International Experience in Fuel Cells and Hydrogen for Electric Power Applications

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Presentation Outline

• IEA Hydrogen Implementing Agreement Task 18: Evaluation of Integrated Hydrogen Systems
• Hydrogen and fuel cell demonstration projects
• Hydrogen system analysis
• Utility-scale hydrogen fuel cell systems
• Market transformation needs
Task 18 - Integrated Systems Evaluation

- **Objectives:** Establish database of international hydrogen development activities, capabilities and demonstrations; Evaluate hydrogen systems performance, cost, safety, and Codes and Standards permitting policies; Develop and disseminate lessons learned.

- **Demonstration focus**
  - Hydrogen vehicles and refueling stations
  - Stationary hydrogen/fuel cell systems

- **Task 18 Schedule**
  - 1 January, 2004 through 31 December 2009

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**Participating Countries:**
- Canada (Natural Resources Canada)
- Japan (AIST Laboratory)
- Italy (ENEA)
- Germany (Expert to be named)
- Denmark (Gas Technology Center)
- Norway (IFE)
- Spain (INTA)
- Switzerland (EMPA)
- United Kingdom (EA Technology)
- Greece (CRES)
- France (CEA)
- New Zealand (Industrial Research)
- The Netherlands (ECN)
- United States (Department of Energy)
- UNIDO-ICHET
# Task 18 Stationary Fuel Cell Projects (1)

<table>
<thead>
<tr>
<th>Project / location</th>
<th>Hydrogen source / Grid connection</th>
<th>Fuel cell description / application</th>
<th>Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIRST telecom power / Spain</td>
<td>PV electrolysis / none</td>
<td>400 W Remote telecom power</td>
<td>MH</td>
</tr>
<tr>
<td>Energy station / Las Vegas</td>
<td>Steam reformer / local grid</td>
<td>50 kW Plug Power stationary fuel cell / grid</td>
<td>gas</td>
</tr>
<tr>
<td>RES2H2 / Canary Islands, Spain</td>
<td>Wind electrolysis / none</td>
<td>PEM; integrated with desalination plant</td>
<td>Compressed gas</td>
</tr>
<tr>
<td>Hydrogen and Renewables Integration (HARI) project / UK</td>
<td>PV/wind/hydro electrolysis / none</td>
<td>2 kW residential heat and power; 5 kW power</td>
<td>Gas, MH</td>
</tr>
<tr>
<td>Italian hydrogen house “Hydrogen from the Sun”</td>
<td>PV electrolysis / none</td>
<td>5 kW PEM estate power</td>
<td>Gas, MH</td>
</tr>
<tr>
<td>EPACOP / France</td>
<td>Natural gas reforming</td>
<td>(5) 4 kW residential for heat and power</td>
<td></td>
</tr>
<tr>
<td>Lolland Hydrogen Community, Denmark</td>
<td>Wind electrolysis / local grid back-up</td>
<td>2 kW IRD PEM, Residential CHP</td>
<td>Gas</td>
</tr>
</tbody>
</table>
## Task 18 Stationary Fuel Cell Projects (2)

<table>
<thead>
<tr>
<th>Project / location</th>
<th>Hydrogen source / Grid connection</th>
<th>Fuel cell description / application</th>
<th>Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential fuel cell project / Japan</td>
<td>Small reformers / local grid</td>
<td>PEM / home water heating</td>
<td>Gas</td>
</tr>
<tr>
<td>HyLink / Totara Valley, New Zealand</td>
<td>Wind electrolysis / none</td>
<td>PEM, Residential power and water heating</td>
<td>Low pressure gas in pipeline</td>
</tr>
<tr>
<td>IHAVU (Single family home) / Spain</td>
<td>PV electrolysis / grid back-up</td>
<td>2 kW PEM, household power with hydrogen energy storage</td>
<td>Gas / MH</td>
</tr>
<tr>
<td>Hawaii Power Park / Kahua Ranch, Hawaii</td>
<td>Wind / PV electrolysis / local grid</td>
<td>5 kW Plug Power stationary fuel cell / ranch operations office</td>
<td>Gas</td>
</tr>
<tr>
<td>Takasago integrated system / Japan</td>
<td>Renewable to grid / local grid</td>
<td>5 kW regenerative / building load-leveling</td>
<td>MH</td>
</tr>
<tr>
<td>Hydrogen Office</td>
<td>Wind electrolysis / local grid</td>
<td>20 kW PEM / building heat and power; fuel cell test facility</td>
<td>Gas</td>
</tr>
<tr>
<td>RES2H2 / Greece</td>
<td>Wind electrolysis / local grid</td>
<td>PEM, wind interface testing</td>
<td>Gas / MH</td>
</tr>
<tr>
<td>Intelligent Energy / integrated fuel cell system / Japan</td>
<td>Renewable Biofuel / local grid</td>
<td>Commercial PEM / CHP; distributed generation</td>
<td>Gas</td>
</tr>
<tr>
<td>Japan</td>
<td>City gas</td>
<td>Solid Oxide fuel cell</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Roles of Energy Storage, On- and Off-grid

Systems Designed for Off-grid

Hydrogen and Renewables Integration Project - UK

- HyLink - A hydrogen energy pipeline-store
  - Wind / hydro / PV source

Totara Valley, New Zealand
Renewable Hydrogen Energy System
Objective: To make the estate fully powered by renewable energy
Domestic Fuel Cell Systems

EPACOP (PEM Fuel Cells Operating in Real Conditions)

5 4-kW Building Fuel Cell Systems

The Large-scale Stationary Fuel Cell Demonstration Project in Japan
Objective: **Large Building** thermal and electrical load-leveling; detailed MH storage thermal control
Community Systems: Denmark
Hydrogen Community - Lolland

32 houses to be powered and heated by community hydrogen from wind
RE-H2 Power Park - Hawaii

- Separate Power & Energy
- Long term storage
- H2 supply
- Heat generation
- Environmentally friendly

Remove fossil fuel consumption
Test Facility for Stationary Hydrogen Storage System
Analysis: Community Power - Resource and Load Not in Phase

- Load peaks in morning and evening
  - Generation does not match load
- Load continues during evening

Community Hybrid System Design

- Input and output to each component is controlled.
- State-of-Charge: use batteries first, then hydrogen.
- Neural Net: look ahead and always make sure batteries are used to full potential.

Renewables and Hydrogen Projects (RES2H2 - EU Framework 5)

Gran Canaria, Spain
Wind / Desalination / Electrolyzer / Fuel Cell

Athens, Greece
CRES Wind farm
Distributed Generation Applications

- H₂ fuel cell technologies
- Peak shaving
- Distribution upgrade deferral
- Power quality / frequency regulation

Power Park / Multi-use Concepts

Las Vegas Energy Station
Air Products Reformer and 5 kW Plug Power Fuel Cell - Hydrogen for both power and vehicle fuel

Intelligent Energy
Bio-reformer / Fuel cell
Distributed Nodes for Local and Regional Load-leveling

Hydrogen Pipeline, US

1,000 miles Hydrogen Gas Pipeline 36" diameter, 1,000 - 500 psi

Pipeline Storage = 120 GWh

Geologic Storage?

Bozcaada H₂ Island, Turkey

20 kW PV panels

30 kW Windturbine

Local grid 220V

25 kW Electrolyzer

H₂ storage @15 bar

Compressor

H₂ storage cylinders @220 bar

15 kW Fuel cell

25-40 kW H₂-ICE + generator

Governor’s House

5 kW Fuel Cell Boat

5 kW Fuel Cell Golf-cart

5 kW Fuel Cell UPS

Hospital
Hydrogen: Attractive for Long-term and Seasonal Storage - Days


Wind: Supply, Forecast, and Demand Not Matched

How much storage would be necessary to make wind power a base load?

Source: IfR / TU Braunschweig

Significant power fluctuations from the mean and from forecasts
- Short term (minutes)
- Long term (days)
- Seasonal (months)

Source: Heide Meiwes, Electrochemical Energy Conversion and Storage Systems Group; Dirk Uwe Sauer, Institute for Power Electronics and Electrical Drives (ISEA), RWTH Aachen University
H$_2$ competes with other large-scale storage technologies

- Bulk Energy Storage Technologies
  - Hydrogen
  - CAES
  - Pumped hydro

Long-term storage system

- 500 MW, 100 GWh, 200 h full load, 
  ~1.5 cycles per month

Source: Heide Meiwes, Electrochemical Energy Conversion and Storage Systems Group; Dirk Uwe Sauer, Institute for Power Electronics and Electrical Drives (ISEA), RWTH Aachen University
Market Transformation Needs:
Systems and Analyses in all sizes

- In distribution systems
- Combined with intermittent and seasonal renewables
- H₂ geologic storage, as used in oil refining industry (US, UK)

Today and tomorrow - Technology

H₂ pipelines und H₂ caverns: Texas, USA

Conclusions / Recommendations

• Stationary hydrogen and fuel cell applications complement the electric system across a spectrum of sizes
  – Residential and communities
  – Distributed generation
  – Load and source - leveling
• An ideal match for renewables of all scales
• \( \text{H}_2 \) storage can have major impact on \( \text{H}_2 \) supply for both transportation and power distribution schemes
• Underground storage offers opportunities to store \( \text{H}_2 \)
  – High capacity & Cost competitive

Out-of-the-box analysis of system-optimized \( \text{H}_2 \) storage installations is needed to fully appreciate the synergies between applications.
Summary – Position Statement

Need and issues for international cooperation

Transport sector

Hydrogen – The Inevitable Element in the Renewable Energy System

Power sector

“... In addition, the direct use of hydrogen (from underground storage) for the transport sector or other industrial processes is viable. Hence, direct conversion back to electricity is no necessity. Economic synergies from the direct use of hydrogen as transport fuel are therefore expected.

“...

Source: Energy storage in power supply systems with high share of REN energies, German Electrotechnical Society (VDE) ETG Task Force Energy Storage, 2008

Source: Presentation by GM-Opel at HydroGen4 (= Chevrolet Equinox) Launch Event in Berlin, early December 2008