IEA Hydrogen Task 18: Evaluation of Integrated Demonstration Systems

Susan Schoenung
Longitude 122 West, Inc.
June 9, 2008

This presentation does not contain any proprietary, confidential, or otherwise restricted information
Overview of IEA Integrated Systems Project (Task 18)

<table>
<thead>
<tr>
<th>Timeline</th>
<th>Barriers Addressed from MYPP</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Project start date: January 1, 2004</td>
<td>• Tech validation</td>
</tr>
<tr>
<td>• Project end date: December 31, 2009</td>
<td>– Storage</td>
</tr>
<tr>
<td>• Percent complete: ~70%</td>
<td>– Hydrogen Refueling Infrastructure</td>
</tr>
<tr>
<td></td>
<td>– Codes and Standards</td>
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<tr>
<td></td>
<td>– Hydrogen from Renewable Sources</td>
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<td></td>
<td>– Hydrogen and Electricity Co-Production</td>
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<tr>
<td></td>
<td>• Safety, codes and standards</td>
</tr>
<tr>
<td></td>
<td>– Conflicts between domestic and international C&amp;S</td>
</tr>
<tr>
<td></td>
<td>– Large Footprint requirements for hydrogen fueling stations</td>
</tr>
<tr>
<td></td>
<td>• Systems analysis</td>
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<tr>
<td></td>
<td>– Lack of consistent data, assumptions and guidelines</td>
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<tr>
<td></td>
<td>– Lack of consensus on modeling tools</td>
</tr>
</tbody>
</table>

Budget

<table>
<thead>
<tr>
<th>Total project funding</th>
<th>Partners / Collaborators</th>
</tr>
</thead>
<tbody>
<tr>
<td>• DOE share: $625K</td>
<td>• International Energy Agency, Hydrogen Implementing Agreement</td>
</tr>
<tr>
<td>• Contractor co-share: contributed labor (~$125K)</td>
<td>Task 18 members:</td>
</tr>
<tr>
<td>• International partners: 42 FTE</td>
<td>• Fifteen countries</td>
</tr>
<tr>
<td>• Funding received in FY06: $125K</td>
<td>• European Commission</td>
</tr>
<tr>
<td>• Funding for FY07: $170K</td>
<td>• Sandia National Laboratories (Lutz, Stewart)</td>
</tr>
</tbody>
</table>
Participants of IEA Hydrogen Task 18

Canada
Natural Resources Canada

Japan
AIST Laboratory

Italy
ENEA

Norway
IFE

Spain
INTA

Sweden
EO.N.

New Zealand
Industrial Research

Switzerland
EMPA

Canada

Japan

Italy

Norway

Spain

Sweden

New Zealand

Switzerland

United Kingdom
EA Technology

United States
Department of Energy

Denmark
Gas Technology Center

Germany
Research Center Jülich

New Members: Turkey, UNIDO-ICHET
Objectives of IEA Hydrogen Task 18

• Operate international working group to address hydrogen technology integration in member countries.

• Establish database of international hydrogen development activities, capabilities and demonstrations

• Evaluate hydrogen systems performance, cost, safety, and Codes and Standards permitting policies

• Disseminate lessons learned

• Participate in the International Energy Agency Hydrogen Implementing Agreement hydrogen resources study: “Where will the hydrogen come from?”
Upcoming Milestones

• Meetings:
  ➢ June 2008: Spring Executive Committee Meeting
  ➢ September 2008: Fall Experts Meeting
  ➢ November 2008: Fall Executive Committee Meeting

• Deliverables:
  ➢ May 2008: Semi-annual report
  ➢ October 2008: Semi-annual report
  ➢ January 2009: Annual report

• There are no go-no-go decision points
Approach => Collaboration

• Members of IEA Hydrogen Implementing Agreement Task 18 work collaboratively within three subtasks:
  – Subtask A: Information Base Development
  – Subtask B: Demonstration Project Evaluation
  – Subtask C: Synthesis and Lessons Learned

• **U.S. DOE Sponsors the Operating Agent; Subtask Leaders are sponsored by US, Canada and Spain**

• Members/experts meet twice per year to review progress; ongoing collaboration is carried out electronically

• Members deliver progress reports annually
Approach => Collaboration

- **Subtask A: Members Responsibilities:**
  - Deliver to searchable web portal national documents and national data

- **Subtask B: Members Responsibilities:**
  - Work as a group to establish a list of desired data for each project
  - Bring to the group data from that country's project
  - Clarify with the data provider any limitations on data release or use
  - Make use of appropriate modeling & analysis tool for selected projects
  - Provide assessment & evaluation of project based on analysis results

- **Subtask C: Members Responsibilities:**
  - Contribute Case Studies
  - Synthesize Lessons Learned
  - Provide trend analysis
Technical Accomplishments/Progress/Results

• Subtask A: Database contains over 300 documents (publicly accessible)
  – Includes Hydrogen resources database
• Subtask B: Analysis of 8 new projects underway
  – Spain - Renewables to Hydrogen project (RES2H2)
  – Greece - Center for Renewable Energy Studies
  – Italy - Ecological House
  – Hawaii - Hydrogen wind farm and hydrogen for park buses
  – Denmark - Lolland hydrogen community
  – Spain - Expo 2008 buses and fueling station
  – Norway - HyNor fueling station, hydrogen highway node
  – US/UK - Intelligent Energy bio-reformer / fuel cell system
• All assessments include documentation of safety, codes and standards, and permitting requirements
• Case studies: 3 new underway within the last year
  – CRES (Greece)
  – Peterhead power station with carbon capture (UK)
  – Fuel cell boat (Netherlands)
Subtask A: Information Base Development

= Public Information Dissemination

- National plans
- Demonstration progress
- Hydrogen resources
- Vendors
- Utilization rates
- Geographic information
- Refueling projections
- Costs
- Infrastructure
- Codes and Standards
- Economic analysis

Annex 18 website: Searchable portal
Subtask A: Information Bases

- Task 18 (Private)
- Subtask C (initially private)
- Subtask B (Private)
- Subtask A (Private)
- Public Site
  - Case Studies
  - External Links
  - National Documents (public, Dec. 06)
  - National Organizations (public, Dec. 07)
  - National Projects (public, Dec. 07)
- HySociety Technology Database
- Hydrogen Production (Resource Study)
- New information bases proposed
Subtask B: Modeling, Analysis and Evaluation of Demo Projects

Technical:
- Performance (efficiencies, operating hours)
- Economics (investments, O&M → COE)
- Environment (emissions, fuel savings, RE-penetration)

Quantitative Analysis

Modeling Tools:
- Sandia National Laboratories: Simulink, H2A
- IFE, Norway: Hydrogems
- Hidrogeno Aragon: HOGA, Hysys
- CRES: HOMER

Quantitative Modeling

Non-Technical:
- System Design (components, technology & market readiness, permitting & safety)
- Project Design (planning & management)
- Overall Performance (user-friendliness, utilization)

Qualitative Analysis
## Subtask B Analysis Project Portfolio

<table>
<thead>
<tr>
<th>Country</th>
<th>Projects</th>
<th>Location</th>
<th>Modeling focus</th>
<th>Modeling being done by:</th>
<th>Simulation / model in use</th>
<th>Evaluation status</th>
<th>Estimated Completion date</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Refueling Stations</strong></td>
<td></td>
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</tr>
<tr>
<td>Sweden</td>
<td>Hydrogen filling station (re grid/electrolysis)</td>
<td>Malmö</td>
<td>System sizing</td>
<td>IFE</td>
<td>Hydrogems</td>
<td>Expansion in progress</td>
<td>End 2008</td>
</tr>
<tr>
<td>Spain</td>
<td>Hydrogen filling station at Expo 2008 (grid/electrolysis)</td>
<td>Zaragosa</td>
<td>Station and bus performance</td>
<td>Zaragosa University</td>
<td>Hysys</td>
<td>Data acquisition system in design</td>
<td>End 2009</td>
</tr>
<tr>
<td>Norway</td>
<td>Hydrogen filling station (grid/electrolysis), HyNor node</td>
<td>Romerike (Oslo)</td>
<td>System performance</td>
<td>IFE</td>
<td>Hydrogems</td>
<td>Initial stages</td>
<td>2009</td>
</tr>
<tr>
<td>Canada</td>
<td>Pacific Spirit station</td>
<td>Vancouver</td>
<td>Compressor / Performance</td>
<td>IFE</td>
<td>Hydrogens</td>
<td>In negotiation</td>
<td>2008</td>
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<tr>
<td><strong>Grid-connected or stand-alone power systems</strong></td>
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<tr>
<td>Spain</td>
<td>RES2H2 (combined wind power and desalination)</td>
<td>Gran Canaria</td>
<td>System performance</td>
<td>INTA</td>
<td>Hysys / HOGA</td>
<td>In progress</td>
<td>2009</td>
</tr>
<tr>
<td>Denmark</td>
<td>Island power</td>
<td>Lolland</td>
<td>System performance</td>
<td>HydrogenAragon</td>
<td>HOGA</td>
<td>In progress</td>
<td>2009</td>
</tr>
<tr>
<td>Italy</td>
<td>Hydrogen from the Sun</td>
<td>Brunate</td>
<td>Control strategy</td>
<td>Sandia, Emma Stewart</td>
<td>Simulink</td>
<td>In progress</td>
<td>2008</td>
</tr>
<tr>
<td>UK</td>
<td>RE/H2-project (HARI)</td>
<td>Loughborough</td>
<td>Economic performance</td>
<td>EA</td>
<td>Transys</td>
<td>Continuing analysis and dispatch strategy</td>
<td>2009</td>
</tr>
<tr>
<td><strong>Combined fuel and electricity generation</strong></td>
<td></td>
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</tr>
<tr>
<td>USA/UK</td>
<td>Hydrogen, energy, CHP refuelling station (bio fuels)</td>
<td>US / UK</td>
<td>System performance</td>
<td>Sandia, Intelligent Energy</td>
<td>Simulink</td>
<td>In definition</td>
<td>2009</td>
</tr>
<tr>
<td>USA</td>
<td>Hydrogen power park (RE)</td>
<td>Hawaii</td>
<td>Performance, economics</td>
<td>Sandia, Andy Lutz</td>
<td>Simulink / H2A</td>
<td>In progress</td>
<td>2009</td>
</tr>
</tbody>
</table>
Project / Member Locations

- UK
- NORWAY
- SWEDEN
- JAPAN
- US
- SPAIN
- ITALY
- DENMARK
- GERMANY
- FRANCE
- NEW ZEALAND
- CANADA
- ICELAND
- GREECE
- JAPAN
- US
- SPAIN
- FRANCE
- ITALY
- DENMARK
- GERMANY
- FRANCE
- NEW ZEALAND
The Italian Hydrogen House Simulation – Emma Stewart, Andy Lutz

- High pressure alkaline electrolyser
  - Produces 1 NM$^3$/hr H$_2$ at 200 bar
- 5 kW PEM fuel cell
- 3000 Ah battery
- 30 NM$^3$ Hydrogen stored in metal hydride
- 120 NM$^3$ Hydrogen in storage cylinders
- 11 kW peak power available from photovoltaic panels

Main Tasks
- Control System Development
  - Load Management and Hydrogen Control
  - Event monitoring and control
- Analysis of demonstration economics
Hydrogen flow and hybrid battery/fuel cell control systems are being designed using Simulink

- **Hydrogen Flow Control System Methodology**
  - Goal of house is to analyze metal hydride (MH) performance and applicability
  - Optimization of H2 flow depends on load and fuel cell operation strategy
  - Designed using fuzzy logic toolbox

- **Hybrid Battery/Fuel Cell Control System Methodology**
  - Goals of house are to demonstrate fuel cell technology and run a grid-independent system
  - Optimization of energy management governs the system economics
  - Cost of grid electricity plays a large part in the cost of H2
  - New strategy simulated using proportional-integral control of a DC/DC converter
System economics show that grid-independent operation affects cost of electricity

**Hydrogen Cost:**
- Analysis based on off-peak power rates (0.05 $/kWh)
  - Electricity cost is 70% of total cost-of-hydrogen
  - Capital is 25% of total

<table>
<thead>
<tr>
<th>CONTRIBUTION</th>
<th>COH ($/kg-H₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital</td>
<td>2.37</td>
</tr>
<tr>
<td>Feedstock (electricity)</td>
<td>6.64</td>
</tr>
<tr>
<td>O&amp;M</td>
<td>0.34</td>
</tr>
<tr>
<td>TOTAL</td>
<td>9.36</td>
</tr>
</tbody>
</table>

**Electricity Cost:**
- Electricity produced from fuel cell at 0.63 $/kWh
- Cost of supplemental grid energy is 7.20 $/day (144 kWh/day) when control system is not optimized for grid-independent operation
- Optimization using new control system shows how the system can operate independently from the grid (the goal of this demonstration)
Technology Assessment – Hawaii H2 Power Park
HNEI: Rick Rocheleau, Mitch Ewan, Severine Busquet

Big Island Hydrogen Sites
   10 kW wind turbine + 10 kW PV; Load-following, pressurized PEM electrolyzer.
   5 kW PEM Fuel Cell

2. Hawaii Gateway Energy Center
   Rented lab + 4,000 sf pad area
   Micro-grid component testing
   Energy storage testing

3. Hawaii Volcanoes National Park
   5 hydrogen shuttle buses
   Geothermal hydrogen
   Hydrogen fueling
Kahua Ranch PV-Wind-Hydrogen System

- Integrates PV, wind, batteries, electrolyzer, and fuel cell with remote operation via internet
- Validates emerging hydrogen and renewable technologies
- Partners include Kahua Ranch, PICHTR, Plug Power, and EH!

- Sandia analysis will examine:
  - System efficiency
  - Wind & solar capacity factors
  - Cost of H2 & electricity

- Modeling approach:
  - Use average wind speed (pdf shown)
  - Wind turbine power map

![Probability Density Function]

- Frequency (%)

- Wind Speed (m/s)
Fuel Cell model specified by IE data

- Efficiency vs Power curve used in simple model for system analysis
  - Net efficiency = 53%
  - Includes parasitic power and H2 purge
  - Not including DC converter
- Detailed FC model used IE’s V-I curve to compare gross efficiency
  - Model uses a fit to V-I data
  - Balances mass, energy
  - Model recovers the observed efficiency data
Exergy analysis quantified inefficiency

- Exergy balance for reformer shows destruction of useful energy
- Inputs:
  - Fuel, Retentate, Work
- Outputs:
  - Syngas, Exhaust
- Difference is exergy destroyed by irreversible processes
RES2H2 Wind-Hydrogen-Desalination Plant

Project objective: Integration of H2, wind and the desalination plant
Modeling objective: Performance evaluation and optimization
RES2H2 Gran Canaria System

- System commissioned 25 October 2007
- Operations underway
- Data gathering and Performance analysis in Subtask B
- Optimization evaluation using HOGA model
Hydrogen System Optimization Analysis

Hybrid Optimization by Genetic Algorithms

HOGA 1.92
Rodolfo Dufo López - José Luis Bernal Agustín

http://task18b.hidrogenoaragon.org/
Phase 1 Subtask B Final Report
System Studies - Optimization for the Future

FINAL REPORT

for

IEA – International Energy Agency
HIA – Hydrogen Implementing Agreement

Task 18: Integrated System Evaluations
Subtask B: Demonstration Project Evaluations

Prepared by:

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November 2007
### Subtask C: Synthesis and Learning

<table>
<thead>
<tr>
<th><strong>Activity 1: Documenting Experiences/ Practical Lessons Learned/ Guidance</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Categorization of the project portfolio and case studies</td>
</tr>
<tr>
<td>B. Categorize/ outline a guidebook.</td>
</tr>
<tr>
<td>C. Complete guidebook</td>
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</table>

<table>
<thead>
<tr>
<th><strong>Activity 2: Case Studies</strong></th>
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<tbody>
<tr>
<td>A. Complete draft of new template</td>
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<tr>
<td>B. Complete list of new case studies and completion dates</td>
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<tr>
<td>C. New case studies include:</td>
</tr>
<tr>
<td>i. Spain,</td>
</tr>
<tr>
<td>ii. Greece,</td>
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<tr>
<td>iii. Netherlands</td>
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<tr>
<td>iv. Etc</td>
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</tbody>
</table>

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<thead>
<tr>
<th><strong>Activity 3: Trend analysis</strong></th>
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</thead>
<tbody>
<tr>
<td>A. Categorize trend attributes for trend analysis</td>
</tr>
<tr>
<td>B. Publish interim trend analysis reports</td>
</tr>
<tr>
<td>i. Interim Report</td>
</tr>
<tr>
<td>ii. Interim Report</td>
</tr>
<tr>
<td>iii. Interim Report</td>
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<tr>
<td>C. Publish final trend analysis report</td>
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</table>

<table>
<thead>
<tr>
<th><strong>Activity 4: Comparative &amp; Technical Analysis</strong></th>
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</thead>
<tbody>
<tr>
<td>A. Comparisons of:</td>
</tr>
<tr>
<td>i. Electrolyzers</td>
</tr>
<tr>
<td>ii. Permitting and Safety Experiences</td>
</tr>
<tr>
<td>iii. Control Systems &amp; Strategies</td>
</tr>
<tr>
<td>iv. Literature Review of Grid Connected Stationary applications</td>
</tr>
<tr>
<td>v. Comparison of Stationary systems</td>
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</table>

<table>
<thead>
<tr>
<th><strong>Activity 5: Outreach/ Dissemination Activities</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Prepare a list of papers, reports and schedule where/when for delivery.</td>
</tr>
<tr>
<td>B. Decide on outreach venues for our high level findings</td>
</tr>
<tr>
<td>C. Regularly publish on our public site high level findings of our work.</td>
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</table>

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<thead>
<tr>
<th><strong>Activity 6: Regional &amp; National Plans</strong></th>
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<tbody>
<tr>
<td>A. Develop and publish comparison of different types of government support initiatives</td>
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</table>

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<thead>
<tr>
<th><strong>Activity 7: Economic Analysis</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Cost saving potential for present &amp; future</td>
</tr>
<tr>
<td>B. Niche market opportunities</td>
</tr>
</tbody>
</table>
Subtask C: Early Outcomes

Funding and Co-ordination of Projects Survey

Number of Companies

Number of companies developing hydrogen projects in different countries.

Government spending

Government spending on hydrogen projects
<table>
<thead>
<tr>
<th>Country</th>
<th>Projects</th>
<th>Location / Site Description</th>
<th>Hydrogen Storage</th>
<th>Permitting authority: Safety Requirements / Codes and Standards</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Refueling Stations</strong></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Sweden</td>
<td>Hydrogen filling station (re grid/electrolysis)</td>
<td>Malmö / Industrial site, bus yard</td>
<td></td>
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<tr>
<td>Spain</td>
<td>Hydrogen filling station at Expo 2008 (grid/electrolysis)</td>
<td>Zaragosa / Public fair grounds</td>
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</tr>
<tr>
<td>Norway</td>
<td>Hydrogen filling station (grid/electrolysis), HyNor node</td>
<td>Romerike (Oslo) / public fueling station</td>
<td></td>
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<tr>
<td>Canada</td>
<td>Pacific Spirit station</td>
<td>Vancouver / private laboratory site</td>
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<tr>
<td><strong>Grid-connected or stand-alone power systems</strong></td>
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<tr>
<td>Spain</td>
<td>RES2H2 (combined wind power and desalination)</td>
<td>Gran Canaria / industrial laboratory facility</td>
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<tr>
<td>Denmark</td>
<td>Island power</td>
<td>Lolland / residential community</td>
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<tr>
<td>Italy</td>
<td>Hydrogen from the Sun</td>
<td>Brunate / private home</td>
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</tr>
<tr>
<td>UK</td>
<td>RE/H2-project (HARI)</td>
<td>Loughborough / private estate</td>
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<tr>
<td><strong>Combined fuel and electricity generation</strong></td>
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<tr>
<td>USA/UK</td>
<td>Hydrogen, energy, CHP refuelling station (bio fuels)</td>
<td>US / UK; site TBD</td>
<td></td>
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</tr>
<tr>
<td>USA</td>
<td>Hydrogen power park (RE)</td>
<td>Hawaii / Research laboratory, National Park</td>
<td></td>
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</tbody>
</table>

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Future Work: Plans for 2008-2009

Technical progress plans

• Completion of analysis: “The Ecological House” in Brunate, Italy (Joint with Sandia National Laboratories); RES2H2, Spain.
• Continue analysis: Intelligent Energy and Hawaii projects; HyNOR and Zaragosa bus refueling stations.
• Case studies: German Clean Energy Project; Lolland Hydrogen Community.
• “Lessons Learned” tasks; trend analysis; guidebook assessment
• Hydrogen resources literature review
• Financial survey
• Remote communities survey

Management plans

• Task Experts meet twice per year; fall 2008 meeting is scheduled for Copenhagen; spring 2009 meeting is tentatively planned for Germany
• Operating agent meets twice a year with Executive Committee; spring 2008 meeting in Australia; fall 2008 meeting in Greece in November
• Semi-annual reports due in October and April, annual in January
2008 joint Denmark / Sweden meeting

- Danish micro-grid at Lolland hydrogen community is Task 18 modeling and evaluation project.
- Hythane bus expansion / fueling station at Malmö.
Relationship to Other International Hydrogen Activities

Task 18: Evaluation of Integrated Systems

Small Reformers (Task 23)
- Modeling and analysis
- Database

Wind Integration (Task 24)

Safety (Task 19)

IPHE Demonstration Working Group collaboration

Common demonstration project
Summary

Relevance: Technology validation, modeling and analysis, consistent permitting, especially with regard to footprints

Approach: Collaboration among member nations of IEA-HIA (16 nations); IPHE

Technical accomplishments: Database of documents and vendors; Design tools for system optimization; lessons learned; Financial survey; Remote communities survey

Future Plans: Complete analysis of new projects; control strategies for economic performance; more lessons learned; and trend analysis
Publications and Presentations

2007 Fuel Cell Seminar

WHEC 2008 Submittals
• Emma M. Stewart, Susan Schoenung, Maria Chiesa, Andy Lutz, and Andrew Cruden, “Modeling, Analysis and Control System Development for the Italian Hydrogen House”
• Ismael Aso, Luis Correas, Rodolfo Dufo, José Luis Bernal, and Susan Schoenung, “Demand side management in hybrid systems with hydrogen storage in several demand scenarios”
• Ismael Aso, Luis Correas, Leire Romero, Jose Angel Peña, and Pablo Marcuello, “Zaragoza EXPO 2008 hydrogen fuelling station: Simulation and optimization of process variables and strategies in different scenarios”
• Øystein Ulleberg, Torgeir Nakken, and Arnaud Eté, “The Utsira Wind/Hydrogen Demonstration System in Norway: An Evaluation of the System Design and Operation”


Public Website: www.port-h2.com/IEA-Annex-18
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