-long strategic planning session at the ExCo meeting in Athens; information gathering for the Strategic Plan continued after the meeting. The EOT and Strategic Plan are scheduled for presentation to REWP in late March 2009 and the CERT in early June 2009.

The IEA HIA recognizes how important an asset our people really are: their many contributions are appreciated and those who leave IEA HIA “family” are invariably missed. At the end of 2008, Dr. Jurgis Vilemas retired as Lithuanian Representative after many years of IEA HIA service. Dr. Estathios Peteves retired as Representative for the European Commission to take on other responsibilities at the JRC Petten. After successfully launching Task 25, Mr. Gilles Rodriguez of CEA relinquished his Operating Agent position to assume new duties at CEA.

OUTREACH AND COMMUNICATION

For some time, the IEA HIA has been interested in expanding its conference presence consistent with the Agreement’s goals and priorities. Task 19—Hydrogen Safety is investigating effective risk management techniques and contributing to development of fundamental knowledge on hydrogen safety. The Task 19 Operating Agent, Mr. William Hoagland, has advised the ExCo of the possibility of securing a Co-Organizer role for the third International Conference on Hydrogen Safety (ICHS3). ICHS3 will be held in September 2009 in Corsica under the auspices of the newly formed International Association of Hydrogen Safety (IA HySafe). IA HySafe is the successor organization to HySafe, the European Commission funded Network of Excellence that has recently ended. Mr. Hoagland and Ms. de Valladares are now pursuing this opportunity.

As for the near-term outlook, 2009 promises to be both a busy and a landmark year for the IEA HIA.
HYDROGEN R, D&D:
SELECTED MEMBER HIGHLIGHTS AND NON-MEMBER ACTIVITIES IN 2008

Mary Rose de Valladares
M.R.S. Enterprises, LLC
IEA HIA Secretariat Manager

Behind this international R,D&D collaboration lie 22 member initiatives that range in size and scope from discrete hydrogen research activities to full hydrogen R,D&D programs. For some members, hydrogen has a large national presence. (In the case of the European Commission it’s now a pan-national presence.) For other members, initiatives are smaller in scale but strategically targeted to member conditions and interests. This article highlights some key features and interesting aspects of our members’ 2008 hydrogen investments.

These hydrogen investments are concrete evidence of the global interest in hydrogen. However, IEA HIA members are not the only nations investing in hydrogen. The IEA HIA hopes non-member countries investing in hydrogen - in both the developed and developing worlds - will one day join our collaboration. In so doing, they stand to benefit by leveraging their existing hydrogen R,D&D efforts. Indeed, non-member countries in the developing world are well positioned to leapfrog today’s energy infrastructure in favor of hydrogen technology. To provide a more complete picture of trends in hydrogen R,D&D around the world, this article also acknowledges some pivotal efforts of non-IEA HIA members.

For the full story on IEA HIA member R,D&D policies, budgets and activities, please refer to the Member Updates in this Annual Report. For immediate insight into member involvement in the 2008 hydrogen-related “discovery” process, as well as the 2008 hydrogen activities of select non-member countries, read on.¹

IEA HIA MEMBERS

POLICY, LAW AND REGULATION

The year 2008 witnessed continued formulation of hydrogen-related policy, law and regulatory measures.

- In 2008, Denmark took action to exclude hydrogen-fuelled and electric vehicles from taxation.
- Finland established the Strategic Competence Center of Energy and Environment (www.cleen.fi). The Center envisions the energy and environmental industries as a leading Finnish sector by 2050. It also envisions Finland as a global industry leader in selected energy and environmental businesses.
- In a key strategic development, France made a commitment to invest as much money in renewables as in nuclear, both of which are hydrogen sources.
- Korea proclaimed “low carbon green growth” as a new development priority, targeting hydrogen and fuel cells as areas of industrial growth.
- This year Japan has invested 1.4 B ¥ of NEDO’s hydrogen and fuel cell budget in laws and standards for “soft infrastructure” of a hydrogen economy society.
- In the Netherlands, the Working Group on Hydrogen (Platform New Gas: EnergyTransition) determined that it was essential to establish a foundation that will push market introduction of hydrogen and fuel cells forward. The foundation, to be established next year, will be comprised
SECRETARIAT’S REPORT

of industry and municipalities and closely linked to the EU Joint Technology Initiative for Fuel Cells and Hydrogen (JTI FCH).

- **New Zealand** developed an Energy Strategy that sets a target of 50% reduction in transport related emissions by 2040. The strategy views hydrogen as a potential long-term contributor toward that goal.
- The **UK** established a new Department of Energy and Climate Change (DECC), combining the energy policy and climate change functions from other departments.

ROADMAPS AND KEY ENABLING STUDIES

Policy, legal, regulatory, and technical activities benefited from development of roadmaps and enabling studies

- Three important documents related to hydrogen energy in **Australia** were released in 2008:
  - *The Hydrogen Technology Roadmap* prepared for the Australian Government Department of Resources
  - *Energy and Tourism; Australian Hydrogen Activity 2008* prepared for the Department of Resources
  - *Energy and Tourism*; and the Australian Academy of Science’s Toward Development of an Australian H2 Energy Research Publications and Funding.

- In the **U.S.A.**, the U.S. National Research Council (NRC) published *Transitions to Alternative Transportation Technologies: A Focus on Hydrogen*. This report examines the investments in R&D, demonstrations, education and infrastructure required for the development of fuel cell technologies and for the successful transition from petroleum to hydrogen vehicles in a significant percentage of the U.S. vehicle markets by 2020. The report contained the following important findings:
  - Fuel cell vehicles and hydrogen production technologies could be ready for commercialization in the 2015—2020 timeframe
  - Up to 2 million hydrogen fuel cell vehicles could be operating by 2020
  - By 2050 hydrogen fuel cell vehicles could account for more than 80 percent of new vehicles entering the fleet.

R&D

The IEA HIA’s core business of R&D&D is thriving. Our member R&D&D efforts are flourishing as well, as illustrated in the following examples:

- In October 2008 the **European Commission** launched the Joint Technology Initiative on Fuel Cells and Hydrogen (JTI FCH) as a public-private partnership of European industry and the European research community. It will invest nearly €1 billion over six years in the 7th Framework Programme. As part of the partnership OSEL (French agency for innovation support) granted €67.6M for the French Horizon Hydrogen Energy (H2E) Program, which is coordinated by Air Liquide Group. The H2E Program is slated to invest €200M over 7 years to build sustainable and competitive hydrogen solutions.
- The **Finnish** hydrogen and fuel cell technology program began its first phase in 2008 with over 300 participants from 60 companies and organizations that are engaged in 22 corporate and 15 research projects valued at €27M. Tekes, the Finnish Funding Agency for Technology and Innovation, is contributing €17.4M.
• **Germany** launched the ten-year National Innovation Program (NIP), an alliance that includes the German hydrogen and fuel cell activities. Over NIP’s lifespan, the federal government will provide €700M in funding, which will be matched or exceeded by industry contributions. The National Organization of Hydrogen and Fuel Cell Technology, GmbH (NOW) was established to operate NIP as a public-private partnership.

• **Italy** is in the third year of its five year National Research Plan, which features hydrogen and fuel cells. The Italian National Agency for New Technologies, Energy, and the Environment (ENEA) plans a coal hydrogenation pilot plant with carbon capture for zero emission power for 2010.

• At the **Lithuanian** Energy Institute, a successful application for EU structural funds resulted in support for a new department called the Centre for Hydrogen Energy Technologies. The Centre was established in a completely renovated laboratory area.

• The **Swedish** Energy Agency continued to finance a major hydrogen project in the production arena: “Hydrogen from solar energy and water - from natural to artificial photosynthesis,” which is now in the middle of its three year cycle form 2007-2009 at the University of Uppsala.

**FUELING STATIONS AND OTHER DEMONSTRATIONS**

Early infrastructure-related installations and demonstrations populate the global landscape, introducing hydrogen energy technologies and applications to society at large.

• The **Canadian** Hydrogen Program takes a comprehensive approach that features demonstrations. In early 2008, a technology demonstration and exhibit centre showing Canada’s leading hydrogen and fuel cell industry was officially opened at the Natural Resources Institute in Vancouver. This year, the first of 20 Olympic-bound buses was delivered to BC Transit for use in its sustainable transportation technologies project at the 2010 Olympic Games in Whistler, British Columbia.

• The second phase of **Denmark**’s national Micro-cogeneration Program (including low and high temperature PEM fuel cells and SOFC micro-generation units) began this year. Planning is underway for H₂ demonstrations at the 2009 COP15 climate change conference in Copenhagen and its parallel Bright Green exhibition.

• In **Greece**, work began on the 18 partner EC funded large-scale integrating project “H2SusBuild” Lavrion Technological Park of the National Technical University of Athens (NTUA).

• The **Japanese** Hydrogen & Fuel Cell Demonstration Project Phase II is gathering data on the performance of fuel cell vehicles and infrastructure in order to inform development of full-scale mass production and widespread use of fuel cell vehicles.

**The HyNor nodes**

Source: StatoilHydro
• Hy-Nor, a Norwegian public-private partnership created to demonstrate real life implementation of a hydrogen energy infrastructure along a 580 kilometer route from Oslo to Stavanger, signed a contract this year for delivery of 30-40 Mazda RX8 hydrogen cars for the HyNor project. These vehicles will complement the 15 Quantum US hydrogen cars already in operation by local drivers. New filling stations were planned, including four near term stations, one for Oslo and the other for Drammen. The HyNor route in Norway is being extended to Sweden and Denmark through the Scandinavian Hydrogen Highways Partnerships (SHHP).

• In Spain, a hydrogen filling station with on-site hydrogen production via an alkaline electrolyser was developed in conjunction with the Zaragoza EXPO 08. The station is slated to operate for eight years.

• In Switzerland, the “iHPoS,” an air-cooled PEM fuel cell system with metal hydride storage, is being integrated into a “Minibar” operated on Swiss trains in the railway company SBB. The hydrogen powered minibar tackles the issue of electricity availability during rush hour.

• Among the many projects underway in Turkey, a natural gas reformer system with catalytic combustion was successfully constructed for integration into a 5kW fuel cell microgeneration system. The reformer system, consisting of a series of reactors for hydrogen production and carbon monoxide removal, is capable of producing 5 Nm³ H₂/hour.

• Intelligent Energy, the UK developer of proton exchange membrane (PEM) fuel cells, successfully completed a three (3) year project with Peugeot Citroen (partially-funded by the UK Technology Strategy Board) to convert an existing electric vehicle van to fuel cell-hybrid configuration. The vehicle, known as the H2Origin, included a 10kW fuel cell and on-board compressed hydrogen stored on an exchangeable rack. Use of the exchangeable rack demonstrated a clever hydrogen distribution alternative. The advantage of fuel cell hybridization was shown in the increase in range from 78km for the battery only vehicle to 300km for the fuel cell hybrid.

This completes our survey of 2008 member highlights.

ACTIVITIES IN NON-IEA HIA MEMBER COUNTRIES

We continue with some 2008 highlights of hydrogen activities in non–IEA HIA member countries:

• Austria, known for its interest in biomass, also has an on-going interest in hydrogen, evidenced by participation in the task definition process for Task 27–Near-Term Markets to Hydrogen by Co-Utilization of Biomass as a Renewable Energy Source with Fossil Fuels. Portugal is similarly interested in the Task 27 definition process. Both Portugal and Singapore express continuing interest in IEA HIA bioHydrogen activities that comprise Task 21–BioHydrogen.

• The Russian Federation has an active program in hydrogen storage and a strong interest in the safety area. Indeed, the Russian Federation has conveyed a Letter of Intent (LOI) to the IEA HIA, agreeing to join the IEA HIA and indicating its interest in participating in two of our tasks: Task 22–Fundamental and Applied Hydrogen Storage Materials Development, and Task 19–Hydrogen Safety.

• China’s vision for transition to a hydrogen economy sets three milestones: a technology development phase by 2020; a market penetration phase by 2050; and beyond 2050, a fully developed market and infrastructure phase.
• **Brazil** prepared a Roadmap for the Hydrogen Economy which forecasts that hydrogen will be part of Brazilian energy resources in 2020. Ethanol is expected to be the main source of hydrogen, followed by biomass and biogas.

• The **Indian** Hydrogen Roadmap envisions one million hydrogen vehicles and 1,000 MW of Hydrogen power by 2020. These milestones are to be realized through two major initiatives: 1) Green Initiative for Future Transport (GIFT) and 2) Green Initiative for Power Generation (GIP).

• In **Malaysia**, a Solar, Hydrogen and Fuel Cells Road Map provides guidelines for R&D tailored to a future energy business scenario in which hydrogen is an attractive and competitive energy carrier.

• **South Africa** approved its Hydrogen and Fuel Cell Strategy in 2007. Given its dominant position in platinum reserves, South Africa anticipates a role as a leading supplier of the key catalytic material used in hydrogen fuel cells.

**FINDINGS AND CONCLUSIONS**

Interest in and commitment to hydrogen is evident around the globe, in developing as well as developed nations. The levels of activity and investment are impressive, as are the sheer number of countries engaged in hydrogen RD&D. While approaches vary in size and scope, they are coherent and focused. Each nation has crafted an initiative that reflects its resources, conditions, and interests. There are a significant number of non-IEA HIA member nations with hydrogen activities, and from our perspective, they are qualified prospects for IEA HIA membership. Given the IEA HIA’s value proposition, membership in the Agreement can offer serious leverage for non-member hydrogen investment. Broader membership may increase collaboration worldwide and spur further progress.

Significantly, there was progress in 2008 in all areas required for advancement of hydrogen, including policy and regulation, preparation of roadmaps and key enabling documents, and R&D, as well as demonstrations. These developments serve to elevate hydrogen’s international profile. In conclusion, both the collective IEA HIA efforts and individual country efforts contribute to the case for a future with hydrogen.

**REFERENCES**

1] The source of material for member countries is member updates found in this 2008 Annual Report. The source for non-member countries is the November 2008 Presentation by UNIDO ICHET at the 60th IEA HIA Executive Committee Meeting. The presentation is entitled “Review of Hydrogen Energy Strategies in Developing Countries,” by Oznur Tabakoglu, UNIDO ICHET Project Engineer and Nicolas Lymberopoulos. UNIDO ICHET Associate Director.
<table>
<thead>
<tr>
<th>Task</th>
<th>Description</th>
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<tr>
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<td>Task 2</td>
<td>High Temperature Reactors</td>
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<td>Electrolytic Production</td>
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<td>Task 5</td>
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<td>Task 6</td>
<td>Photocatalytic Water Electrolysis</td>
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<td>Task 7</td>
<td>Storage, Conversion, and Safety</td>
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<td>Task 9</td>
<td>Hydrogen Production</td>
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<td>Metal Hydrides for Hydrogen Storage</td>
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<td>Solid and Liquid State Storage</td>
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<td>Task 21</td>
<td>Biophydrogen</td>
<td>2005-2010</td>
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<td>Task 23</td>
<td>Small-Scale Reformers for On-Site Hydrogen Supply (SSR for Hydrogen)</td>
<td>2006-2009</td>
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<td>Task 24</td>
<td>Wind Energy and Hydrogen Integration</td>
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<td>Task 26</td>
<td>WaterPhotolysis</td>
<td>2008-2011</td>
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<td>Current and Completed Tasks</td>
<td><strong>Infrastructure and Bulk Storage</strong></td>
<td>Proposed</td>
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**TASK 18 TASK DESCRIPTION**

**PURPOSE**

The overall goal of Task 18 is to provide information about integration of hydrogen in societies around the world. Specific objectives are:

- to provide information, data, and analysis to the Task members and the hydrogen community in general;
- to use modeling and analysis tools to evaluate hydrogen demonstration projects in participating countries; and
- to perform trend analysis and disseminate lessons learned from projects studied.

**FRAMEWORK**

Task 18 has three Subtasks, described below. Experts meet twice yearly and communicate between meetings using email, the Task website, and occasional conference calls.

**VITAL STATISTICS**

**Term**

Phase 1: 2004 – 2006
Phase 2: 2007 – 2009

<table>
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<tr>
<th>COUNTRY</th>
<th>EXPERT NAME</th>
<th>INSTITUTION / COMPANY</th>
<th>SUBTASK</th>
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<tr>
<td>Canada</td>
<td>Shannon Miles (current Subtask C leader)</td>
<td>Natural Resources Canada</td>
<td>C</td>
<td><a href="mailto:shannon.miles@nrcan.gc.ca">shannon.miles@nrcan.gc.ca</a></td>
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<tr>
<td>Denmark</td>
<td>Henrik Iskov</td>
<td>Danish Gas Technology Center</td>
<td>all</td>
<td><a href="mailto:bis@dg.dk">bis@dg.dk</a></td>
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<tr>
<td>France</td>
<td>Aline Rastetter</td>
<td>ALPHEA</td>
<td>all</td>
<td><a href="mailto:aline.rastetter@alpha.com">aline.rastetter@alpha.com</a></td>
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<td>France</td>
<td>Touraya Dib</td>
<td>University of Corsica</td>
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<td><a href="mailto:dib@u-corsica.fr">dib@u-corsica.fr</a></td>
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<tr>
<td>Germany</td>
<td>Jochen Linssen</td>
<td>Research Center Julich</td>
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<td><a href="mailto:j.linssen@fr.juelich.de">j.linssen@fr.juelich.de</a></td>
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<tr>
<td>Greece</td>
<td>Elli Varkaraki</td>
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<td><a href="mailto:evarkara@crees.gr">evarkara@crees.gr</a></td>
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<tr>
<td>Italy</td>
<td>Agostino Iacobazzi</td>
<td>ENEA</td>
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<td><a href="mailto:iacobazzi@casaccia.enea.it">iacobazzi@casaccia.enea.it</a></td>
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<tr>
<td>Italy</td>
<td>Maria Chiesa</td>
<td>Catholic University</td>
<td>all</td>
<td><a href="mailto:maria.chiesa@unicatt.it">maria.chiesa@unicatt.it</a></td>
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<tr>
<td>Japan</td>
<td>Hiroshi Ito</td>
<td>AIST</td>
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<td><a href="mailto:ito.hi@ait.ac.jp">ito.hi@ait.ac.jp</a></td>
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<td>Japan</td>
<td>Osamu Miyashita</td>
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<td>all</td>
<td><a href="mailto:ad03ka@ena.or.jp">ad03ka@ena.or.jp</a></td>
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<td>New Zealand</td>
<td>Marcel Weeda</td>
<td>ECN</td>
<td>all</td>
<td><a href="mailto:weed@ecn.nl">weed@ecn.nl</a></td>
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<tr>
<td>Norway</td>
<td>Preben Vie</td>
<td>IFE</td>
<td>all</td>
<td><a href="mailto:preben.vie@ife.no">preben.vie@ife.no</a></td>
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<td>Norway</td>
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<td><a href="mailto:bjorn.simonsen@ife.no">bjorn.simonsen@ife.no</a></td>
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<td>Spain</td>
<td>Maria del Pilar Argumosa (current Subtask B leader)</td>
<td>INTA</td>
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<td><a href="mailto:argumosa@inta.es">argumosa@inta.es</a></td>
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<td>Spain</td>
<td>Ismael Aso</td>
<td>Hidrogena en Aragon</td>
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<td>Hidrogena en Aragon</td>
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<td>Grontmij</td>
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</tr>
<tr>
<td>Switzerland</td>
<td>Michael Bielmann</td>
<td>EMPA</td>
<td>guest</td>
<td><a href="mailto:michael.bielmann@empa.ch">michael.bielmann@empa.ch</a></td>
</tr>
<tr>
<td>United Kingdom</td>
<td>Mary Gillie</td>
<td>EA Technology</td>
<td>all</td>
<td><a href="mailto:mary.gillie@eatechnology.com">mary.gillie@eatechnology.com</a></td>
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<tr>
<td>United States</td>
<td>Susan Schoenung</td>
<td>Longitude 122 West, Inc.</td>
<td>Operating Agent</td>
<td><a href="mailto:susan.schoenung@sbeglobal.net">susan.schoenung@sbeglobal.net</a></td>
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<td>United States</td>
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<td>EC</td>
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<td><a href="mailto:stathios.peteves@ec.europa.eu">stathios.peteves@ec.europa.eu</a></td>
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</table>

Table 1. Members / Experts
SUBTASKS

Task 18 Phase 1, has three major subtasks:

- Subtask A: “Information Base” Development
- Subtask B: Demonstration Project Evaluation
- Subtask C: Synthesis and Learning

The leader for Subtask A has been Dr. Emma Stewart, a researcher at Sandia National Laboratories. The leader for Subtask B is currently Ms. Maria del Pilar Argumosa of INTA. The leader of Subtask C is currently Ms. Shannon Miles Halliday of Canada.

SUBTASK A

Subtask A has an overall objective to provide data and analysis to the hydrogen community in the form of inventory databases and/or compiled summaries regarding the developing use of hydrogen. Subtask A information bases are structured as indicated in the figure below. The National Documents, National Organizations, and National Projects databases are all publicly accessible.

The revival of the Hydrogen Resources Study is also taking place under the umbrella of Subtask A. The new literature search and bibliography activity is using the Subtask A database structure.

SUBTASK B

The overall objective of Subtask B is to use modeling and analysis tools to evaluate hydrogen demonstration projects, to guide their design, and to validate models and assumptions.

The method used in Subtask B is to gather data on hydrogen projects and exercise modeling and analysis capabilities to evaluate demonstration projects. In some cases, models have been used to design or optimize demonstration or operational systems. Participants, in collaboration with industry, identify specific projects for evaluation. Projects are evaluated
by applying analysis tools such as Hydrogems or Simulink. Industry-led demonstration projects provide data for further validation of existing models. Experts advise on hydrogen process analysis and simulation.

Member countries have brought data from demonstration projects in their countries for review and assessment. The projects must demonstrate integrated systems of a non-trivial nature. Specifically, they must consist of multiple hydrogen components or subsystems, categorized as production, storage or utilization. In general, the projects are based on a matrix whereby the hydrogen is produced either from renewables (RE) or fossil fuel (natural gas), and is used either in an electric power production application (grid), a transportation fuel application, or a combination of the two. The project portfolio under evaluation in Subtask B is shown in Table 2.

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>PROJECTS</th>
<th>LOCATION</th>
<th>MODELING FOCUS</th>
<th>EVALUATION STATUS</th>
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<td>Sweden</td>
<td>Hydrogen filling station (RE grid/electrolysis)</td>
<td>Malmö</td>
<td>System sizing</td>
<td>Expansion in progress</td>
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<td>Spain</td>
<td>Hydrogen filling station at Expo 2008 (grid/electrolysis)</td>
<td>Zaragoza</td>
<td>Station and bus performance</td>
<td>Data acquisition system in design</td>
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<td>Norway</td>
<td>Hydrogen filling station (grid/electrolysis), HyNor node</td>
<td>Oslo</td>
<td>System performance</td>
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<td>Spain</td>
<td>RES2H2 (combined wind power and desalination)</td>
<td>Gran Canaria</td>
<td>System performance</td>
<td>In progress</td>
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<td>Denmark</td>
<td>Island power</td>
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<td>System performance</td>
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<td>Italy</td>
<td>Hydrogen from the Sun</td>
<td>Brunate</td>
<td>Control strategy</td>
<td>Complete</td>
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<td>USA/UK</td>
<td>Hydrogen, energy, CHP refuelling station (biofuels)</td>
<td>USA / UK</td>
<td>System performance</td>
<td>In progress</td>
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<td>USA</td>
<td>Hydrogen power park (RE)</td>
<td>Hawaii</td>
<td>Performance, economics</td>
<td>In progress</td>
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<tr>
<td>New Zealand</td>
<td>Renewable hydrogen at remote site, pipeline to small village</td>
<td>Totara Valley</td>
<td>Performance, economics</td>
<td>In progress</td>
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</tbody>
</table>

Table 2: Project Portfolio under Evaluation in Subtask B.
Subtask C is focused on synthesizing work from member countries, information bases, demonstration projects, and the case studies to derive lessons learned. A list of products has been developed, including comparative analysis.

ACTIVITIES AND RESULTS IN 2008

PROGRESS AND ACCOMPLISHMENTS

Expert Meetings

Task 18 members met twice in 2008. The spring Experts Meeting was held in Athens, Greece, where experts visited the wind park and hydrogen project designed under the RES2H2 program. The fall Experts Meeting took place in Denmark. Experts met first at the office of the Danish Gastechnology Center. They also visited the community of Lolland, where hydrogen produced from wind power is being used in home power and heating systems. Finally, we visited the Swedish city of Malmö, where city buses are being converted to run on a mixture of hydrogen and natural gas.

Hydrogen Resources Literature Search and Bibliography

In response to a request from the Hydrogen Analysis Committee, which was prompted by the renewed ExCo effort to develop a Hydrogen Resources Study, the Task 18 experts provided 26 annotated bibliographies. The database contents include the following categories:

1. Document identification: Title, Author, Sponsor, Publisher, Date, Website
2. Demand projections
3. Timeframe
4. Geographic coverage
5. Hydrogen sources
6. Modeling processes
7. Assumptions
8. Environmental considerations
9. Key findings
OUTREACH AND COMMUNICATION

Task 18 publishes papers, makes conference presentations, and produces reports. In addition, we invite guests to our expert meetings for additional outreach.

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<thead>
<tr>
<th>DATE</th>
<th>ARTICLE/PRESENTATION NAME</th>
<th>EVENT</th>
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<td>“Hydrogen Demonstration Project Evaluations”</td>
<td></td>
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<td>IEA HIA Publication ISBN: 978-0-9815141-0-0</td>
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<td>Croatia</td>
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Table 3: Papers, Presentations, Interviews

Websites

The Task 18 websites have been moved. The private and public websites can now be found at:
http://iea-hia-annex18.sharepointsite.net/
http://iea-hia-annex18.sharepointsite.net/Public

FUTURE WORK

ACTIVITIES AND/OR TARGETS FOR 2009

The next Expert Meeting is scheduled to be held 6-8 May, 2009 in Oslo, Norway where Task 18 will be hosted by IFE and StatoilHydro. We will visit the HyNor refueling station on the Norwegian hydrogen highway at Porsgrunn. A possible meeting site for the fall 2008 Experts Meeting is Hawaii, with a visit to the Hawaii Power Park and Hydrogen
fuelling station at Hawaii Volcanoes National Park. We will close out Task 18 work by the end of 2009. We will finish our database and analysis work, and complete the following case studies.

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<td>Fuel Cell Boat</td>
<td>The Netherlands</td>
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<td>Sustainable Office</td>
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<td>Res2h2 – Canaria</td>
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<td>Lolland Island Project</td>
<td>Denmark</td>
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<td>Hawaii Power Park</td>
<td>USA</td>
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<td>Intelligent Energy Triple-gen</td>
<td>USA/UK</td>
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<td>Elohy</td>
<td>France</td>
</tr>
<tr>
<td>Totara Valley</td>
<td>New Zealand</td>
</tr>
</tbody>
</table>

Table 4. Case Studies in Progress

ACTIVITIES AND/OR TARGETS BEYOND 2009

We are considering task definitions for at least two tasks to succeed Task 18. One will conduct the Hydrogen Resources analysis that has begun with the literature study and bibliography. The second will be a community-based hydrogen assessment task, following the current survey work of islands and remote communities. A possible third could continue the detailed simulation work of Task 18 if committed analysts can be identified. These potential follow-on activities will be discussed during expert meetings in 2009.

CHALLENGES

Task 18 successfully transitioned its private and public websites to a new server and operator. In addition, discontinuity caused by Experts’ career moves is an ongoing challenge.

ADDITIONAL REFERENCES

Presentations scheduled for 2009:

NHA Annual Meeting, South Carolina, April 2009

- Susan M. Schoenung, “Further Experiences in Permitting and Safety of Integrated Hydrogen Systems”

Hypothesis VIII, Lisbon, Portugal, April 2009


Hydrogen and Fuel Cells Conference, Vancouver, Canada, June 2009

HYDROGEN SAFETY

Mr. William Hoagland
W. Hoagland & Associates
Operating Agent for Natural Resources Canada & US Department of Energy

SUMMARY OF FRAMEWORK

Acceptability of new systems is traditionally measured against regulations, industry and company practices, and the judgment of design and maintenance engineers. However, contemporary practice also incorporates systematic methods to balance risk measurement and risk criteria with costs. Management decisions are increasingly reliant on Quantitative Risk Assessment (QRA) for attainment of acceptable levels of safety, reliability and environmental protection in the most effective manner. QRA is being applied more frequently to individual projects and may be requested by regulators to assist in making acceptance and permitting decisions. This task was approved by the Executive Committee of the IEA Hydrogen Implementing Agreement in October 2004.

MEMBERS

- Canada
- France
- Germany
- Greece
- Italy
- Japan
- Norway
- Switzerland
- The Netherlands
- United Kingdom
- United States

VITAL STATISTICS

Term

Phase 1: 2004–2007
Phase 2: 2007–2010

Number of Participants
Currently 11

Number of Experts
Currently at least 21 Experts
Attend the Task 19 Meetings

2008 Meetings
March 3-6
Sacacomie, Québec, Canada
September 10-14
Oslo, Norway

The specific objectives of this Task are:

- to survey risk assessment methodologies based on case studies provided by collaborative partners;
- to survey available test data, develop recommendations on modeling and testing methodologies, and share future test plans around which collaborative testing programs can be conducted, thus avoiding duplication of work among collaborative partners;
- to collect information on the effects of component or system failures of hydrogen systems;
- to use the results obtained to develop targeted information packages for selected hydrogen energy stakeholder groups.

SUBTASKS

This task is aimed at reducing the barriers to widespread adoption of hydrogen energy systems, and it is being accomplished within three subtasks.

The goal of the Hydrogen Safety Task is to survey and analyze effective risk management techniques, testing methodologies, and test data, contribute to development of fundamental knowledge on hydrogen related to hydrogen safety, and develop targeted information products that will facilitate the accelerated adoption of hydrogen systems.
Subtask A: Risk Management – Leader: Canada (Andrei Tchouvelev, AVT & Assoc.)

Purpose: To survey Quantitative Risk Assessment (QRA) methodologies and compare assessments of hydrogen systems with conventional fuels to develop recommendations for modeling and testing methodologies around which collaborative testing programs can be conducted.

Activities for the Subtask's second second three (3) year phase follow:

- Activity A1: Develop uniform risk acceptance criteria and establish link with risk-informed codes & standards. (Activity leaders: Jeff LaChance, SNL, USA and Angunn Engebo, DNV, Norway.)
- Activity A2: Develop a list of appropriate engineering models and modeling tools. Develop simple but realistic physical effects models for all typical accident phenomena (i.e., jet fires, vapor cloud explosions, flash fires, BLEVEs, pool fires, etc.) for education and training, design evaluation, and simplified quantitative risk analysis purposes. (Activity leaders: Pierre Benard, HRI, Canada and Jay Keller, SNL, USA.)
- Activity A3: Develop methodology for consistent site risk assessment based on HyQRA approach. (Activity leaders: Olav Hansen, GexCon, Norway, Koos Ham, TNO, Netherlands and Alessia Marangon, UNIPI, Italy.)
- Activity A4: Release updates (at least once) to all original Subtask A products: Risk Assessment Methodology Survey, Knowledge Gaps White Paper and Review, and Comparison of Risk Assessment Studies. (Activity leader: Andrei V. Tchouvelev, AVT, Canada.)

Subtask B: Testing and Experimental Program – Leader: The Netherlands (Nico Versloot, TNO Defense, Security and Safety)

Purpose: To conduct a collaborative testing program to evaluate the effects of equipment or system failures under a range of real life scenarios, environments, and mitigation measures.

Subtask C: Development of Information Packages for Stakeholder Groups – Leader: U.S.A. (Steven Weiner, Pacific Northwest Laboratories)

Purpose: To disseminate results of the task through targeted information packages for stakeholders.

ACTIVITIES AND RESULTS IN 2008

PROGRESS AND ACCOMPLISHMENTS

In 2008, Task 19 on Hydrogen Safety turned its attention to detailed planning according to the approved work plan for the follow-on period 2007–2010. A key factor was the level of effort required for the Task and what commitments would be received. Individual participating Experts were asked to discuss their respective contributions and whether a sufficient commitment could be made. The Task work plan establishes the technical basis for the required codes and standards for the commercial application of hydrogen systems. The final plan was contingent upon the Task receiving a sufficient level of effort via the National Participation Letters (NPL). Nevertheless, the Task has enjoyed full participation from Experts since the inception of the collaboration. This is important as managers assess whether the Task will have the resources needed to complete the products anticipated at the end of the follow-on period (October 2010).
In May, several Task 19 Experts participated in the planning meeting for the Third International Conference on Hydrogen Safety (ICHS III) to be held in September 2009. A meeting of Task 19 Experts was held on September 10-12, 2008 in Oslo, Norway. This was the eighth Experts Meeting held since the Task was officially approved at the Hydrogen Implementing Agreement Executive Committee meeting in London, October 10-13, 2004. The meeting was hosted by Det Norske Veritas (DNV). The purpose of the meeting was to share information and to discuss and approve the scope of continued collaboration during the 3-year follow-on period 2007-2010, with particular attention to the products to be completed during that time. Technical progress on the development of Risk Informed Approval Criteria for hydrogen projects and to provide a solid basis for Risk Informed Codes and Standards was presented, and this subtask is expected to be completed on schedule.

With regard to the publication of the Task products, the experts agreed that electronic copies would be the main means of publication of the Task results; however, a limited number of hard copies will be produced for special uses, such as conferences and the Executive Committee.

**SUBTASK A: RISK MANAGEMENT**

See the 2007 Annual Report for Subtask A: Activities and Results.

**SUBTASK B: TESTING AND EXPERIMENTAL PROGRAM**

*Leader: The Netherlands – (Nico Versloot, TNO)*

This Subtask will summarize and ultimately coordinate and guide the experimental programs being conducted within the eleven countries participating in the Task. The approach is intended to identify such testing programs, the facilities being used, and to coordinate the activities to fill in the data and knowledge gaps for the development of risk-informed codes and standards. Subtask B focuses on both testing and experimental data, i.e., testing data as collected by checking the performance of applications, equipment, and experimental data as collected by experiments with hydrogen release, ignition, fire, explosions, and preventive and protective measures. Testing data are more equipment specific, whereas experimental data are more hydrogen specific. Experimental data in particular provide could give new insight in controlling (the size of) hazardous areas. The smaller such an area, the less equipment will remain in a hazardous area, resulting in less strict mitigating measures for the equipment. Data will be characterized by a broad range of input parameters, from reference and contact information and type of test and/or equipment to liquid and/or gas, pressure, and temperature conditions. In particular, adding failure frequencies for test data will be a very useful source of information in linking Subtask B with Subtask A “Risk Management” (through Activity B3). This Task was originally planned to start during the first three-year period, however it has now picked up momentum and results will be available during the follow-on period which concludes in 2010.
The Task is being conducted within the following activities:

**Activity B1: Survey of Existing Testing and Experimental Data**

An inventory of existing testing and experimental data is in progress and the participants have started sharing information during and beyond the Task 19 meetings. This has been extended (and will be included in the future activities) by a search by the partners for any data existing in their respective countries and around the world. In order to secure a continuing refinement of the survey, the data and/or references will be stored in the database on HYdrogen Testing and EXperimental data, HYTEX. This database will be available through the Task 19 website and will only be reachable by the Task 19 partners through a dedicated (password protected) members’ area.

**Activity B2: Survey of Ongoing or Planned Projects**

An inventory of hydrogen testing and experimental facilities existing worldwide has been started by sharing information (mainly through presentations) during and beyond the Task 19 meetings. The data and/or references will be stored in the database on HYdrogen Testing and Experimental Facilities (HYTEF), which will be available through the Task 19 website but only be reachable by the Task 19 partners through a dedicated (password protected) members’ area.

An inventory of ongoing or planned projects has been started by sharing information (mainly through presentations) during and beyond the Task 19 meetings. This has been extended (and will be included in the future activities) by a search by the partners for any ongoing or planned projects in their respective countries and around the world. In order to assure continued refinement of the survey, the data and/or references will be stored in the database on performed, ongoing or planned HYdrogen PRojects (HYPRO). This database will be available through the Task 19 website and will only be reachable by the Task 19 partners through a dedicated (password protected) members’ area.

**Activity B3: Analyzing Existing Data in Relation to Risk Management**

The Subtask B databases HYTEX, HYPRO, and HYTEF will be used as a source of information for any missing data in relation to the knowledge gaps as defined by and resulting from Subtask A activities. If data are not available, no new testing and experimental programs may be pursued. The existing data may also be checked on its relevance and completeness. A first set of knowledge gaps has been identified in Subtask A and described in the white paper, “Knowledge Gaps in Hydrogen Safety.” Presently identified knowledge gaps are: spontaneous ignition, protective barriers and consequence modeling.

**SUBTASK C: DEVELOPMENT OF TARGETED INFORMATION PACKAGES FOR STAKEHOLDER GROUPS**

**Leader: USA - Steven C. Weiner, Pacific Northwest National Laboratory**

The targeting of information packages for selected hydrogen energy stakeholder groups is central to the work and objectives of Task 19, currently focused on risk assessment methodologies and studies, testing and experimental programs, safety training and knowledge resources, and hydrogen facility siting. Information packages can take a variety of forms, including IEA publications, publicly available web-based tools, databases, and documents for use by Task 19 partners.
Over the course of the three-year period, a portfolio of products described in this report has been developed and contributed by Task 19 partners in support of the objectives of Subtask C:

- Hydrogen Siting Compliance and Planning Expert (HySCAPE™): an interactive three-dimensional workplace to define and layout a hydrogen facility.
- Hydrogen Public Official Safety Training (HyPOST™): an interactive three-dimensional workplace for fundamentals of hydrogen properties, generic hazards and responses, simulations from releases, thermal effects, risk assessments, and risk mitigation options from Subtask A work.
- Hydrogen Incident Reporting Tool: a database that contains records of events involving either hydrogen or hydrogen-related technologies.
- Hydrogen Safety Best Practices Manual: a resource to share the benefits of extensive experience by providing suggestions and recommendations pertaining to the safe handling and use of hydrogen.
- Hydrogen Safety Bibliographic Database: a database that provides references to reports, articles, books, and other resources for information on hydrogen safety as it relates to production, storage, distribution, and use.

An important aspect of information dissemination is to ensure that the review and vetting of all work products for Task 19 are consistent with the requirements and procedures for producing, approving, and distributing various types of IEA reports and other information products. A protocol has been adopted by Task 19 partners and is being applied appropriately for Task 19 work. It is expected that several of these Subtask C products will be updated and enhanced over the course of the period covering Task 19 through October 2010.

ACCOMPLISHMENTS

DEVELOPED UNIFORM RISK ACCEPTANCE CRITERIA

NOV 2008

- Types of risk measures
- Risk targets
- Survey currently used risk criteria and their rationale
- Recommend uniform risk acceptance criteria and provide rationale

DEVELOP UNIFORM CONSEQUENCE PARAMETERS OR HARM CRITERIA FOR USE IN HYDROGEN QRA

- Define measures for all types of hydrogen accidents and screen based on relative risk
- Survey of currently used measures and their rationale
- Recommend uniform consequence parameters and provide rationale behind them
OUTREACH AND COMMUNICATION

STRATEGY AND ACTIVITIES

Most experts on hydrogen safety are participating in this Task. They are also active in the biennial International Conference on Hydrogen Safety, the next being in Corsica, France in September 2009. A large part of the communication and outreach strategy is participation in such conferences and presentation of papers on the key elements of the Task. Participants are involved in the ICHS in a major way, with virtually every expert being an author or co-author of a paper. Several are also session chairs and keynote speakers.

FUTURE WORK

ACTIVITIES/TARGETS FOR 2009

• Development of a simplified method for assessing risk Dec 2009
• Complete development of HYTEX Database Nov 2009
• Complete development of HYPRO database Nov 2009

ACTIVITIES/TARGETS BEYOND 2009

• Completion of a simplified methodology for risk-informed criteria for use in developing codes and standards.

R&D CHALLENGES

The main challenge to realizing the R&D needed to achieve the Task objectives is overcoming the instability of national budgets so that the participating Experts can conduct the activities prerequisite to meeting Task milestones. This is a collaboration in which participants share the results of their individual programs, so the actual R&D will be conducted and made available for incorporation into the Task products.
INTRODUCTION AND OBJECTIVES

Task 21 covers the integrated areas of research, technological/economic evaluation, and the adaptation to society, which are of mutual interest to the countries and researchers participating in the IEA Hydrogen Implementing Agreement. This Task provides a basis for establishing actual collaborative research projects and an overall coordinated program.

BioHydrogen, the production of hydrogen by microorganisms, has been studied in Japan, Europe and the USA. Many research projects are now carried out in Asian countries, where the energy demand is rapidly growing.

The Task will carry out collaborative research activities on the biological production of hydrogen using bacterial dark fermentation, photosynthetic microbes, and in vitro and bio-inspired systems. The overall objective is not only to sufficiently advance the basic and applied science in this area of research over the next five years, but also to evaluate BioHydrogen’s economic and sociological aspects. A five-year period is considered sufficient to initiate a significant directed research program, achieve some advances, and define metrics for evaluation of the developmental status and promise of this field of research and technology.

Task 21 consists of four (4) subtasks. The Task addresses the development of basic and applied science of BioHydrogen, as well as total integration of the state-of-the-art of each subtask into a techno-economic evaluation. Dark fermentation, hydrogen production by microalgae and cyanobacteria from water, and in vitro systems will be studied with close connection to techno-economic evaluation. The following R&D areas will be investigated in four subtasks.

ACHIEVEMENTS IN 2008

Subtask A: BioHydrogen Systems

**Goal:** Increase achievable H₂ production from substrates above currently achievable yields (e.g., 3 to 4 moles H₂/mole of glucose).

Hydrogen production by fermentative bacteria from biomass (bio-residues or primary products) as substrate is an important field of BioHydrogen. Biomass is renewable and can be considered a sink for energy from sunlight.

The status of dark H₂ fermentation is the closest to the stage of realistic application. However, the bottleneck is the relatively low yield of H₂ per unit of biomass consumed. Hydrogen is also produced during photofermentation of, preferably, organic acids. Here, the bottleneck is the efficient administration of light and the performance of the bacteria.

**Overview of Recent Progress:**

Over the past three years within Task 21, several pure cultures have been studied using defined substrates. These include, among others, enterobacteria (Escherichia and Enterobacter), mesophilic and thermophilic strict anaerobic Gram-positive microbes such as Caldicellulosirruptor. The stoichiometry of substrate conversion and the formation of side products have been studied, and for some bacteria, genomic information was implemented for some bacterial strains, especially for enterobacteria.
Lactate and ethanol are undesired side products of facultative and strict anaerobes. Much has been studied about the genetics and regulation of facultative anaerobes, and a set of mutants was found that does not form ethanol and lactate. One of the limitations of facultative anaerobic bacteria is that $H_2$ is formed by formate $H_2$ lyase, which only permits a maximum of 2 $H_2$ per glucose. Based on the above findings, we are considering that $H_2$ yields could potentially be further enhanced by introducing genes coding enzymes that are involved in $H_2$ formation from NADH. Strict anaerobes have the ability to form 4 $H_2$ per glucose, but they grow slower and they are less well studied. The challenge in the coming years is to take full advantage of the potential of the two types of $H_2$ producers, which may result in fast growth, rapid substrate conversion and in maximal $H_2$ yields. The available expertise within the Task 21 members is invaluable in these respects.

Fermentative and electrohydrogenic approaches to hydrogen production research focused on hydrogen from lignocellulosic biomass, using corn stover as the model substrate and steam-explosion or dilute-acid hydrolysis as the model pretreatment technology. The fermentation of corn stover hemicellulose used a consortium derived from sewage sludge, while the cellulolytic bacteria, Clostridium thermocellum, was used to ferment the lignocellulose (cellulose and lignin). This organism was reported to have the highest rate of cellulose conversion. The rate-limiting steps of the hydrogen-production reaction were the rate of cellulose hydrolysis and byproducts formation. The latter lowers the hydrogen molar yield.

**Subtask B: Basic Studies for BioHydrogen Production**

**Goal:** Demonstrate potentially practical processes for the conversion of water or organic substrates to $H_2$ using solar energy.

Although $H_2$ evolution mediated by hydrogenase(s) was discovered in green algae over 65 years ago, and subjected to extensive investigations over the ensuing decades, there are still many important, fundamental, and applied issues that must be addressed before this type of process can be considered for practical application. $H_2$ production from organic substrates using anoxygenic photosynthetic bacteria has also been extensively studied to improve the efficiency. Refinements will require a fundamental understanding of the genetics, biochemistry, and physiology of hydrogen-producing enzymes, including metabolisms and factors affecting the growth of photosynthetic microbes. Furthermore, efficiency of photosynthesis and the conversion of light energy to biochemical energy ultimately limit the efficiency of $H_2$ production. Understanding photosynthetic mechanisms in relationship to $H_2$ production and trials to improvement of photosynthetic efficiencies are ambitious and challenging targets. These will require the application of modern and advanced tools of molecular biotechnology and microbial physiology, which are already available at leading research laboratories in the participating countries.

The EU has made special efforts to launch several new research projects on BioHydrogen. Japan and the USA also have projects on basic photosynthesis and genetics research. The efficiency of photon capture systems have been intensively studied in photosynthetic bacteria, cyanobacteria and algae. Balancing the amount and capability of Light Harvesting and Reaction Center systems is a key to maximize the efficiency of photon to $H_2$ production in a real cell culture. Genetic engineering has been studied to improve energy conversion.
Physiology of and cultivation practices with photosynthetic microbes are other important subjects in maximizing H₂ production from water or organic wastes. Since the collection of cyanobacteria by the late Professor A. Mitsui, many important new strains have been found, and the mechanisms of electron supply from substrates have been studied. The metabolic pathway and the regulation of hydrogenase are controlled by the physiological/physical condition of the cell and the chemicals added. Methods to control the mechanism of the cell are the major subject of study in science and engineering.

Overview of Recent Progress:

Photosynthetic hydrogen production

The unicellular green alga Chlamydomonas reinhardtii possesses a [FeFe]-hydrogenase HydA1 (EC 1.12.7.2), which is coupled to the photosynthetic electron transport chain. Large amounts of H₂ are produced in a light-dependent reaction for several days when C. reinhardtii cells are deprived of sulfur. Under these conditions, the cells drastically change their physiology from aerobic photosynthetic growth to an anaerobic resting state. The understanding of the underlying physiological processes is not only important for getting further insights into the adaptability of photosynthesis, but will help to optimize the biotechnological application of algae as H₂ producers. Two of the still vigorously debated questions regarding H₂ generation by C. reinhardtii concern the electron source for H₂ evolution and the competition of the hydrogenase with alternative electron sinks. The analysis of the H₂ metabolism of S-depleted C. reinhardtii cultures showed that electrons for H₂-production are provided both by PSII activity and by a non-photochemical plastoquinone reduction pathway, which is dependent on previous PSII activity (Kosourov et al., [2003] Plant Cell Physiol. 44; 146-155; Hemschemeier et al., [2008] Planta. 227: 397-407). In a Rubisco-deficient strain, which produces H₂ also in the presence of sulfur, H₂ generation seems to be the only significant electron sink for PSII activity and rescues this strain at least partially from a light-sensitive phenotype. The latter indicates that the down-regulation of assimilatory pathways in S-deprived C. reinhardtii cells is one of the important prerequisites for a sustained H₂ evolution.

Chlamydomonas reinhardtii H₂ production, narrowly linked to the photosynthetic process, results from complex metabolic reactions highly dependent on the environmental conditions of the cells. A kinetic model has been developed to relate culture evolution from standard photosynthetic growth to H₂-producing cells (Fouchard et al (2009) Biotechnol. Bioeng. 102: 232-245). It represents transition in sulfur-deprived conditions and the two main processes then induced, which are an over-accumulation of intracellular starch and a progressive reduction of PSII activity for anoxia achievement. Because these phenomena are directly linked to the photosynthetic growth, two kinetic models were associated, the first introducing light dependency (Haldane type model associated to a radiative light transfer model), the second making growth a function of available sulfur amount under extracellular and intracellular forms (Droop formulation). The model parameters identification was realized from experimental data obtained with specially designed experiments and a sensitivity analysis of the model to its parameters was also conducted. Model behavior was finally studied, showing interdependency between light transfer conditions, photosynthetic growth, sulfate uptake, photosynthetic activity, and O₂ release, during transition from oxygenic growth to anoxic H₂ production conditions.
Subtask C: Bio-Inspired Systems

**Goal:** Identify promising applications of enzymes and biologically-inspired processes for H₂ production and fuel cells.

Hydrogen production by in vitro and bio-inspired systems and construction of biological fuel cells are a most modern part of nano-technology and molecular handling technology. In the bio-inspired systems for H₂ production, photosynthetic apparatus from cyanobacteria, algae or photosynthetic bacteria and hydrogenase enzymes from various kinds of bacteria are separated and artificially re-constituted in the consideration for effective electron transportation among the components. These technologies can resolve the problematic limit in the photosynthetic efficiency. Furthermore, research and development for biological fuel cell systems is environmentally acceptable technology because of no use of much rare metals.

Research on the hydrogenase enzyme has been done in many countries, especially in Europe, Japan, and the USA. Biological functions are starting to be understood at genetic and molecular level. However, for practical applications, significant progress is required. The most important issue is the durability of the hydrogenase protein, especially oxygen tolerance. A more complete understanding of the relationship between protein structure and function is required together with additional efforts in engineering the protein. Though there have been various international co-operations in basic studies, the number of collaborations in applied research area has been limited. In this field, catalysts are bacteria and/or enzyme hydrogenase. Bacterial technology is studied in EC FP7 BIOWATT project composed of 13 research teams from 9 countries.

**Overview of the Recent Progress:**

In France several research groups are involved in the development of bioinspired catalysts, biofuel cells, and hydrogenase engineering.

a. **Bio-inspired Systems:**

The synthesis and characterisation of the pro-ligand LH₄₄, in which L is the o-phenylenebisamide-2-imidazole and its nickel (II) complexes, are interesting models of the active site of [NiFe] hydrogenase. The study of the entire redox revealed that deprotonation of the imidazole functions has a strong effect on the electronic structure of the complexes (Lasalle-Kaiser et al. (2008) Chemistry. 14:4307-17).

Several compounds have been prepared and examined as structural and functional models for the active site of [FeFe]-hydrogenases. One of the questions still open relies on the role of the bridging ligand of the di-iron active site.

The most efficient molecular photocatalytic systems reported so far for hydrogen production, which compete with some platinum-based systems, are based on diimine derivatives of ruthenium, cyclometallated iridium or tricarbonylrhenium as photosensitizers and cobaloxime H₂-evolving catalytic centers (Fihri et al. (2008) Dalton Trans. 7:5567-9). Quantum yield values up to 16% under visible irradiation associated with high turnover frequencies of approximately 50 h⁻¹ and stability (up to 273 turnovers), characterize these new systems.

In the Netherlands, the extreme thermophile Pyrococcus furiosus has two types of NiFe-hydrogenases, a heterotetrameric soluble hydrogenase and a multimeric transmembrane
hydrogenase. The soluble hydrogenase was proposed to be a new type of H₂ evolution hydrogenase. By measuring enzyme kinetics it was concluded that the soluble hydrogenase from P. furiosus likely is involved in the regeneration of NADPH and thus reuses the hydrogen produced by the membrane-bound hydrogenase in proton respiration.

In Canada, Dr. Hallenbeck’s group has been looking at the heterologous expression of the [FeFe] hydrogenases. They cloned the hydE, hydF, hydG, hydA, and hydB genes of Desulfovibrio vulgaris Hildenborough and used His-tag pull-down assays to study the potential interaction between HydE, HydF, and HydG with the HydA and HydB protein subunits of the D. vulgaris [FeFe] hydrogenase (a heterodimeric H₂ase). Findings suggest that specific protein–protein interactions may be required during [FeFe] cluster synthesis and/or insertion. Dr. Hallenbeck’s group also examined the effects of nutrient limitations (glucose, nitrogen, sulfur and phosphate) on hydrogen yields during fermentation by chemostat cultures of Escherichia coli. Under most conditions, total hydrogen production and yield were inversely related, with higher production, but lower yields, at increasing dilution rate. A metabolically engineered strain, DJT135, mutated in the uptake hydrogenases, in lactate dehydrogenase, and with constitutively active FhlA gave the highest H₂ production and greatest H₂ to glucose yields.

Figure 1: 1/2 Glucose - HTP/NADH
In the USA, bio-hybrid/biofuel cell efforts are investigating hydrogenases as biocatalysts for creating hybrid charge-transfer complexes with nanomaterials, and as catalysts in photoelectrochemical devices. This research, led by Dr. King at NREL, supports a long-term objective of the DOE to design catalysts and catalytic systems for conversion and storage of solar energy as H₂ gas. Parallel efforts have successfully immobilized hydrogenases on electrodes, which have been integrated into a photoelectrochemical (PEC) cell. The PEC cell exhibited sustained periods of solar H₂ production with the hydrogenase electrode, though efficiencies were low due to an insufficient overpotential.

**b. Biofuel cells:**

In France, modification of gold and graphite electrodes with commercially available carbon nanotubes is a useful technique for immobilization of Desulfovibrio fructosovorans [NiFe] hydrogenase, for hydrogen evolution or consumption (Lojou et al. (2008) J Biol Inorg Chem. 13:1157-67). Multiwalled carbon nanotubes, single-walled carbon nanotubes (SWCNs), and amine-modified and carboxyl-functionalized SWCNs were used and compared.

Protein film voltammetry studies of the [NiFeSe]-hydrogenase from Desulfomicrobium baculatum showed it to be a highly efficient H₂ cycling catalyst (Parkin et al. 2008 J Am Chem Soc. 130:13410-6).

In Korea, bioelectrocatalytic hydrogen (H₂) production was studied using Thio capsella roseopersicina hydrogenase in a two-compartment proton-exchange-membrane (PEM) fuel-cell system equipped with carbon-paper electrodes. This study indicates that T. roseopersicina hydrogenase has a high potential for bioelectrocatalytic H₂ production; still, much effort could be required to develop a proper biofuel-cell system that provides for efficient transfer of electrons and protons.

In the Netherlands, the interaction between bacteria and electricity is being studied. Bacterial processes can be used to produce electricity in biofuel cells. However, microbial processes can also be stimulated by electricity, e.g. for hydrogen production from acetate in the dark.

In the USA, the Maness group at NREL has collaborated with Dr. Bruce Logan (Penn State Univ.) in testing a novel concept, combining dark fermentation with a microbial electrolysis cell (MEC) to improve H₂ molar yield.

In the UK, a hydrogen-producing Bio-Fuel Cell was developed. The possibility of biological ammonia oxidation with current generation was investigated by intermittent dosing of reactors with ammonia and by conducting cyclic voltammetry.
c) Enzyme engineering:

Hydrogenases are among the metalloenzymes for which a gas-substrate tunnel has been described by using crystallography and molecular dynamics. However, the correlation between protein structure and gas-diffusion kinetics is unexplored. Two quantitative methods for probing the rates of diffusion within hydrogenases were recently described (Leroux et al. 2008 Proc Natl Acad Sci U S A. 2008 105:11188-93).

A theoretical QM/MM study of the [NiFe] hydrogenase from Desulfovibrio fructosovorans has been performed to investigate possible routes of proton transfer between the active site and the protein surface (Galván et al. 2008 Proteins. 73: 195-203). The results show one of the studied pathways to be preferred for transport from the active site to the surface, but the preference is not so strong when transport occurs in the opposite direction.

Maturation of the [FeFe]-hydrogenase active site depends on at least the expression of three gene products called HydE, HydF, and HydG. The structure at high resolution of the recombinant, reconstituted S-adenosine-L-methionine-dependent HydE from Thermotoga maritima was solved recently (Nicolet et al. 2008 J. Biol. Chem. 283:18861-72).

Subtask D: Overall Analysis

Goal: Find the solution to realize the BioHydrogen process in the coming H2 society. Adaptation of the technology is analyzed from the economical, technological and social point of view.

Interest in and support for renewable energy technologies like BioHydrogen has been increasing not only due to its environmentally acceptable characteristics, but also due to the recent rise in oil prices. BioHydrogen has quite different characteristics from energy systems based on fossil fuels; the energy sources are sunlight (which is dispersed), water, and biomass (not uniformly available). Therefore, we have to evaluate the implementation
of this technology from sociological and economic points of view. Effects of BioHydrogen on social systems and human life are to be evaluated. Analysis of unstable factors (i.e., availability of sunlight and biomass) and risks (i.e., outflow of genetically manipulated microorganisms) should be studied. Other important subjects are economic analysis and social acceptance.

Overview of the recent progress:

A new assessment method suitable for BioHydrogen was screened (overall analysis, including the above human factors). We have examined previous studies, mostly from the perspective of economics and safety.

1. Social acceptance examination was applied by the Yakushima island project performed in 2004 and 2005 as academic research.

2. Safety studies have also been conducted based on New Energy and Development Organization/Ministry of Economy, Trade and Industry (NEDO/METI), emphasizing the safe utilization of H₂ to promote the acceptance and distribution of fuel cell technology. Safety studies have also been done in the USA. In these projects, aspects of performance, economic efficiency, reliability (dependability), durability, and miniaturization are assessed regarding production, distribution, storage, and safety for utilization of H₂ technology in various areas. NEDO/METI started the new project about H₂ station gas diffusion safety to promote H₂ as infrastructure. H₂ storage volumes, safety ranges, and various prevention techniques against disaster are compared. In addition, research on social acceptability was done in academic groups and in local and central governments.

3. Cost evaluation should be surveyed during the extension period.

For more information on the BioHydrogen activities in Task 21 member countries as well as selected references, please visit the IEA HIA website.
TASK 22

FUNDAMENTAL AND APPLIED HYDROGEN STORAGE MATERIALS DEVELOPMENT

Professor Bjørn C. Hauback,
Institute for Energy Technology, Kjeller, Norway.
Operating Agent for The Research Council of Norway

VITAL STATISTICS

Term
2006-2009

Number of Participants
53 Experts from 18 countries

Number of Experts
53

2008 Meetings
2-5 March
Hotel Sacacomie, Québec, Canada
7-10 October
Villa Mondragone
Castelli Romani (Rome), Italy

PURPOSE

One of the main technological barriers to introduction of hydrogen in global energy systems is an effective and safe storage method. At present no hydrogen storage system, including pressurized and liquefied hydrogen and hydrogen stored in solid compounds, satisfies the international targets for on-board hydrogen storage in mobile applications. Without effective storage systems, a hydrogen economy will be difficult to achieve. Task 22 addresses hydrogen storage in solid materials. The research efforts will require new materials and solutions, rather than simple, incremental improvements in current technologies. The specific goals and objectives for research on hydrogen storage materials in Task 22 are:

a. to develop a reversible or regenerative hydrogen storage medium fulfilling international targets for hydrogen storage,

b. to develop the fundamental and engineering understanding of hydrogen storage for the various hydrogen storage media that have the capability of meeting Target A, and

c. to develop hydrogen storage materials and systems for use in stationary applications.

The targets are not quantitative, but instead refer to national and international targets. This provides more flexibility, and will include other parameters more relevant than the conventional weight percentage and hydrogen release temperatures.

SUMMARIZED FRAMEWORK

Task 22 started 1 December 2006 with a duration of 3 years. It is open to a broad spectrum of project types:

- Experimental
- Engineering
- Theoretical
- Modelling
- Safety aspects of hydrogen storage materials

The following classes of materials are included:

- Reversible metal hydrides
- Regenerative hydrogen storage materials (chemical hydrides)
- Nanoporous materials
- Rechargeable organic liquids and solids

Task 22 is built on projects with international collaboration strongly encouraged. A project plan is prepared for each project.

IEA HIA and International Partnership for a Hydrogen Economy (IPHE) approved an agreement on collaboration in 2007. This agreement, comprised of a Memorandum of Understanding and an Annex on Task 22 cooperation, allows IPHE countries that are non-IEA HIA members to collaborate on Task 22 with the understanding that they will
join the IEA HIA within 18 months. IPHE member countries that are possible new Task 22 participants are Russia, Brazil, India, and China. Russia and Brazil have already signed the agreement.

MEMBERS

At present there are 53 Experts from 18 countries with a total effort of about 61 person years/year.

C. Ahn, USA
E. Akiba, Japan
A. Albinati, Italy
Y. Andersson, Sweden
D. Anton, USA
T. Autrey, USA
D. Book, UK
C. Buckley, Australia
R. Cantelli, Italy
R. Chahine, Canada
D. Chandra, USA
Y. W. Cho, Korea
M. Conte, Italy
B. David, UK
D. Dedrick, USA
M. Dornheim, Germany
P. Edwards, UK
M. Fichtner, Germany
C. Filiou, EC
D. Fruchart, France
N. Gallego, USA
J. Graetz, USA
E. Gray, Australia
R. Griessen, The Netherlands
K. Gross, USA
Z. X. Guo, UK
B. C. Hauback, Norway
M. Heben, USA
M. Hirscher, Germany
J. Huot, Canada
T. R. Jensen, Denmark
C. M. Jensen, USA
H. Jonsson, Iceland
H. J. Kim, Korea
Y. Kojima, Japan
N. Kuriyama, Japan
M. Latroche, France
D. Milčius, Lithuania
D. Mosher, USA
D. Nöréus, Sweden
P. Notten, The Netherlands
S.-I. Orimo, Japan
E. Ronnebro, USA
D. K. Ross, UK
G. Sandrock, USA
T. Steriotis, Greece
T. Vegge, Denmark
G. Walker, UK
K. Yvon, Switzerland
J. C. Zhao, USA
R. Zidan, USA
M. Zoppi, Italy
A. Züttel, Switzerland
At present there are 49 R&D projects led by project leaders from the participating countries. Most involve international collaboration. The projects are divided into three categories: Hydride (H), Nanoporous (N) and combined Hydride and Nanoporous (HN). The following is the list of projects with the project leader in parentheses:

- Project H-1. IEA/DOE/SNL hydride databases (G. Sandrock, USA)
- Project H-3. Light metal complexes for hydrogen storage (C. Buckley, Australia)
- Project H-5. Hydrogen storage in borohydrides and light-metal hydrides (D. Book, UK)
- Project H-6. Synthesis and characterization of novel metal hydrides (E. Akiba, Japan)
- Project H-8. Hydrogen storage in futuristic solids (P. Edwards, UK)
- Project H-9. Lithium-based hydrogen storage materials (E. Gray, Australia)
- Project H-10. Novel borohydrides for hydrogen storage (C. M. Jensen, USA)
- Project H-11. Exploration of Mg(BH4)2 as a reversible hydrogen storage material (J.-C. Zhao, USA)
- Project H-12. Stability and reversibility of boranates for hydrogen storage (A. Züttel, Switzerland)
- Project H-15. Crystal structures, stability and hydrogen dynamics in borohydrides and alanates (T. Vegge, Denmark)
- Project H-17. Development and application of new high capacity hydrogen storage materials (D. Mosher, USA)
- Project H-18. Extrinsic effects of impurities on long-term behavior of complex hydrides (D. Chandra, USA)
- Project H-20. Hydrogen storage in metastable lightweight hydrides (D. Noréus, Sweden)
- Project H-21. Nanocrystalline light alloys for mass hydrogen storage at rather low temperatures (D. Fruchart, France)
- Project H-22. Synthesis and hydrogen sorption characterisation of magnesium-rich compounds with transition metals (Y. Andersson, Sweden and C. Filiou, EC)
- Project H-25. Fundamental safety testing and analysis of hydrogen storage materials and systems (D. Anton, USA; D. Mosher, USA; M. Fichtner, Germany; N. Kuriyama, Japan; R. Chahine, Canada)
- Project H-26. Safety properties of hydrogen storage materials in the context of systems (D. Dedrick, USA)
- Project H-27. International standardized testing practices for hydrogen storage materials (K. J. Gross, USA)
- Project H-28. Decomposition kinetics of aluminum hydride (J. Graetz, USA)
- Project H-29. Nanocrystalline light-metal hydrides and hydride composites for hydrogen storage (M. Dornheim, Germany)
• Project H-30. Chemical hydrogen storage in amine boranes (T. Autrey, USA)
• Project H-31. Borohydride materials discovery and development (E. Ronnebro, USA)
• Project H-32. Synthesis of metal hydrides by cold rolling and their characterization (J. Huot, Canada)
• Project H-33. Synthesis and characterization of new tetrahydroboranate compounds (M. Fichtner, Germany)
• Project H-34. Search of light-weight complex hydrides by means of Hydrogenography (R. Griessen, The Netherlands)
• Project H-35. Experimental and theoretical studies of metal hydrides (H. Jónsson, Iceland)
• Project H-36. New metal hydrides for hydrogen storage with PEM fuel cell systems (K. Yvon, Switzerland)
• Project H-37. Basic research of nano-composite materials for hydrogen storage (Y. Kojima, Japan)
• Project H-38. Development of Light-Weight and Compact Hydrides (S.-I. Orimo, Japan)
• Project H-39. The electrochemistry of hydride-forming materials (P. H. L. Notten, The Netherlands)
• Project N-1. Metal-carbon IEA collaboration (G. Walker, UK)
• Project N-2. Effect of metal doping on the hydrogen storage capacity of activated carbon fibers (N. C. Gallego, USA)
• Project N-4. H2 storage in nanoporous structures (R. Chahine, Canada and M. J. Heben, USA)
• Project N-5. Enhanced physisorption in Ni modified carbon aerogels (C. Ahn, USA)
• Project N-8. Development and molecular design of nanoporous material for high efficiency hydrogen storage (H. J. Kim, Korea)
• Project N-10. Hydrogen physisorption on MOFs (M. Hirscher, Germany)
• Project N-11. Synthesis and characterization of metal doped carbon foams (T. A. Steriotis, Greece)
• Project HN-1. Development and characterization of novel hydrogen storage materials (R. Zidan, USA)
• Project HN-2. Synthesis and characterization of light metal hydrides and nanoporous materials (T. R. Jensen, Denmark)
• Project HN-3. Theoretical and experimental investigations of hydrogen storage materials (Z. X. Guo, UK)
• Project HN-4. Multicomponent hydride systems (G. Walker, UK)
• Project HN-5. Microscopic characterization and modeling of hydrogen storage materials (metal hydrides, carbon and nanoporous materials, clathrates) by Raman spectroscopy and neutron scattering techniques (M. Zoppi, Italy)
• Project HN-6. Neutron scattering and thermodynamic measurements on molecular hydrogen and solid hydride stores (D. K. Ross, UK)
• Project HN-7. Hydrogen storage in nanostructured complex hydrides, molecular compounds and metal alloys (A. Albinati and R. Cantelli, Italy)
• Project HN-8. Hybrid solutions build from intermetallic compounds dissolved in porous materials for hydrogen storage (M. Latroche, France)
ACTIVITIES AND RESULTS 2008

PROGRESS AND ACCOMPLISHMENTS

Two Expert meetings were conducted in 2008:

- Hotel Sacacomie in Québec, Canada 2-5 March 2008 – 49 participants. See Figure 1.
- Villa Mondragone in Castelli Romani (Rome), Italy 7-10 October 2008 – 52 participants. See Figure 2.

The projects in Task 22 showed significant progress during 2008, with new results and a significant international collaboration (in particular involving other Task 22 experts). A few key points related to the progress are:

- New promising complex hydrides including different boron-based compounds.
- New results on several physisorption systems, like metal-assisted carbon-materials, nanocomposites with high hydrogen contents and microporous organic framework compounds.
- “Nano-engineering” of hydrogen storage materials.
- Nano-composites including borohydrides and magnesium-based hydrides.

OUTREACH AND COMMUNICATION

In total, 450 publications in international peer-review journals and more than 450 presentations in national and international meetings/conferences related to work performed in Task 22 have been reported over the life of the task.

Updates about the activities in Task 22 are found on [www.hydrogenstorage.org](http://www.hydrogenstorage.org).

Fig. 1: Participants at the Task 22 meeting at Hotel Sacacomie, Canada, March 2-5, 2008.
FUTURE WORK

ACTIVITIES AND/OR TARGETS FOR 2009

Two Task 22 meetings will be organized in 2009. The first will be held on Jeju-do Island in the Republic of Korea from April 20-23, hosted by the Korea Institute of Science and Technology (Dr. Y. W. Cho). The second meeting will be in Paris, France from October 12-15, and will be hosted by Centre Nationale de la Recherche Scientifique (CNRS) (Dr. M. Latroche and Dr. D. Fruchart). The meetings are 3 ½ day events with a major focus on scientific presentations showing progress of the projects and discussions addressing challenges and progress in the field. In addition, plans to extend the Task will be discussed.

In 2009, Task 22 will address research on the following classes of compounds: new magnesium-based compounds, different complex hydrides with a particular focus on boron-containing compounds, different new nanoporous materials, and multi-component systems. Safety aspects of the materials and applications will be covered, as well. Discussion, exchange of experience, and collaborative efforts are crucial for Task 22, and significant time will be available both for organized and informal discussions. It will also be our goal to involve more IPHE-countries in the work in Task 22 in 2009.

ACTIVITIES AND/OR TARGETS BEYOND 2008

We are planning an extension of the Task for 2-3 years from 2010, and similar Expert meetings in 2010 and beyond.

R&D CHALLENGES

Storage of hydrogen remains one of the major challenges related to the introduction of a hydrogen-based economy. We hope that the extensive work related to Task 22 in IEA HIA will contribute to a solution for the storage problem. Task 22 is the largest international effort in this field addressing several promising materials, and the Experts on the Task will play a key role in the future of this field.
TASK 23

PURPOSE

The main objective of Task 23 is to provide a basis for harmonization of technology for on-site hydrogen production from hydrocarbons – fossil and renewable. The overall objectives are:

- To develop a basis for harmonized capacities for the on-site hydrogen reformer unit.
- To identify and examine issues related to the promotion of widespread use of on-site hydrogen reformer units.
- To develop a global market–guide for the use of on-site hydrogen reformers.
- To describe the technology link to renewable sources.

FRAMEWORK SUMMARY

Task 23 is organized in three subtasks:

- Subtask 1 – Harmonized Industrialization
- Subtask 2 – Sustainability and Renewable Sources
- Subtask 3 – Market Studies

The leader of Subtask 1 is Anne Marit Hansen (Norway), the leader of Subtask 2 is Corfitz Nilsson (Sweden) and the leader of Subtask 3 is Isamu Yasuda (Japan).

The figure below shows the relationships between the subtasks, and links them to the global challenges related to the development of refuelling infrastructures for hydrogen vehicles.

Figure 1: Relations between the Subtasks
## Task Member and Expert Table

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>ORGANIZATION</th>
<th>EXPERT</th>
<th>CONTACT ADDRESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denmark</td>
<td>Haldor Topsoe</td>
<td>J.B. Hansen</td>
<td><a href="mailto:Jbh@topsoe.dk">Jbh@topsoe.dk</a></td>
</tr>
<tr>
<td>Germany</td>
<td>Mahler AGS</td>
<td>R. Stauss</td>
<td><a href="mailto:Ralph.stauss@mahlertags.com">Ralph.stauss@mahlertags.com</a></td>
</tr>
<tr>
<td>Japan</td>
<td>Tokyo Gas</td>
<td>I. Yasuda</td>
<td><a href="mailto:iyasuda@tokyo-gas.co.jp">iyasuda@tokyo-gas.co.jp</a></td>
</tr>
<tr>
<td>Japan</td>
<td>Mitsubishi Kakoki Kaisha</td>
<td>A. Obuchi</td>
<td><a href="mailto:obuchi@kakoki.co.jp">obuchi@kakoki.co.jp</a></td>
</tr>
<tr>
<td>Norway</td>
<td>StatoilHydro</td>
<td>A.M. Hansen</td>
<td><a href="mailto:anmha@statoilhydro.com">anmha@statoilhydro.com</a></td>
</tr>
<tr>
<td>Norway</td>
<td>StatoilHydro</td>
<td>E. Ochoa-Fernández</td>
<td><a href="mailto:eoch@statoilhydro.com">eoch@statoilhydro.com</a></td>
</tr>
<tr>
<td>Norway</td>
<td>SINTEF</td>
<td>I. Schjølberg</td>
<td><a href="mailto:Ingrid.Schjolberg@sintef.no">Ingrid.Schjolberg@sintef.no</a></td>
</tr>
<tr>
<td>The Netherlands</td>
<td>HyGear</td>
<td>B. Creemers</td>
<td><a href="mailto:Boudewijn.creamers@hygear.nl">Boudewijn.creamers@hygear.nl</a></td>
</tr>
<tr>
<td>The Netherlands</td>
<td>ECN</td>
<td>E. van Dijk</td>
<td><a href="mailto:h.vandijk@ecn.nl">h.vandijk@ecn.nl</a></td>
</tr>
<tr>
<td>Sweden</td>
<td>SGC</td>
<td>C. Nelson</td>
<td><a href="mailto:Corfritz.nelsson@sgc.se">Corfritz.nelsson@sgc.se</a></td>
</tr>
<tr>
<td>Sweden</td>
<td>Catator</td>
<td>F. Silversand</td>
<td><a href="mailto:Fredrik.silversand@catator.se">Fredrik.silversand@catator.se</a></td>
</tr>
<tr>
<td>USA</td>
<td>PNNL</td>
<td>D.L. King</td>
<td><a href="mailto:David.king@pnl.gov">David.king@pnl.gov</a></td>
</tr>
<tr>
<td>USA</td>
<td>Intelligent Energy</td>
<td>C. Hulbrecht</td>
<td><a href="mailto:Christian.hulbrecht@intelligent-energy.com">Christian.hulbrecht@intelligent-energy.com</a></td>
</tr>
<tr>
<td>USA</td>
<td>Intelligent Energy</td>
<td>D. Aagesen</td>
<td><a href="mailto:Diane.Aagesen@intelligent-energy.com">Diane.Aagesen@intelligent-energy.com</a></td>
</tr>
<tr>
<td>USA</td>
<td>Richard Lugar Centre for RE</td>
<td>A. Hsu</td>
<td><a href="mailto:anhsu@iupui.edu">anhsu@iupui.edu</a></td>
</tr>
<tr>
<td>Turkey</td>
<td>TÜBİTAK</td>
<td>A. Ersoy</td>
<td><a href="mailto:Atilla.Ersoy@mam.gov.tr">Atilla.Ersoy@mam.gov.tr</a></td>
</tr>
<tr>
<td>France</td>
<td>Gaz de France</td>
<td>Isabelle da Costa</td>
<td><a href="mailto:Isabelle.da-costa@gazdefrance.com">Isabelle.da-costa@gazdefrance.com</a></td>
</tr>
<tr>
<td>France</td>
<td>N-GHY</td>
<td>D. Grouset</td>
<td><a href="mailto:Didier.grouset@ng-ly.com">Didier.grouset@ng-ly.com</a></td>
</tr>
<tr>
<td>France</td>
<td>N-GHY</td>
<td>P. Marty</td>
<td><a href="mailto:Philippe.marty@ng-ly.com">Philippe.marty@ng-ly.com</a></td>
</tr>
<tr>
<td>France</td>
<td>H2Plus Ltd</td>
<td>J. Saint-Just</td>
<td><a href="mailto:Jacques.Saint-Just@h2plus.net">Jacques.Saint-Just@h2plus.net</a></td>
</tr>
</tbody>
</table>

Table 1. Member list

Figure 2: Experts at the Experts Meeting in Paris
Outreach and Communication

Task 23 activities were presented at the WHEC 2008. Results will also be presented at WHEC 2010. A list of world wide suppliers of reformer technologies is being generated and the list will be published on the IEA HIA website. Moreover, Task 23 Experts are members of ISO TC 197 working groups, enabling dissemination of information. Several experts are members of other implementing agreements enabling cooperation across groups.

Subtask 1 Harmonized Industrialization

The overall Subtask objective is to develop a harmonized approach related to reformer capacity. This can facilitate industrialization and cost reduction. For example, there is a need for a framework for design of refuelling stations, and technology providers require cost guidelines (e.g., trucked in versus on-site production).

Subtask 2 Sustainability and Renewable Sources

The overall Subtask objective is to develop systems for fuel diversification and the use of renewable sources, and furthermore to study on-site emissions and how to handle them.

Subtask 3 Market Studies

The overall subtask objective is to facilitate and support market development through the dissemination of technology information. The market will be studied with respect to quality and quantity. Three cases will be used as the basis for a market study: Japan, Northern Europe, and California. These cases represent markets with different characteristics.

Activities and Results in 2008

PROGRESS AND ACCOMPLISHMENTS

Two Expert meetings were held in 2008.

• Tokyo, Japan, hosted by NEDO, ENAA and Tokyo Gas, in April with 15 experts present. A workshop with NEDO, ENAA, Tokyo Gas and MKK was arranged.
• Paris, France, hosted by Gaz de France in November with 15 participants.

Outreach and Communication

Task 23 activities were presented at the WHEC 2008. Results will also be presented at WHEC 2010. A list of worldwide suppliers of reformer technologies is being generated and the list will be published on the IEA HIA web site.

Future Work

ACTIVITIES 2009

Two expert meetings are planned for 2009.

• Oslo, May 5-7. Hosted by StatoilHydro. The meeting will include a visit to the StatoilHydro Renewable Park in Porsgrunn, and a joint workshop with Task 18.
• Istanbul, October. Hosted by Tübitak.

ACTIVITIES BEYOND 2009

Further activities will depend on extension of Task 23.

R&D Challenges

Harmonization of on-site production units is essential in the development of refueling infrastructure for hydrogen vehicles. The main R&D challenges are related to equipment design (size and capacity), operability, operation issues, safety requirements, costs, and emissions handling. Today, reformers can be made in any size and with any capacity. Task 23 will contribute to solving some of the identified challenges to support market development, facilitate industrialization, and reduce costs.
TASK DESCRIPTION

PURPOSE

The purpose of Task 24 is:

- to explore in detail all possible issues (technical, economic, social, environmental, market and legal) related to hydrogen production using electrolysis with wind energy
- to explore in detail possible applications for hydrogen produced using electrolysis with wind energy, with special emphasis on wind and hydrogen integration by means of hydrogen storage and electrical conversion that balances the original wind energy production

FRAMEWORK

There is currently a broad interest in hydrogen production by means of renewable energy sources, as hydrogen is expected to be one of the main energy carriers in the near future. The IEA HIA has studied several possible renewable energy sources for hydrogen production. Within the current set of possibilities, water electrolysis by means of wind energy ranks high as a competitor to fossil fuel in terms of technical and economic feasibility.

Today, both water electrolysis and wind energy technologies are considered mature, although R&D efforts are still undertaken to enhance performance and cost savings in both technology fields. In principle, however, water electrolysis technologies were not conceived for such variable input conditions as those inherent to the nature of wind resources. Therefore, the current state of the art must be upgraded to avoid redundant power electronics. System integration improvements are expected to increase efficiency and reduce capital and O&M costs.

Although hydrogen applications are virtually unlimited, transportation and early markets in portable applications are expected to be near-term drivers for advancement of the hydrogen economy. At the same time, there is an interesting stationary application that arises related to wind energy and other renewable energies, such as solar PV. Their inherent variable nature presents integration problems for market and grid operators. These conditions may retard their development in certain markets (e.g., wind energy in Denmark, Germany or Spain) where market penetration has already occurred. Storage systems can provide a solution to this problem by allowing wind energy to be stored closer to conventional energies, thereby increasing wind energy’s capability to follow demand, guaranteeing a desired amount of energy, and offering a flat curve or a smoother curve, etc.

The fully integrated wind and hydrogen application connects wind technology with various hydrogen-related technologies such as electrolysis (for production), hydrogen to electricity converters (for utilization), and storage systems.

If wind farms can be coupled to energy storage systems, wind energy will become available to offset the growth in network capacity. Furthermore, wind farms would become multi-purpose, decentralized producers of either electricity or hydrogen for fuel when the automotive industry enters mass production of hydrogen-fuelled vehicles. In the short term, marginal but significant benefits can be obtained by improving dispatchability and offering reserve power and grid services. In any case, the goal is to enhance the value of wind electricity itself.

VITAL STATISTICS

Term
2006-2009

Number of Participants
10 member countries

Number of Experts
19 Experts

2008 Meetings
9-11 April in Athens, Greece
1-3 October in Bex, Switzerland

TASK 24

WIND ENERGY AND HYDROGEN INTEGRATION

Dr. Luis Correas,
Ismael Aso:
Foundation for the
Development of New
Hydrogen Technologies in
Aragon (Spain)
Operating Agent for Spain
iaso@hidrogenoaragon.org
Another important niche market will be off-grid systems relying solely on renewable energy sources. It makes sense to include these systems in the scope of this annex due to the inherent high cost of off-grid power systems; their role as an early adopter application; and the reality that most current operational wind/hydrogen applications are serving off-grid applications. Projects have been developed or proposed in various countries. These represent a good starting point for learning experience since they include very different stakeholders from every segment of the value chain, including research institutions, equipment manufacturers, and utilities.

MEMBERS

Three new participants joined during 2008: Gas Natural (Spain), Ariema (Spain), and Juelich (Germany). The complete list appears below.

<table>
<thead>
<tr>
<th>EXPERT NAME</th>
<th>INSTITUTION NAME</th>
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<tbody>
<tr>
<td>Luis Correas (Operating Agent)</td>
<td>Aragon Hydrogen Foundation</td>
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<tr>
<td>Ismael Aso</td>
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<td>Bryte Energy Ltd</td>
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<td>Joerg Linnemann (Subtask C Leader)</td>
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<td>Rafael Ben</td>
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<td>Natural Resources of Canada</td>
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<td>NEDO</td>
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<tr>
<td>Dennis Krieg</td>
<td>Juelich</td>
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Table 1 – Task 24 Members

SUBTASKS

SUBTASK A: STATE OF THE ART

In this Subtask, the goal is to conduct an in-depth review of the current state of the art in wind turbines, electrolysers, and intermediate equipment, as well as a survey of market and electrical system regulations. A detailed review will also be performed which includes the current state of the art as well as lessons learned relative to hydrogen production using wind energy and fully integrated wind energy & hydrogen technology projects.
SUBTASK B: NECESSARY IMPROVEMENTS & SYSTEM INTEGRATION. TECHNOLOGY DEVELOPMENT ON MAIN EQUIPMENT AND SYSTEM INTEGRATION CONCEPTS

In this part of the study, the scope is focused on the two main components for hydrogen production, the wind turbine and the electrolyzers, as well as the intermediate connecting components. The in-depth analysis will research future technical optima. The goal of this Subtask is not to provide an enhanced design for equipment, but to develop appropriate specifications.

This Subtask addresses the following issues:

• Dynamics
• Electrolyser durability under a very dynamic workload
• Development of specific wind turbines

SUBTASK C: BUSINESS CONCEPT DEVELOPMENT

This Subtask will address:

• Economic assessment with a detailed hydrogen production cost study of different concepts within representative market conditions and prognosis of the potential market size.
• Conceptual development and validation of layouts, extending to logistics and final use of the hydrogen produced, differentiating remote applications, weak grids, and large-scale wind generation. Two applications in particular will be considered: hydrogen as fuel for transportation, and on-site conversion of hydrogen to electricity for grid balancing.
• Cross-cutting issues, including social and environmental acceptability of increasing wind power capacity devoted to hydrogen production. Technical, environmental and market regulations affecting hydrogen production using wind power. An analysis of competing technologies should be included, as well as safety regulations.

SUBTASK D: APPLICATIONS EMPHASIS ON WIND ENERGY MANAGEMENT

In this Subtask, near term applications for the hydrogen produced shall be studied with an emphasis on wind energy management, which is one of the main applications addressed in Subtask C - the wind and hydrogen full-integration concept. Given the noticeable synergy between hydrogen and wind energy, as well as the inherent non-continuous and random nature of renewable “wind” energy, it is considered appropriate to deal with this application in a separate Subtask.

An analysis similar to the ones performed in Subtasks A through C shall be performed for the components contributing to full wind energy and hydrogen that were not previously taken into account. These components are basically hydrogen to electricity converters such as fuel cells, internal combustion engines, and gas turbines.

The key issue for such system integration is the development of control and operation software that could enable wind and hydrogen integrated plants to operate under variable conditions.

Cross-cutting issues include the social and environmental acceptability of increasing wind power capacity instead of other solutions (grid reinforcement, fossil and nuclear
generation), comparative analysis of different technical, market and environmental regulations affecting wind power.

More information about this Task is available on the Task 24 Web page (http://task24.hidrogenoaragon.org/), which was visited 1,300 times last year.

Figure 1: Web page Task 24

**ACTIVITIES AND RESULTS IN 2008**

**MEETINGS IN 2008**

The third Task 24 meeting was held 9–11 April in Athens, Greece, hosted by the Center for Renewable Sources (CRES, www.cres.gr). There were 18 representatives from 11 countries. This meeting had a parallel session with Task 18 “Integrated System Evaluation.”

The fourth Task 24 meeting took place in Bex (Switzerland) 1-3 October, hosted by IHT, an electrolyzer manufacturer (www.iht.ch) with an attendance of 15 Experts.

Figure 2: Attendees at the third Experts Meeting – Acropolis Athens
COMMUNICATION

Task 24 activities have been presented in different international hydrogen seminars.

WIND-HYDROGEN PROJECT CASE STUDIES

The main wind/hydrogen projects being studied worldwide are listed below:

- **ITHER Project** – Hydrogen Technological Infrastructure and Renewable Energies, promoted by Aragón Hydrogen Foundation, Huesca (Spain)
- **Sotavento Project** – promoted by Gas Natural, Lugo (Spain)
- **Tahivilla Project** – promoted by Endesa, Cadiz (Spain)
- **ES2H2 Project** – promoted by ITC and CRES (Spain, Greece)
- **Akkanai Project** – promoted by ENAA (Japan)
- **Ramea and Prince Edward Hydrogen/Wind Project** – promoted by Natural Resources Canada (Canada)
- **Wind2H2 Project** – promoted by NREL (USA)

Main wind-hydrogen projects being studied:

- **ITHER Project**
  Hydrogen Technological Infrastructure and Renewable Energies, promoted by Aragón Hydrogen Foundation, Huesca (Spain)

- **Sotavento Project**
  promoted by Gas Natural, Lugo (Spain)

- **Tahivilla Project**
  promoted by Endesa, Cadiz (Spain)

- **ES2H2 Project**
  promoted by ITC and CRES (Spain, Greece)

- **Akkanai Project**
  promoted by ENAA (Japan)

- **Ramea and Prince Edward Hydrogen/Wind Project**
  promoted by Natural Resources Canada (Canada)

- **Wind2H2 Project**
  promoted by NREL (USA)
OPEN SOURCE SOFTWARE AVAILABLE (HOGA/GRHYSO)

Newly-developed free software, such as Hybrid Optimization by Genetics Algorithms (HOGA) and Grid-connected Renewable Hybrid Systems Optimization (GRHYSO), has been CD edited, and is available on the Web. Both are developed in C++ for hybrid renewable energy systems for generation of electricity (DC and/or AC) and/or hydrogen. Both programs were developed by the Electrical Engineering Department, Saragossa University (Spain).

![Figure 5: HOGA/GRYSO Software available (http://task24.hidrogenoaragon.org/)](image)

NEXT STEPS 2009

The fifth meeting will take place in April 2009 in Denver, Colorado, hosted by the National Renewable Energy Laboratory (NREL), and the sixth meeting will take place by the end of the year in Oldenburg, Germany, hosted by Planet GbR. First draft reports related to Subtasks A and C will be completed, and several diffusion activities worldwide will be conducted to show results and lessons learned related to wind/hydrogen initiatives.

RECOMMENDED READING

- Olga Álvarez, Ismael Aso Aguarta “Determinación de la estrategia de producción de Hidrógeno en un parque eólico real.” III Congreso nacional de Pilas de Combustible Septiembre 2008 Zaragoza (Spain).
CONTACTS:

Dr. Luis Correas  
lcorreas@hidrogenoaragon.org

Mr. Ismael Aso  
iaso@hidrogenoaragon.org

Foundation for the Development of New Hydrogen Technologies in Aragon (Spain)
Tel: +34 974 21 52 58
Fax: + 34 974 21 52 61

Figure 6: IATHER Project – Green Hydrogen from Wind and Solar for Mobile Applications

Task 24 presented at the following international seminars:

US DOE Hydrogen Program Annual Merit Review, Washington, DC (USA)

National Hydrogen Association Fall Forum on Renewable Hydrogen, Colorado (USA)

17th World Hydrogen Energy Conference, Brisbane (Australia)

II European Mediterranean Conference, Bari (Italy)

International (summer) Hydrogen Seminar, Lisbon (Portugal)

Hydrogen Course, Teruel (Spain)

I Renewable Hydrogen Seminar, Punto Fijo (Venezuela)

Hydrogen Training Course, Santo Domingo, (Dominican Republic)
TASK 25

HIGH TEMPERATURE PRODUCTION OF HYDROGEN

Sabine Poitou, CEA
Operating Agent for France

TASK DESCRIPTION

PURPOSE
The purpose of Task 25 is to support production of massive \( \text{H}_2 \) with zero-emission through use of high temperature processes (> 500°C) coupled with nuclear and/or solar heat sources. The underlying objective is to share existing worldwide knowledge on high temperature processes (HTPs) and to further develop expertise in global assessment of the HTPs that can be integrated in Hydrogen Production Road Mapping.

The specific objectives are:
- to identify and classify the HTPs and establish different and coherent criteria for each family of identified HTPs, based on a scientific/technological approach.
- to identify and classify key issues and key technologies depending on the process and synergies with others technological fields.
- to establish the state of the art and investigate existing knowledge, programs, projects on HTPs, and other innovative ideas for massive hydrogen production.

FRAMEWORK SUMMARY

Until the end of 2008, IEA/HIA Task 25 Operating Agent was Gilles Rodriguez from CEA. However, due to internal CEA needs, Sabine Poitou of CEA will replace him in January 2009.

IEA/HIA Task 25 consists of four Subtasks whose objectives are described in part D.

VITAL STATISTICS

Term
2007-2010

Focus on 3 Process Families:
- Steam Electrolysis
- Thermochemical Cycles (Including Pure and Hybrid Thermochemical Processes)
- Innovative Direct Water Splitting

2008 Meetings

San Diego, USA (March 2008)
26 participants from 12 countries and 15 research institutes

Rome, Italy (October 2008)
26 participants from 10 countries and 12 research institutes

SUBTASKS

Task 25 is split in four Subtasks that are listed and described below:

Subtask A - Scientific, Technological Review and Analysis of Temperature Processes and the State of the Art (Subtask Leader: Christian Sattler, DLR)
Development of summary sheets describing every process using the same evaluation method and presentation format. This will include worldwide mapping and technical review of the high temperature process studies, as well as database development (relevant papers, books and websites).

Subtask B - Development of a Methodology Approach and Integration of HTPs (Subtask leader: Alberto Giaconia, ENEA)
Subtask B defines the main criteria for integration of HTPs into the hydrogen chain, including the interface and primary energy source. It is defining and applying a methodology and multi-criteria approach to assess and compare the different HTPs. Subtask B focuses on proving tools designed to pilot the technological choices, making it possible to meet the increasing demand on the hydrogen energy vector.
Subtask C - Establishment of Benchmarks, Recommendations for HTP R&D and Future Industrial Deployment

Subtask C identifies the most promising technologies and recommendations for R&D needs based on the Subtasks A and B reviews. It develops studies and recommendations to meet the needs in large future facilities and/or demonstration programs required to facilitate accelerated introduction of HTPs.

Subtask D - Coordination and Links with Other International Organizations: Dissemination of Information (Subtask Leader/Operating Agent: Sabine Poitou, CEA)

Subtask D focuses on communication to develop and ensure coherence between this task and other projects and groups. It also facilitates exchanges and utilization of experimental facilities.

ACTIVITIES AND RESULTS IN 2008

PROGRESS AND ACCOMPLISHMENTS

Subtask A: State of the Art

- Review the different processes using the results of the INNOHYP project.
- Finalization of four “process sheets” (in collaboration with Subtask D): CDNG, Screening analysis of solar thermochemical hydrogen concepts, Zn-ZnO and Alkaline Electrolysis.

Subtask B: Benchmarking of Calculation and Methodology

- Benchmarking will be done by a university contact and with help from an economist in I-tésé CEA but not by a Ph.D candidate. It includes development of a Figure of Merit.
- This Subtask was one of the subjects discussed during the second official meeting.

Subtask C: HTP R&D and Future Industrial Deployment

- Define the Figure of Merit done by Subtask B:
  - Currently, there is no Subtask Leader. Subtask Leader to be identified.
  - The Objective: Hydrogen for which industry, with what kind of process, and what objective schedule?
- For deployment approach and generic R&D requirements, refer to INNOHYP review.
- For definition of demonstrations, platform and R&D needs, refer to the European JTI.

Subtask D: Communications

- An Internet site has been made to host a common documentation base: https://www-prodh2-task25.cea.fr
- This site is a place for exchange between Task Experts. (Password protected).
- Papers describing high temperature processes for hydrogen production: each HTP will be described in a paper. These papers will allow an easier comparison between the processes. Four sheets have been finalized during this year, in collaboration with Subtask A, and have been published on the eDOC database.

Outreach and communication

The first scientific communication coming from this Annex was made during the 17th WHEC held in Australia in June 2008. During this conference, 11 oral presentations or posters were presented by Task 25 participants.
For 2009, the following actions must be taken:

- Populate the eDOC database.
- Finalize papers on the description of each process (review of the partners).
- Enhance industry participation.
- Continue to review the INNOHYP results and start to populate the INNOHYP database with recent scientific results.
- Create a national projects inventory on Hydrogen production for members.
- Validate the hydrogen production processes' criteria of choice.

**ACTIVITIES BEYOND 2009**

See the timetable established for Task 25 after the Project Definition Phase meeting.

**R&D CHALLENGES**

Countries and international initiatives are aiming to demonstrate hydrogen production from either solar or nuclear energy in the next decade. The technical challenges in achieving this goal are significant, but the development of emission-free hydrogen production technologies is essential to the long-term viability of a hydrogen economy. Solar and nuclear energy have the potential to play a major role in assuring a secure and environmentally sound source of carbon-free energy. The fundamental challenge is to focus research and development on those processes which have the highest probability of producing hydrogen at competitive costs.

**ARTICLE REFERENCES**

- 12 conferences and posters have been presented by IEA/HIA Task 25 partners during the 17th World Hydrogen Energy Conference Brisbane, Australia, June 2008 (see side-bar).
TASK DESCRIPTION

PURPOSE
Photoelectrochemical (PEC) hydrogen production, using sunlight to directly split water, is one of the paramount enabling technologies for a future in which hydrogen is widely deployed as an energy carrier. Figure 1 shows the conventional two-electrode PEC configuration (Fig. 1a) along with a high-efficiency PEC photoelectrode prototype (Fig. 1b) based on high-quality III-V semiconductor materials developed at the US National Renewable Energy Laboratory (NREL)[1, 2]. Unfortunately, the “traditional” semiconductor-based PEC material systems studied to date, particularly the simple metal oxides such as TiO₂, WO₃ and Fe₂O₃, have been unable to meet all the performance, durability and cost requirements for practical hydrogen production. The III-V materials have demonstrated high efficiency, but are quite costly and have limited durability.

Technology-enabling breakthroughs are needed in the development of new, advanced materials systems. Toward this end, the IEA Hydrogen Implementing Agreement Task 26 is working in close conjunction with the U.S. Department of Energy’s “Working Group on PEC Hydrogen Production” to bring together international experts in analysis, theory, synthesis and characterization from the academic, industry and national laboratory research sectors across the world.

FRAMEWORK
The four “big picture” objectives of the Task 26 program concern:

• Intensification of international collaboration, making use of extended fields of expertise in areas of materials theory, synthesis and characterization, as well as data and data-base management.
• Advancement of PEC materials science, particularly addressing the discovery of new practical materials, with bulk and surface properties specifically engineered to meet the requirements for efficient and stable PEC water splitting.
• Demonstration of stable and efficient water splitting in the leading materials systems, using standardized performance characterizations and round-robin testing procedures.
• Promotion of photolysis of water through publications, education and outreach program.

Within the framework of Task 26, international “task forces” are being assembled to advance the state of the art in PEC materials theory, synthesis and characterization; and to apply these techniques to develop promising broad-ranging PEC materials systems. Key supporting activities include establishing standardized testing/screening protocols.
for candidate PEC materials; coordinating international PEC research and development efforts and results; and performing techno-economic analyses of PEC production systems based on the materials systems being developed.

MEMBERS

Task 26 participants include the United States, the United Kingdom, Switzerland, Germany, Australia, Japan, South Korea, and the Netherlands.

Task Member and Expert Table

<table>
<thead>
<tr>
<th>PRIMARY EXPERTS</th>
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<tbody>
<tr>
<td>USA</td>
<td>Drs. John Turner, Eric McFarland, Clemens Heske, Mowafak Al-Jassim and Eric Miller</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>Dr. Roel van de Krol</td>
</tr>
<tr>
<td>Japan</td>
<td>Drs. Kazuhiro Sayama and Lionel Vayssieres</td>
</tr>
<tr>
<td>S. Korea</td>
<td>Dr. Jae Sung Lee</td>
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<tr>
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<td>Dr. Upul Wijayantha</td>
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<tr>
<td>Australia</td>
<td>Drs. Ian Plumb and Grant Mathieson</td>
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<th>INTERNATIONAL TASK FORCE EXPERTS</th>
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SUBTASKS

Subtask A: Materials Theory

Theoretical predictive guidance and understanding of synthesized materials is viewed as critical to the development of new PEC materials. The insight gained from calculations of relevant semiconductors can augment experimental results, and prompt or guide further experimental work depending on favorable or unfavorable outcomes of the theoretical studies. Critical materials properties such as band-gap, band-edge positions, optical absorption, and stability can be understood through calculation of band-structure, band-alignment, optical absorption coefficient, and total energies. In this sub-task, ab-initio methods such as density functional theory (DFT) are being employed [3, 4] along with other, less computing-intensive methods.

Subtask B: Materials Synthesis

The primary objective of the materials synthesis research efforts is the development of films which meet photocurrent and durability goals, and which are compatible with device fabrication. The most promising candidate materials are being identified, with the short-term goal of demonstrating laboratory-scale water-splitting devices, and with a long-term goal of transferring the fabrication processes toward the commercial scale. The synthesis and optimization of promising classes of materials are the focus of this Subtask.

Subtask C: Materials / Interface Characterizations

Materials structure and composition play a key role in PEC cell performance. In fact, several studies based on both material and device characterizations have shown that the optimum PEC cells working point can be obtained only with specific material properties, which require fine process tuning. Nevertheless, good intrinsic material properties do not
guarantee optimal PEC cells performance. The integrated cell performance is closely tied to both physical phenomena localized at the solid-solid and the solid-liquid interfaces. As a result, the choice of materials requires careful consideration of the intrinsic bulk properties as well as the detailed interface properties. The development of new and effective PEC materials will therefore require experimental studies based on material, interface and device characterizations. Activities in this Subtask focus on developing the most advanced characterization techniques for PEC studies, and on developing standardized protocols for testing and reporting PEC results.

Subtask D: PEC Information Coordination

This critical Subtask will entail important technical aspects of organizing and integrating the theory, synthesis and characterization efforts of all of the participating members, and developing and maintaining an up-to-date PEC information base accessible to all in the international PEC community.

ACTIVITIES AND RESULTS IN 2008

PROGRESS AND ACCOMPLISHMENTS

Subtask A: Materials Theory

A new Theory Task Force has been assembled, led by scientists at the U.S. National Renewable Energy Laboratory and the Lawrence Livermore National Laboratory.

Subtasks B and D: Materials Synthesis, PEC Information Coordination

International Task Forces have been assembled to study different focus materials classes. For each material class under investigation, a “White Paper” has been drafted as a living document which concisely summarizes the benefits, barriers, research status and approaches for addressing the barriers, all closely tied to the latest advancements in theory and synthesis. The White Papers also maintain a record of active research participants as well as a database of references documenting past achievements. To date, White Papers have been drafted for a number of key focus materials classes including:

- **Tungsten-oxide and related modified compounds**
  Tungsten oxide, particularly in thin-film and nano-particle forms, has been a workhorse in photoelectrochemical applications for years. It is inexpensive and stable, but its high bandgap (~2.6 eV) is limiting to PEC performance. Photocurrent densities of approximately 3 mA/cm² have been achieved [5, 6], with STH efficiencies over 3% in tandem configurations. To break the performance barrier, current research is focused on reducing bandgap through ion incorporation into the WO₃ structure [7, 8], and further integration in multi-junction devices.

- **Iron-oxide and related modified compounds**
  Iron-oxide is abundant, stable, inexpensive and has a near-ideal bandgap (~2.1 eV) for PEC applications. Unfortunately, its poor absorption, photo-carrier lifetime and transport properties have been prohibitive to practical water-splitting. Current research to overcome these barriers has been encouraging, with recent progress in thin films [9, 10] and nano-structured materials [11]. Iron oxide in tandem configurations may also be of interest for practical solar water-splitting.

- **Amorphous silicon compounds, including silicon carbides and nitrides**
  Amorphous silicon compounds have recently demonstrated interesting performances in PEC applications [12, 13, 14]. The progress of this material class in photoelectrochemical...
Subtasks B and D

Material Classes:

- **Tungsten-oxide and related modified compounds**
- **Iron-oxide and related modified compounds**
- **Amorphous silicon compounds, including silicon carbides and nitrides**
- **Copper chalcopyrite compounds**
- **Tungsten and molybdenum-sulfide nano-structures**
- **Semiconductor classes**

Applications has benefitted from decades of research in the PV community. Technical barriers remain in PEC stability and interface properties, but electrolyte and surface modification studies could help overcome these barriers. With material and interface improvements, monolithically fabricated multi-junction devices using amorphous silicon compound films can have practical appeal for PEC water splitting.

- **Copper chalcopyrite compounds**
  Copper chalcopyrite thin films are among the best absorbers of solar energy. As a result, chalcopyrite alloys formed with copper and gallium, indium, sulfur and selenium have been widely characterized in the PV world. A great advantage of this material class for PEC applications is the bandgap tailoring based on composition [15, 16]. The CuGaSe$_2$ bandgap of 1.6eV is attractive for PEC applications, and photo-current densities exceeding 13 mA/cm$^2$ have been demonstrated with this material [17] in biased PEC cells. Stability, surface kinetics and surface energetics remain as current barriers, but if current research can successfully address these, high STH efficiency could be achievable in low-cost thin-film copper chalcopyrite system.

- **Tungsten- and molybdenum- sulfide nano-structures**
  As bulk materials, tungsten- and molybdenum-sulfides are excellent hydrogen catalysts, but their bandgaps (below 1.2 eV) are too low for PEC water-splitting. Quantum confinement using nano-structuring, however, can increase the bandgap up to 2.5 eV. Current studies into nanostructured MoS$_2$ are focused on stabilized synthesis routes and integration of the nano-structures into practical bulk PEC devices [18].

- **Semiconductor classes**
  High-quality crystalline semiconductor compounds of gallium, indium, phosphorous and arsenic have been studied for decades. In PEC experiments to date, STH efficiencies between 12-16% have been demonstrated in GaInP$_2$ /GaAs hybrid tandem photocathodes [1, 2]. High cost and limited durability are the barriers to practical PEC hydrogen production, and breakthroughs in synthesis and in surface stabilization are being pursued.

Subtask C: Materials / Interface Characterizations

Advanced characterization techniques used to enhance understanding of PEC materials and interfaces and to promote breakthrough discoveries [19] continue to be developed. The materials characterization efforts employ the most advanced microstructural, optoelectronic, and electrochemical characterization techniques available to paint a comprehensive picture of the materials properties in relation to PEC performance. Techniques include X-ray photoelectron spectroscopy (XPS), ultraviolet photoelectron spectroscopy (UPS), Auger, Inverse photoemission spectroscopy (IPES), in ex-situ as well as new, advanced in-situ arrangements. Figure 2 shows the state-of-the-art facility developed at the University of Nevada Las Vegas (UNLV), a cornerstone of the PEC research activities.
Critical progress has been made in the development of standardized testing and reporting protocols for evaluating candidate PEC materials systems on a level playing-field. In the past, the lack of standardized conditions and procedures for reporting PEC results has greatly hampered research progress across the board. To date, the Standardized Testing Task Force, which is being coordinated jointly between the US and Australia, has made significant initial progress. The Task Force recently drafted eighteen extremely detailed testing protocol documents, which are being refined for near-term publication.

Furthermore, it is noteworthy that the European Commission awarded funding to the NANOPEC project, a major European PEC project bringing together collaborative partners from the countries indicated in Figure 3.

OUTREACH AND COMMUNICATION

- Integration of the international research community with the US has continued, as well as DOE PEC Working Group activities through joint meetings and conference calls.
- The implementation of international Task Forces as nucleation points for ever-growing international collaborations is ongoing.

FUTURE WORK

ACTIVITIES AND/OR TARGETS FOR 2009

Continued advances in theory, synthesis and characterization, including in situ interface measurements, is planned along with continued development of standardized testing and screening protocols and focus on PEC materials classes.

ACTIVITIES AND/OR TARGETS BEYOND 2009

Down-selection of the most promising PEC materials, optimization of selected materials systems, and implementation into PEC water-splitting systems are planned.

R&D CHALLENGES

Materials, Materials, Materials! Materials critical to the success of practical PEC hydrogen production continue to be the core challenge.

REFERENCES


SUGGESTED READING
- US DOE Multi-Year Program Plan: http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/
**TASK DESCRIPTION**

**PURPOSE AND OBJECTIVES:**

The overall objective of Task 27 is to advance the development of hydrogen production based on renewable sources in the market place, focusing on biomass and opportunities of interest for industrial application.

The specific objectives are:

- to identify and evaluate the most attractive and realistic process pathways towards a large-scale demonstration of biomass co-gasification with fossil fuels;
- to quantify the potential for a renewable-based H₂ supply chain based on upgrading biomass waste near source into a tradable intermediate (a “biomass carrier”), its commercial transport and use in centralised gasification plants;
- to evaluate the most attractive way of utilizing stand-alone biomass gasification technology in near-to-medium term H₂ markets;
- to develop and verify a roadmap for market introduction of biomass-based routes to H₂.

These objectives form the basis for the four Subtasks in Task 27, which will have Subtask leaders from industry and technology institutes.

**SUMMARY FRAMEWORK**

**BACKGROUND**

Hydrogen can be produced from a large number of energy sources with different conversion technologies. It is generally expected that hydrogen production in the near and medium-term will be based mainly on carbon-containing materials. However, to introduce large scale hydrogen usage in the energy market, it must be obtained from sources and by processes that are more sustainable than current energy carriers in terms of lower greenhouse gases and reduced fossil fuel dependence. To achieve this, carbon-lean, and ideally carbon-free, pathways must be favored for hydrogen production.

In the near-term, locally available and traded biomass resources can be used in combination with fossil fuel sources—primarily coal, but also crude oil residues—in order to achieve a high ultimate volume, potentially creating a huge new outlet for biomass and enabling possible early market penetration with the potential for contributing to, and even leading to, the transition to a continent-wide hydrogen economy.

**DESCRIPTION**

**Subtasks and Members**

**Subtask A: Co-gasification of Biomass with Fossil Fuels**
(Subtask leader Claudio Zeppi, ENEL, Italy)

**Subtask B: Hydrogen Market Facilitation Based on Distributed Processing of Biomass to New Tradable Intermediates**
(Subtask leader Bert van de Beld, BTG, The Netherlands)

**Subtask C: Near Term, Stand-alone Biomass Gasification**
(Subtask leader Esa Kurkela, VTT, Finland)
Subtask D: Roadmap Development and Verification: a Business-Oriented Roadmap for Hydrogen Produced with Biomass as a Renewable Source
(Subtask leader Jan-Erik Hansen, I-Tech)

The work will be based on market expectations and will prioritize technological solutions that can be realized within a reasonable time frame by a focused collaborative effort.

The participants are experts from industry, technology institutes, and academia, and come from Italy, The Netherlands, Norway, Finland, Turkey, USA and Spain. Other countries and experts are invited to join for the start-up in 2009. The Task will collaborate with the IEA Bioenergy IA, to avoid duplication of efforts and achieve synergies.

ACTIVITIES AND RESULTS IN 2008

A Task Definition Meeting was held in Italy in March 2008, hosted by Enel. A detailed program of work has been submitted, and Task 27 was approved with two co-chairs in November 2008.

Also during 2008, a draft report was prepared by VTT, reviewing dedicated biomass gasification processes and projects titled “Hydrogen Production via Thermal Gasification of Biomass in Near to Medium Term.” Participants reviewed the document, which will be revised and updated every six months as a “live document” within the Task.

NEXT STEPS:

Proposed 1st Year Deliverables

The Subtask leaders have proposed the following first phase (12 months) deliverables as follows:

- D1: Assessment of biomass/coal compatibility for co-gasification
- D2: Mapping gasifier locations vs. transport/logistics for pyrolysis oil
- D3: Review of dedicated biomass gasification processes & projects
- D4: Quantification of key parameters of the “integral/split” process concept for hydrogen production via co-gasification of biomass with fossil fuels

These will be discussed and further developed in the meeting scheduled for March 2009, hosted by VTT in Finland.
AUSTRALIA

Dr. Ian Plumb and Dr. John Wright
Commonwealth Scientific and Industrial Research Organization (CSIRO)

INTRODUCTION AND BACKGROUND

- Australia joined the IEA Hydrogen Implementing Agreement in mid-2005
- Australia’s membership is sponsored by the Australian Federal Government’s Department of Resources, Energy and Tourism (DRET)
- DRET also contributes funding on a matching basis to support Australian experts’ attendance at HIA task meetings
- Australia currently participates in Tasks 22, 25, and 26
- Australia hosted the 17th World Hydrogen Energy Conference (WHEC2008)\(^1\) and associated IEA/HIA 58th Executive Committee meeting in Brisbane in June 2008
- Australia is represented on the HIA Executive Committee by officers from the Commonwealth Scientific and Industrial Research Organisation (CSIRO)

PRIMARY ENERGY STRUCTURE

AUSTRALIAN ENERGY STATISTICS 2005-06

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<th>Production (PJ)</th>
<th>Black coal</th>
<th>Lignite</th>
<th>Gas</th>
<th>Oil</th>
<th>Propane, butane, LPG</th>
<th>Biofuels/biomass</th>
<th>Hydro</th>
<th>Non-hydro renewables</th>
<th>Uranium</th>
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<tr>
<td>PJ</td>
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<td>697.4</td>
<td>1672.3</td>
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<td>%</td>
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<td>4.2%</td>
<td>10.1%</td>
<td>5.4%</td>
<td>0.8%</td>
<td>1.2%</td>
<td>0.3%</td>
<td>0.1%</td>
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<tr>
<td>Imports PJ</td>
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<td></td>
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<td></td>
<td></td>
<td>34.7%</td>
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<td></td>
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<tr>
<td>Exports PJ</td>
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<td>459.8</td>
<td>71.9</td>
<td></td>
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<td>%</td>
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<td>5.3%</td>
<td>3.6%</td>
<td>0.6%</td>
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<td></td>
<td></td>
<td>37.7%</td>
<td>1.2%</td>
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</tbody>
</table>

Electricity – production and consumption (2005-06)

- Generation Capacity: 45 GW
- Capacity Utilisation: 62%
- Electricity Generation: 220 TWh

Electricity Generation by Fuel

- Black Coal: 54.5%
- Brown Coal: 21.1%
- Gas: 15%
- Oil: 1.8%
- Hydro: 6.4%
- Wind: 0.7%
- Biomass: 0.4%
- Biogas 0.1%

VITAL STATISTICS

Population
21,608,504 as at 5/3/2009
(Source: Australian Bureau of Statistics, Australian Population Clock\(^2\))

 Territory
7,692,024 km\(^2\) (Source: Australian Year Book, 2008\(^3\))

 Capital
Canberra, Australian Capital Territory (A.C.T.)

 GDP/capita
AUS$51,229 (2007/08) (Source: Australian Bureau of Statistics\(^3\))

 Average GDP Growth
3.6% (2007-08) (Source: Australian Bureau of Statistics\(^3\))

(Source: modified from ABARE – “Energy in Australia”, 2008\(^4\))
Figure 1: Projected fuel type share for Australia of road kilometres, as calculated by the CSIRO Future Fuels program\textsuperscript{22} and presented at WHEC2008. Hydrogen fuel cell powered vehicles are projected to account for a quarter of road kilometres travelled by 2050.

Figure 2: Transport fuel usage (in energy units) for Australia for 2006 (left) and projected for 2050 (right)\textsuperscript{23}.
The Australian Government recognizes that the development of commercially viable low or zero emission energy technologies is essential to achieve significant and affordable reductions in greenhouse gas emissions. The government has a target of 20% renewable power generation by 2020. In March 2009, draft legislation was introduced for an emissions trading scheme, the Carbon Pollution Reduction Scheme (CPRS), which is scheduled to commence operation in 2010. The draft legislation calls for reductions in GHG emissions (relative to 2000 emissions) of 5-15% by 2020, to be achieved through a cap and trade scheme. The 5% target is unconditional, while reductions greater than 5% and up to 15% are dependent on international agreements at the Copenhagen global climate change discussions in December 2009. The government remains committed to meeting its long-term target of a 60 per cent reduction in greenhouse gas emissions from 2000 levels by 2050.

The Department of Resources, Energy, and Tourism is Australia’s lead agency for clean energy technology development. The Department is responsible for a number of initiatives that provide assistance for research, development, and large scale demonstration of clean energy technologies, including:

- a $500 million Renewable Energy Fund to support development and demonstration of renewable energy technologies;
- a $500 million National Clean Coal Initiative, which will generate $1.5 billion in new investment by working in partnership with the private sector; and
- a $150 million Energy Innovation Fund, which will provide $100 million for solar research (PV and solar thermal), and $50 million for general clean energy research.

2008 saw the release of three important documents relating to hydrogen energy in Australia:

- Towards development of an Australian scientific roadmap for the hydrogen economy, Analysis of Australian hydrogen energy research publications and funding, Australian Academy of Science (March 2008)

The Hydrogen Technology Roadmap is one of three roadmaps commissioned by the Council of Australian Governments in April 2007. The other two roadmaps address solar thermal and geothermal. A bioenergy roadmap funded by the Departments of the Environment, Water, Heritage, and the Arts and prepared by the Clean Energy Council was published in 2008.
UPDATE ON RELEVANT PROGRAMS AND PROJECTS

While the following programs do not specifically target hydrogen research, development, and demonstration, they are an indication of the government’s commitment to cleaner energy technologies.

The Australian Solar Institute16, which is funded from the Government’s Energy Innovation Fund9, was officially launched at its Newcastle headquarters on January 15, 2009. The Australian Solar Institute will provide much needed support for the Australian solar community, helping to retain Australian solar expertise and develop the next generation of Australian solar researchers. The Institute will foster greater collaboration between researchers in universities, research institutions, and industry, and help forge strong links with peak overseas research organisations.

In July 2008, the government announced the formation of a National Low Emissions Coal Council and a Carbon Storage Taskforce8, backed by the Australian Government’s $500 million commitment, as well as more than $1 billion from industry and the states to drive the adoption of low emissions coal technologies. The initiative includes a $75 million National Low Emissions Coal Research Program, whose research priorities are expected to include coal gasification, CO₂ capture from coal combustion, clean power from lignite, geological storage, and the integration of renewable energy with low emission coal technologies.

The Government will spend $100 million to establish the Australia-based Global Carbon Capture and Storage Institute (GCCSI)17, which will coordinate funding and research for new projects, with the aim of facilitating the development of 20 commercial scale international CCS demonstration projects by 2020.

HYDROGEN R,D&D SPECIFICS

The National Hydrogen Materials Alliance (NHMA)18 is a partnership between CSIRO, 11 Australian universities, and the Australian Nuclear Science and Technology Organization. The NHMA was launched in October 2006 to develop new materials that improve the efficiency and economics of hydrogen generation, storage, and end use. It provides a focal point for hydrogen research in Australia and, through collaborative research programs between the partner organizations, has facilitated the development of critical mass research programs. Several researchers from the Alliance participate in IEA/HIA tasks. The 3-year term of the Alliance finishes in October 2009, and efforts are underway to identify funding mechanisms to allow the collaborative research programs to continue beyond the initial lifetime of the Alliance.

In addition to the research in the NHMA, there are R&D programs in a number of universities, government research laboratories and industrial laboratories, as described in the Australian Hydrogen Activity 2008 report10. Some of these programs have international linkages either through the IEA/HIA or otherwise.

Demonstration programs include the development of a 1 kW combined heat and power Solid Oxide Fuel Cell (SOFC) by Ceramic Fuel Cells Limited19, development of hydrogen storage systems based on proprietary, Mg-based hydrides by Hydrexia Pty. Ltd.20, and a fuel cell technology trial by Ergon Energy21.
**VITAL STATISTICS**

| **Population** | 32,976,026 (2007) |
| **Territory** | 9,984,670 km² |
| **Capital** | Ottawa |
| **GDP/capita** | CDN $36,363 (2007) |
| **GDP Growth** | 2.7% (2006-07) |
| **Primary Energy Production** | 16,796 Petajoules |
| **Energy Demand** | 7,560 Petajoules |
| **Energy Imports** | 2,936 Petajoules |
| **Electricity Generation** | 592.6 million megawatt hours (2006) |
| Hydroelectric | 349.5 |
| Coal | 100.8 |
| Nuclear | 92.4 |
| Natural Gas | 31.3 |
| Petroleum | 7.0 |
| Biomass | 6.7 |
| Wind and Tidal | 2.5 |
| Other thermal | 2.4 |

**CANADA**

Mr. N.R. Beck and Ms. L. Palombo  
CanmetENERGY  
Natural Resources Canada

**INTRODUCTION**

Canada has been involved in the development of hydrogen and fuel cell technologies for over two decades. Canada is well-positioned to be a leading developer and adopter of hydrogen and fuel cell technologies for two reasons. Firstly, Canada is the largest per capita producer of hydrogen in the OECD, producing approximately 3 million tons annually. And second, Canada is a world leader in the development of fuel cell technology and hydrogen infrastructure.

The hydrogen and fuel cell sector in Canada is characterized by highly innovative small companies which are investing heavily in R&D to commercialize technology. The largest cluster of hydrogen and fuel cell companies in Canada, and possibly the world, is located in Vancouver, BC. Other clusters are located in Calgary, AB; Toronto, ON; and Montreal, QC. The sector supports a well-educated labour force with advanced skills – key ingredients in building Canada’s knowledge economy.

**PROGRAM STRUCTURE**

Canada’s program targets four areas: sustainable hydrogen production, hydrogen storage, fuel cells and safety, and codes and standards.

**Hydrogen Production:** Hydrogen’s value as an energy carrier stems from the wide base of primary energy sources which can be employed to produce it. These include both renewable sources such as hydro, wind, solar and biomass, and non-renewable sources such as natural gas, coal, and nuclear energy.

Historically, the main thrust of Canada’s investments has been electrolysis, systems for hydrogen production from wind, hydrogen from low-value materials such as hydrogen sulphide, and from coal or petroleum coke via the steam/iron process (a technology for centralized hydrogen production allowing easier carbon capture). Smaller program elements included purification and separation. Activities have steered away from technologies which are developed extensively in other countries and for which there was not a unique Canadian capability. Going forward, Canada’s activities in the short term will focus almost exclusively on electrolytic hydrogen production.
Hydrogen Storage: Hydrogen storage is a key enabling technology for the deployment of fuel cell technologies in stationary, portable, and transportation applications. The challenge for all end-uses is to produce reversible, lower cost, lighter weight, and higher-density hydrogen storage systems. For transportation, the overarching technical challenge for hydrogen storage is how to store the amount of hydrogen required for a conventional driving range (>300 miles), within the vehicular constraints of weight, volume, efficiency, safety, and cost. Durability over the performance lifetime of these systems must also be verified and validated, and acceptable refueling times must be achieved.

Going forward, Canada will focus on solid hydrogen storage. Canada will concentrate on applications for back-up power and portable fuel cells where there is expertise and commercial applicability in Canada. Weight, volume, and cost will be the key parameters addressed.

Fuel Cells: Canada is working to improve fuel cell technologies for transportation, stationary, and portable applications. For transportation, small-scale stationary generation (e.g. back-up power), and portable devices, the focus is on proton exchange membrane (PEM) fuel cells due to their low temperature operation and capability for fast start-up. For larger-scale distributed energy generation, the focus is on the high temperature solid oxide fuel cell (SOFC), which can directly use natural gas or other hydrocarbon fuels.

Codes, Standards and Safety: The successful global commercialization of hydrogen and fuel cells depends on internationally accepted codes and standards. These will help to increase the experience, knowledge, and confidence of local, regional, and national officials in the use of hydrogen and fuel cell technology, and facilitate the development of smart regulations. R&D supports the development of performance-based, rather than product-specific, codes and standards.

International collaboration in this area is essential. Canada has played a leading role as chair of the ISO Technical Committee 197 (Hydrogen Technologies) and as a strong contributor to the IEA Hydrogen Implementing Agreement Task 19. Task 19 participants have been working to identify the physical properties of hydrogen which impact the issue of safety.

Canada has also developed the Canadian Hydrogen Installation Code. Published by the Bureau de Normalisation du Québec (BNQ) as a National Standard of Canada, the Canadian Hydrogen Installation Code (CHIC) [CAN/BNQ 1784-000] will help pave the way for greater use of hydrogen as an energy carrier by guiding safe design and facilitating approval processes for hydrogen installations across Canada.

HIGHLIGHTS

The following are examples of significant accomplishments that are helping to build Canada’s hydrogen and fuel cell industry.

Canadian Fuel Cell Commercialization Roadmap

In 2003, Canada released its first Commercialization Roadmap. The Roadmap was aimed at accelerating full-scale commercialization of Canadian hydrogen and fuel cell technologies, to capture benefits from substantial industrial investments in research and development, and to develop long-term solutions to meet Canada's climate change goals. In 2008, Canada updated the Canadian Fuel Cell Commercialization Roadmap. The
update begins by outlining why hydrogen and fuel cells are considered an essential part of the future low carbon energy system for transportation and stationary power, and an energy innovation in portable electronics. It continues by providing an overview of global hydrogen and fuel cell markets as background and context for the activities of the Canadian industry.

National Hydrogen and Fuel Cell Research Directory

The Hydrogen and Fuel Cell Research Directory is a public online database of information on researchers and facilities in Canada. The purpose of the Research Directory is to increase the visibility, researcher collaboration and use of Canadian research and laboratory services in hydrogen and fuel cell technology.

Hydrogen and Fuel Cell Gateway

In early 2008, a technology demonstration and exhibit centre showcasing Canada’s world-leading hydrogen and fuel cell industry was officially opened. The Hydrogen and Fuel Cell Gateway is located at the NRC Institute for Fuel Cell Innovation in Vancouver, and was conceived through a public-private partnership between the National Research Council, Natural Resources Canada, Industry Canada, the Government of British Columbia and the Canadian Hydrogen & Fuel Cell Association.

2010 Olympics: First Bus Delivered as Part of World’s Largest Development of Hydrogen Fuel Cell Buses

The first of 20 buses was delivered and successfully tested as part of the world’s largest hybrid electric fuel cell bus fleet. The bus is part of BC Transit’s project to demonstrate sustainable transportation technologies for the 2010 Olympics in Whistler, B.C. Twenty new hybrid electric fuel cell buses and two Hydrogen Highway fuelling stations are planned for regular service by fall of 2010 in Whistler, Vancouver and Victoria. The low-floor buses will have a range of 500 km, a top speed of 90 km/h and a life expectancy of 20 years. They are the sixth generation of a fuel cell bus developed in Canada. Several Canadian companies are involved in this project such as Ballard Power Systems, Dynetek Industries, Hydrogenics Corporation, New Flyer Industries, Questair Technologies, Air Liquide Canada, and Sacre-Davey Engineering.

Establishment of AFCC Automotive Fuel Cell Cooperation Corp.

AFCC Automotive Fuel Cell Cooperation Corp. (AFCC) is a private Vancouver-based automotive fuel cell technology company founded in 2008 and owned 50.1% by Daimler AG, 30% by Ford Motor Company and 19.9% by Ballard Power Systems. AFCC was created to focus on fuel cell research, development and design specifically for automotive applications. AFCC will work closely with Daimler and Ford to evolve automotive fuel cell technology.

REFERENCES

Canadian Hydrogen & Fuel Association Canada: http://www.chfca.ca/

CONTACT
Nick Beck
S&T Director, Hydrogen, Fuel Cells and Transportation Energy
CanmetENERGY
Natural Resources Canada
nbeck@nrcan.gc.ca
ENERGY DEMAND AND PRODUCTION

Danish primary energy production has increased dramatically since 1980 due to the oil and gas fields in the North Sea. Oil production peaked in 2004, and natural gas production is expected to peak around 2010. In 2007, Danish energy production was 130% of domestic energy consumption. Renewable sources (wind and biomass) are increasing and becoming an essential part of the energy supply.

Denmark’s energy consumption shows a decrease in oil and coal consumption while the use of renewable energy and natural gas has increased. The energy consumption in the industrial, commercial, and residential sector has been more or less constant since 1980 while the transport sector’s energy consumption is constantly increasing.
An agreement on the Danish energy policy was reached in February 2008 between the Danish government and other parties in the Parliament. The agreement includes improved conditions for wind power and renewable energy such as biomass and biogas. In 2011, renewable energy should cover 20% of Danish energy consumption. The energy consumption in 2020 shall be four per cent lower than in 2006.

There will also be no tax on hydrogen-fuelled and electric vehicles. Special R&D funding to electric vehicles, wave energy, and photovoltaics was also part of the agreement. Hydrogen and fuel cell activities have significant government funding from different programs.

HYDROGEN AND FUEL CELL HIGHLIGHTS IN 2008

Several collaborations have advanced the development of Danish hydrogen and fuel cell technologies. The public-private “Partnership for Hydrogen and Fuel Cells” has
groups for PEM and SOFC fuel cells, development and demonstration of mobile and stationary applications, and a group for scientific issues and education as well. Moreover, there are groups with a specific focus such as the Danish national micro-cogeneration demonstration program (www.dk-mchp.eu) and the HotMEA high-temperature PEM program, which were launched in early 2009.

In 2008, a number of hydrogen-related events occurred that are worth mentioning. The second phase of the national micro-cogeneration demonstration program saw its first field test installation in September 2008. The program is unique in the sense that low-temperature PEM, high-temperature PEM, and SOFC micro-cogeneration units were developed in parallel. Hydrogen-fuelled low-temperature PEM fuel cells are supplied with fuel from a hydrogen grid in the small village of Vestenskov 120 km south of Copenhagen. Hydrogen is generated in an electrolyzer supplied with (surplus) wind electricity. The 1.5 kW fuel cell unit from IRD (www.ird.dk) shows an electric efficiency of 47% at nominal load in laboratory tests. In 2009, natural gas fuelled high-temperature PEM and SOFC will be installed in southern Jutland.

A number of hydrogen filling stations in western Denmark and fuel cells in small vehicles and industrial trucks were developed by H2Logic (www.h2logic.dk).

The construction of H2College, a youth residential living complex, began in 2008, and the first students moved in during January 2009. The buildings have a very low heating demand (15 kWh/m² year). Sixteen high-temperature PEM fuel cells (www.serenergy.com) are used for power generation and hot water generation. Hydrogen is produced in a common electrolyzer for the entire system.

Planned hydrogen demonstration activities at the COP 15 climate change conference in Copenhagen in December 2009 include 15 small fuel cell powered cars. Also, Bright Green (www.brightgreen.dk), exhibition on energy and environment technologies will take place in parallel to COP 15.
EUROPEAN COMMISSION

Dr. M. Steen
European Commission, Joint Research Centre, Institute for Energy

BACKGROUND

The European Commission (EC) is the executive arm of the European Union (EU), a unique treaty-based, economic and political partnership of (currently) twenty seven member states, covering a territory of 4,323,000 km².

The most recent data on the EU and of the individual member states’ primary energy structure and on electricity production and consumption can be found in the EC issued statistical pocketbook for 2009, “EU energy and transport in figures.”

The EC is responsible for proposing policy and legislation, implementing decisions, ensuring that all abide by the European treaties and laws, and management of general ongoing EU affairs. It therefore handles a number of policy areas and portfolios, including science and research. The Joint Research Centre (JRC) operates as a Directorate-General under the EC’s jurisdiction providing independent scientific and technological support for EU policy-making. Knowledge comes from specific application- and issue-oriented research within the seven JRC Institutes and close co-operation and networking at the European level and globally.

The JRC Institute for Energy, located in Petten, the Netherlands, focuses on energy issues, and represents the EC in the IEA HIA. The JRC has extensive involvement in all EC hydrogen matters.

2008 RELEVANT POLICY UPDATES & MILESTONES

On 14 October, the Joint Technology Initiative (JTI) was officially launched, marking an important milestone for European Fuel Cells and Hydrogen (FCH) research. This is a public-private industry-led partnership, which is composed of the European Commission, the European industry, and the European research community. It was established to overcome fragmentation and co-ordinate the European research, technological development, and demonstration efforts in this field, in an upstream and market-driven fashion. The JTI will invest nearly 1 billion Euros over six years while ensuring the involvement of all key stakeholders in the field and striving for enhancement of international collaboration. The goal is to deliver “fit-for-use” hydrogen energy and fuel cells technologies and to achieve mass-market roll-out of these promising technologies before 2020. The expected key deliverables are new generation prototypes and demonstrators for testing and validation, in the fields of transport, stationary and portable applications. The anticipated outcome is a shorter time to market by between two and five years, earlier gains for the energy system, and an improved competitive position for the industry.

The legal entity through which the partners in the FCH JTI come together to implement RTD activities is the Joint Undertaking (JU) which was established by a European Council Regulation in May 2008. The FCH JU is responsible for overcoming fragmented research activities, leveraging resources and defining the short, medium, and long term research agendas on hydrogen and fuel cells, whilst guaranteeing the linking of fundamental
research and demonstration projects. Its members come from the European Community and the “JTI Industry Grouping,” a not-for-profit organisation that brings the industrial sector’s key players together and is open to any private legal entity sharing the objectives of the FCH JTI.

The respective RTD activities are supported by annual competitive calls for proposals, organised according to the strategic priorities set out in the annual and multi-annual Implementation Plans. The JU published its first call in October 2008 and the shortlisted projects are currently under negotiation.

**EC PARTICIPATION IN THE IEA HIA**


**EC-JRC/IE INVOLVEMENT IN TASK 22**

JRC/IE actively participates in Task 22–Fundamental and Applied Hydrogen Storage Materials Development through a collaborative experimental project with the University of Uppsala. The project focuses on magnesium-rich compounds and ways of enhancing their potential for hydrogen storage. The research activity includes synthesis of the compounds, and subsequently micro- and macroscopic performance characterizations. It makes use of the material production and crystallographic characterization facilities at the Uppsala University, and of the hydrogen sorption instruments and microstructural analysis services at JRC.

The underlying strategy in this project is to explore the role of alloying elements in Mg-based systems in an attempt to address the shortcomings of slow hydride formation and poor thermodynamic properties that hamper these materials’ performance and reduce their chances for application. The idea behind it is to gain a fundamental understanding of phase relations in such metal-hydrogen systems and of the associated crystallographic structures and their evolution.

So far in this project a number of material combinations have been studied in a quest for the most promising “formula.” Work on Mg-Y and Mg-Ga systems, such as Mg24Y5 and Mg5Ga2, showed that hydrogen absorption is accompanied by microstructural modifications. In the case of Mg24Y5 hydrogen absorption, led to the formation of MgH2 whiskers and micro-particles, which upon desorption were transformed into carved nanotubes of Mg [1], [2] (Figure 1) that could enhance the potential for storage.

The Mg-Y based system also demonstrated improved kinetics of hydrogen desorption, possibly due to the presence of Y hydrides acting as catalysts. Indeed, comparing thermal desorption data from the bulk MgH3 with the Mg24Y5-H, a distinct lowering of the maximum desorption temperature and of the activation energy was noted, but not at the desired level. Moreover, a small extra peak was observed in the thermal desorption spectra which was not present in the pure Mg–occurring at a lower temperature. It was attributed to the hydrogen desorption from the formed MgH2 whiskers and micro-particles. This is a welcome feature indicating further potential for improvement in kinetics [2].
Following cycling, the thermal stability of the hydrogen desorption was further lowered at the expense of the total desorbed hydrogen capacity, whereas both whiskers and microparticles were depleted into clusters of nanoparticles.

The last systems examined in this reporting period were also based on the method of alloying Mg with Y, since yttrium appears to improve the diffusion of hydrogen. The systems were ternary compounds: Mg-Y-Ti and Y-Mg-Ga. The Mg-Y-Ti system, which is a mixture of different Mg-rich phases, was shown to have Mg24Y5 and Mg crystal structures and a similar microstructural behaviour upon hydrogen hydrogenation/dehydrogenation (Figure 2), with the previously reported Mg24Y5. First results on thermal desorption have also pointed to similar trends with respect to the thermodynamic properties of the interaction of this material with hydrogen.

A parallel investigation on the Y-Mg-Ga system has proven to be more fruitful. The hydrogen absorption behaviour of this system was studied by in situ powder X-ray diffraction, and the respective (de-)sorption properties were investigated at JRC/IE using thermal desorption spectra and pressure-composition-isotherms. Our results showed that this compound can absorb more than 2 wt%, but with a maximum reversibility of 1.1 wt.% (Figure 3 left)—a behaviour which remained rather stable during further hydrogenation/dehydrogenation cycling, up to thirteen cycles.

A plateau pressure was noted at very low pressures, indicating the formation of YH2 (as confirmed by XRD), followed up by an increase of the hydrogen content with pressure. The total storage capacity is believed to be coming from the main part, hydrogen in YH3 and a smaller part from the formation of small amounts of MgH2, along with Mg and yttrium gallides. The thermal desorption data were also encouraging, showing better kinetics and lower thermal stability, as compared to the pure Mg hydride system, which were even further improved with cycling (Figure 3 – right).

A closer look at the XRD data obtained after desorption [3] revealed that neither YH3, nor MgH2 were present, whereas the YGa2 was found to increase significantly. Also, the initial YMgGa phase was formed once again, though at the expense of YH2, which was found to be much less than the YH3 in the fully hydrogenated sample. More interestingly, and quite encouragingly, this occurred at temperatures below 450°C, which is really unexpected since pure YH2 desorbs hydrogen at temperatures above 800°C [3].
In conclusion, from the systems examined so far, the Y-Mg-Ga showed the most promise with its improved thermodynamic and kinetic properties compared to pure YH$_3$ and demonstrated the possibility to significantly lower the desorption temperature of alloy materials, tailoring them for hydrogen storage applications.

ENDNOTES


FINLAND

VITAL STATISTICS

EU member state

Population 5.3 million, urbanization 71%

 Territory 338,000 km², of which 10% is water and 69% forest; 187,888 lakes, 5,100 rapids and 179,584 islands; Europe’s largest archipelago

 Capital Helsinki

 GDP/capita around 31,700 euros (2007)

 Recent Average GDP Growth +0.9% during 2008

 Primary Energy Structure See pie chart

 Total Consumption See table

 Net Energy Import mostly concerns electricity

 Electricity Production and Consumption (www.energia.fi)

INTRODUCTION AND BACKGROUND

The table below depicts total energy consumption in Finland for 2008.

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<td>Wind Power</td>
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Net Imports 12557 13.9 10.1 12788 14.7 1.7

UPDATE ON MEMBER’S ENERGY FRAMEWORK

Update on Relevant Policies

The Strategic Competence Center of Energy and Environment (www.cleen.fi) was recently established. Among existing energy policy measures and actions, new trends have been highlighted.

There is great interest in the pulp mills’ increasing power production. Promising new technologies gasify solid biofuels to yield a gas mixture containing large amounts of carbon monoxide and hydrogen. A number of gasification concepts and reactor designs have been suggested. These include oxygen-blown entrained flow gasification of black liquor, and fluidized bed gasification of bark and other solid biomass.

Finland’s nuclear energy policy was also updated. R&D is a precondition for continuing reliable and safe operation of existing reactors. Significant research is ongoing in order to ensure safe spent nuclear fuel management and geological disposal. Plant life management
is also an important nuclear R&D topic devoted to extending the time for which existing plants can be operated safely and economically. Finland has a strong track record in all these aspects related to the employment of nuclear energy production.

Additionally, nuclear technology development aims for new and improved plant concepts to be built in the long-term future, including the so-called “Generation IV plants,” a family of advanced nuclear designs featuring thermal neutron spectrum (TNS) systems (Very-High-Temperature Reactor (VHTR) and Supercritical-Water-Cooled Reactors (SCWR)) with coolants and temperatures that enable hydrogen or electricity production with high efficiency, fast neutron spectrum (FNS) systems (Gas-Cooled (GFR), Lead-Cooled (LFR), and Sodium-Cooled (SFR) fast reactors) that will enable more effective management of actinides through recycling of most components in the discharged fuel, and the molten salt reactor (MSR). The FNS option is of particular interest, as a hundred times more energy could be acquired from uranium, and also because the more abundant thorium could be utilized, thus extending the fissile fuel resources for thousands of years.

The renewable sources policy continues to strengthen the role of wind power, small-scale hydropower and partial solar-power (including thermal solar heat). On the energy consumption side, efforts are being made for more rational use of energy, CHP, district heating and cooling, and low-energy utilities implementation (www.motiva.fi, www.energia.fi).

Update on relevant programs and projects

The biomass processing development needs identified to date are thermochemical conversion processes for biofuels like gasification, pyrolysis, catalysis, and synthesis technologies; biotechnical conversion processes, fermentation to alcohols, biogas, and other products; and process and system integration to CHP, forest and food industry, and agriculture. These will also require efforts in development of sustainable and reliable raw material supplies, LCA, solutions for transportation fuel qualities, fuel standardization and regulations, laboratory, process development units, pilot infrastructure, and significant demonstration investments. Biofuel users should rely on engine and vehicle development for biofuels, emission reduction, “drivability,” support from respective modelling, simulation, and new business concepts for international trade (www.cleen.fi).

These actions are expected to provide long-term options for a sustainable hydrogen economy.

HYDROGEN R&D SPECIFICS – PROGRAMS, PROJECTS, INITIATIVES IN BRIEF

SCOPE AND ACCOMPLISHMENTS

The new Tekes’ (www.tekes.fi) Fuel Cell and Hydrogen technology program aims to improve opportunities for Finnish industry to create breakthrough products in selected fuel cell product segments. The overriding idea is to develop solutions and value networks ranging from fuels to end applications. The value of the end product comes from fuel handling, material solutions, system components, and application integration and services. The Tekes Fuel Cell program creates an environment in which the development of fuel cell technologies and services can succeed. The duration of the program is 2007–2013 with a total volume of €144M.
The program is Finland’s commitment to the Joint Technology Initiative on Hydrogen and Fuel Cells under the EU Framework 7 Program. It also provides foreign players in the sector with a channel for creating cooperation partnerships between researchers and enterprises alike.

PARTICIPATION

Large RTDD activities here are focused on fuel cell development and the fuel conversion technologies to hydrogen. Natural gas is a typical fuel, and by a reforming step, it can be fed to various types of fuel cells. Large-scale stationary applications will need a totally new type of sustainable hydrogen production technology, storage, and logistics solutions. Various primary energy sources will be used; nuclear, renewable energy sources, natural gas, and oil products. A project on the production of hydrogen from bioethanol by reforming in a catalytic membrane reactor has been performed (University of Oulu).

Furthermore, there is an on-going project studying the structure/function relationships, as well as the regulation and assembly of the photosynthetic protein complexes at systems biology level (University of Turku). Main research targets have been the water splitting different complexes. Novel research interests include the harnessing of solar energy for biohydrogen production using cyanobacteria, and the interactions between the bioenergetic reactions and the toxins in toxin-producing cyanobacteria.

A Fuel Cell and Hydrogen Joint Technology Initiative (JTI) has been established in EU, governed by a board of 12 members, six of whom represent industry. One member represents an association of research organizations, and a research group called N.ERHGY, which was established in 2008. Wärtsilä Finland will participate in the industry group, and VTT and TKK (Helsinki University of Technology) will participate in the research group.

Within IEA framework, Finland has joined the HIA Task 25 “High-temperature processes for hydrogen production.” Helsinki University of Technology (TKK) coordinates the project for advanced materials solutions for high-temperature SI (Bunsen) and hybrid cycles.

FUNDING

In its first stage (2008), the Finnish hydrogen and fuel cell technology program has gathered over 300 active participants from 60 companies and organizations, carrying out R&D in 11 corporate and 15 research projects with a total value of €27M, of which Tekes’ contribution is €17.4M.
UPDATE ON MEMBER’S ENERGY FRAMEWORK

France has made a commitment to use renewables for 23% of its energy consumption mix by 2020, mainly through wind and biomass development:

- Main R&D priorities: solar, biofuels, hybrid and electric cars, and energy efficiency.

Updates on relevant programs and projects:
- New Ademe fund for research demonstration projects: 400 M€ over 4 years.
- French National Agency (ANR) on Renewables: 100 M€/year.
- French platform on hybrid and electric vehicles to develop and test Li-Ion batteries, power electronics, and energy management.
- 2nd generation biofuels projects with IFP, Total, CEA, and Sofiproteol.

HYDROGEN R,D&D SPECIFICS

Programs, projects, and initiatives are mentioned in brief below.

DEVELOPING RESEARCH ON BREAKTHROUGH TECHNOLOGIES

1. Decrease Costs of PEMFC
   - Decrease platinum content: 0.3 g/kW
   - Develop modular and compact PEMFC stack

2. Improve Reliability of SOFC: New Materials
   The availability of appropriate new materials is expected to positively impact the reliability of SOFCs.
3. Program on Hydrogen Production Coupled with Nuclear Energy:
Thermochemical and High Temperature Electrolysis Processes at CEA (below)

**High Temperature Steam Electrolysis CEA Programme**

<table>
<thead>
<tr>
<th>Components</th>
<th>Stacks</th>
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</thead>
</table>
| Materials, Processes & Behavior<br>Seals – leak management<br>Ceramic Cells<br>- Innovative materials<br>- New processes to enhance the cells’ area<br>Interconnects – coatings<br>- Corrosion of materials<br>- High temperature sealing<br>- Management of connection<br>Modeling<br>- Multi physics Design tool<br>Integration, Tests & Modeling<br>Stacks development<br>- Specific benches and procedures | Integration, Tests & Modeling<br>Stacks development<br>- Specific benches and procedures<br>Pressure: 700 bar, 32 l, 5.4 weight%<br>Leak rate < 0.05 cm3/l/h, Burst pressure > 1800 bar<br>Endurance tests > 5000 h | System & Technico-economy<br>Net Exportation<br>Consumption<br>Nuclear<br>Renewables<br>Fossils<br>Electricity Production<br>570 TWh<br>78%<br>12%<br>10%<br>480 TWh<br>57 TWh<br>480 TWh<br>78%<br>12%<br>10%<br>Electricity Consumption<br>570 TWh<br>Nuclear<br>78%<br>Renewables<br>12%<br>Fossils<br>10%<br>Net Exportation<br>57 TWh<br>Endurance tests > 5000 h<br>PEM Electrolyser System up to 50 bars<br>PEM Electrolysis<br>Nuclear + SMR + Capture<br>Nuclear / thermocycles<br>SMR + Capture<br>SMR<br>Nuclear + SMR<br>Coal + Capture<br>Nuclear / electrolysis<br>Coal<br>Solar PV<br>Solar photocatalysis<br>Wind<br>Tidal<br>Solar biomass<br>Hydroelectric<br>Thermal cracking<br>Solar + SMR | Leader: Magna Steyr<br>Partners: DC, BMW, PSA, Air Liquide, …<br>CEA: HP tanks, evaluation, core group |<br>FRANCE |<br>FRANCE
DEMONSTRATION AND DEPLOYMENT IN EARLY MARKETS

LARGE PROJECT H2E, LED BY AIR LIQUIDE 200 M€/7 YEARS

- On 8 October 2008, the European Commission authorized the 67.6 M€ in funding granted by OSEO (French agency for innovation support) at the end of 2007 for the Horizon Hydrogen Energy (H2E) Innovation Program, coordinated by the Air Liquide Group, in the field of hydrogen and hydrogen fuel cells.
- The H2E program, which represents an overall investment in research and technology of almost 200 M€ over 7 years, aims at building sustainable and competitive hydrogen energy solutions. The research and development will cover the full hydrogen energy value chain. In particular, it will investigate the development of innovative technologies for hydrogen production using renewable energy, hydrogen storage, and industrialization of fuel cells. H2E will also contribute to the establishment of a suitable regulatory framework, and will include a program of demonstrations and educational measures to familiarize the wider public with this new, clean energy vector.
- Coalescing around Air Liquide, this ambitious program brings together twenty partners in the field of hydrogen energy: industrial groups, small and medium-sized companies, and French public research laboratories. This is a unique opportunity to place France and Europe at the leading edge of this key sector for sustainable mobility.
- The H2E program focuses on markets with wireless energy needs not met by any current solutions. For example, captive vehicle fleets, portable generators, or the supply of backup energy.

COUPLING WIND WITH HYDROGEN: EOLY PROJECT WITH AIR LIQUIDE AND AXANE

- Produces electricity from a wind turbine (6 kW) and PV cells (15 kWc)
- Produces hydrogen from an electrolyser (3 Nm3/h)
- Stores energy in batteries and in hydrogen
- Coupled to PEM Fuel Cell 2.5 kW from Axane
- Provides constant electrical power to a load (1 – 5 kW)
HYDROGEN IMPLEMENTING AGREEMENT

STARTING A NEW PROJECT ON COUPLING PV PLANT AND HYDROGEN PRODUCTION AND STORAGE IN CADARACHE: PEPITE PROJECT (25 KW PV AND H2), AND CORSICA (MYRTHE PROJECT)

- Partners: HELION, CEA, ARMINES, LAPLACE, CNRS Corsica
- System modelling and optimization

PARTICIPATION:
1. National laboratories (CEA, CNRS) and universities (Poitiers, Montpellier, et. al.)
2. Large companies: Air Liquide, Total Areva, GDF-Suez
3. SME: NGHY, MacPhy, Axane, Helion
4. Regional level: Paca region, Rhone Alpes, Lorraine, Belfort, North region, Pays de la Loire

NATIONAL PUBLIC FUNDING: AROUND 35 M€/YEAR
1. Direct funding to national laboratories and universities
2. French ANR: 11 M€/year

- The Hpac Program will succeed the Pan-H Program (2005-2008) in 2009. It will support the positioning of French companies and research institutions in the domain of Hydrogen and Fuel Cells R&D, consistent with the SET Plan and the FCH JTI at the European Level.
- It aims at developing fuel cell technologies for early markets for stationary applications: cogeneration, emergency units, non-centralised electricity production, portable applications, auxiliary power generation units, and renewable energies management.
- Pan-H is pointed at the development of innovative fuel cell technologies for automobile applications while Hpac is aiming at consolidating obtained results and pursuing them for captive fleet.
- 73 projects were funded following calls in 2005, 2006, 2007 and 2008.
Additional information about funding for the ANR Pan-H program appears below.

**Figure 1:** Funding in Millions (€)

![Graph showing funding in Millions (€) from 2005 to 2008.]

**Figure 2:** ANR total funding in the Pan-H program: 84 M€, following the 4 year calls.

*Project total budget: 154 M€*

**REFERENCES**
4] www.alphea.com

**CONTACT**
1] Paul Lucchese, CEA
   paul.lucchese@cea.fr
INTRODUCTION


The National Innovation Programme provides a common framework for numerous hydrogen and fuel cell research projects conducted by academic institutions and industry. The strategic alliance is scheduled to run for 10 years. Over this period, the Federal Government will provide 700 million €, with the industry contributing at least the same amount to the project, resulting in a total investment of 1,400 million €. Further activities could be added by pure industrial efforts, programmes of Federal States, and European cooperation, which are not included in NIP.

Table 1: Estimated needs of resources of the National Innovation Programme [1]

*supplemented by funding which is not included in NIP, e.g., the Federal Ministry of Education and Research for basic research and institutional funding, programmes of Federal States, and European cooperation

The objective of NIP is to develop viable market products from hydrogen and fuel cell technology research and development projects. The process of development should involve
industry, including small and medium-sized enterprises, users, and research institutions along the whole value chain of industrial production processes. Illustrative demonstration projects are to prove that hydrogen and fuel cell projects are now ready for deployment and everyday use. The research funds are thus not only an investment in sustainable energy technologies, but also help to establish employment and technological know-how in Germany.

<table>
<thead>
<tr>
<th>TOPICS</th>
<th>RESEARCH AND DEVELOPMENT GOALS</th>
<th>DEMONSTRATION LIGHTHOUSE PROJECTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobile</td>
<td>Cost reduction, increase of lifetime, and efficiency</td>
<td>Fleet operation, Deliverance of $H_2$</td>
</tr>
<tr>
<td>Stationary household application</td>
<td>Cost reduction, increase of reliability, and lifetime efficiency</td>
<td>Operation under aging conditions:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- 450 systems till 2010</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- 2000 systems till 2012</td>
</tr>
<tr>
<td>Stationary application in industry</td>
<td>Cost reduction, increase of reliability, and lifetime efficiency</td>
<td>Technology certification:</td>
</tr>
<tr>
<td>Early markets</td>
<td>Miniaturisation, Production technologies</td>
<td>- $H_2 &gt; 50 %$ till 2010</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- lifetime of the stack 40,000 h till 2015</td>
</tr>
</tbody>
</table>

Table 2: Topics, R&D Targets, and Lighthouse Projects of the National Innovation Programme Hydrogen and Fuel Cells [1]

Initially, the activities are to be focused in selected clusters. They will then gradually be extended and interlinked, both nationally and internationally. The common use of infrastructure and the exchange of experience will help to exploit synergies and to prevent an ineffective fragmentation of funding.

In accordance with the national scale of NIP, the complexity of the task, and the number of project partners, a professional programme and financial management team was installed to coordinate the programme activities. For this purpose, in February 2008, the Federal Government created the National Organization for Hydrogen and Fuel Cells technology (NOW GmbH), which is headquartered in Berlin. NOW represents a new form of a public-private partnership. For the first time, the activities of individual participants from politics, science, and industry are united in a single program. The Federal Government itself – represented by the Federal Ministry of Transport, Building, and Urban Affairs – is the public shareholder of NOW.

The core element of the National Innovation Programme is to continue to expand R&D in these fields, ranging from basic research to demonstration projects and market preparation measures. Under the NIP, a large part of the available resources will be used in demonstration projects (aka “lighthouse projects”) to prepare the everyday practical and reliable components and systems for subsequent commercial use. The following lighthouse projects have been established or initiated:

CLEAN ENERGY PARTNERSHIP

The “Clean Energy Partnership” (CEP), demonstrates the production, handling, and use of hydrogen as a fuel for road transport. In this project, a number of technical and political boundary conditions and economic issues are clarified, e.g., safe refueling of vehicles, hydrogen storage, and low-cost production. CEP is intended to demonstrate

**Demand/Consumption**

**Final Energy Consumption 2007**

- Industry: 28.5 %
- Transport: 30.3 %
- Residential: 25.6 %
- Commercial: 15.6 %

**Total Final Energy Consumption:** 8584 PJ

**Electricity**

**Gross Electricity Production 2008:**

- 639 TWh (share of renewable electricity production: approx. 15 %)

**Gross Electricity Consumption 2008:**

- 617 TWh
the production of fuels from renewable sources. In September 2008, the CEP entered a second phase and currently it represents the largest demonstration project in Europe, with over 30 passenger cars in day-to-day operation. In the cities of Berlin and Hamburg, there are hydrogen-fuelled bus fleets in operation for public transport. The number of hydrogen refueling stations will increase.

NEEDS

Within the industrial energy supply sector, the “NEEDS” lighthouse project demonstrates the build-up of standardised fuel cell plants in combination with biomass utilisation plants (bio gas, sewage gas, pyrolysis, synthesis). A first system will be operated by the company Dalkia Germany. The system consists of a Molten Carbonate Fuel Cell and a gas engine combined heat and power plant with a newly developed control system.

CALLUX

In the Callux lighthouse project, 800 fuel cell heating appliances will be in operation until 2015 to supply households with electricity and heat. The goal of the Callux project is the further development of existing technologies into reliable systems suited for everyday life through acquisition, installation, and operation of a larger number of fuel cell heating appliances.

SPEICHERSTADT POTSDAM

The lighthouse project “Speicherstadt Potsdam” focuses on the highly efficient and CO₂-neutral power supply of a city area in Potsdam. The project combines innovative low consumption civil engineering with a highly efficient Molten Carbonate Fuel Cell combined heat and power unit with biomethanation from organic residues.

BODENSEE

Within the BODENSEE demonstration project, onboard power supply units for camping vehicles (trailers and motorhomes) and the propulsion of recreational vehicles (ships and light vehicles) with Fuel Cell Electric propulsion systems will be tested. The test will take place under day-to-day conditions. One of the major goals is to generate public awareness in this special market application.

ENDNOTES


2] NATIONALE ORGANISATION WASSERSTOFF- UND BRENNSTOFFZELLEN-TECHNOLOGIE, project finder, 18th June 2009; www.now-gmbh.de

CONTACTS

1] J. - Fr. Haken
  jfh@fz-juelich.de

2] J. Linssen
  j.linssen@fz-juelich.de
**GREECE**

**Dr. Elli Varkaraki**
National Representative for the Ministry of Development in the IEA HIA

**INTRODUCTION AND BACKGROUND**

Figure 1. Contributions to total energy consumption in Greece (2006)

The Greek electrical system consists of approximately 13 GW of installed capacity with some 850 MW of interconnectors for imports. The electricity balance is reported below:

<table>
<thead>
<tr>
<th></th>
<th>2004 TWH</th>
<th>(%)</th>
<th>2006 TWH</th>
<th>(%)</th>
<th>2008 TWH</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignite</td>
<td>32.5</td>
<td>58.4</td>
<td>29.2</td>
<td>49.2</td>
<td>29.9</td>
<td>48.5</td>
</tr>
<tr>
<td>Oil</td>
<td>7.1</td>
<td>12.8</td>
<td>8.1</td>
<td>13.7</td>
<td>7.2</td>
<td>11.7</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>8</td>
<td>14.4</td>
<td>10.2</td>
<td>17.2</td>
<td>13.3</td>
<td>21.6</td>
</tr>
<tr>
<td>Hydroelectric</td>
<td>4.2</td>
<td>7.5</td>
<td>5.6</td>
<td>9.5</td>
<td>2.9</td>
<td>4.6</td>
</tr>
<tr>
<td>RES</td>
<td>1</td>
<td>1.9</td>
<td>2</td>
<td>3.4</td>
<td>2.7</td>
<td>4.5</td>
</tr>
<tr>
<td>Import-Export</td>
<td>2.8</td>
<td>5.1</td>
<td>4.2</td>
<td>7.1</td>
<td>5.6</td>
<td>9.1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>55.7</strong></td>
<td><strong>100</strong></td>
<td><strong>59.3</strong></td>
<td><strong>100</strong></td>
<td><strong>61.6</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

**VITAL STATISTICS**

- **EU member state since 1981**
- **Population**: 11.15 million
- **Territory**: 131,990 km²
- **Capital**: Athens
- **GDP/capita (PPP) 2008**: around 30,500 $US
- **Recent average GDP growth**: estimated at around 6%

**Primary Energy Structure**

**The Total Energy Consumption (2006)**

Estimated at 1.42 quadrillion Btus (around 426000 GWh) and is broken into segments in Figure 1.

**Imports**

Oil and natural gas are almost exclusively imported, while coal is a domestic energy resource exploited in electricity production.

**Electricity**

Production and Consumption
UPDATE ON MEMBER’S ENERGY FRAMEWORK

UPDATE ON RELEVANT POLICIES

Ten years after the publication of Law 2773/1999 “Liberalization of the Electricity Market,” the Public Power Corporation still owns 99.7% of the Greek electricity market [4].

Renewable Energy Sources and Cogeneration Systems, Law 3468/2006, aimed to simplify the licensing procedures and architecture of the legal framework set by Law 2773/1999. However, this law has not yet stimulated a market for these systems.

UPDATE ON RELEVANT PROGRAMS AND PROJECTS

The installed capacity of Renewable Energy Sources (RES) in Greece is presented in the following table. For 2020, the share of RES in the total energy consumption should reach 18%, which means that the share in the gross electrical consumption should be around 30-35%.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>480.4</td>
<td>576.1</td>
<td>749.3</td>
<td>853.6</td>
<td>1015.6</td>
</tr>
<tr>
<td>Biomass</td>
<td>20.5</td>
<td>20.5</td>
<td>37.6</td>
<td>37.6</td>
<td>39.4</td>
</tr>
<tr>
<td>Small hydro</td>
<td>43.3</td>
<td>48.2</td>
<td>73.7</td>
<td>95.5</td>
<td>158.4</td>
</tr>
<tr>
<td>PV</td>
<td>0.3</td>
<td>0.5</td>
<td>0.7</td>
<td>0.7</td>
<td>11</td>
</tr>
<tr>
<td>Total</td>
<td>544.5</td>
<td>645.3</td>
<td>861.2</td>
<td>987.4</td>
<td>1224.4</td>
</tr>
</tbody>
</table>

HYDROGEN R,D&D SPECIFICS

PROGRAMS, PROJECTS, INITIATIVES IN BRIEF

Hydrogen and fuel cells were included in the national research agenda, mainly in the fields of energy and environment, but there is still no specific national plan.

The hydrogen R&D is mainly performed within research institutes and academia, with only minor participation from related industry.

On the basis of the national projects in operation during 2008, the matching funds for projects co-funded by the European Commission and national structural funds, and the annual budget for hydrogen and fuel cells was estimated at around 3 M €.

Within the framework of the EC co-funded HydroSol II project led by the Aerosol and Particle Technology Laboratory of CERTH/CPERI, in Thermi (Greece), hydrogen was produced by splitting water in a high-temperature solar reactor at the Almeria Solar Platform (Spain).

Greece commissioned a national project, a small renewable hydrogen system at the premises of Sunlight Systems at Neo Olvio. The system is comprised of small roof-mounted wind turbines, PV, a PEM electrolyser, hydrogen storage, and a PEM fuel cell.
Among the different hydrogen projects initiated in 2008, the Large-scale Integrating Project “H2SusBuild” co-funded by the EC is briefly presented below.

The project’s scope is the “development of a clean and energy self-sustained building in the vision of integrating H₂ economy with renewable energy sources,” and it includes the construction of one laboratory-scale and one real-size installation at the Lavrion Technological Park of the National Technical University of Athens (NTUA) in Greece.

The consortium is composed of 18 partners led by D’Apollonia (Italy), and the total budget of the 4-year project is around 10 Million €. The conceptual diagram of the RES-H₂ building energy system is shown in Figure 2.

Figure 2. Conceptual diagram of a RES – H₂ building energy system [5]

ENDNOTES

5] Collaborative Project H₂SusBuild, FP7, Grant Agreement No. CP-IP 214395-2, Annex I – “Description of Work”

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Ministry of Development, www.ypan.gr
General Secretariat for Research and Technology, www.gsrt.gr
Regular Authority for Energy, www.rae.gr

CONTACT

Elli Varkaraki, evarkara@cres.gr
Mr. Agostino Iacobazzi and Dr. Marco Brocco
Ente per le nuove Tecnologie, L’Energia et l’Ambiente (ENEA)

UPDATE ON MEMBER’S ENERGY FRAMEWORK

KEY POLICY DEVELOPMENTS:

• Fuel switching to NG continues
• Regasifiers for LNG
• Commitment for 20-20-20 EU strategy Energy efficiency RES goal 17% CO₂ reduction
• Nuclear (Site identification – 5 plants)

UPDATE ON RELEVANT PROGRAMS AND PROJECTS:

• Funding: Public funding in the energy sector has been declining over the last ten years relative to overall expenditure for R&S

Figure 1: Public funding in the Energy Sector

Figure 2: Primary Energy and Electricity
HYDROGEN R,D&D SPECIFICS – PROGRAMS, PROJECTS, INITIATIVES IN BRIEF

SCOPE AND ACCOMPLISHMENTS

Hydrogen-Natural Gas Blends

The Emilia Romagna region is funding the development of two buses fuelled with HCNG (5-25% H\textsubscript{2}) as a first step towards a project proposal in FP VII (LIFE+). Project goals:

- Performance and fuel consumption test
- Evaluation of CO\textsubscript{2} emission reduction
- Emission analysis of regulated pollutants (CO, HC, Nox)
- Emission analysis of VOC and particulate
- Driving behavior evaluation
- WTW LCA analysis
In the city of Milan, the Lombardy region has bought 20 natural gas Pandas modified for HCNG use (up to 30% vol of hydrogen) by the FIAT Research Centre. In the meantime, ENI is building two filling stations in the neighborhood of Milan in Assago and Monza.

**Industrial Development in 2009**

The Ministry of Industry created a program titled “Industry 2015,” to fund 3-year projects of innovation in Energy Efficiency (200 M€) and Sustainable Mobility (180 M€). One of the thematics was Hydrogen and fuel cells. The program included:

- Hydrogen boat for Venice Lagoon 9.3 M€
- 3.7 M€ development of hydrogen storage systems
- 12.0 M€ fund 5.3 M€ fuel cells 30 kW cogenerator with PEM fuel cells (NG)
- 15.0 M€ fund 6.0 M€
- 2.5 kW residential generator with SOFC (NG) 22.6 M€ fund 10.9 M€
Fuel cell component development (ENEA)
- PEM FC components development
- Hydrogen-on-demand systems development for portable application
- MCFC components development
  - Military program
  - Hydrogen FC submarine systems development
  - Oxygen storage

**FUNDING**

- Industry: 201526 M€ (2009-2012)
- HCNG (regional funding): 3 M€
- Total funding 2008: 23-25 M€

**REFERENCES**

www.enea.it

**CONTACT INFORMATION**

Agostino Iacobazzi
agostino.iacobazzi@enea.it

Marco Brocco
marco.brocco@enea.it
**Overview of Relevant Programs and Projects**

<table>
<thead>
<tr>
<th>Development of Fuel Cell Technology</th>
<th>Development of Hydrogen Utilization Technology</th>
<th>Standardization and Safety Research</th>
<th>Demonstration</th>
</tr>
</thead>
<tbody>
<tr>
<td>· Development of technology on basic and common issues</td>
<td>· Development of technology on basic and common issues</td>
<td></td>
<td>· Demonstrative Research on Solid Oxide Fuel Cells (SOFC) Japan Hydrogen &amp; Fuel Cell (JHFC) Demonstration Project, Phase II</td>
</tr>
<tr>
<td>· Development of elemental technology</td>
<td>· Development of technology for practical application</td>
<td></td>
<td></td>
</tr>
<tr>
<td>· Development of next-generation technology</td>
<td>· Development of next-generation technology</td>
<td></td>
<td></td>
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</tbody>
</table>

**DEVELOPMENT OF FUEL CELL AND HYDROGEN TECHNOLOGIES**

Fuel cell technology is being strategically developed for the establishment of a hydrogen society. Fuel cell technology is integrated into a wide range of technologies and is expected to stimulate the creation of a new, broad-based industry.
In order to commercialize fuel cell technology, it is vital to assess the basic mechanisms and develop innovative breakthroughs, such as performance and durability improvements, while driving down costs. Other major challenges include building the infrastructure to allow fuel cells to be used practically, and establishing technology to produce, store, transport, and supply hydrogen, while simultaneously establishing safety measures.

**FY2008 OBJECTIVES**

The primary applications for fuel cells are fuel cell vehicles and stationary fuel cell systems. Since these two applications have different introduction scenarios, NEDO is identifying research goals for two different types of research and development activities.

For fuel cell vehicles, NEDO is developing technology on basic and common issues, such as understanding reaction and degradation mechanisms, and developing elemental technology to improve efficiency and durability.

In the field of stationary fuel cells, NEDO is fostering technology development and conducting a large-scale demonstration study with the objective of accelerating the commercialization of stationary fuel cells. In the field of hydrogen technology development, NEDO is clarifying basic mechanisms for the hydrogen storage process, including hydrogen embrittlement and hydrogen absorption, and developing hydrogen utilization technology. The creation standards and the development of safety assessment technology, with a focus on the future introduction of fuel cell vehicles, are also being promoted in order to establish the infrastructure for a hydrogen society.

The Ministry of Economy, Trade, and Industry (METI) is conducting the Japan Hydrogen & Fuel Cell (JHFC) Demonstration Project, Phase II. This aims to gather and share fundamental data on the performance of FCV and Infrastructure with the object of developing the road map for the full-scale mass production and widespread use of FCVs.

**STRATEGIC DEVELOPMENT OF PEFC TECHNOLOGIES FOR PRACTICAL APPLICATION**

**FY2005-FY2009; FY2008 PROJECT BUDGET: 5.57 BILLION YEN**

This project promotes the development of technology for practical applications during the initial introduction stage, the development of elemental technology for the full introduction stage, and the development of next-generation technology for the full dissemination stage in order to comprehensively develop highly efficient, highly reliable, and low cost polymer electrolyte fuel cells (PEFCs).

**DEVELOPMENT OF TECHNOLOGY ON BASIC AND COMMON ISSUES**

NEDO is carrying out research to address basic and common issues, such as clarifying PEFC degradation mechanisms, in order to improve the durability, economic efficiency, and performance of individual unit cells, fuel cell stacks, and entire systems.

**DEVELOPMENT OF ELEMENTAL TECHNOLOGY**

In order to improve the advanced elemental technology required for the practical application of fuel cells for vehicles and to establish elemental technology required for the practical application of stationary fuel cells, NEDO is undertaking the development of high-risk high-return elemental technology for PEFC electrodes, electrolytes (including hydrogen storage materials, including cathode materials, and provision of cell modules to facilitate the development of fuel cell systems.)
membrane-electrode-assemblies), auxiliary equipment, and reformers that markedly improve durability and efficiency, and reduce costs.

**DEVELOPMENT OF TECHNOLOGY FOR PRACTICAL APPLICATION**

To foster a market for stationary fuel cells, NEDO is developing production process technology for PEFC separators and other components, as well as basic material production technologies for commercial mass production.

**DEVELOPMENT OF NEXT-GENERATION TECHNOLOGY**

NEDO is undertaking pioneer and basic research and development for new electrolytes and non-platinum electrocatalysts for highly efficient, highly reliable, and low cost fuel cells for the commercialization of fuel cell vehicles, research and development for high-performance fuel cells that differ significantly from conventional fuel cells, as well as basic research for advanced analysis and evaluation technology that contributes to the research and development of fuel cells.

**STRATEGIC DEVELOPMENT OF PEFC TECHNOLOGIES FOR PRACTICAL APPLICATION/RESEARCH ON NANOMATERIALS FOR HIGH PERFORMANCE FUEL CELLS**

FY2008–FY2014; FY2008 Project Budget: 1.10 billion ¥

This research and development project combines the knowledge of reaction and degradation mechanisms with cutting-edge technologies, especially utilizing brand-new nanotechnology, to study new materials such as catalysts, polymer electrolyte membranes, and membrane electrode assemblies (MEA). The aim of this project is to establish basic technology for advanced fuel cells that can achieve high performance, high durability, and low cost at the same time, thereby contributing to the massive dissemination of polymer electrolyte fuel cells (PEFCs).

**FUEL CELL CUTTING-EDGE SCIENTIFIC RESEARCH PROJECT**


This project promotes development of innovative measurement, and evaluation and analytical techniques for polymer electrolyte fuel cell (PEFC) technologies, such as electrolyte materials, catalysts, and mass transport phenomena. The objective is to understand electrode catalysts, electrolyte materials, mass transport, and reaction mechanisms in depth, and thereby apply it to PEFC development.

**DEVELOPMENT OF HIGHLY DURABLE MEMBRANE LPG REFORMERS**

FY2006–FY2008; FY2008 Project Budget: 80 million ¥

Maintaining a stable energy supply and streamlining the energy distribution system for the residential sector are key issues since energy consumption in this sector is forecast to increase. Because liquefied petroleum gas (LPG) is used in more than one-half of Japanese households, it is necessary to promote the dissemination of fuel cell cogeneration systems that utilize LPG, in order to conserve energy and improve the environment.
To popularize residential fuel cell cogeneration systems that use LPG, this research and development project develops and evaluates simple, compact, low-cost, and highly efficient LPG reformers that utilize hydrogen permeable membranes.

DEVELOPMENT OF SYSTEM AND ELEMENTAL TECHNOLOGY ON SOLID OXIDE FUEL CELLS (SOFC)

FY2008–FY2012; FY2008 Project Budget: 1.35 billion ¥

Solid oxide fuel cells (SOFCs) have higher generating efficiency than other types of fuel cells, and can use various fuels such as natural gas and coal gas. SOFCs are thus widely adaptable, from small-scale distributed power generation systems to large-scale thermal power generation systems, and there are high expectations that they will be put into practical use. The aims of this project are to conduct basic research, to develop elemental technologies, and to establish the fundamental technologies required to accelerate the introduction of SOFC systems to the market.

Basic research will be carried out in order to improve the durability and reliability of SOFCs. First, various subjects such as thermodynamics, chemical structures, and mechanical properties, will be analyzed. Next, degradation mechanisms will be clarified, some measures will be taken and their effects verified, and an accelerated test method will be established. In order to improve the utility of SOFCs, elemental technologies such as inexpensive cell stack/module technology, stop-start technology to improve operability, and high-pressure operation technology to achieve ultra-high efficiency will also be developed.

Figure 1: R&D Activities SOFC
FUNDAMENTAL RESEARCH PROJECT ON ADVANCED HYDROGEN SCIENCE
FY2006–FY2012; FY2008 Project Budget: 1.75 billion ¥

To construct a hydrogen energy society, it is necessary to establish technology that enables the transportation and storage of large volumes of compressed hydrogen. To accomplish this, high-pressure hydrogen or liquid hydrogen handling capabilities will be essential. Unfortunately, there is a dearth of in-depth data and scientific knowledge, both in Japan and abroad, regarding the basic behaviors of hydrogen in relation to its safe use and handling. In particular, scientific knowledge of the embrittlement of metals (caused by their absorption of hydrogen in high-pressure or liquid states), and hydrogen tribology (i.e., phenomena such as friction, abrasion, lubrication, etc., of the contact surfaces of two objects in a hydrogen atmosphere), are essential for the manufacture and use of storage/transportation systems, parts, and other materials.

Against this backdrop, the objective of this project is to determine the basic physical properties of hydrogen in high-pressure or liquid states, to identify the basic mechanisms of hydrogen embrittlement, and to study possible measures, addressing a broad spectrum of areas. In order to facilitate the realization of a hydrogen energy society based on the safe and simple use of hydrogen, this project will provide industries with guidance and information on materials, device engineering, degradation evaluation methods, etc.

ADVANCED RESEARCH ON HYDROGEN STORAGE MATERIALS
FY2007–FY2011; FY2008 Project Budget: 908 million ¥

To supply fuel cell vehicles with hydrogen, storage materials, including alloys, are currently being examined for their potential to transport significant amounts of hydrogen in a safe, simple, efficient, and low cost manner. Currently available materials, however, are deficient and need to be significantly improved before they can be put into practical use.

To address this challenge, this advanced research project will examine a wide range of areas and will focus on identifying the basic principles of hydrogen storage that are required to develop advanced high-performance hydrogen storage materials and material application technologies. Another objective of this project is to establish essential application technologies for material research, such as computational research.

DEVELOPMENT OF TECHNOLOGIES FOR HYDROGEN PRODUCTION, DELIVERY, AND STORAGE SYSTEMS
FY2008–FY2012; FY2008 Project Budget: 1.70 billion ¥

Based on recent developments and the progress of concurrent projects, this project’s goal is to develop low-cost and durable systems and components for hydrogen production, transport, storage, and refueling. The aim of this project is to establish comprehensive practical system technologies for the hydrogen supply infrastructure market, which is expected to be launched and disseminated around 2015. Technology development conducted under this project will be coordinated with demonstration research on hydrogen refueling stations and standardization activities in order to put fuel cells into practice use, expand markets, and ensure international competitiveness.
MULTI-PURPOSE COAL GASIFICATION TECHNOLOGY DEVELOPMENT (EAGLE)

FY1998–FY2009; FY2008 Project Budget: 2.32 billion ¥

With abundant deposits worldwide, coal is an important energy resource that will likely be available for the foreseeable future. Coal, however, generates more CO₂ than any other fossil fuel per calorific value and releases soot, dust, NOx, and SOx when combusted. Coal utilization needs to be made more efficient and cleaner in order to promote its utilization in harmony with the environment. This is why the government, together with the private sector, is promoting overseas cooperation and the development, commercialization, and transfer of clean coal technology.

To reduce the burden on the environment, and in particular the emission of gases that cause climate change, the Multi-purpose Coal Gasification Technology Development project (EAGLE: Coal Energy Application for Gas, Liquid & Electricity) aims to develop the most advanced oxygen-blown, two-stage, entrained-flow gasifier that can efficiently produce synthetic gas (CO+H₂), as well as technology for advanced refining (dust extraction, dehydrogen sulfide, dehalogenation, etc.) of the coal gas produced. This will establish coal gasification technology and gas purification technology to produce gas with a wide range of uses, such as for the production of electric power, chemical materials, hydrogen, and synthetic liquid fuel. Utilization of this type of gasifier could be combined with gas turbines, steam turbines, and fuel cells, thereby achieving highly efficient power generation in which CO₂ emissions would be decreased by up to 30% compared to existing coal-fired thermal power plants. Furthermore, this oxygen-blown gasification process has features that will facilitate the efficient capture and sequestration of CO₂ from coal gas.

ESTABLISHMENT OF CODES & STANDARDS FOR HYDROGEN ECONOMY SOCIETY


In order to broadly and smoothly disseminate hydrogen and fuel cells to the general public, it is essential to develop soft infrastructure as well as new technology. The review and establishment of laws, codes and standards (C&S), and regulations is particularly important for promoting the widespread use of fuel cell vehicles and stationary fuel cell systems and for developing the necessary infrastructure. These efforts must be undertaken with an eye toward global markets and in close cooperation with industry.

This project aims to develop advanced methods to examine and evaluate new technologies and products that are necessary to obtain data in order to establish domestic and international technology standards. Through this effort, NEDO is promoting the establishment of soft infrastructure for building a hydrogen economy society.

The Multi-purpose Coal Gasification Technology Development project (EAGLE: Coal Energy Application for Gas, Liquid & Electricity) aims to develop the most advanced oxygen-blown, two-stage, entrained-flow gasifier that can efficiently produce synthetic gas (CO+H₂), as well as technology for advanced refining (dust extraction, dehydrogen sulfide, dehalogenation, etc.) of the coal gas produced.
DEVELOPMENT OF STANDARDS FOR ADVANCED APPLICATION OF FUEL CELLS

FY2006–FY2010; FY2008 Project Budget: 250 million ¥

Today’s mobile communications society presents promising applications of fuel cells, such as cordless consumer electronic devices, backup power supplies, and power supplies for mobile use. In order to expand fuel cell applications, the technical development of new concepts of fuel cells is being conducted.

This project intends to obtain the basic data necessary for setting safety and environmental standards and for relaxing unnecessary regulations in view of performance improvements (e.g., higher output power and other features), in line with new usage and the associated environmental conditions of use. In addition, applicable test methods will be developed and the technical development of new concepts of fuel cells will be carried out in compliance with the specifications and standards to be established.

DEMONSTRATION OF RESIDENTIAL PEFC SYSTEMS FOR MARKET CREATION

FY2005–FY2008; FY2008 Project Budget: 2.71 billion ¥

In order to facilitate the dissemination of residential polymer electrolyte fuel cell (PEFC) systems, a large-scale and broad-based experimental study of 1 kW stationary PEFC systems is being conducted under this project. The aim is to advance the practical application of fuel cells by identifying issues for future technological development from actual data obtained through this real life and practical use of stationary fuel cells in ordinary households.

DEMONSTRATIVE RESEARCH ON SOLID OXIDE FUEL CELLS (SOFC)

FY2007–FY2010; FY2008 Project Budget: 800 million ¥

As mentioned above in the outline for the Development of System and Elemental Technology on Solid Oxide Fuel Cells (SOFC) project, the potential for SOFCs is highly promising. However, a lack of evaluation data, including data on durability, means there are still a number of unknowns.

In response, this research will be focused on the collection and analysis of evaluation data under actual power loads. The objective is to identify technological development issues and to reflect these results in SOFC system development in order to facilitate practical application.

JAPAN HYDROGEN & FUEL CELL (JHFC) DEMONSTRATION PROJECT, PHASE II

FY2006–FY2010; FY2008 Project Budget: 1.30 billion ¥

The JHFC Demonstration Project, Phase II consists of road test demonstrations of FCVs, HICE (Hydrogen internal combustion engines), small mobility vehicles, and the operation of hydrogen refueling stations. The project aims at clarifying a technical subject while it carries out collection analysis of data about environmental characteristics, synthesis energy efficiency, fuel quality and safety, etc. under actual operating conditions. This project includes:
• Fleet test runs, such as FCVs by the third person
• A new entry in the Demonstration of Hydrogen internal combustion engine vehicles
• An escalation of the Demonstration area (Metropolitan area, Chubu area and Kansai area)
• Two hydrogen stations completed in Kansai Area.
• Kansai Airport Hydrogen Station started its operation in May 2007. Osaka Hydrogen Station started in August 2007.
• Monitor examination of small mobility vehicles (FC-wheel chair, FC-Cart, FC-assistance bicycle) and establishment of a hydrogen refueling station
• 4 existing hydrogen stations (Senju, Yokohama Asahi, Yokohama Daikoku and Funabashi) were modified so that they might be able to supply 70MPa compressed hydrogen. All modifications completed and 70MPa refueling started by the end of January 2009.

REFERENCES
New Energy and Industrial Technology Development Organization (NEDO)
www.nedo.go.jp/english/index.html
UPDATE ON ENERGY FRAMEWORK

In 2008, Korea proclaimed "low carbon green growth" as a new development objective and announced 22 industries as new growth engines. Korea's green growth strategy has three pillars: creating new growth engines, minimizing energy/resources consumption, and reducing CO₂ and other emissions.

The hydrogen and fuel cell power-generation system as a growth engine received much more public attention. The government and private sector prepared a long-term plan to focus on the market growth by expanding incentives, R&D, and manufacturing facilities.

PROGRAM OVERVIEW AND R&D ACTIVITIES

NATIONAL RD&D ORGANIZATION FOR HYDROGEN AND FUEL CELL

The two main Korean government agencies involved in both hydrogen and fuel cells are the Ministry of Education, Science, and Technology (MEST), and the Ministry of Knowledge Economy (MKE). Between them, the Korean government formed the National R&D&D Organization for Hydrogen and Fuel Cells (http://www.h2fc.or.kr) in 2004 to promote overall R&D, validation, demonstration, and commercialization of hydrogen and fuel cell technologies. Under the 21st Century Frontier Program, MEST launched the Hydrogen Energy R&D Center (http://www.h2.re.kr), which focuses on facilitating the development of hydrogen production and storage technologies. By 2007, MKE and the major Korean companies together (50:50 ratio) invested US$250 million for R&D and validation and demonstration of hydrogen refueling stations and fuel cells (stationary, transportation, portable devices, etc.). In 2008, 14 new projects (US$100 million) were started. MEST contributed US$10 million for R&D of hydrogen production and storage in the same year. Table 1 lists the titles of the on-going hydrogen and fuel cell projects in 2008.

MONITORING AND DISSEMINATION PROJECT FOR FC VEHICLES

Since 2004, MKE has launched 56 aggressive R&D and monitoring projects to accelerate the commercialization of FC vehicles. These R&D projects are involved in making a breakthrough for proton exchange membrane fuel cell (PEMFC) technology, and the monitoring projects are planned to validate and demonstrate the overall feasibility of PEMFC vehicles along with hydrogen refueling stations before full-scale dissemination begins. Two R&D projects are the 80 kW PEMFC Vehicle Program, with US$33.4M budgeted from 2004 to 2009, and the 200 kW PEMFC Bus Program, with US$49M budgeted from 2005 to 2010.
Hyundai-Kia Motors has been cooperating with MKE as the main contractor for the projects, contributing half of the project budget. Hyundai-Kia Motors would disseminate 200 FC buses and 3,000 FC cars by 2015. This project aims to reduce the cost of the PEMFC system from the current US$10,000/kW to US$100/kW by 2015, which would reduce the overall price of FC vehicles. This project also has targets of increasing the durability of PEMFC system from the current 750 hours to 5,000 hours (10 years of operation), and increasing the driving distance from the current 200 km to 500 km by 2015.

Table 1: Hydrogen and Fuel Cell Project List in 2008

<table>
<thead>
<tr>
<th>Related Party</th>
<th>Field</th>
<th>Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>MKE and Private Sector</td>
<td>Hydrogen Station</td>
<td>7 Hydrogen station using LNG, LPG, Naphtha, (SK, GS-Caltex, KOGAS, and etc.) 2004–2009</td>
</tr>
<tr>
<td>Monitoring</td>
<td>Monitoring and Dissemination for RPG (210 kW RPG by 2010, GS Fuel Cell, FCP)</td>
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<tr>
<td>Monitoring and Dissemination for transportation (30 cars and 4 buses by 2010: Hyundai-Kia)</td>
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<td></td>
</tr>
<tr>
<td>Transportation</td>
<td>80 kW Passenger car system development (Hyundai-Kia)</td>
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<tr>
<td>Development of core components, such as Membrane Electrode Assembly (MEA), Metal Bipolar Plate, and etc. (Hyundai-Kia)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RPG</td>
<td>Validation for 1 kW PEMFC (GS Fuel Cell, FCP)</td>
<td></td>
</tr>
<tr>
<td>Development for SOFC (1–3 kW, KEPCO, KIER)</td>
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<tr>
<td>Power Generation</td>
<td>250 kW internal reforming MCFC (KEPCO, POSCO)</td>
<td></td>
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<tr>
<td>300 kW external reforming MCFC (DOOSAN)</td>
<td></td>
<td></td>
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<tr>
<td>Portable</td>
<td>Portable 50W PEMFC (Samsung SDI), Robot 1 kW PEMFC (KIST)</td>
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<tr>
<td>Portable 50W DMFC (LG Chem)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Portable 1 kW DMFC (KIST) Robot</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MEST (Hydrogen Energy R&amp;D Center)</td>
<td>Hydrogen Production</td>
<td>Compact NG steam reforming system for H₂ refueling station</td>
</tr>
<tr>
<td>Scale-up and optimization of fermentative H₂ Production and process development of Bio-mimetic H₂ production system</td>
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<td></td>
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<tr>
<td>Photochemical Hydrogen Production by Using New Photocatalysts with the Visible Light Sensitivity</td>
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<tr>
<td>Development of Water splitting system by Visible Light Sensitized Photocatalyst</td>
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<tr>
<td>Hydrogen production using PEC cell</td>
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<td></td>
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<tr>
<td>Development of tandem – type photoelectrochemical cell module for water splitting, using solar light</td>
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<td></td>
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<tr>
<td>Hydrogen Production by Thermochemical Water Splitting</td>
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<td></td>
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<tr>
<td>Development of high efficiency hydrogen production technology by water electrolysis</td>
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<tr>
<td>Development of metal hydride hydrogen storage materials and small scale storage systems for a fuel cell vehicle</td>
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<tr>
<td>Development of Mg based hydrogen storage material and application system</td>
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<td></td>
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<tr>
<td>Development of Hydrogen Storage Technologies by Carbonaceous Materials</td>
<td></td>
<td></td>
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<tr>
<td>Development of hydrogen storage in the porous nanostructured materials</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Hydrogen and Fuel Cell Project List in 2008
MKE launched two aggressive monitoring projects to validate and demonstrate FC performance before full-scale dissemination begins (Table 2). The FC Vehicle Monitoring Project is expected to promote the hydrogen infrastructure by validating and demonstrating both FC vehicles and hydrogen refueling stations simultaneously. As of 2008, the FC Vehicle Monitoring Program covers the operation of 30 FC cars, 4 FC buses, and 7 hydrogen refueling stations, with US$48 M budgeted from 2006 to 2008.

MKE planned to construct hydrogen refueling stations (30 Nm3/hr) nationwide with different usage of fuels. The Station in Seoul (GS-Caltex) provides hydrogen fuel made from naphtha. The national LNG wholesale monopoly KOGAS participates in an FC vehicle monitoring project by establishing a new type of LNG hydrogen refueling station in Inchon. SK built the station using hydrogen produced from LPG in Daejon. In 2007, MKE opened two more hydrogen refueling stations on Cheju Island, which produce hydrogen by water electrolysis using wind power. MKE will open two hydrogen refueling stations in the southern province, which may provide hydrogen by truck-in methods, which would then deliver the by-produced hydrogen from a nearby petrochemical refinery complex.

### Table 1: Hydrogen and Fuel Cell Project List in 2008 (Continued)

<table>
<thead>
<tr>
<th>Classification</th>
<th>Validation</th>
<th>Demonstration</th>
<th>Dissemination</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Phase I (07-09)</td>
<td>Phase II (10-12)</td>
<td>Phase I (13-15)</td>
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<tr>
<td>Passenger Car (80kW)</td>
<td>number</td>
<td>30</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td>avg. price</td>
<td>$0.41M</td>
<td>$0.23M</td>
</tr>
<tr>
<td>Bus (200kW)</td>
<td>number</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>avg. price</td>
<td>$1.56M</td>
<td>$1.23M</td>
</tr>
<tr>
<td>Hydrogen Fueling Stations</td>
<td>number</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>avg. price</td>
<td>$2.3M</td>
<td>$2.3M</td>
</tr>
</tbody>
</table>

Table 2: Monitoring and Dissemination Target for FC Vehicles
RESIDENTIAL FC POWER GENERATION (1-3 KW)

MKE is planning to commercialize both PEMFC and solid oxide fuel cell (SOFC) technologies for residential power generation (RPG). Currently, two Korean companies, GS Fuel Cell and FCP, have domestically developed their respective PEMFC systems for RPG. These companies, which are the main contractors of the government program, are leading R&D and validation projects to decide on a commercial model suited to the Korean lifestyle, to solve the inherent problems in reforming the current city gas grid connection, and to overcome technological and economic barriers for RPG. Since 2006, KOGAS has participated in the RPG monitoring project along with GS Fuel Cell and FCP, and 10 city gas companies. Since 2006, MKE has planned to purchase RPG units from manufacturers at the target price. However, the current price (US$100,000/kW) is much more expensive than our ultimate target price (US$10,000/kW). MKE has a plan to promote dissemination by purchasing the RPG units with a government subsidy and to reduce the target price year by year until the ultimate target price is achieved. In total, 38 RPGs were newly installed in 2008 and 170 RPGs will be disseminated by 2010.

Korea Electric Power Corp (KEPCO) developed 1kW SOFC for RPG and works for the development of 5kW SOFC for cogeneration plant. Korea Institute of Energy Research (KIER) is developing 3kW SOFC for auxiliary power system.

FUEL CELL FOR INDUSTRIAL POWER GENERATION

MKE is planning to demonstrate the MCFC-based distributed power generator for industrial power generation. Target for MCFC is to develop 40,000hr durability, 80% efficiency, and US$1,500/kW by 2012. KEPCO and the steel giant POSCO plans to develop a 250 kW external reforming MCFC system from 2005 to 2009, with a budget of US$43.7 million. Doosan Heavy Industry is developing 300kW internal reforming MCFC (2007–2010). Ultimately, it will develop, demonstrate, and disseminate the MW class MCFC system after 2010.

Meanwhile, the Korean government is searching for international partnerships with foreign companies and the PoscoPower installed three 250 kW MCFC systems made by
The government has implemented a Feed in Tariff system, or FIT system, since 2006. FIT is an incentive program supporting the margin between the standard price of fuel cells and the average price in the electricity market, as the electricity price of conventional power plants are cheaper than that of fuel-cell energy. This program started to secure a certain profit at the beginning of the unstable new and renewable energy business.

Fuel Cell Energy (FCE). These 250 kW MCFC systems would be operated to supply power for steel mills and sewage treatment facilities, using the coke oven gas from steel mills and the biogas from sewage as fuel feedstock.

In the private sector, POSCO has injected US$11.5 M to develop technology and establish product lines. In 2007, POSCO started a 5-year project to develop 180 kW SOFC systems with the aim of establishing the world’s first company to commercialize the next generation fuel cell power system. So far, POSCO has developed a 5 kW stack and completed the basic design on a 50 kW stack system. The accomplishment of this SOFC project would be recorded as a significant milestone in the Korean energy industry because it means localization of the most advanced power generation. In 2008, POSCO completed construction of the world’s largest fuel cell power generation facility with a capacity of 50 MW MCFC BOP (Balance of Plant) at Pohang. This plant generates 50 MW through MCFC—enough electricity for 17,000 households. An additional 50 MW MCFC BOP plant will be constructed near the already completed plant by 2011.

**FEED IN TARIFF SYSTEM**

The government has implemented a Feed in Tariff system, or FIT system, since 2006. FIT is an incentive program supporting the margin between the standard price of fuel cells and the average price in the electricity market, as the electricity price of conventional power plants are cheaper than that of fuel-cell energy. This program started to secure a certain profit at the beginning of the unstable new and renewable energy business.

According to FIT, the standard price of fuel cells using LNG is preserved up to US$ 0.217/kWhr ($1=1,300 won) at present. The supporting program has limitations of up to 50 MW of the accumulative installation capacity. However, the market size is growing faster than expected and the 50 MW ceiling is likely to be reached within one or two years.

**HYDROGEN AND FUEL CELL INFRASTRUCTURE IN SEOUL**

**MW PEMFC Power Plant in Seoul:** Seoul plans to construct the world’s largest hydrogen fuel-cell power plant at collective energy project sites in Mok-dong (2.4 MW) and Nowon (2.8 MW). Two PEMFC power plants will be built by March 2010 with US$ 23 M. In addition, construction of 10 MW PEMFC Power Plant at Magok area is also planned.

**Energy Zero House:** Seoul plans to build an “Energy Zero House” as a recyclable energy landmark. It will set an example of saving energy and maximize the use of recyclable energy. A hydrogen refueling station (US$4 M) will be built by the end of 2009 through the direct production of hydrogen from landfill gas at World Cup Park. The Fuel Cell Shuttle Bus will be operated after the station’s completion.

**21ST CENTURY FRONTIER HYDROGEN R&D PROGRAM**

The Hydrogen Energy R&D Center (HERC) supports projects in hydrogen production, storage, and utilization technologies with a total budget of about US$10.0 M. Four important accomplishments in hydrogen storage and utilization are reported here.
DISPERSION OF ALKALINE EARTH METALS AND HYDROGEN ADSORPTION IN 3D POROUS MATERIALS (JHISH@POSTECH.AC.KR)

The interaction of hydrogen molecules with metal atoms is a key physicochemical process involved in many energy related technologies such as fuel cell catalysts and hydrogen storage. Defective 3D porous graphitic materials dispersed with alkaline earth metals using quantum mechanical simulations were designed. Ca atoms bind to the sp3-bonded CBG vertex sites more stably than other planar graphene sites. As Ca atoms are ionized upon binding to CBG, the strength of H₂ adsorption to Ca is increased to about 0.2 eV/H₂.

A FACILE WAY TO CONTROL THE NUMBER OF WALLS IN NANOTUBES FOR HYDROGEN STORAGE THROUGH THE SYNTHESIS OF EXPOSED-CORE/ SHELL CATALYST NANOPARTICLES (JEUNGKU@KAIST.AC.KR)

The number of walls in multi-walled nanotubes with a controlled wall distance is crucial to increase the energy storage capacity for hydrogen and lithium. A new method was developed to control the diameter and the number of walls in the prototype multi-walled nanotubes using carbon nanotubes with an Exposed Core Shell (ECS) catalyst. ECS might be also used as the template to grow other nanotubes, including organic nanotubes and inorganic nanotubes with the interlayer distance required for hydrogen storage. The most exciting application is for hydrogen storage, where ECS use can optimize both the diameter and the number of walls in nanotubes. Later, it can be used to control their interlayer distance as well.

DEVELOPMENT OF REGENERATION PROCESS FOR NABH₄ HYDROGEN STORAGE

The reaction between NaBO₂, aluminum and hydrogen is taking place at the solid-solid interface between NaBO₂ and aluminum, and it is important to increase the interfacial area to get reasonable conversion of the reactants. By applying fine particles (3.5μm) of aluminum, it was possible to obtain a reasonable NaBO₂ conversion of 42%. It was not possible to produce NaBH₄ using aluminum of 30μm particle size. Further improvement of the conversion up to 76% was achieved by chemical treatment of the reactants. An addition of the small amount of Mg to the Al enhanced the NaBO₂ conversion up to 82%.
PD-PT ALLOY AS A CATALYST IN GASOCHROMIC THIN FILMS FOR HYDROGEN SENSORS (HCHEONG@SOGANG.AC.KR)

The gasochromic material used in the hydrogen sensor was mainly Pd/WO3 or Pd/V2O5. However, the tendency for the gasochromic film to lose its sensitivity to hydrogen over time—which was the major problem in this type of sensor—was resolved by using an alloy of Pd and Pt as the catalyst layer material in an optical hydrogen sensor film. Both the sensitivity and the durability of the sensor film when exposed repeatedly to diluted hydrogen gas show dramatic improvement over the case of a Pd single component catalyst. The sensor film also exhibited excellent selectivity to other hydrocarbon vapors and gases.

Figure 6: Comparison of the sensitivity to 1% hydrogen for (left) Pd/WO3 and (right) Pd-Pt/WO3.

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3] HTTP://www.h2.re.kr
4] HTTP://www.hydrogen.or.kr

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Yongsug Tak, Inha University (www.inha.ac.kr)
Kee-Suk Nahm, Chonbuk National University (www.chonbuk.ac.kr)
Jong-Won Kim, HERAC (www.h2.re.kr)
Seong-Ahn Hong, H2FC (www.h2fc.or.kr)
Seung-Young Chung (www.kemco.or.kr)
LITHUANIA

Dr. Rolandas Urbonas
Lithuanian Energy Institute

INTRODUCTION

Lithuania inherited a highly developed power infrastructure from the former Soviet Union, including natural gas and oil supply systems. The capacities of these systems significantly exceed even today’s needs. But the country depends heavily (90%) on primary energy imports from Russia. The primary energy structure is indicated in Figure 1, and primary energy consumption is shown in Figure 2. Three major energy sources—nuclear, natural gas and oil—contribute almost equal parts to the country’s energy. More than 70% of the country’s electricity is generated in a nuclear power plant (capacity 1350 MW), which is scheduled to be closed before 2010.

VITAL STATISTICS

EU member state
Population 3.36 million
Territory 65,300 km²
Capital Vilnius
GDP/capita 33193 LTL (€9600) (2008)
Average Annual GDP Growth 7–8% during recent years
Average Annual GDP around 3%; an 18% GDP decrease is forecast for 2009
OVERVIEW OF LITHUANIA’S ENERGY FRAMEWORK

On January 18, 2007, the Parliament announced Lithuania’s new national energy strategy. The main objectives are the security of the energy supply, diversification of primary energy suppliers, sustainable development, anticipated utilization of nuclear and local energy resources, competition in all liberalized markets, and cooperation and coordination of energy policies of three Baltic countries.

Some of the major goals include the construction of a 400 MW Combined Cycle Gas Turbine (CCGT) unit at an existing thermal plant before 2012; the commissioning of a new nuclear power plant no later than 2018–2020, construction of power networks interconnecting Lithuania and Poland (capacity approximately 1000 MW) and Lithuania and Sweden (capacity approximately 700 MW) before 2015; bringing the share of electricity produced in modern CHP plants to 35% by 2025; and bringing the share of biofuels in transport sector to 15% by 2025. The nuclear power plant will be owned by three Baltic countries and Poland.

Research priorities are clearly presented in the strategy. Among them are hydrogen energy, nuclear safety, participation in international programmes on fusion research, and renewable energy technologies.

HYDROGEN R, D&D SPECIFICS – PROGRAMS, PROJECTS, INITIATIVES

R&D ACTIVITIES: IEA TASK 22 “FUNDAMENTAL AND APPLIED HYDROGEN STORAGE MATERIALS DEVELOPMENT”.

H-19 project title: Development of Nanocrystalline Metal Hydrides using Vapour Deposition Technologies

Project Leader: Darius Milčius (Laboratory of Materials Testing and Research, Lithuanian Energy Institute)

International Collaborations:
Stockholm University (Prof. Dag Noreus); Institute for Energy (JRC), (Dr. Constantina Filiou)

Project plans and experimental results

A developed magnetron sputtering technique, which can rapidly grow and control the relevant Mg-Ni, Mg-TM mixture films to high accuracy, will be used for thin film synthesis. Hydrogenation of thin films will be realized at high pressure after deposition and during growth using reactive deposition in hydrogen plasma, enabling the injection of hydrogen ions, thus simulating high pressure, and directly forming hydride films on different substrates.

Experimental results: During the last year, the Lithuanian Energy Institute investigated whether the stability of thin film samples of Mg,NiH₃ could be modified by introducing defects and impurities. Moreover, we wanted to see if it could be used in a switchable mirror or window device by utilizing the high-to-low temperature transition at about 510 K. The new thin film Mg,NiH₃ samples were produced by reacting hydrogen with magnetron sputtered Mg,Ni films on quartz glass or CaF₂ substrates. However, we could
not obtain the monoclinic low temperature phase upon cooling the samples. Instead, a cubic phase, related but not identical to the cubic high temperature phase, was formed at temperatures both below and above 510 K. TEM pictures revealed the new cubic phase in the films to have the same cell parameter as the FCC high temperature phase, but the symmetry was lower with similar streaking patterns as observed for the monoclinic low temperature phase. IR-spectroscopy indicated an identical vibration frequency for the allowed stretching mode of the tetrahedral NiH4-complex both in film and powder samples. Band gap measurements indicated a band gap of 2.3 eV for the films, but 1.1 eV for monoclinic Mg2NiH4 powders. A typical first order phase transition from a low-to-high temperature phase could not be observed with DSC when heating through the low-to-high temperature phase transition at 510 K. Unfortunately, there were no significant hydrogen releases up to the temperatures of 600 K.

R&D ACTIVITIES: PARTICIPATION IN EU FP6

The European Research Training Network (RTN) “Hydrogen Storage Research Training Network” (HyTRAIN)

HyTRAIN is a Marie Curie Research Training Network, funded under the EC’s 6th Framework Human Resources and Mobility Programme. The network is comprised of eighteen of the leading European research centres, with the primary objective to train researchers in the area of hydrogen storage in solid media.

Our student, Emmanuel Wirth, successfully defended his PhD thesis, “Study of Dynamic Surface Barrier Effects on Hydrogen Storage Properties of Mg-Ni-Based Films.” The work is related to hydrogen storage areas. The Mg-Ni based films are deposited by the magnetron sputter deposition technique and then hydrogenated under different conditions. The study emphasizes the surface effects, which are essential for the understanding of complex hydrogen sorption phenomenon. In the presence of small quantities of oxygen impurities, a barrier is formed, which influences the hydrogen storage properties. In the present work, the barrier is considered dynamic with variable hydrogen permeation properties during hydrogenation.

The hydrogen absorption and desorption properties are studied employing ion beam techniques (NRA, ERDA, RBS) for the analysis of hydrogen and oxygen distribution profiles, the thermal desorption spectroscopy (TDS) for the kinetics of hydrogen release, as well as XRD structural and SEM surface topography analysis. It is shown that there are correlations between surface morphology and hydrogen storage capacity. The simultaneous growth of the oxide layer on the surface and the hydride phase in the bulk defines hydrogen uptake rate. To find out more about the role of additives, a limited amount of Ti (less than 15 at atomic weight %) is added in the bulk of growing Mg-Ni film. Ti modifies some sorption characteristics but thermodynamic properties are not improved.

An attempt was made to model experimental results. The model was based on the solutions of a diffusion equation with variable concentration of hydrogen on the surface. The qualitative agreement was obtained assuming that the hydrogen concentration on the surface changes in time.

The results showed that in the studies of the hydrogen storage properties of materials, the surface dynamic properties have to be considered for many practical applications.
The work was done in close collaboration with the Lithuanian Energy Institute, Centre for Hydrogen Energy Technologies and European Commission DG Joint Research Centre - Institute for Energy research groups on hydrogen storage.

**Specific Support Action project HySIC (Enhancing International Cooperation in running FP6 Hydrogen Solid Storage Activities)**

The objectives of the HySIC project were mainly related to sample preparation and exchange among HySIC partners for round-robin testing that involves structural, thermodynamic and kinetic characterization using various methods, including microgravimetric techniques, electrochemical measurements and neutron scattering.

During the HySIC project, the Lithuanian Energy Institute, in close collaboration with Stockholm University (Prof. D. Noreus) and NESSHY partner JRC Institute for Energy (Dr. C. Filiou), investigated whether the stability of thin film samples of Mg$_2$NiH$_4$ could be modified by introducing defects and impurities. Moreover, we wanted to see if it could be used in a switchable mirror or window device by utilizing the high to low temperature transition at about 510 K.

**Partners:** National Centre for Scientific Research Demokritos (Greece), University of Salford (UK), Stockholms Universitet (Sweden), Institutt for Energiteknikk (Norway), General Research Institute For Nonferrous Metals (P. R. China), Institute of Solid State Physics of the Russian Academy of Sciences (Russian Federation), Institute of New Energy Material Chemistry of Nankai University (P. R. China), and Lithuania Energy Institute (Lithuania).

**R&D Activities in Nordic Energy Research Programme: Nordic Center of Excellence on Hydrogen Storage Materials.**

The main objective is to identify a material that can be used for reversible storage of hydrogen in vehicles powered by hydrogen fuel cells so that target specifications defined by the automotive industry are met, in particular:

- 6% hydrogen by weight;
- release temperature of 1 bar hydrogen at around 100°C;
- and fast loading and unloading.

While we focus on the well-defined requirements of the automobile industry, other portable applications of hydrogen as fuel, ranging from portable electronics to vessels, would benefit as well from the identification of new, hydrogen-rich materials as well as better understanding of the ways in which the properties of hydrogen storage materials can be improved.

**Partners:** Science Institute of University of Iceland, (Reykjavik, Iceland); Institute for Energy Technology, (Kjeller, Norway); University of Oslo, (Oslo, Norway); Stockholm University, (Stockholm, Sweden); Uppsala University, (Uppsala, Sweden); The Technical University of Denmark, (Lyngby, Denmark); Riso National Laboratory, (Roskilde, Denmark); Helsinki University of Technology, (Espoo, Finland); Lithuanian Energy Institute, (Kaunas, Lithuania); Saint-Petersburg State University, (Saint-Petersburg, Russia).
Education and Training Activities

Lithuanian Energy Institute and Vytautas Magnus University continue projects related to the preparation of courses and training specialists in the field of hydrogen technologies in 2005–2008. The project was implemented and funded by the European Social Fund and the funds of the Republic of Lithuania, according to the Single Programming Document of Lithuania for 2004–2006, the second priority “Development of human resources,” measure 2.5, “Improvement of human resources quality in the field of science research and innovations,” as well as through the funds of the Lithuanian Energy Institute and Vytautas Magnus University. As a part of the project activities, the graduate level Masters Program on “Energy and Environment” was prepared and approved by the Centre for Quality Assessment in Higher Education (CQAHE) in Lithuania. The Program “Energy and Environment” provides multi-disciplinary knowledge, and encompasses courses in electrochemistry, alternative energy courses, biofuel, hydrogen energy, anthropological changes of environment, etc. They emphasize renewable energy sources such as solar power, wind power, geothermal power, tides, and hydroelectric power, including atomic power station and thermonuclear synthesis reactions (fusion energy).

Apart from the preparation of skillful personnel for the Centre for Hydrogen Energy Technologies, the “Organisation of Hydrogen Energy Technologies Training” became a fundamental foundation for application for the EU Structural Funds. The application was successful and after receiving the support, a new department, the Centre for Hydrogen Energy Technologies, was established at the Lithuanian Energy Institute. The Centre was established in a completely renovated laboratory area, totalling 800 square meters. Moreover, laboratory facilities were equipped with new world class equipment for material synthesis and analysis.

Lithuanian Hydrogen and Fuel Cell Technology Platform

On June 12, 2006, twelve partners signed a contract on joint activities (partnership) and established the Lithuanian Hydrogen and Fuel Cell Technology Platform, which is supposed to become the general instrument of the development of hydrogen economy on a national level.

The main activities of the Lithuanian Hydrogen and Fuel Cell Technology Platform are:

1. The participation in different research and technological development projects, which are financed by national funds, European Union funds, and third countries’ funds, as well as the creation of the European poles of competence for the development of the hydrogen and fuel cell technologies.

2. The disseminations of the needs and achievements of the modernization of Lithuanian hydrogen and fuel cell technologies at the national, European Union, and international levels.

3. The implementation of the projects of larger added value in the sector of hydrogen and fuel cell technologies using technological and management innovations.

4. Training the engineers and staff with high quality knowledge in hydrogen and fuel cells technologies.
The Lithuanian Hydrogen and Fuel Cell Technology Platform was established by twelve partners, representing the stakeholders of industry and research institutions. They are:

1] Hydrogen Energy Association
2] Lithuanian Energy Institute
3] Kaunas University of Technology
4] Vytautas Magnus University
5] Vilnius University
6] Achema Hidrostotys, LLC
7] Norta, LLC
8] Energenas, LLC
9] Sklypo Energija, LLC
10] Acetilenas (Personal Enterprise)
11] Perspektyvinių technologijų taikomųjų tyrimų institutas (Public Establishment)
12] Veroloda, LLC

REFERENCES

Lithuanian Hydrogen and Fuel Cell Technology Platform:
www.h2lt.org
Centre for Hydrogen Energy Technologies:
www.hydrogen.lt

CONTACTS

IEA HIA ExCo Member:
Dr. Rolandas Urbonas
Lithuanian Energy Institute
Breslaujos 3, 44403 Kaunas
Lithuania
Tel. 370 (37) 40 18 32
Fax: 370 (37) 35 12 71
Email: rolandas@mail.lei.lt

IEA HIA Task 22 expert:
Dr. Darius Milčius
Head of Centre for Hydrogen Energy Technologies
Lithuanian Energy Institute
Breslaujos 3, 44403 Kaunas
Lithuania
Tel. 370 (37) 40 19 09
Fax: 370 (37) 35 12 71
Email: milcius@mail.lei.lt
THE NETHERLANDS

Mr. Frank Denys
SenterNovem
Energy Research Programme

MEMBER’S ENERGY FRAMEWORK

RELEVANT POLICIES
In 2008 the policy concerning energy research was focused on the transition to a sustainable energy system. A major step was realized with the publication of the Energy Innovation Agenda in June 2008. This agenda will lead the development of new policy measures and subsidized programs. The Energy Innovation Agenda was written in strong interaction with representatives of industry, government and knowledge institutes. The programs will focus on implementation and development. The budget of the program will be around 438 M € (2008-2012).

HYDROGEN R,D&D SPECIFICS

The budget for Hydrogen and Fuel Cells in the framework of the new Energy Innovation Agenda has not yet been decided. Besides the Energy Innovation Agenda the current Energy Research Strategy programme (EOS) will continue (see the 2007 report for details). Several EOS sub programmes will continue in 2009, when they will be evaluated and updated. This year. This will result in a new set of R&D focus points and targets.

The ACTS (Advanced Chemical Technologies for Sustainability) program, in which hydrogen plays an important role, is nearing its final term. The NWO will set up a process to identify new developments and topics for future research.

The working group on Hydrogen (Platform New Gas: EnergyTransition) gave its final guidance on the development of hydrogen and fuel cell introduction in the Netherlands. The working group concluded that it was essential to establish a foundation that will push hydrogen and fuel cell introduction forward. The foundation will be comprised of active industry, cities and provinces. It will also be closely linked to the EU initiative, JTI FCH. In 2009, “DutchHY” will be launched.

VITAL STATISTICS

EU founding member state
Population 6.5 million
Territory 41,526 km²
Capital Amsterdam
National Income 500 meld € (2007)
Recent Average GDP Growth 5%
Primary Energy Structure

Production
2843 PJ (2008, natural gas and oil)
Imports
8979 PJ (2008)
Exports
7598 PJ (2008)
Demand/Consumption
3330 PJ (2008)

Electricity

Production
233 PJ
Imports
90 PJ
Exports
33 PJ
Consumption
307 PJ

Figure 1: A Dutch hydrogen-powered boat in 2006
The Israel Export & International Cooperation Institute
HYDROGEN IMPLEMENTING AGREEMENT

REFERENCES

<table>
<thead>
<tr>
<th>Ministry of Economic Affairs</th>
<th>Responsible for Energy policy in The Netherlands</th>
<th><a href="http://www.ez.nl">www.ez.nl</a></th>
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<td>Agency of Ministry of Economics Affairs</td>
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<td>EOS</td>
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<td><a href="http://www.senternovem.nl/">www.senternovem.nl/</a> eos</td>
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<td>Energy transition</td>
<td>Website of the platform New Gas</td>
<td><a href="http://www.energietransitie.nl">www.energietransitie.nl</a></td>
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<td>ECN</td>
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<td><a href="http://www.ecn.nl">www.ecn.nl</a></td>
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<tr>
<td>CBS</td>
<td>Central Bureau for Statistics</td>
<td><a href="http://www.cbs.nl">www.cbs.nl</a></td>
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<tr>
<td>NWV</td>
<td>Dutch Hydrogen Association</td>
<td><a href="http://www.waterstofvereniging.nl">www.waterstofvereniging.nl</a></td>
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<td>ACTS NWO</td>
<td>ACTS Sustainable Hydrogen program</td>
<td><a href="http://www.nwo.nl">www.nwo.nl</a></td>
</tr>
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</table>

CONTACT

Mr. F.J.R. Denys (Frank)
SenterNovem (agency of Ministry of Economic Affairs)
Energy Research Program, Hydrogen and Fuel Cells
f.denys@senternovem.nl
0031 70 373 5928
0031 6 46 42 40 56 (cell phone)
NEW ZEALAND

Dr. Steven Pearce
Solid Energy New Zealand

OVERVIEW

New Zealand joined the IEA HIA in mid-2005. The New Zealand Council for Sustainable Business Development (NZBCSD) is the contracting agent on behalf of the New Zealand government. The NZBCSD co-ordinates several members who, along with the Ministry for Economic Development (MED) support New Zealand's involvement in the IEA HIA. Participating members are: BP Oil New Zealand Ltd, Honda New Zealand Ltd, Landcare Research Ltd, Solid Energy New Zealand Ltd and Toyota New Zealand Ltd. In 2008, the New Zealand government released a New Zealand Energy Strategy that set a target of 50% reduction in transport related emissions by 2040 and sees hydrogen as a potential contributor in the long term towards meeting that target.

Eleven projects related to hydrogen production, storage, demonstration, and education are underway or recently completed. Projects are funded by government and private expenditure and the majority of the research is being conducted by Industrial Research Limited (IRL) and CRL Energy Limited (CRL Energy). The major government funding agency is the Foundation for Research Science and Technology which has committed in aggregate about NZ$8 million over a six year period to various projects.

HYDROGEN PRODUCTION

Six of the eleven projects relate to hydrogen production. The largest is the Hydrogen and Clean Energy project being jointly carried out by IRL and CRL Energy. This programme is a successor to the recently concluded Hydrogen Energy for the Future of New Zealand programme that produced economically viable high-quality hydrogen from New Zealand's abundant reserves of low-rank coal and converted it to electricity using a hydrogen fuel cell. The programme also generated hydrogen from distributed renewable energy sources via electrolysis, with particular emphasis on wind-based generation. The new programme is focused on the oxygen-blown fluidized bed co-gasification of low-rank coal/biomass for co-production of synthetic fuels and hydrogen and integration of the electrolyser as a potential source of oxygen.

Figure 1: The low-rank coal gasifier and hydrogen production line.
Other hydrogen production projects completed are related to small-scale steam reformation of bio-methanol and bioethanol, and the use of a biomass-based iron oxide reduction and steam oxidation cycle. A new Nanomaterials for Energy programme has commenced to research new, more efficient and lower-cost separation membranes for hydrogen purification. Alumina substrates with highly regular porous structures developed through electrochemical etching processes are being coated with a range of materials with a goal to produce cost effective high temperature separation systems suitable for hydrogen and other gas purification (see photos).

A programme to identify ways of purifying micro-algal hydrogenase for development of a hydrogenase electrode has also recently been initiated, as has research into the preparation of highly active electro-catalytic particles for use in proton exchange membrane electrolysis.

HYDROGEN STORAGE

This programme relates to development of new materials and process technologies for safe and energy efficient storage of hydrogen gas as a chemical hydride. It addresses two different chemical storage systems: one relating to regeneration routes for sodium borohydride, and the other to storage in amino-borane systems. Parts of this research are included in a much larger US DoE-led programme that is endorsed by the International Partnership for the Hydrogen Economy (IPHE).

HYDROGEN DEMONSTRATION

Several demonstrations have taken place or are currently running. The best known relates to a remote rural wind-hydrogen power link and alkaline fuel cell grid-connected demonstration at Totara Valley near Palmerston North in the North Island of New Zealand. In this demonstration wind-sourced hydrogen is transmitted from a hilltop site to the farmhouse in the valley 2 km below. The system provides daily buffer storage for the local wind energy supply within the low-cost polymer fuel pipe, while a fuel cell and water heater demonstrate the viable stationary uses for this hydrogen energy. In late 2008, this project was added to the IEA Task 18 Evaluation of Integrated Hydrogen Energy Systems activities, and performance data are now being collected and used in sub-task activities. A demonstration related to options for providing hydrogen to a US Department of Defence PEM Fuel Cell at the Antarctic Centre in Christchurch was also concluded. This programme ran successfully over a twelve-month period during which 10,500 cubic meters of hydrogen were supplied.
The major activity in this area is the CRL Energy/IRL Transitioning to a Hydrogen Economy programme. This programme aims to improve understanding of hydrogen energy systems among stakeholders, identify likely scenarios for the uptake of hydrogen into the future energy system, as well as the research needed to facilitate the uptake. The programme includes a significant scenario-modeling component (being performed by Unitec, Auckland) to highlight the contributions of a range of well-to-wheels and source-to-user hydrogen supply chains and identify critical knowledge gaps. The programme is being carried out alongside a much wider EnergyScape programme in which similar analyses are being performed to identify the role of energy resources in meeting future energy needs through 2050. The results of the hydrogen uptake programme are being incorporated into this bigger picture overview.
HYDROGEN ROADMAPPING ACTIVITIES IN NEW ZEALAND

Previous work on the Transitioning to Hydrogen project analysed potential hydrogen supply chains and identified the most favourably in terms of economics, energy requirements, and emissions footprint (E3 analysis). Over one hundred potential supply chains were analysed, and two types of end-use application were considered: transport and stationary. In the case of transport, for example, the chain began with the resource and ended with hydrogen being consumed in a fuel cell vehicle. In the case of stationary applications, it was either produced centrally and fed into a fuel cell for distributed generation of combined heat and power, or delivered as a conventional fuel (e.g., natural gas) and produced on-site in an integrated reformer. Although the volumes of hydrogen required for these stationary applications are relatively small, it was considered that these applications could play an important role in the introduction of hydrogen as an energy carrier, and they were included for this reason.

Nine chains were eventually chosen for more in-depth analysis against a range of twelve possible 2050 energy futures in New Zealand. The end result of this modeling stage showed that four production chains—electrolysis, natural gas reformation, coal gasification with CCS and biomass gasification—were required to meet the hydrogen demands associated with the twelve future scenarios. Knowledge gaps associated with these chains were identified, as was the best means for filling these gaps (either through a New Zealand led programme of research, or through international linkages), and a corresponding research strategy was identified. Results of the scenario-modeling were presented at a Roadmapping Workshop session of the World Hydrogen Energy Conference in Brisbane.

REFERENCES

New Zealand Business Council for Sustainable Business Development (NZBCSD)
http://www.nzbcsd.org.nz/

CONTACTS

Dr. Steven Pearce
steven.pearce@solidenergy.co.nz
NORWAY

Dr. Stian Nygaard
The Research Council of Norway

INTRODUCTION AND BACKGROUND

Per capita energy use in Norway is somewhat higher than the OECD average. However, the proportion of energy use accounted for by electricity is considerably higher than in other countries; the main reason for this is that Norway has a large power intensive industrial sector. In addition, electricity is used to a much wider extent for indoor heating and hot water production than in other countries. The net domestic consumption of energy rose by 2%, and reached 226 TWh in 2007. Total energy production in Norway was more than 2500 TWh.

Norway's energy situation is quite special compared to most other countries. Whereas most countries have to import a substantial part of their energy supply and energy security is highly focused, in Norway, the annual production of energy is approximately ten times its domestic use, and more than 99% of electricity production comes from hydropower. However, Norway is integrated with the international energy market, and energy costs in Norway reflect international levels.
ELECTRICITY: PRODUCTION AND CONSUMPTION

About 99 percent of the electricity production in Norway comes from hydropower, so weather conditions had a large impact for the years 2006 and 2007. In 2006, there was a situation with low precipitation and relatively low electricity production. The net exports (exports minus imports) of electricity in 2007 were 10 TWh, while the net import was 1 TWh in 2006. Also, the production of wind power increased from 2006 to 2007 by 42%. In total, the production of wind power reached 0.9 TWh, but wind power accounted for only 0.7 percent of the total electricity production of 138 TWh in 2007.

UPDATE ON MEMBER’S ENERGY FRAMEWORK

UPDATE ON RELEVANT POLICIES

The objective of research and development in the field of energy and water resource management is both to strengthen economic growth and to promote sound use of energy resources while ensuring that environmental considerations are fully taken into account.

A recent broad-based political agreement reached by the Storting (the Norwegian national assembly) will enable Norway to pursue a new, long term climate policy. This provides a major boost to research and innovation within climate and energy research. The Research Council of Norway is now translating the new initiative into action with the development of eight new Research Centres for Environment-friendly Energy Research and increased programme budgets.

An important policy event was the agreement that provided additional funding to establish Centres for Environmental-friendly Energy Research. The goal is to establish time-limited research centres that conduct concentrated, focused, and long-term research of high international calibre in order to solve specific challenges in the field. Funding for these centres is 12M € per year for 8 years, with total additional funding 100M €.

UPDATE ON RELEVANT PROGRAMS AND PROJECTS

Funding

About half of the overall research funding in the energy sector is provided by the public sector. For 2008, MNOK 175 was available for energy research and development through the programme RENERGI (Clean energy for the future). The primary objective of the programme is to develop knowledge and solutions that are environmentally friendly, more efficient and more effective. These will form the basis for managing the country’s energy resources, security of supply, and internationally competitive economic development in the energy sector. Another important program is CLIMIT: Gas Power with CO₂ capture and storage. This is a collaboration program on CO₂ capture and storage (CCS) between Research Council and Gassnova. The objective is to develop technology for power production with CO₂ capture and safe and reliable storage of CO₂.

... in Norway, the annual production of energy is approximately ten times domestic use, and more than 99% of electricity production comes from hydropower
HYDROGEN R, D&D SPECIFICS: PROGRAMS, PROJECTS, INITIATIVES IN BRIEF

The public part of hydrogen research in Norway is financed through two research programmes: RENERGI (Energy) and NANOMAT (Nanomaterials). The total amount spent on hydrogen R&D&D was 81 MNOK in 2008 and includes projects related to storage, hydrogen production and transportation. The demonstration activities received 21 MNOK of the budget.

![Graph showing hydrogen R&D&D 2008 Breakdown (MNOK)]

DEMONSTRATION PROJECTS

Norway has two major on-going demonstration projects, the Utsira Project and the HyNor Project.

The **Utsira Project**, the demonstration of an autonomous wind-hydrogen system off the west coast of Norway, is now into its 5th year of testing. Owned by StatoilHydro and operated in collaboration with German Enercon, this project now has two years in stand-alone mode. System improvement continues. Extension of the project is being considered, and could include installation of a new electrolyser, upgrading to a new H₂ generator, and setting up a dispenser and hydrogen car on the island.

The **HyNor project** is a joint public-private partnership initiated to demonstrate real life implementation of hydrogen energy infrastructure along a 580 kilometers route from Oslo to Stavanger. In 2008, a contract was signed for the delivery of 30–40 Mazda RX8 hydrogen cars. These cars will be used in addition to the 15 Quantum US hydrogen cars already in operation by local drivers. The establishment of new filling stations along the HyNor route was also prepared in 2008, and four new stations are planned in the short term, at least two of which will be opened in 2009 in Oslo and Drammen. The filling stations will use different resources and technologies for production and supply of hydrogen as indicated in Figure 5.

The HyNor route is being extended through Sweden and Denmark through the Scandinavian Hydrogen Highways Partnerships (SHHP), with two new filling stations planned for 2009 and eight more being evaluated for Sweden and Denmark.
The HyNor nodes

- **Bergen**: Plans for station in phase II (2010), H₂ from refinery by-product
- **Stavanger**: 2006: trucked-in, H₂ from biogas reforming
- **Kristiansand**: Trucked-in hydrogen (2010), By-product or electrolysis
- **Grenland**: 2007: Pipeline supply
- **Drammen**: Trucked-in hydrogen (2009)
- **Oslo**: Plans for station in phase II (2010), H₂ from electrolysis
- **Romerike**: H₂ from electrolysis

Vehicle fleet in HyNor/SHHP

- **Hydrogen Prius**: converted to hydrogen operation by Quantum US, 15 cars in Norway
- **Think Hydrogen**: A hydrogen/electric hybrid, 5 cars to HyNor in 2009
- **Mazda RX8**: Hydrogen/petrol, dual fuel, 30-40 cars to HyNor/SHHP in 2008-2010
- **Buses**: Plans for 8 buses in HyNor 2010-2011
- **More cars**: Dialogue ongoing with several car manufacturers for larger series of cars to HyNor and SHHP

Figure 5: The HyNor Nodes

Figure 6: Vehicle Fleet in HyNor/SHHP
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www.hynor.no

CONTACT
Stian Nygaard
The Research Council of Norway
Division for Strategic Priorities
Department of Energy and Petroleum Research
Postboks 2700 St. Hanshaugen
N-0131 Oslo
e-mail: sny@rcn.no
www.forskningsradet.no

Figure 7: Developing Hydrogen as a Transport Fuel. Source: StatoilHydro
Mr. Antonio G. García-Conde and Ms. Esther Chacón
Instituto Nacional de Técnica Aerospacial (INTA)

INTRODUCTION

Spain’s 2007 energy consumption, excluding electricity demand, was 108,197 metric tons of oil equivalent (ktoe), 3.3% higher than in 2006. Therefore, final consumption is similar to previous years.

Primary energy consumption for 2007 reached 146,779 kilotonnes of oil equivalent (ktoe), 1.8% higher than in 2006. This figure represents electricity consumption and the losses to the final energy consumption.

Primary energy production in Spain for 2007 was 30,612 kilotonnes of oil equivalent (ktoe), which is 2.3% lower than in 2006, with higher proportions of renewable energies and less fossil fuel.

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<th>Primary Energy Structure</th>
<th>2006</th>
<th>2007</th>
<th>2007/06</th>
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<tr>
<td>Coal</td>
<td>18.477</td>
<td>20.236</td>
<td>13.8</td>
</tr>
<tr>
<td>Oil</td>
<td>70.759</td>
<td>70.848</td>
<td>48.3</td>
</tr>
<tr>
<td>OIL</td>
<td>70.759</td>
<td>70.848</td>
<td>48.3</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>30.298</td>
<td>31.602</td>
<td>21.5</td>
</tr>
<tr>
<td>Nuclear</td>
<td>15.669</td>
<td>14.360</td>
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<tr>
<td>Renewable Energies</td>
<td>9.211</td>
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<td>Hydropower</td>
<td>2.200</td>
<td>2.341</td>
<td>1.6</td>
</tr>
<tr>
<td>Other renewable energies</td>
<td>7.011</td>
<td>7.887</td>
<td>5.4</td>
</tr>
<tr>
<td>Wind</td>
<td>2.012</td>
<td>2.368</td>
<td>1.6</td>
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<tr>
<td>Biomass and waste</td>
<td>4.732</td>
<td>4.995</td>
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<tr>
<td>Biofuels</td>
<td>171</td>
<td>382</td>
<td>0.3</td>
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<tr>
<td>Geothermal</td>
<td>8</td>
<td>8</td>
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<tr>
<td>Solar</td>
<td>86</td>
<td>135</td>
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<tr>
<td>Electric Balance (imp. - exp.)</td>
<td>-282</td>
<td>-495</td>
<td>-0.3</td>
</tr>
<tr>
<td>Total</td>
<td>144.132</td>
<td>146.779</td>
<td>100.0</td>
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Figure 1: Primary Energy Consumption 2007

Figure 2: Primary Energy Consumption 2007
Increasing demand and falling production resulted in a 20.9% energetic self-sufficiency rate. The energy self-sufficiency rate is broken down into segments:

<table>
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<th>Energy Source</th>
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<td>Coal</td>
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<td>Oil</td>
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<tr>
<td>Total</td>
<td>21.7</td>
<td>20.9</td>
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Spain has set its electricity exporting rate at 11,221 GWh for 2008, 95% higher than in 2007. The principal reason is the increase in the amount of electricity production from renewable energies.

Exceptional...renewable energy resource and electricity production capacity make hydrogen an alternative for the Spanish energy system.

**ELECTRICITY: PRODUCTION AND CONSUMPTION**

Spain’s electricity demand at the energy station in 2007 was 290,039 GWh and the final electricity demand, once transport and distribution losses were subtracted, was 257,234 GWh. Both figures are 2.7% higher than those for 2006. The increase, which is much lower than that in previous years, comes primarily from the improvements in end use energy efficiency and the milder weather conditions over the last two years.

According to the 2008 Spanish Electric Network (R.E.E.) data, Spain has set its 2008 electricity exporting rate at 11,221 GWh. This figure is 95% higher than the 2007 figure. The principle reason for this increase in electricity production is use of renewable energies.

On 15 December 2008, the average maximum power demand per hour reached 42,961 MW. The sources for that power production were:

- 18% Wind
- 13% Hydraulic
- 11% Other renewables and cogeneration
- 27% Gas thermic and combined cycle
- 16% Coal
- 14% Nuclear
- 1% Fuel/gas

It is clear that renewable energies are gaining considerable importance in Spain. On 24 November, 43% of the electricity demand was covered by wind energy production. Even more remarkable was the situation on 2 November at daybreak, when wind power production was so great that it was impossible to integrate it into the electric system, leading REE to order a reduction of wind power production. Consequently, almost 2,800 MW of “free” wind energy were lost. Robust renewable energy resources and electricity production capacity make hydrogen an alternative for the Spanish energy sector.
In order to reduce external energy dependence, increase the use of renewable energies, and apply efficient technologies to optimize fossil fuels processes, the Spanish government has developed the “Energy Saving and Efficiency Strategy 2004–2012.” This strategy was implemented in the 2005–2007 and the 2008–2012 Action Plans.

During 2006, primary energy savings of 7 million toes was achieved as a result of activities associated with the 2005–2007 Action Plan. Likewise, during 2007, primary energy consumption was reduced by 15 million teps, thereby avoiding emissions equivalent to 40 million tons of CO₂/year.

The adopted measures included economic support to foster investment in legal actions, diffusion, and education activities. Activities at the Energy Saving and Diversification Institute (IDAE) and in the regions included replacing old traffic lights with LED lights (light emitting diode) and low energy consumption light bulbs, etc.

The 2008–2012 Action Plan sets a primary energy savings goal of 87,933 ktoes. This level of savings will avoid 238 million tons of CO₂ emissions during the 2008-2012 period.

The plan will executed using public funds and a share-management model between the General State Administration and the Regional Administrations.

HYDROGEN R, D&D

Spain’s exceptional position with respect to renewable energy technology makes “clean” H₂ production one of the most interesting issues for research and development projects. That is why many institutes and companies are working on it by means of public and private initiatives. In addition, Spain has been involved for several years in the Hydrogen Implementing Agreement of the International Energy Agency (Task 18–Evaluation of Integrated H₂ Systems; Task 22–Fundamental and Applied Hydrogen Storage Materials Development; Task 24–Wind Energy and Hydrogen Integration; and Task 25–High Temperature Hydrogen Production Processes). Spanish experts work with international experts to gain and share experience in the hydrogen economy issues most relevant to the country’s needs.

Wind and solar powered electrolysis of water for H₂ production appears to be one of the most promising solutions, and its implementation will theoretically permit a 100% penetration of renewable energies in the power-generation market. Storing wind electricity as hydrogen is now becoming an increasingly important business. Three projects regarding this technology are being carried out in Spain by private companies: Sotavento wind farm, W₂H₂—Wind to Hydrogen, and Wind-Hy.

A new project, “PSE: Mini Wind Power” (PSE: strategic & singular project), has entered the Spanish technology arena. Funded partially by the Education and Science Ministry, the project will last from 2007 to 2010. Its goal is to foster small wind power technology development of turbines with a capacity up to 100 kW) for use in grid-connected and remote facilities as well as in innovative applications for hydrogen production. These PSE projects will try to solidify the relationships between science-technology companies.
The task regarding hydrogen production consists of three parts:

**1st part:** Wind potential evaluation – set up of a mini wind power grid-connected demonstrator for hydrogen production and storage – by means of an electrolyser and metal hydrides.

**2nd part:** Simulation of the system using the commercial code TRNSYS. System validation, different tests performance, and energetic optimization of the system will be addressed.

**3rd part:** Application of the conclusions obtained from the simulation to the real system.

Relative to the promotion of solar energy to H\textsubscript{2} production by electrolysis, two technologies stand out: thermal and photovoltaic energies. The outstanding project relationed to solar thermal \( H_2 \) is being carried out by Solucar Energy, a subsidiary of the Abengoa, a Spanish company. This project is called SolterH and consists of the identification and demonstration of a 5Kw prototype for \( H_2 \) generation by thermochemical cycles with solar concentration and high temperatures. Solhycarb, another project about solar \( H_2 \) production by means of methane reforming with concentrated solar energy, is being carried out in the same facilities. Project related use of photovoltaic projects should be mentioned.

The **Hercules project** consists of hydrogen generation from photovoltaic energy for use as a fuel in an electric vehicle based on fuel cell technology. It belongs to the PSE projects group funded partially by the government and constitutes the science/technology–company interaction. The Hercules Project pursues hydrogen economy development in Spain through hydrogen production from the sun.

![Figure 5: Hercules Project layout](image)

The project started in January 2006 with two main objectives: (1) construction of a real prototype of a hybrid FC vehicle, and (2) construction of a real hydrogen fueling station whose hydrogen comes from an electrolyser powered by photovoltaic energy. Five different solar tracking systems have been used and compared. Currently, the design of all parts of the vehicle has been finished with the help of the simulation tool ADVISOR\textsuperscript{TM}, developed by the NREL. All the systems concerning the production of hydrogen and the hydrogen refueling station have are complete.

The propulsion system is divided into three parts: (1) a two-stack fuel cell with a lump peak power of 56 kW, (2) a set of eight Li-ion batteries with 18.5 kW of power and 9.5 kWh of energy in total, and (3) a self-developed electric motor with 60 kW of peak power. The vehicle has a storage system of 100 liters of 350 bar hydrogen. The “Hercules” vehicle is estimated to be able to reach a maximum velocity of 131 km/h with a range of 150 km in a mixed urban-highway cycle.
A photovoltaic field of 70 kW of peak power has been installed to produce electricity to feed a 55 kW electrolyser. The system is supposed to produce an average of 10.5 kg(H_2)/day, which gives the vehicle the potential to be driven around 500 km per day.

Project Hercules has a budget of around €7.2 million and involves eight companies and research centres.

**Solar hydrogen:** This project constitutes the 11th task of the strategic industrial research project “Consolida” (2008–2011), a solar national consortium in R&D. This project is about the development of different concentration solar thermal technologies with the aim of consolidating the leadership of Spain in thermosolar technology.

The Consolida project is divided into different tasks, one of them devoted to hydrogen technology. It comprises the production, storage, applications and integration of H_2 systems. The H_2 production subtask is mainly dedicated to the study of the most promising thermochemical cycles for H_2 production and its integration with high temperature solar energy. It also deals with the design of a hybrid solar plant for H_2 production from high and low temperature electrolysis. The H_2 storage subtask will carry out a comparative study (energetic, economic, etc.) of different storage solutions. Regarding the H_2 applications, a feasibility study of gas turbines, internal combustion engines and fuel cells running with H_2 will be addressed, and an optimized conventional gas turbine adapted for H_2 will be virtually designed.

**Hydrogen filling station, Zaragoza EXPO 08:** One of the year’s most remarkable projects was the set up of the first hydrogen filling station with public service in Spain. It was built for the EXPO 08 in Zaragoza. The project entails four stages or processes. The first stage, hydrogen production and purification, is carried out using an alkaline electrolyser. In the second stage, hydrogen is compressed to 420 bar. In the third stage, compressed gas is stored in a three stage cascade system. Finally, the last stage consists of the dispenser unit. This station has been running since June 2008 and is scheduled to operate for eight years.

Presently, the vehicle fleet that refuels at this station is composed of three Hydrogenic MidiBuses (hybrid vehicle with a 10 kW fuel cell) and twenty bikes that include a PEMFC as a support.

Apart from H_2 production from renewable sources, fuel cell technology is also included in the Spanish R&D&D projects portfolio.

**Spanish Hydrogen Kart:** A Spanish hydrogen kart was developed in Zaragoza by FHA (Foundation for the Development of New Hydrogen Technologies in Aragon) and Team Elias to take part in Formula Zero, a race for fuel cell powered cars. The first race took place in Rotterdam 23 August. The FHA hydrogen kart was the winner in the speed race.

**Boeing Airplane:** Boeing [NYSE: BA] has, for the first time in aviation history, flown a manned airplane powered by hydrogen fuel cells. The recent milestone is the result of the work of an engineering team at Boeing Research & Technology Europe (BR&TE) in Madrid, with assistance from industry partners in Austria, France, Germany, Spain, the United Kingdom, and the United States.
A two-seat Dimona motor-glider with a 16.3 meter (53.5 foot) wingspan was used as the airframe. Built by Diamond Aircraft Industries of Austria, it was modified by BR&CTE to include a Proton Exchange Membrane (PEM) fuel cell/lithium-ion battery hybrid system to power an electric motor coupled to a conventional propeller. Three test flights took place in February and March 2008 at the airfield in Ocaña, south of Madrid, operated by the Spanish company SENASA. During the flights, the pilot of the experimental airplane climbed to an altitude of 1,000 meters (3,300 feet) above sea level using a combination of battery power and power generated by hydrogen fuel cells. Then, after reaching the cruise altitude and disconnecting the batteries, the pilot flew straight and level at a cruising speed of 100 kilometers per hour (62 miles per hour) for approximately 20 minutes on power generated solely by the fuel cells.

Avizor: The Avizor project consists of an unmanned aircraft powered by a PEM fuel cell. It is a new version of the SIVA project, a sophisticated unmanned aerial surveillance system developed by INTA (the National Institute for Aerospace Technology). It has multiple applications in civil and military fields, and can be used as an observation vehicle in real time. In the first step, the vehicles from the SIVA project have been powered by a conventional internal combustion engine. In the second phase, the Avizor project, the electrical engine will be powered by a PEMFC fueled by hydrogen. At the present time, integration of the system is being carried out at INTA facilities.

DEIMOS Project stands for “Development and Innovation in Polymer Electrolyte Membrane and Solid Oxide Fuel Cells.” The short-term objectives of this project are to increase fuel cells activities in Spain and to obtain a good international overview. In the mid term, the objective is development of the latest technologies in fuel cells. In the long term, the objectives are the development of a Spanish Fuel Cell industry and a sustainable energetic system that includes fuel cell technology.
The DEIMOS project started in 2007 and will finish in 2010, and has a budget of €28 million. Its R&D&D guidelines include:

- Development of high and low Polymeric Electrolyte Membrane Fuel Cell (PEMFC) stacks
- Development of Solid Oxide Fuel Cell (SOFC) stacks
- Integration in different applications: portable, emergency, aerospace and stationary
- “On-site” reforming for hydrogen generation on a small scale
- “On-site” H₂ storage on a small scale

**Epico Project:** This is another PSE project whose main objective is to coordinate the R&D efforts of Spanish companies involved in low power PEMFC development to manufacture a PEMFC with Spanish technology — from the membrane to the bipolar plates. Two prototypes are going to be developed: three mini-fuel cells of around 4 W with monopolar structure, and three 250 W bipolar PEMFC. Both prototype and applications development are contemplated. The applications to be developed under the project are: an electric bike, a toy, and an auxiliary power generator system for a convoy. The budget is around €6 million for a period of four years, beginning January 2006.
INTRODUCTION AND BACKGROUND

Total energy supply 2007 624 TWh
Conversion losses in nuclear plants amount to 124 TWh, i.e. 20% of total energy supply

<table>
<thead>
<tr>
<th>Final energy use</th>
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<tbody>
<tr>
<td>Industry</td>
<td>157 TWh</td>
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<tr>
<td>Buildings</td>
<td>143 TWh</td>
</tr>
<tr>
<td>Transport</td>
<td>105 TWh</td>
</tr>
<tr>
<td>Final energy use</td>
<td>404 TWh</td>
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</table>

Renewable energy amounts to 44% of final energy use, which is the highest value in Europe. Bioenergy, 120 TWh (supply), and hydroelectricity, 66 TWh, are the main sources. According to current EU goals, the renewable part in Sweden shall increase to 49% by 2020.

<table>
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<th>Imports</th>
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<tr>
<td>Oil and oil products</td>
<td>199 TWh</td>
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<tr>
<td>Uranium for nuclear plants</td>
<td>191 TWh</td>
</tr>
<tr>
<td>Coal</td>
<td>28 TWh</td>
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<tr>
<td>Natural gas</td>
<td>11 TWh</td>
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<tr>
<td>Total Imports</td>
<td>429 TWh</td>
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</table>

Electricity 2007: Production

<table>
<thead>
<tr>
<th>Hydro</th>
<th>66 TWh</th>
<th>46% (of production)</th>
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<tr>
<td>Nuclear</td>
<td>64 TWh</td>
<td>44%</td>
</tr>
<tr>
<td>From biomass</td>
<td>9 TWh</td>
<td>6%</td>
</tr>
<tr>
<td>Wind</td>
<td>1.4 TWh</td>
<td>1%</td>
</tr>
<tr>
<td>Other</td>
<td>5 TWh</td>
<td>3%</td>
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<tr>
<td>Total production</td>
<td>145 TWh</td>
<td>100%</td>
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Consumption

<table>
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<tr>
<th>Industry</th>
<th>56 TWh</th>
<th>38% (of consumption)</th>
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<tbody>
<tr>
<td>Transport</td>
<td>3 TWh</td>
<td>2%</td>
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<tr>
<td>Buildings</td>
<td>72 TWh</td>
<td>49%</td>
</tr>
<tr>
<td>Other (e.g., losses)</td>
<td>14 TWh</td>
<td>10%</td>
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<tr>
<td>Import</td>
<td>1.3 TWh</td>
<td>1%</td>
</tr>
<tr>
<td>Total consumption</td>
<td>146 TWh</td>
<td>100%</td>
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</tbody>
</table>

Figure 1: Primary energy structure
UPDATE ON MEMBER’S ENERGY FRAMEWORK

UPDATE ON RELEVANT POLICIES

Swedish energy and environmental policies aim to promote the establishment of a sustainable society. A major focus lies on combating climate change. Sweden plays an active role in this field in the European theatre. Implementation and commercialisation of research results are receiving increased attention.

In the transport sector, the EU biofuel directive states that 5.75% of the motor fuels should be renewable by the year 2010 in each member state. A 2008 directive from the EU Commission proposes a level of 10% renewable energy for motor fuels in 2020. Greenhouse gas emission-free electricity used in the transport sector can also be included to fulfill this goal. The current level of renewable motor fuels in Sweden is nearly 4%.

Research on renewable motor fuels has a high priority in Sweden. Development of gasification of black liquor from kraft pulp mills, which can produce electricity and/or motor fuels, is a highly prioritized research field. Another major research activity is focused on developing production of ethanol from cellulose and on producing syngas via direct gasification of biomass for the production of other motor fuels. Biogas is also receiving more attention. Vehicles fueled by renewable motor fuels account for a significant portion of new cars sold, compared to their share of the current vehicle fleet. This trend has been very clear during recent years. The Swedish Parliament decided some years ago, that major fuel stations should have at least one pump with a renewable fuel. Today, the ethanol fuel E85 is available at 1,100 filling stations, a figure that comprises over 25% of the filling stations in Sweden. All gasoline sold in Sweden contains 5% ethanol.

Transport issues have become increasingly important over the last few years, generating interest in electric and hybrid vehicles and fostering the opening of a competence center for hybrid technology.

EU’s energy goals for 2020 provide a strong driving force for climate change. There is political consensus in Sweden to increase its wind power generation considerably over the next 10 years. The annual production is around 1 TWh, and the aim is to increase it to 10 TWh in 2020. The potential of Swedish wind energy is estimated at 30 TWh.

In Sweden, a special fund 875 million SEK had been reserved for the three-year period 2009–2011 to support large-scale demonstration activities, and in particular for renewable fuel production. Support may also be given to vehicle development and other energy technologies with significant export potential.

UPDATE ON RELEVANT PROGRAMS AND PROJECTS

Funding

Government funding of energy R,D&D has been significantly increased in 2009 and now amounts to approximately 1.1 billion SEK. Major research areas encompass:

- Development of renewable energy production (solid, liquid, gas)
- Improvement of energy efficiency (industry, buildings, transport)
- Transport (biofuels and vehicles)
- System aspects
HIGHLIGHTS OF PROGRESS

Despite large production increases, the industrial energy demand has remained essentially constant for the last 40 years, around 150 TWh/year, due to continuous improvements in efficiency. Significant progress has been made in the development of renewable energy sources and their implementation, and in the development of clean technologies.

HYDROGEN RD&D SPECIFICS – PROGRAMS, PROJECTS, INITIATIVES IN BRIEF

SCOPE AND ACCOMPLISHMENTS

Sweden has been a member of the IEA Hydrogen Implementing Agreement for many years. Over time, research efforts have been directed to the renewable production of hydrogen by photobiological and photochemical routes. Work on the storage of hydrogen in the form of metal hydrides has also been supported for a long time. Interest in various aspects of the system has increased in recent years.

Sweden participates in the following IEA HIA Tasks:

• Task 18 Integrated Systems Evaluation
• Task 21 Biohydrogen
• Task 22 Fundamental and Applied Hydrogen Storage Materials Development
• Task 23 Small Scale reformers for On-Site Hydrogen Supply

E.ON Gas Sverige in Malmö started the operation of the first European hydrogen fuelling station that delivers a mixture of natural gas and hydrogen (hythane, 8/20% H₂) in September 2003. Some of the local city buses in Malmö have used this fuel for several years with significantly lower fuel consumption and fewer harmful emissions.

Task 18 started in 2004 and will be completed in 2009. Of special interest are the case studies, which are demonstration projects described in detail. Some of the projects have also been subject to in-depth evaluation through modeling and analysis. The fall 2008 Expert Meeting was held in Copenhagen, Denmark, and a visit to the hydrogen filling station in Malmö, Sweden was included. Grontmij is the Swedish participant in this Task, financed by the Swedish Energy Agency.

The Swedish Energy Agency finances the major hydrogen project, Hydrogen from Solar Energy and Water - from Natural to Artificial Photosynthesis, which will last three years (2007–2009). The project is performed at the University of Uppsala. Government support for the whole period amounts to 32 million SEK (approximately 3 million €), but there is also significant funding from other sources. It is multidisciplinary and engages competences in molecular biology, biochemistry and biophysics, metal organic synthesis, and physical chemistry. One objective is to synthesize and characterize catalytic molecules whose function is based on natural photosynthesis. The aim is to create molecules capable of producing hydrogen from solar radiation and water. Rutenium compounds are studied for the absorption of sunlight. Fe-Fe-compounds occur

Figure 2: Hydrogen fuelling station in Malmö. Courtesy E.On Gas AB
naturally in oxygen-limited environments and studies of such substances are an important research field. In a recent breakthrough, Fe-molecules were shown to be able to produce hydrogen (H₂).

Another research area within this project is the development of cyanobacteria by genetic and biochemical means, which can produce hydrogen in an efficient way. Peter Lindblad of the University Uppsala participates in Task 21– BioHydrogen. He has obtained funding for a project related to studies on hydrogen production.

Stockholm University is engaged in research on hydrogen storage materials and metal hydrides, and participates in HIA Task 22 – Fundamental and Applied Hydrogen Storage Materials.

Sweden has been engaged in the EU Hydrogen and Fuel Cells Technology Platform, HFC TP, with E.ON Sverige AB, Grontmij and the Swedish Energy Agency as participants. The EU research networking activity ERA-net HY-CO (ERA = European Research Area; HY-CO = Hydrogen Cooperation) is linked to the HFC TP. Sweden and some 20 other European countries and regional organisations have been engaged in the ERA-net activity.

Several Swedish stakeholders are active members of the Fuel Cells and Hydrogen Joint Technology Initiative that was launched in October 2008. Volvo AB and E.ON Sverige AB are members of the NewIG, Industry Group. KTH, The Royal Institute of Technology in Stockholm and Uppsala University are members of the Research Group. Prof. Dr. Lars Sjunnesson from E.ON Sverige is one of eight appointed members in the Scientific Advisory Board for the EU FCH JTI.

A partnership for the promotion of hydrogen in Sweden, Hydrogen Sweden (Vätgas Sverige) was formed in late 2006 with the website www.vatgas.se. Today some 30 organisations and companies are members.

REFERENCES

WEBSITE
Swedish Energy Agency has a website, in Swedish and in English: www.energimyndigheten.se.

Visit us!

CONTACT INFORMATION
Swedish Energy Agency
Box 310
SE- 310 64 Eskilstuna
Sweden
Phone: +46 16 544 2000
Swedish Executive Committee member:
Lars Vallander
Phone. +46 16 544 2088
OVERVIEW

From the point of view of the Swiss Federal Office of Energy (SFOE), hydrogen has huge potential as an energy carrier that contributes to solving the storage problems associated with a future energy system based on renewable energy sources. The SFOE tries to coordinate various national research and demonstration activities by using its own funds as seed money in combination with other resources from national or cantonal institutions, as well as from industry. The long-term strategy of the SFOE hydrogen research program is to foster projects in the field of hydrogen production by renewable energies and hydrogen storage in solid state systems.

FUNDING, RESEARCH INSTITUTIONS & PUBLIC RELATIONS

Overall funding by public institutions for the hydrogen and solar chemistry activities in 2007 totaled CHF 7 million, roughly one quarter of which is SFOE-controlled. This is slightly below the average of funding in past years.

The main research institutions in the hydrogen research program are the Swiss Federal Institutes of Technology in Zurich (ETHZ) and Lausanne (EPFL), the Paul Scherrer Institut (PSI), the Swiss Materials Science & Technology Center (EMPA), and the Cantonal Universities of Geneva and Basel. The establishment of a National Center of Competence in Photo-electrochemistry (PEC) at the EPFL with satellite institutes at EMPA and the University of Basel allowed for a concentration of research activities in this subfield to take place within the past years. On the industrial side, several companies are active in the field of hydrogen, such as Industrie Haute Technologie SA (IHT) and AccaGen SA. These companies are developing and selling electrolyzers. IHT actively participates in Task 24–Wind Energy and Hydrogen Integration.

Expert actors from research and industry are organised in the Swiss Hydrogen Association Hydropole (www.hydropole.ch), the national network for hydrogen-related matters in Switzerland. This organization prepared a new report last year that maps the different hydrogen activities within Switzerland.

At the end of 2008, Dr. Andreas Luzzi from the University of Applied Sciences in Rapperswil handed the operational management of the Swiss Hydrogen Program over to Dr. Stefan Oberholzer (SFOE). The SFOE conveys special thanks to Andreas Luzzi for his engagement during the last year.

2008 ACCOMPLISHMENTS

For many years the production of hydrogen by renewable energy sources and the development of effective storage possibilities formed the two main topics of the R&D program of SFOE. Fortunately, over the last few years, a few new pilot and demonstration activities have emerged. These activities will enter into a practical test phase in 2009. In the following paragraphs, some of the main results of 2008 are summarized.
HYDROGEN PRODUCTION

The Swiss hydrogen research program has fostered the idea of using solar power to produce hydrogen for more than 20 years. A research group at the PSI investigated thermochemical processes by making use of concentrated solar radiation as the energy source of process heat. Of particular interest is the production of hydrogen by a two step water-splitting cycle process via ZnO/Zn redox reactions. Since hydrogen and oxygen are formed in separate steps of the cycle, the problem of high-temperature gas separation is avoided.

Figure 1: Modeled efficiency for the solar thermal ZnO-decomposition as a function of temperature for different reactors.

Currently, the existing 10 kW solar chemical reactor for the solar thermal decomposition of ZnO will be scaled up to 100 kW. Within the last year, extensive numerical simulations were performed which showed that an improved engineering design of the solar chemical reactor combined with a higher power will result in an increased efficiency for the process of thermal ZnO-decomposition (Figure 2).

National research activities in the field of photo-electrochemical water-splitting are concentrated within a competence center, “PEChouse” (pechouse.epfl.ch), at the EPFL. The same institution also acts as a leading house within a European PEC-project, “NanoPEC,” which started in the last year. The overall objective of the activities at PEChouse is to design and develop novel semiconductor-based materials capable of harvesting and converting solar energy into chemical energy by oxidation of water into oxygen and hydrogen. Since its inception in September 2007, PEChouse research activities have centered on assembling tools and techniques for the development of the next generation of photo-electrochemical technology.
HYDROGEN STORAGE

Complex hydrides as reversible hydrogen storage materials offer an alternative possibility for hydrogen storage, which is safer and energetically more favorable compared to other technologies (e.g., compression/liquefaction). For many years, intensive research on boronates (LiBH4), a material with one of the highest gravimetric and volumetric hydrogen densities, has been pursued at EMPA. The final goal of the project is to describe the mechanism of the hydrogen sorption reaction in great detail. The work is a contribution to the activities in Task 22 – Fundamental and Applied Hydrogen Storage Materials.

PILOT AND DEMONSTRATION ACTIVITIES

Researchers at EMPA and PSI, together with the companies Bucher, Proton Motor, Messer Switzerland, and Brusa, developed a hydrogen-driven communal cleaning vehicle which will operate for 6 months in Basel in 2009 (see Figure 2). The hydrogen is supplied by a mobile station from Messer AG. A dynamic computer model was developed to test the vehicle concept based on the system performance in its practical use. Within the last two years, the fuel cell system was integrated into the existing vehicle from Bucher.

Within the last year, an air-cooled PEM-fuel cell system called “IHPoS” has been developed in the research division of the company CEKA AG, in collaboration with PSI and the University of Applied Science in Biel (see figure 3). The project was continuously supported by the SFOE and the Swiss Innovation Promotion Agency (CTI). The next step for the “IHPoS” system will be its integration into a “Minibar” on trains operated by the Swiss railway company SBB. Hydrogen will be stored within metal hydrides. The hydrogen powered Minibar will allow the operator to solve the problem of electricity availability during rush hour.

OUTLOOK

The Swiss hydrogen research program will continue in 2009, hopefully in collaboration with the R&D programs of the IEA-HIA, and with additional funding from the European Union.

CONTACT

Stefan Oberholzer, Ph.D.
Swiss Federal Office of Energy, Section Energy Research, Hydrogen & Fuel Cells, Photovoltaics, CSP
3003 Bern, Switzerland
Tel: +41 (0)31 325 89 20
stefan.oberholzer@bfe.admin.ch
www.bfe.admin.ch/research/hydrogen

Figure 2: The first hydrogen-driven cleaning vehicle in Europe. Such zero-emission vehicles will operate in downtown areas, where the effects are most noticeable. The needed infrastructure is well-defined and such niche-applications of fuel cells and hydrogen should be accepted despite additional costs of 50%.

Figure 3: A Minibar on trains of the Swiss railways will be powered by a PEM-fuel cell system with solid state hydrogen storage technology, furthering the development of the state-of-the-art α-Fe2O3 photoanodes conceived at EPFL.
**VITAL STATISTICS**

**TURKEY**

*non-EU member state*

**Population**
70,586,256 (December 2007)

**Territory**
814,578 km²

**Capital**
Ankara

**GDP/capita**
$9333 USD (2007)

**Recent Average GDP Growth**
4.5% (2007)

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**Dr. Alper Sarıoğlu, Ms. Aslı Kaytaz**

**Table 1: Energy Production, Imports, Exports and Demand/Consumption by Sectors (amount-ktoe)**

<table>
<thead>
<tr>
<th>Sector</th>
<th>Coal</th>
<th>Petro-Leum</th>
<th>Natural Gas</th>
<th>Hydro+geo</th>
<th>Bio-Fuels</th>
<th>Wind</th>
<th>Electricity</th>
<th>Geo-Thermal</th>
<th>Solar</th>
<th>Total</th>
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<td>827</td>
<td>3217</td>
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<td>74</td>
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<td>87614</td>
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<td>914</td>
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| Table 2: Energy Production, Imports, Exports and Demand/Consumption by Sectors (percentage %) |

<table>
<thead>
<tr>
<th>Sector</th>
<th>Coal</th>
<th>Petro-Leum</th>
<th>Natural Gas</th>
<th>Hydro+geo</th>
<th>Bio-Fuels</th>
<th>Wind</th>
<th>Electricity</th>
<th>Geo-Thermal</th>
<th>Solar</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRODUCTION</td>
<td>72.10</td>
<td>8.16</td>
<td>3.01</td>
<td>11.72</td>
<td>0.04</td>
<td>0.11</td>
<td>0.00</td>
<td>3.35</td>
<td>0.13</td>
<td>100.00</td>
</tr>
<tr>
<td>IMPORTS</td>
<td>18.42</td>
<td>43.64</td>
<td>37.86</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.08</td>
<td>0.00</td>
<td>0.00</td>
<td>100.00</td>
</tr>
<tr>
<td>EXPORTS</td>
<td>0.00</td>
<td>98.58</td>
<td>0.42</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>3.00</td>
<td>0.00</td>
<td>0.00</td>
<td>100.00</td>
</tr>
<tr>
<td>DEMAND</td>
<td>33.36</td>
<td>30.95</td>
<td>31.55</td>
<td>2.99</td>
<td>0.01</td>
<td>0.03</td>
<td>-0.12</td>
<td>0.85</td>
<td>0.39</td>
<td>100.00</td>
</tr>
</tbody>
</table>

| TOTAL CONSUMPTION | 26.47| 35.57      | 19.08      | 0.00      | 0.01      | 0.00 | 16.02       | 2.35        | 0.51  | 100.00|

| Industry          | 44.05| 8.37       | 24.47      | 0.00      | 0.00      | 0.00 | 19.55       | 3.18        | 0.39  | 100.00|
| Iron and steel    | 60.89| 3.24       | 0.02       | 0.00      | 0.00      | 0.00 | 31.71       | 4.14        | 0.00  | 100.00|
| Chemistry-Petrochemistry | 0.78 | 1.70 | 69.48 | 0.00 | 0.00 | 28.03 | 0.00 | 0.00 | 100.00 |
| Petrochemistry Feedstock | 0.00 | 100.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 |
| Fertilizer        | 0.00 | 22.73 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 |
| Cement            | 84.59| 0.54       | 2.33       | 0.00      | 0.00      | 0.00 | 12.55       | 0.00        | 0.00  | 100.00|
| Sugar             | 83.16| 17.37      | 19.67      | 0.00      | 0.00      | 0.00 | 5.91        | 0.00        | 0.00  | 100.00|
| Non-ferrous metals| 3.47 | 0.48       | 90.14      | 0.00      | 0.00      | 0.00 | 22.30       | 4.95        | 0.73  | 100.00|
| Other Industries  | 46.25| 9.46       | 16.30      | 0.00      | 0.00      | 0.00 | 22.30       | 4.95        | 0.73  | 100.00|
| Transport         | 0.00 | 98.40      | 1.08       | 0.00      | 0.00      | 0.00 | 0.46        | 0.00        | 0.00  | 100.00|
| Residential and services | 30.87 | 7.15 | 31.09 | 0.00 | 0.00 | 25.98 | 3.71 | 0.00 | 100.00 |
| Agriculture       | 0.00 | 89.35      | 0.00       | 0.00      | 0.00      | 0.00 | 10.85       | 0.00        | 0.00  | 100.00|
| Other             | 0.00 | 100.00     | 0.00       | 0.00      | 0.00      | 0.00 | 0.00        | 0.00        | 0.00  | 100.00|
INTRODUCTION

Table 4. Electricity Production and Demand/Consumption

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Electrical Energy Consumption (GWh)</th>
<th>Domestic Power Capacity (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>53431</td>
<td>10197.4</td>
</tr>
<tr>
<td>Petroleum</td>
<td>6526.8</td>
<td>2000.2</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>95024.8</td>
<td>14576.4</td>
</tr>
<tr>
<td>Hydro+Geo</td>
<td>36006.7</td>
<td>13417.8</td>
</tr>
<tr>
<td>Biofuels</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wind</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Geothermal</td>
<td>355.1</td>
<td>146.3</td>
</tr>
<tr>
<td>Solar</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Others</td>
<td>213.7</td>
<td>497.7</td>
</tr>
<tr>
<td>Total</td>
<td>191558.1</td>
<td>40835.7</td>
</tr>
</tbody>
</table>

ELECTRICITY – PRODUCTION AND CONSUMPTION

UPDATE ON MEMBER’S ENERGY FRAMEWORK

UPDATE ON RELEVANT POLICIES

Turkey’s Energy Efficiency Law concerning the use of renewable energy resources for electricity production was enacted with the aim of increasing the use of renewable energy resources. The Energy Efficiency Law was enacted on April 18th, 2007. It states that all incentives to increase the use of hydrogen as fuel and biofuel are determined by regulations which will be defined by the Ministry of Energy and Natural Resources.

The national map of wind and solar power of Turkey has been updated by the Electrical Power Resources Survey and Development Administration. The map will serve investors who are interested in renewable energy. It will also inform on-going development of the Renewable Energy Law to regulate electricity production from solar power. Related studies are still in progress.
UPDATE ON RELEVANT PROGRAMS AND PROJECTS

Ministries and other governmental bodies conduct their own research programs in their relevant fields. The Ministry of Industry and Trade has formed a program, SAN-TEZ, to promote cooperation among industry, universities and public entities. The program aims to develop innovative and value-added technologies through R&D, enabling Turkey to leverage its own expertise. The Ministry of Energy and Natural Resources is working on a program, ENAR, Energy Research, to support alternative energy technologies leading to sustainable energy for Turkey. Turkish Coal Enterprises is working on clean coal technologies. All these programs are open to researchers working on alternative energy technologies, including hydrogen.

The Turkish Research Area Program (TARAL), which was implemented by TUBITAK in 2005, funds hydrogen related activities (including demonstrations, R&D projects and others). Bilateral International Collaboration Programs of TUBITAK are other means for supporting hydrogen activities. One of the projects funded by TARAL is “Fuel Cell Microcogeneration System,” coordinated by TUBITAK Marmara Research Center Energy Institute.

HIGHLIGHTS OF PROGRESS FOR THE ONGOING PROJECT

A natural gas reformer system, catalytic combustion system, and PEM-type fuel cells were successfully constructed. The project is in the integration phase. All sub-systems will be integrated to form a first prototype of 5 kWe fuel cell microcogeneration system.

- The reformer system consists of a series of reactors for hydrogen production and carbon monoxide removal. The system is capable of producing 5 Nm₃ H₂/hour.
- PEM fuel cell system consists of two modules, each of which has 3 kWe capacity.
- The catalytic combustion system has performed well, to utilizing anode off gases for heat recovery.
HYDROGEN R,D&D SPECIFICS

PROGRAMS, PROJECTS, INITIATIVES IN BRIEF

1) EU 6th Framework Program Integrated Project: HYVOLUTION

**Scope and Accomplishments:** Research subjects are (i) Physiology and biochemistry of photoheterotrophic bacteria, (ii) Process technology and photobioreactor design, (iii) Proteomics and genomics of photoheterotrophic bacteria, and (iv) Design, construction, and operation of prototype photobioreactor.

**Participants:** 22 partners, 11 EU countries, and South Africa and Russia. Turkey is coordinating WP3 Photofermentation.

**Funding:** EU FP 6.1 Sustainable Energy Systems, Budget €9 million (620 k€ for Turkey).

**Contact Person:** İnci Eroğlu, Meral Yücel, Middle East Technical University (METU) ieroglu@metu.edu.tr

2) The Effect of Heat and Cold Stress on the Hydrogen Production Metabolism of Rhodobacter Capsulatus

**Scope and Accomplishments:** Effect of fluctuating temperature in outdoor conditions on photobiological hydrogen production was investigated by Rhodobacter capsulatus.

**Participants:** Middle East Technical University and partner: RIGEB (Yavuz Öztürk)

**Funding:** TUBITAK-108T455. (2008–2011) Budget k€150

**Contact Person:** Ufuk Gündüz, METU, ufukg@metu.edu.tr

3) Biohydrogen Production from Renewable Resources (Biomass)

**Scope and Accomplishments:** Biohydrogen production from renewable resources by dark and light fermentations were investigated. Waste ground wheat was subjected to dark fermentation using heat treated anaerobic sludge for hydrogen and VFA formation, which was further fermented by the Rhodobacter species, to produce H₂ in the presence of light.

**Participants:** Dokuz Eylül University, Dept. Environmental Engineering with the participation of five (5) researchers.

**Funding:** TUBITAK–105M296: (2006–2009) Budget: k€190

**Contact Person:** Fikret Kargı, Dokuz Eylül University, Department of Environmental Engineering, fikret.kargi@deu.edu.tr

4) FP6-2004-ACC-SSA-2, Aegean Center of Excellence for Bioengineering and Biotechnology.

**Scope and Accomplishments:** The main objective of the BIO-ACE project was to improve the research capacity of the first and most promising Bioengineering Department in Turkey, and establish it as a National Centre of Excellence in bioengineering/Biotechnology.
Participants: EGE UNIVERSITY  
Contact Person: Prof. Dr. Fazilet Vardar Sukan, fazilet.vardar.sukan@sukan.ege.edu.tr

5) Hydrogen from Bio-ethanol using Metal/Oxide Based Catalysts  
Scope and Accomplishments: The activity and selectivity tests of all catalysts were performed in a packed bed reactor using temperatures between 300°C and 500°C. The performances of metal/oxide based catalysts in ethanol steam reforming reaction were found to occur through ethanol dehydrogenation.

Participants: Izmir Institute of Technology, Chemical Engineering Department  
Funding: TUBITAK  
Contact Person: Assoc. Prof. Dr. Erol Şeker, Izmir Institute of Technology, erolseker@iyte.edu.tr

6) Solar Powered PEM Electrolyzer  
Scope and Accomplishments: In the study of the solar panels powered PEM electrolyzer, single and multi-cell proton exchange membrane electrolyzers were constructed and evaluated. It was observed that the stack could generate 388 ml/min hydrogen under 500 mAmp/cm² and 10.1 V at 41.5°C.

Participants: Izmir Institute of Technology, Chemical Engineering Department  
Funding: State Planning Organization of Turkey  
Contact Person: Assoc. Prof. Dr. Erol Şeker, Izmir Institute of Technology erolseker@iyte.edu.tr

7) Photovoltaic - Fuel Cell Hybrid System for Low-Scale Electricity Production  
Scope and Accomplishments: The main objective of the project is to develop and optimize a low-scale electricity generation system by combining photovoltaic and PEM fuel cells. An original PV field characterization unit has been successfully developed. Experimental optimization procedures for the PV-FC system were satisfactorily outlined and performed.

Participants: Harran University Solar Energy Research Center  
Funding: State Planning Organization of Turkey and Harran University Scientific Research Fund Council (HUBAK)  
Contact Person: Dr. Bülent Yesilata, Harran University, byesilata@harran.edu.tr

8) “Construction of a CVD Reactor for Carbon Nanomaterial Synthesis by CVD Method” and “The Improvement of Reactivity of Single and Multi Wall Carbon Nanotubes by Functionalization by Polymer for Hydrogen Storage and Nanotechnical Applications”
**Scope and Accomplishments:** These projects are related to carbon nanomaterial (CNT) synthesis and their surface modification for obtaining CNT/polymer composites with different techniques. The electrical properties of composites are improved for bipolar plates fabrication.

**Participants:** In collaboration with CNRS-LIMHP (Paris 13 University) for development of new materials for hydrogen storage by adsorption and Nalan Tékin (KOU)

**Funding:** TUBİTAK has funded the projects at a level of €115,000.

**Contact Person:** Dr. Saadet Kayiran Beyaz, saadetkayiran@kocaeli.edu.tr

9) Electrolysis and Sodium-Borohydride (SBH) Related Projects

**Scope and Accomplishments:** On the electrolysis project, the major topic is to obtain hydrogen using less power. Electrode surface treatment and use of catalysts are the new items in the company’s agenda. On SBH Projects, several catalysts have been developed to control the reaction in a way that hydrogen is obtained when required. Several prototypes have been developed to show the concept with varying powers. A 500W SBH based electric generator was developed by Vestel Defence Industries, including the fuel cell.

**Participants:** All the projects have been developed in cooperation with universities

**Funding:** Vestel Defence Industries

**Contact Person:** Ibrahim Pamuk, Deputy General Manager, Vestel Defence Industries, ibrahim.pamuk@vestel.com.tr

10) Catalytic Hydrogen Production from Coal

**Scope and accomplishments:** The objective is to develop coal gasification catalysts. Catalyst formulations and operating conditions are being explored for production of syngas. The operating conditions can be adjusted to release CO as CO₂.

**Participants:** Middle East Technical University, Turkish Coal Enterprises

**Funding:** Funded by Turkish Coal Enterprises and Middle East Technical University

**Contact Person:** Prof. Dr. Deniz Üner, Chemical Engineering Department of Middle East Technical University, uner@metu.edu.tr

11) Photocatalytic Hydrogen Production from Water

**Scope and accomplishments:** The objective is to understand the limits of TiO₂ films and powders for water splitting reactions. TiO₂ nanotubes grown on Ti foils were also used in an H type cell to produce H₂ and O₂ in separate chambers.
**Participants:** Dr. Sadig Guliyev from Vestel Defense Industries and Middle East Technical University (METU)

**Funding:** Funded by TUBITAK and Vestel Defense Industries

**Contact Person:** Prof. Dr. Deniz Üner, Chemical Engineering Department of Middle East Technical University, uner@metu.edu.tr

12) Production of Syngas from Methane using Mesoporous Catalysts Under Time Interrupted Conditions

**Scope and accomplishments:** The objective is to synthesize mesoporous materials to be used in time interrupted conditions for syngas production from methane

**Participants:** Dr. Aysen Yılmaz from Chemistry Department of METU

**Funding:** Funded by Middle East Technical University

**Contact Person:** Prof. Dr. Deniz Üner, Chemical Engineering Department of Middle East Technical University, uner@metu.edu.tr

**REFERENCES**


**CONTACT**

Dr. Alper Sarıoğlan, Aslı Kaytaz

Alper.sarioylan@mam.gov.tr

asli.kaytaz@mam.gov.tr
Mr. Ray Eaton  
Assistant Director, Department of Energy and Climate Change  

GOVERNMENT

A further change to the machinery of government was made in October 2008 with the establishment of a new Department of Energy and Climate Change (DECC). The new Department brings together staff working on energy policy in the Department for Business, Enterprise and Regulatory Reform (BERR) and staff working on climate change mitigation in the Department of the Environment, Food and Rural Affairs (DEFRA). DECC is headed by Ed Miliband. There are plans to bring all the staff together within a single building by the middle of 2009.

The objectives of the new Department are:

- to ensure that our energy is secure, affordable, and efficient;
- to bring about the transition to a low carbon Britain; and
- to achieve an international agreement on climate change at Copenhagen in December 2009.

The Government published a consultation on renewable energy strategy (RES) in June 2008. We face the challenge of meeting our share of the European Union’s target to secure 20% of EU energy (not just electricity) from renewable resources by 2020. The consultation is now closed and will help to inform the Government’s Renewable Energy Strategy, which is expected to be published in spring 2009. The Government is currently consulting on the Heat and Energy Savings Strategy (HES) which will set out the Government’s longer term ambitions for how we use energy in our homes and businesses.

HYDROGEN AND FUEL CELLS STATUS

The last year has been a mixed one for those engaged in hydrogen and fuel cell activities. On the one hand, the recognition of the need for innovative energy technologies to enable us to meet our energy and climate change objectives has never been greater. On the other, there has been a shift away from investment in renewable energy and hydrogen projects by some major energy companies. The credit crunch has made it extremely difficult for companies to secure venture capital funding.

There has been a resurgence of interest in the use of battery electric vehicles (BEVs), partly because they offer a more immediate prospect for commercial deployment than fuel cell vehicles (FCVs). In some ways this should be regarded as a positive development because of the synergies between the two technologies. A fuel cell vehicle is a type of electric vehicle, in which the fuel cell, rather than the battery, takes the main role in powering the vehicle. If battery vehicles can achieve significant market penetration, it would help to drive down the costs of the electric drive chain, which would also be needed for fuel cell vehicles. Some experts see a dual market emerging in the future with small BEVs being used predominantly as city cars (where the limited range would not be a problem) and FCVs for longer journeys. However, it is frequently portrayed as an either/or choice, reflecting a view that there can only ever be one winning technology. A number of vehicle
manufacturers have announced plans for significant investments in BEV production, sometimes accompanied by a reduction in scale of their fuel cell development programs.

Against this background there were some encouraging developments. At the start of 2008, the UK did not have a single hydrogen refuelling station. (The one used for the London part of the EU CUTE bus demonstration programme was decommissioned at the end of the trial.) However, in April 2008, a station was opened on the campus of Birmingham University, closely followed by facilities at Loughborough University (also in the Midlands) and Baglan Energy Park (South Wales). Discussions are underway regarding the possibility of linking these up with additional stations to create a hydrogen highway. The intention would be to make the UK an attractive location for the demonstration and testing of fuel cell vehicles, capitalizing on the skills of the vehicle engineering consultancy sector which has been responsible for UK success in motor sport.

In April 2008, the Loughborough-based UK developer of proton exchange membrane (PEM) fuel cells, Intelligent Energy, successfully completed a three (3) year project with Peugeot Citroen to convert an existing electric vehicle—the Peugeot Partner van—to a fuel cell-hybrid configuration. The project was partly funded by the Technology Strategy Board (TSB). The vehicle, known as the H2Origin, included a 10kW fuel cell and onboard compressed hydrogen stored on an exchangeable rack—an interesting potential alternative for depot serviced vehicles. Peugeot was impressed with the performance of the IE system which operated successfully over the temperature range -20°C to +37°C. The advantage of fuel cell hybridization was shown in the increase in range from 78km for the battery-only vehicle to 300km for the fuel cell hybrid. However, Peugeot has no plans to commercialise this system as the original vehicle is no longer in production. Intelligent Energy is currently involved in another TSB part-funded collaborative project to develop a fuel cell powered Black Taxi Cab, which should be ready for the 2012 Olympic Games in London.

A number of significant announcements were made by companies seeking to develop and commercialise fuel cells for residential combined heat and power (CHP) in partnership with Utilities. Crawley-based Ceres Power is developing its intermediate temperature solid oxide fuel cell (SOFC) in separate collaborations with British Gas and Calor for natural gas and LPG fuelled systems respectively. Ceramic Fuel Cells Ltd is developing its SOFC technology in collaboration with a number of companies in Europe including E.ON in the UK. Intelligent Energy and Scottish and Southern Energy have formed a joint venture company to develop fuel cell based CHP systems for light industrial, commercial and residential markets in the UK and Ireland. Approximately 1.5 million boilers are installed annually in the UK and it is believed that CHP units could take 30% of the market by 2015.

**FUNDING LANDSCAPE**

The UK research and development funding landscape has become more complex recently, due to changes in the machinery of government and the entry of new organisations such as the Energy Technologies Institute (ETI). Fuel cell and hydrogen R&D remains a priority and levels of funding have been maintained or increased. University research is supported by the UK Research Councils which report to the Department for Innovation, Universities and Skills (DIUS). There are currently 3 directed programmes dealing with hydrogen or fuel cells research under the umbrella of SUPERGEN. The UK Sustainable
The Hydrogen Energy Consortium (UK SHEC) has been allocated £5.97m funding for a second phase which will run for four (4) years covering production, storage, integrated systems, and socio-economics. A second consortium has been allocated £5m over 4 years for work on sustainable hydrogen production and socio-economics. The SUPERGEN fuel cells consortium is working to improve the performance and durability of fuel cells.

The Technology Strategy Board is continuing to fund collaborative industrial research and development on fuel cells and hydrogen as part of its technology portfolio. A £10m call for proposals was issued in March 2009. The Department of Energy and Climate Change provides support for demonstrations under the Environmental Transformation Fund (ETF). This is also a competitive process. Currently three hydrogen projects are being supported—a bus project in London, a fuel cell vehicle project at Birmingham University and a stationary power/CHP project at an office of Scottish and Southern Energy.

ENDNOTES

2] DECC website http://www.decc.gov.uk/
4] HES CONDOC http://hes.decc.gov.uk/
5] Birmingham University Hydrogen Station http://news.bbc.co.uk/1/hi/england/west_midlands/7352195.stm
13] Department of Innovation, Universities and Skills http://www.dius.gov.uk/
15] UK SHEC http://www.uk-shec.org.uk/
17] SUPERGEN fuel cells consortium http://www.supergenfuelcells.co.uk/about.html

CONTACT

Ray Eaton
Department of Energy & Climate Change
Bay 216, 1 Victoria Street, London SW1H 0ET
Tel: +44 (0) 20 7215 2650
E-mail: ray.eaton@decc.gsi.gov.uk
INTRODUCTION

The mission of the U.S. Department of Energy (DOE) Hydrogen Program is to reduce petroleum use, greenhouse gas emissions, and air pollution, and to contribute to a more diverse and efficient energy infrastructure by enabling the widespread commercialization of hydrogen and fuel cell technologies. The Program’s key goals are to advance these technologies—through research, development, and validation efforts—to be competitive with current technologies in terms of both cost and performance, and to reduce the institutional and market barriers to their commercialization. In pursuit of these goals, the Program coordinates with industry, academia, national laboratories, and other government agencies. Development of hydrogen and fuel cell technologies can help ensure the security, reliability, and affordability of the U.S. energy supply. Hydrogen from diverse, domestic resources can be used in fuel cell vehicles, central station electric power production, and distributed thermal/electric as well as combined heat and power applications.

KEY TECHNOLOGY BARRIERS

The DOE Hydrogen Program has identified milestones that need to be reached to fulfill its mission. Among these, the Program has further identified a number of “critical path” technology goals that must be achieved to enable the technology readiness of fuel cell vehicles in 2015:

- Hydrogen must be produced from domestic resources for $2.00–$3.00 per gallon gasoline equivalent—delivered and untaxed. (The Program has met the upper range of this cost target, by developing technologies for the distributed reforming of natural gas).1
- On-board hydrogen storage systems must be developed that enable a driving range of greater than 300 miles for most light-duty vehicles while meeting packaging, cost, safety, and performance requirements to be competitive with current vehicles.2
- Polymer electrolyte-membrane (PEM) fuel cell technology must improve in terms of cost and durability, to allow for automotive fuel cell systems that cost $30 per kilowatt, with a durability of 5,000 hours of service, which corresponds to roughly 150,000 miles (240,000 km) of driving. For stationary applications, systems must be able to operate for 40,000 hours at a cost of $750 per kilowatt or less.3

PROGRAM STRATEGY

The Program’s RD&D efforts focus on technologies for light-duty vehicles, distributed power generation, auxiliary power, and portable power applications. DOE-funded activities include cost-shared, public-private partnerships to address the high-risk, critical technology barriers that will impede the widespread use of hydrogen. In addition to technical barriers, the Program is addressing institutional and economic hurdles to the widespread acceptance of hydrogen technology. The Program’s strategy is broad and comprehensive, addressing the full range of barriers, from basic research needs to consumer acceptance, for a wide array of applications. Underlying this strategy is the belief that the market success of one application will help pave the way for success in other areas through
increased investment by industry, cost reductions achieved through economies of scale in manufacturing, the growth of a domestic supplier base, and increased public awareness and consumer confidence.

PROGRAM ACTIVITIES

DOE is funding a balanced program of basic and applied research, development, and demonstration activities that will provide the basis for the near, mid, and long-term production, delivery, storage, and use of hydrogen derived from fossil, nuclear, and renewable sources. It is also conducting activities in manufacturing R&D; safety, codes and standards; systems analysis and market transformation, as well as public outreach and education activities. Together, these activities form an integrated effort to enable hydrogen and fuel cell commercialization.

2008 HIGHLIGHTS

PROGRAMMATIC, PLANNING, AND EXTERNAL REVIEW

Budget

![Graph showing budget allocations]

**Table 1. Office of Energy Efficiency and Renewable Energy (EERE) Hydrogen Budget**

In FY 2008, the DOE Hydrogen Program competitively selected many new projects, including:

- Eight projects ($18 million over three years; $26.4 million with cost share) to conduct research, development, and demonstration activities in hydrogen production and delivery, including hydrogen compression, off-board storage, liquefaction, and electrolysis.
- Ten projects (up to $15.3 million federal, plus cost sharing, over five years) to develop novel hydrogen storage materials, develop efficient methods for regeneration of hydrogen storage materials, and increase hydrogen binding energies to enable close to room-temperature hydrogen storage at nominal pressure.
- Thirteen projects ($4.4 million over up to three years; $5.2 million with cost share) in the areas of state and local government outreach, early deployment and education, and university programs.

**Consumption**
*(Quadrillion Btu, 2008)*

- **Fossil Fuels**
  - 83.436 (84.021% of Total Consumption)
- **Nuclear Electric Power**
  - 8.455 (8.514% of Total Consumption)
- **Renewable Energy**
  - 7.300 (7.351% of total consumption)
- **Total Consumption**
  - 99.304

**Electricity**

- **Production**
  - 4.167 trillion kWh (2007 est.)
- **Consumption**
  - 3.892 trillion kWh (2007 est.)

2 [http://www.eia.doe.gov/emeu/aer/overview.html](http://www.eia.doe.gov/emeu/aer/overview.html)
“Critical Path” Technology Goals

Hydrogen must be produced from domestic resources for $2.00–$3.00 per gallon gasoline equivalent—delivered and untaxed (the Program has met the upper range of this cost target, by developing technologies for the distributed reforming of natural gas).

On-board hydrogen storage systems must be developed that enable a driving range of greater than 300 miles for most light-duty vehicles while meeting packaging, cost, safety, and performance requirements to be competitive with current vehicles.

Polymer electrolyte-membrane (PEM) fuel cell technology must improve in terms of cost and durability, to allow for automotive fuel cell systems that cost $30 per kilowatt, with a durability of 5,000 hours of service, which corresponds to roughly 150,000 miles (240,000 km) of driving. For stationary applications, systems must be able to operate for 40,000 hours at a cost of $750 per kilowatt or less.\(^3\)

- One project (anticipated for up to 3 years; $0.3 million for H-prize administration; $1.0 million for the initial hydrogen storage H-prize) to administer and advertise the H-prize competitions, raise funds to contribute to the cash prizes, and work with DOE to develop criteria for the selection of judges and prize winners.
- One project ($0.45 million over three years) in electrolyzers for hydrogen production from nuclear power plants.
- Six projects ($5.5 million over two to three years; $7.5 million with cost share) in hydrogen production from coal.
- Five projects ($12.8 million over four years; $21.7 million with cost share) in research and development of manufacturing processes for fuel cell and hydrogen storage systems.
- In June 2008, the Program announced a new funding opportunity soliciting applicants to conduct R&D in advanced fuel cell technology. This solicitation concentrated on the major topics that need to be addressed to advance the development and use of fuel cells for automotive, stationary, and portable power applications; to demonstrate fuel cells in distributed energy systems; and to support market transformation projects that provide real-world operation data. Total estimated funding available is $130 million, pending congressional appropriations, with an expectation of about 50 selected projects and a private sector cost share of approximately $40 million. The solicitation closed in August 2008. Selections are expected in March 2009.
- The Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) was created in 2006 to advise the U.S. Secretary of Energy on issues related to the development of hydrogen and fuel cell technologies and to provide recommendations regarding DOE’s programs, plans, and activities, as well as safety, economic, and environmental issues related to hydrogen. The Secretary of Energy’s First Biennial Report to Congress Responding to Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) Findings and Recommendations during Fiscal Year 2007 was released in December 2008. The report describes HTAC’s recommendations, addresses how DOE will implement those recommendations, and provides an explanation for those recommendations that will not be implemented.\(^4\)
- The National Research Council (NRC) published its Review of the Research Program of the FreedomCAR and Fuel Partnership: Second Report. The Partnership is a collaborative effort established by DOE to conduct the pre-competitive, high-risk research needed to develop the technologies for deploying vehicles and infrastructure that will reduce the nation’s dependence on imported oil and minimize harmful emissions. In the report, the NRC found that the Partnership is “well planned, organized, and managed,” and that “there has been significant progress in most areas since the Phase I report.” Recommendations include continuing support for hydrogen storage and fuel cell research; continuing studies of the transition to hydrogen, extended into 2030–2035; and maintaining adequate support for technical validation.
- The NRC conducted and published a study to determine the investments in R&D, demonstrations, education, and infrastructure that will be required for the development of fuel cell technologies and for the successful transition from petroleum to hydrogen vehicles in a significant percentage of the U.S. vehicle market by 2020. The report, Transitions to Alternative Transportation Technologies: A Focus on Hydrogen, found that fuel cell vehicles and hydrogen production technologies could be ready for commercialization in the 2015–2020 timeframe, that up to 2 million hydrogen fuel cell vehicles that could be operating by 2020, and that by 2050 they could account for more than 80 percent of new vehicles entering the fleet.
The Program held its Annual Merit Review and Peer Evaluation Meeting on June 9–13, 2008 in Arlington, Virginia. Over 1,000 people attended the review, and 295 projects were presented, of which 232 were peer-reviewed. The Annual Merit Review provides an opportunity for the Program not only to report its accomplishments and progress, but also to obtain an expert peer review of the projects it supports. DOE uses these evaluations to make project funding decisions for the upcoming fiscal year. The next review will be held May 18–22, 2009, in Arlington, Virginia.

TECHNICAL ACCOMPLISHMENTS

In FY 2008, 11 new patents were issued for discoveries or technologies developed in DOE Hydrogen Program projects; 39 more applications were filed or are in the process of being awarded.

PRODUCTION AND DELIVERY

Renewable-Based Hydrogen. Progress made this year in reforming bio-fuels helped to reduce the cost of bio-derived hydrogen. The National Renewable Energy Laboratory (NREL) has improved hydrogen yield and system efficiency of bio-oil reforming. Similarly, Ohio State University (OSU) has demonstrated H₂ yields greater than 90% during bio-ethanol steam reforming. Analysis shows that, with these improvements, the NREL and OSU processes have the potential to meet the 2019 hydrogen production cost target of $3.00/gasoline gallon equivalent including delivery. Cost projections for the active solar thermochemical cycles have been reduced from about $10/gge to below $5/gge and are showing the potential to meet the cost target as well.

Another pathway to renewable-based hydrogen is electrolysis powered from renewable energy sources. Giner Electrochemical Systems, LLC has improved stack efficiency from 61% (400 psi) to 67% (1,200 psi) and has tested a new dimensionally-stabilized membrane (DSM) in a single cell which shows an efficiency of 74%. The DSM is about 1/10 the cost of the current Nafion®-based one.

HYDROGEN DELIVERY

Researchers continued to make major advances in modeling hydrogen delivery infrastructure through the H2A Hydrogen Delivery Model, expanding and improving the analysis of the current costs of hydrogen delivery using pipelines, liquid trucks, and gaseous trucks. In addition, advances have been made this year in reducing hydrogen leakage during delivery. Savannah River National Laboratory (SRNL) and Oak Ridge National Laboratory (ORNL) completed leakage measurements on fiberglass-reinforced plastic pipelines (FRPs) and verified that the leakage rate was less than 0.5%.

Figure 1. Cost of hydrogen (delivered): status and targets in $/gge, untaxed
Progress was made in all three major classes of materials under investigation: hydrogen adsorbents, reversible metal hydrides, and chemical hydrogen carriers. These achievements involved improvements in operational performance, not just in storage capacity. Examples include the following:

- Metal organic framework materials with open-metal sites have been demonstrated to have initial $H_2$ binding enthalpies of between 8 and 12 kJ/mol. Such binding energies may potentially increase the low-pressure $H_2$-capacity by up to 75% over adsorbents with typical physisorption binding enthalpies of ~5–6 kJ/mol. These tailored materials have volumetric hydrogen densities of 24–45 g/L (crystal, not system, densities).

- Mechanistic studies enabled the identification of non-platinum group metal (PGM) heterogeneous catalysts that increased the hydrogen release rate from ammonia borane (NH$_3$BH$_3$, AB) by a factor of two, which can meet the DOE target from a material perspective. The increased kinetics, especially for the release of the second equivalent of hydrogen, effectively increased the capacity to greater than 9 wt% $H_2$ at 70°C.

- Hydrogen storage materials, such as LiBH$_4$, have been incorporated into carbon aerogel scaffolds with improvements in sorption properties. For example, LiBH$_4$ incorporated into a 13 nm scaffold achieved a 60-fold increase in desorption rates, an increase from 0.2 wt%/h for a bulk reference sample to 12.5 wt%/h for the incorporated sample at 300°C, demonstrating that DOE rate targets could be achieved.

- An improved insulation method has led to doubling of the dormancy time for cryocompressed $H_2$. This approach offers the advantage of higher gravimetric and volumetric densities than ambient compressed $H_2$ but requires an insulated container.
FUEL CELLS

- Significant advances were made in increasing the durability of fuel cell membranes and catalysts. 3M has mechanically stabilized the membrane used in its MEA, extending its durability in the lab to over 7,300 hours with voltage cycling. This MEA has the potential to meet the DOE 2010 target of 5,000 hours in an automotive fuel cell system. In addition, the alloy catalyst used for this MEA is approaching the 2010 target for total platinum content (g/kW).

- The cost of 80-kW fuel cell systems was reduced from $94/kW in 2007 to $73/kW, projected to high-volume manufacturing (500,000 systems/year), as shown in Figure 3. This reduction is largely due to the lower platinum content of alloy catalysts.

- Case Western Reserve University demonstrated materials with the potential to meet proton conductivity targets under the most severe conditions, and Giner Electrochemical Systems, LLC has met an interim target for proton conductivity under less severe conditions using dimensionally stable membranes.

![Figure 3. Cost of automotive fuel cell system, projected to high-volume manufacturing of 500,000 units per year](image)

LEARNING DEMONSTRATIONS

- The fourth full year of data collection was completed. The project continued to place second generation vehicles in service and to add hydrogen fueling stations, bringing the number of fuel cell vehicles in the project to 122 and the number of fueling stations to 16. (Hydrogen for the fueling stations is being supplied by truck and through on-site electrolysis or natural gas reforming.)

- More than 50 composite data products were generated. (These ranges of technical values do not identify which company provided the information.) The composite data products cover a number of parameters.

MARKET TRANSFORMATION

- Collaboration with federal agencies enabled the deployment of fuel cell-powered forklifts at Defense Logistics Agency distribution centers across the country; fuel cell systems that provide backup power to military installations in California and South Carolina; fuel cell vehicles used in regular mail delivery service by the U.S. Postal Service; and fuel cell backup power systems at remote telecommunication towers.
SAFETY, CODES & STANDARDS

- The Technical Reference for Hydrogen Compatibility of Materials expanded to include martensitic stainless steels (e.g., 400-series, 17-4 PH), semi-austenitic stainless steels (e.g., 17-7 PH), and polymers.

- Online Permitting Compendium for Hydrogen Facilities, a one-stop information resource to facilitate the permitting of hydrogen fueling stations and stationary fuel cell installations, developed and released.

- A technically traceable, risk-informed approach for separation distances for hydrogen fueling stations was introduced to the NFPA 55 and NFPA 2 code committees.

EDUCATION AND ANALYSIS

- “Introduction to Hydrogen Safety for First Responders” updated to include an audio narration, an extended video explaining the basic properties of hydrogen, an expanded codes and standards module, an expanded stationary facilities section, and the addition of early market fuel cell information on specialty vehicles.

- Deployed radio spots across the country, collaborating with the Orlando Magic to promote “Increase Your H2IQ.” Also launched a MySpace page targeted at teens and young adults as part of the “Increase Your H2IQ Public Information Program,” and disseminated the “H2 Educate!” middle school curriculum materials through one-day teacher training workshops. The Program is completing an iterative prototype testing and revision of the “HyTEC” high school curriculum as well.

- The 2010–2025 Scenario Analysis for Hydrogen Fuel Cell Vehicles and Infrastructure report were published. The report includes feedback from industry, academia, and national models on vehicle penetration scenarios and the requisite infrastructure to support these scenarios. The analysis suggests that costs over the early transition period are feasible, between $10 billion and $50 billion over 14 years.
• Analysis was also conducted to understand the impacts of government purchase programs on fuel cell cost and well-to-wheels greenhouse gas reductions from early market adoption of fuel cells for distributed power and forklifts. Using conservative assumptions for scale economies and learning-by-doing, the analysis found that a federal acquisition program could catalyze a sustainable North American polymer electrolyte membrane (PEM) fuel cell industry, driving down costs enough to make fuel cell products competitive with incumbent technologies by 2015.

• The Macro-System Model was completed, linking models of different architecture and enabling complete hydrogen pathway analysis. The model, which was peer-reviewed, was used to analyze delivered hydrogen cost, well-to-wheels parameters, and hydrogen losses for several pathways.¹⁴

• The results of nine analyses using the Macro-System Model were compared to results from the European Commission-funded HyWAYS project to analyze hydrogen pathway costs and well-to-wheels oil use and greenhouse gas emissions. The comparison showed that the results were fundamentally the same, although there were discrepancies, such as a financial focus on business cases in the Macro-System Model as compared to a focus on policy support in the HyWAYS project.¹⁵

REFERENCES
For further information, the reader is invited to visit the DOE Hydrogen Program website portal, www.hydrogen.energy.gov, and refer to many of its key documents.

ENDNOTES
HYDROGEN IMPLEMENTING AGREEMENT


CONTACT

Dr. Carole Read
carole.read@ee.doe.gov
202-586-3152