122 West

International Experience in Fuel Cells and Hydrogen for Electric Power Applications

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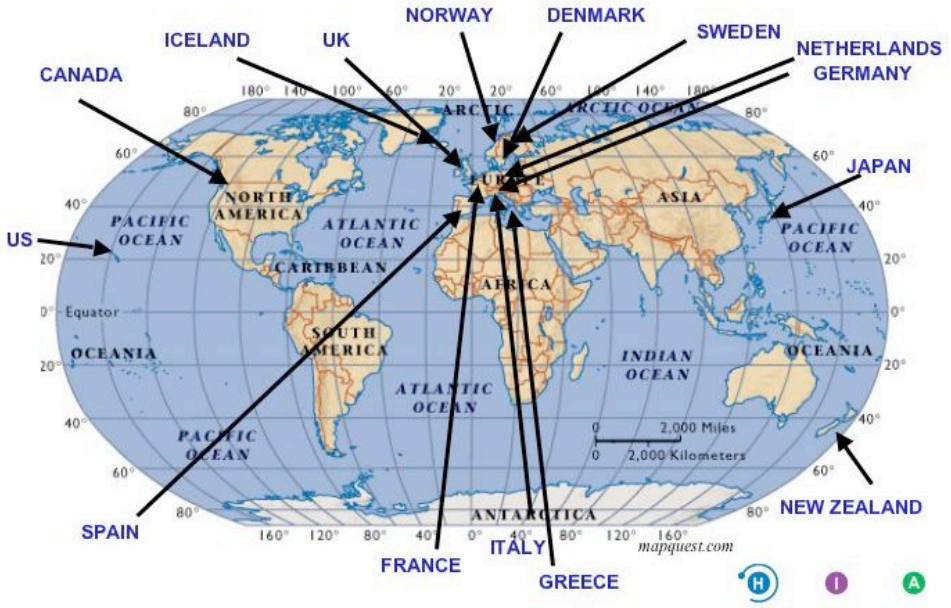
Presentation to HTAC
November 5, 2009

Sponsored by US Department of Energy

Sandia National Laboratories

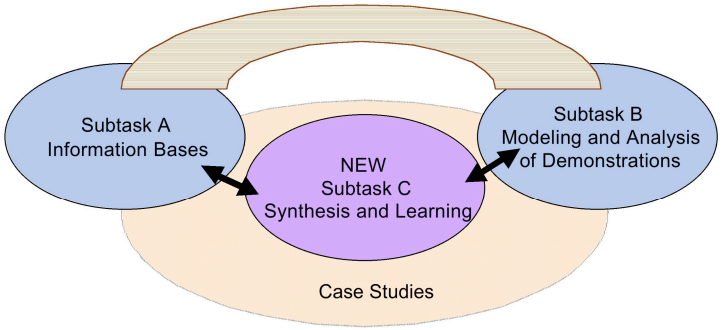
Presentation Outline

- 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



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

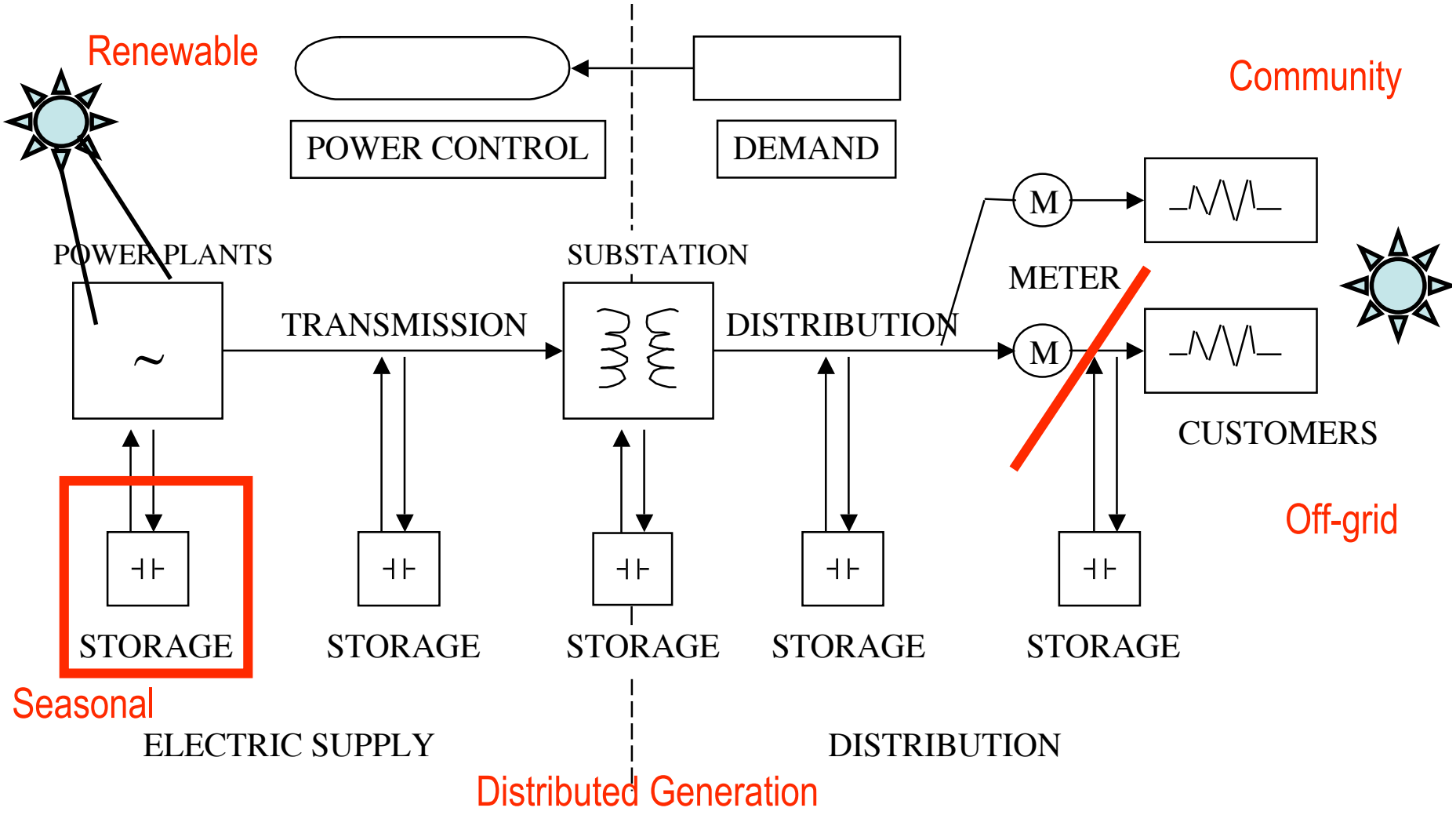
Task 18 Stationary Fuel Cell Projects (1)

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

Task 18 Stationary Fuel Cell Projects (2)

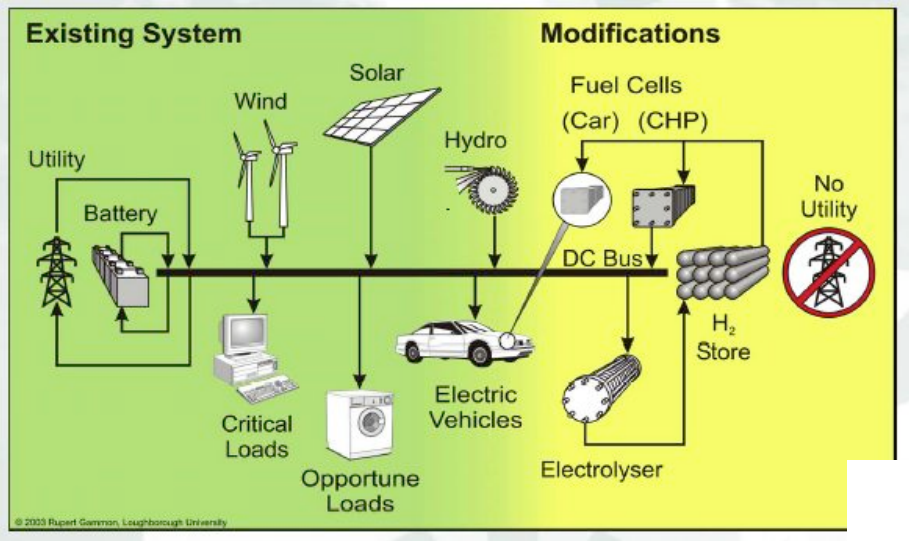
Project / location	Hydrogen source / Grid connection	Fuel cell description / application	Storage
Residential fuel cell project / Japan	Small reformers / local grid	PEM / home water heating	Gas
HyLink / Totara Valley, New Zealand	Wind electrolysis / none	PEM, Residential power and water heating	Low pressure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

Roles of Energy Storage, On- and Off-grid



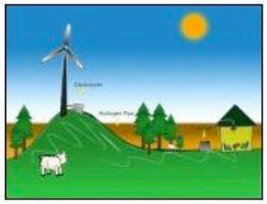
Source: Susan M. Schoenung, "A Comparison of Hydrogen-Fueled Fuel Cells and Combustion Engines for Electric Utility Applications," WSSCI, Fall Meeting, Irvine, California, October 25-26, 1999

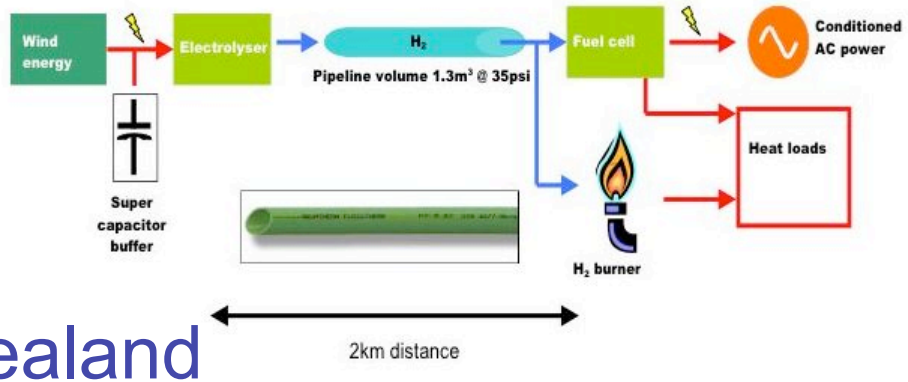
Systems Designed for Off-grid



Hydrogen and Renewables Integration Project - UK

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

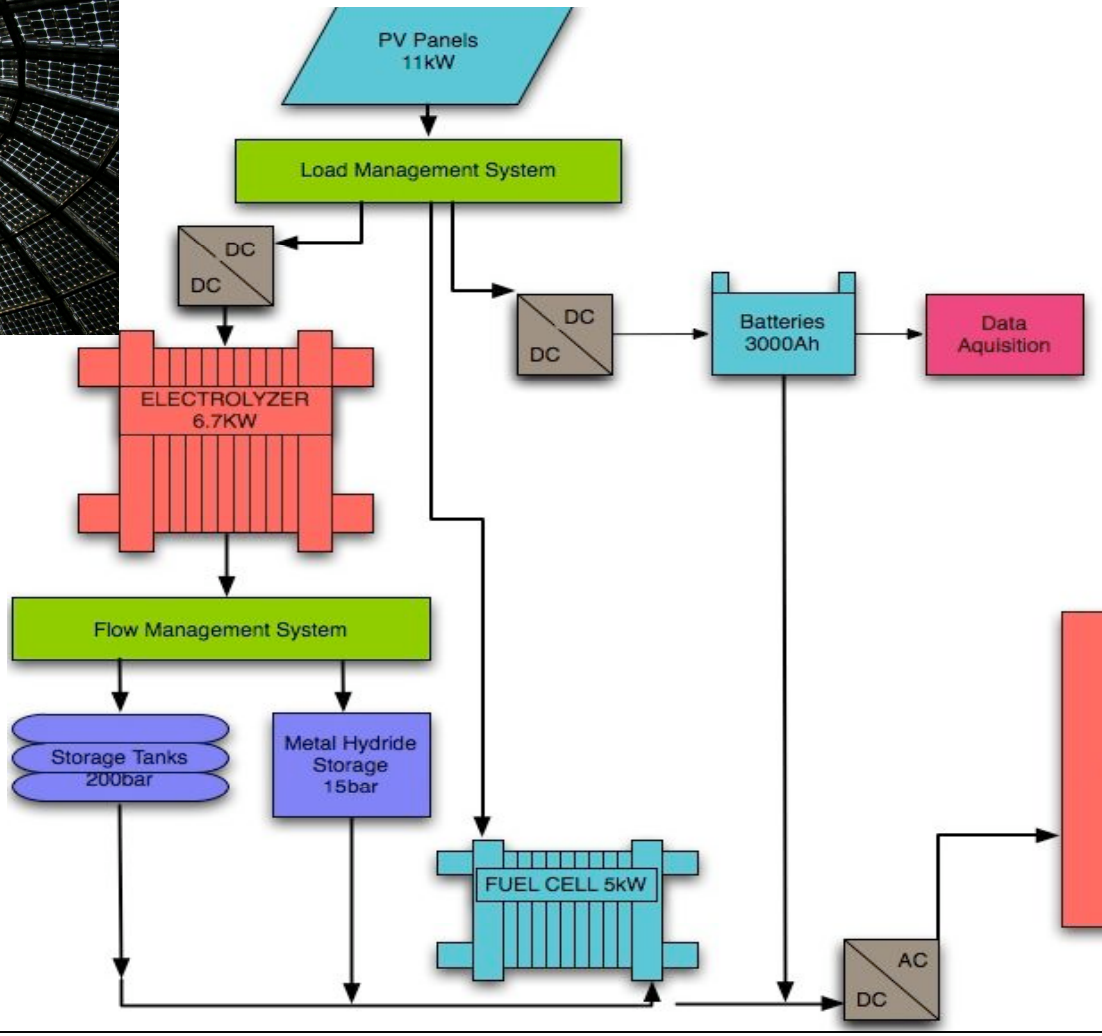


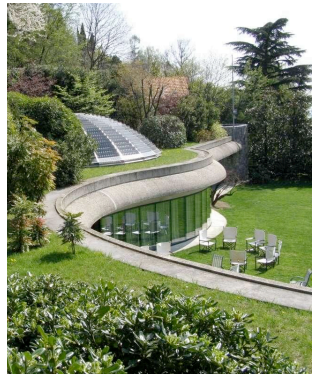


Totara Valley, New Zealand

Renewable Hydrogen Energy System

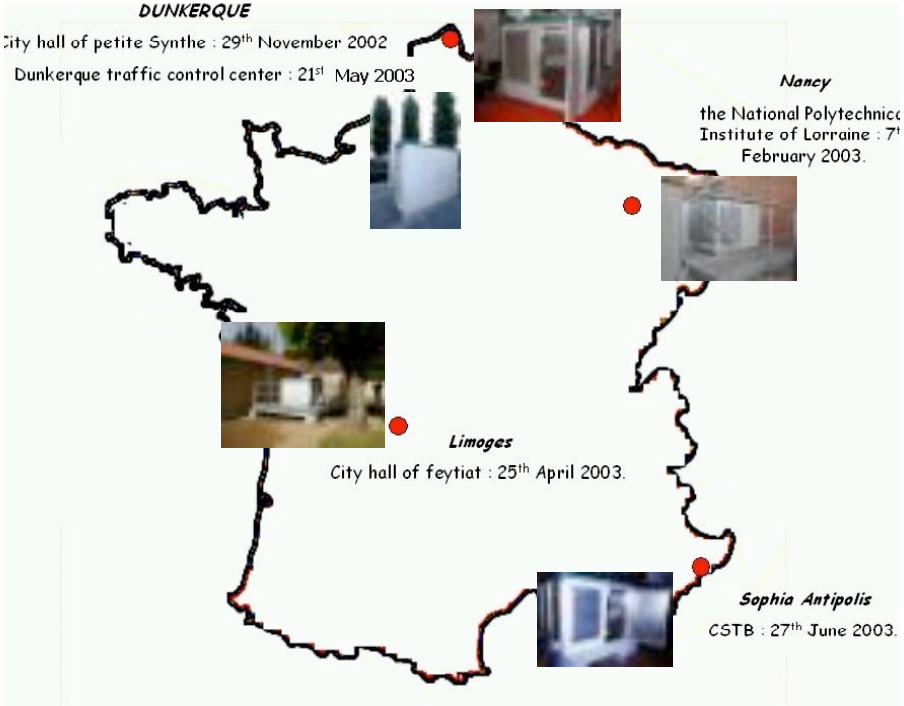
“Hydrogen from the Sun”
Ecological House in Brunate, Italy





Objective: To make the estate fully powered by renewable energy

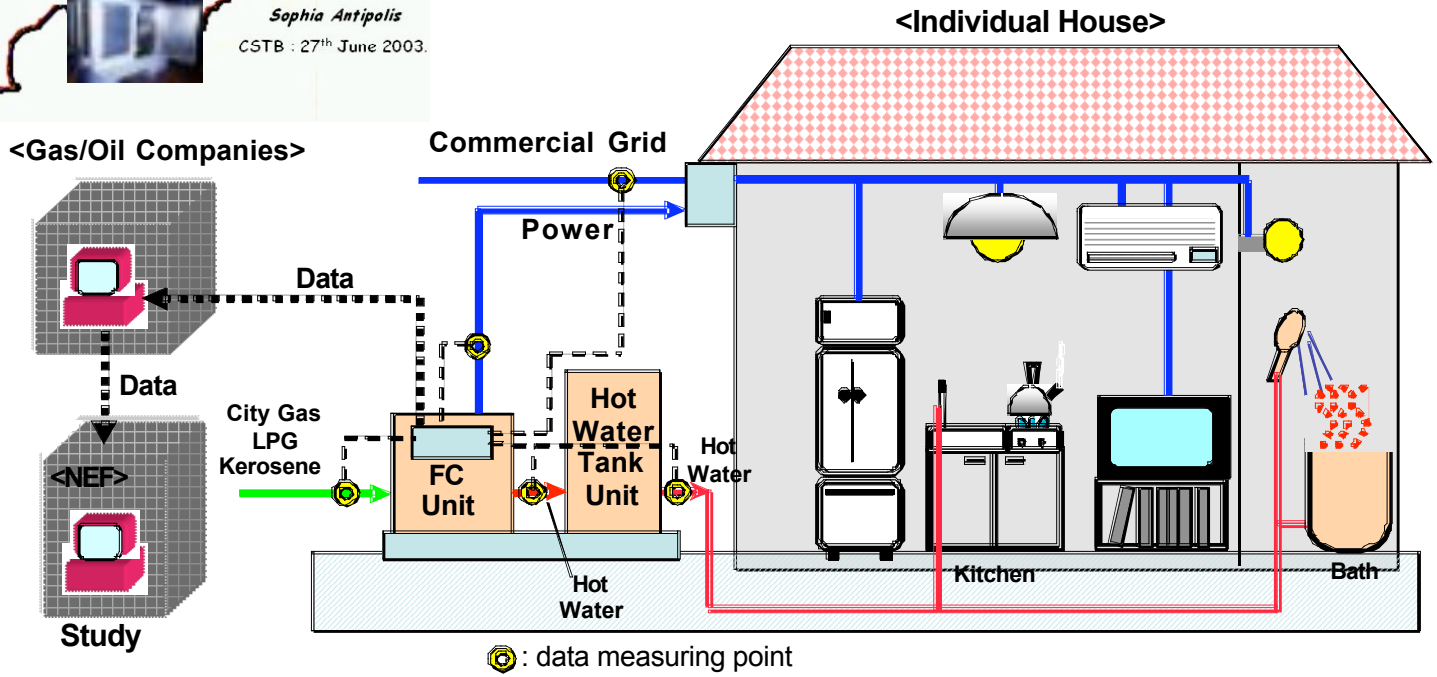
Domestic Fuel Cell Systems



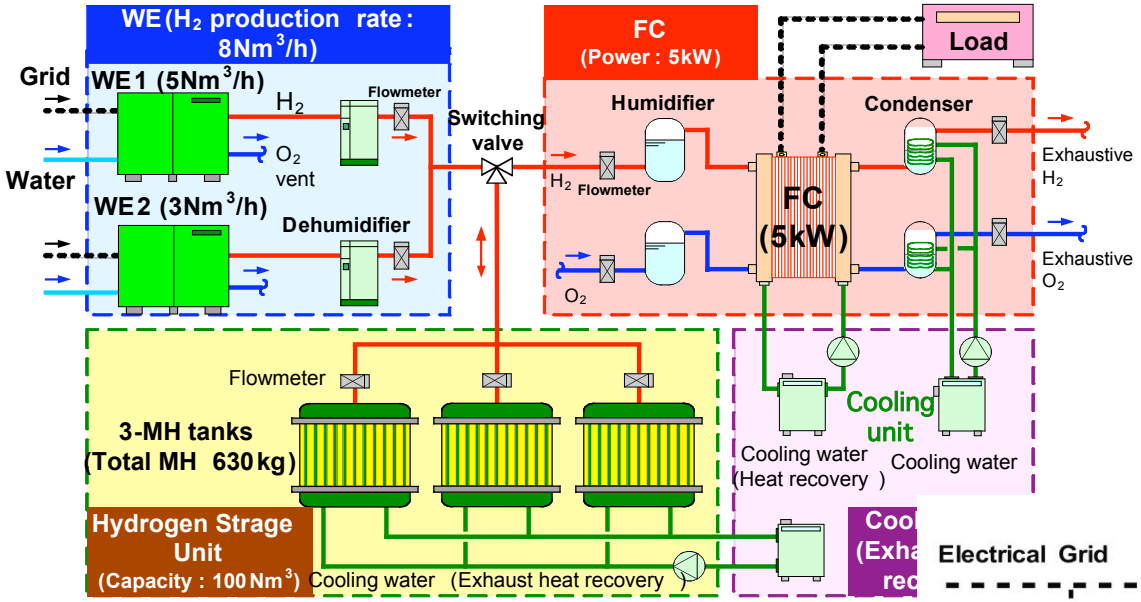
EPACOP (PEM Fuel Cells Operating in Real Conditions)

5 4-kW Building Fuel Cell Systems

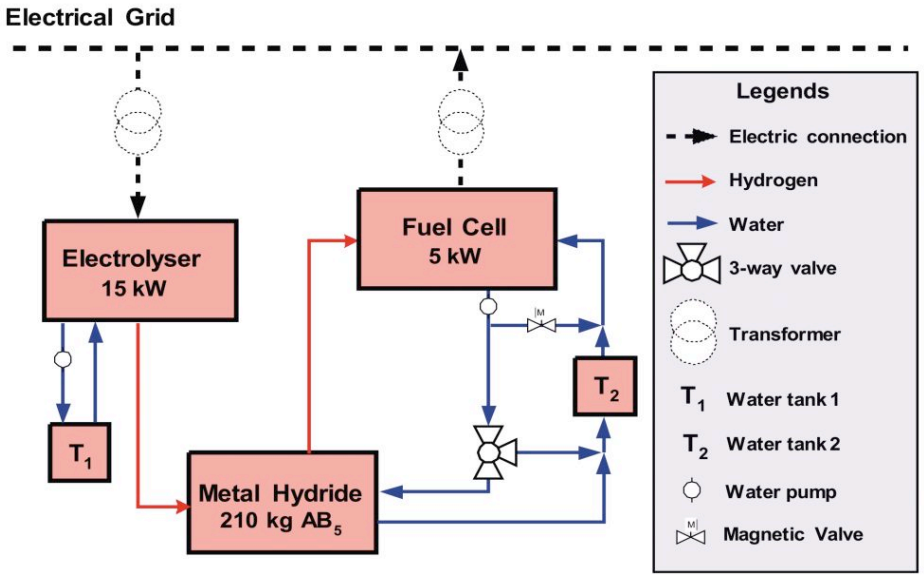
The Large-scale Stationary Fuel Cell Demonstration Project in Japan



Integrated H_2 Building System Takasago, Japan



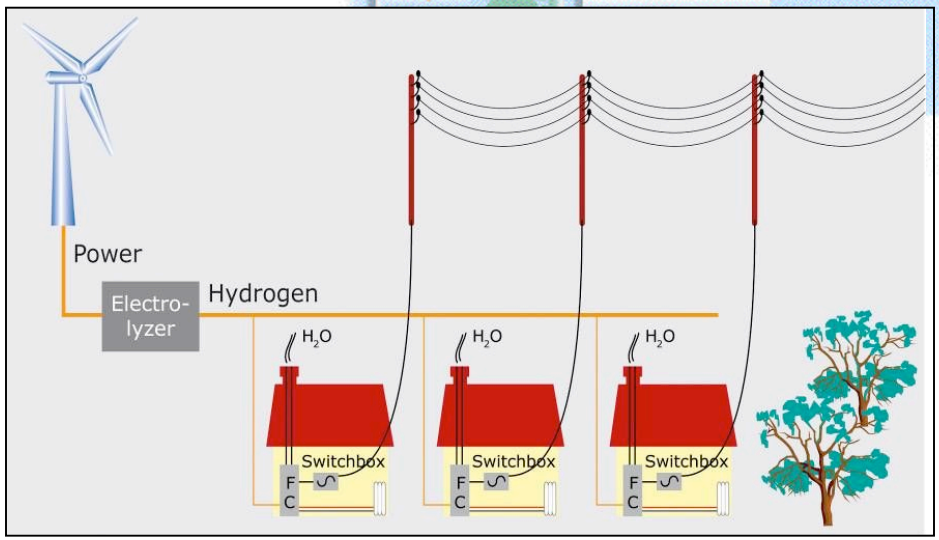
Objective: **Large Building** thermal and electrical load-leveling; detailed MH storage thermal control



Community Systems: Denmark

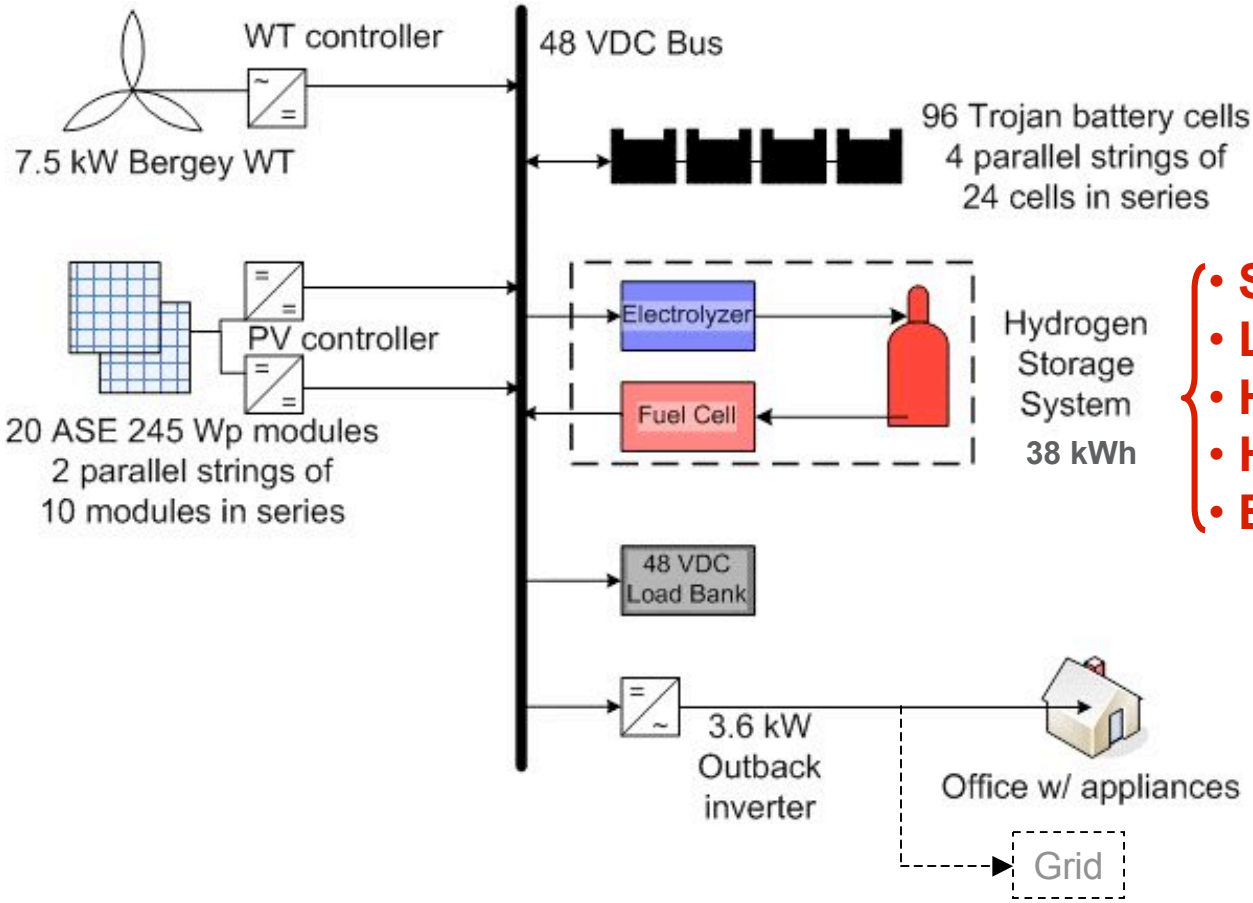
Hydrogen Community - Lolland

32 houses to be powered and heated by community hydrogen from wind



Hydrogen Community LOLLAND

RE-H2 Power Park - Hawaii



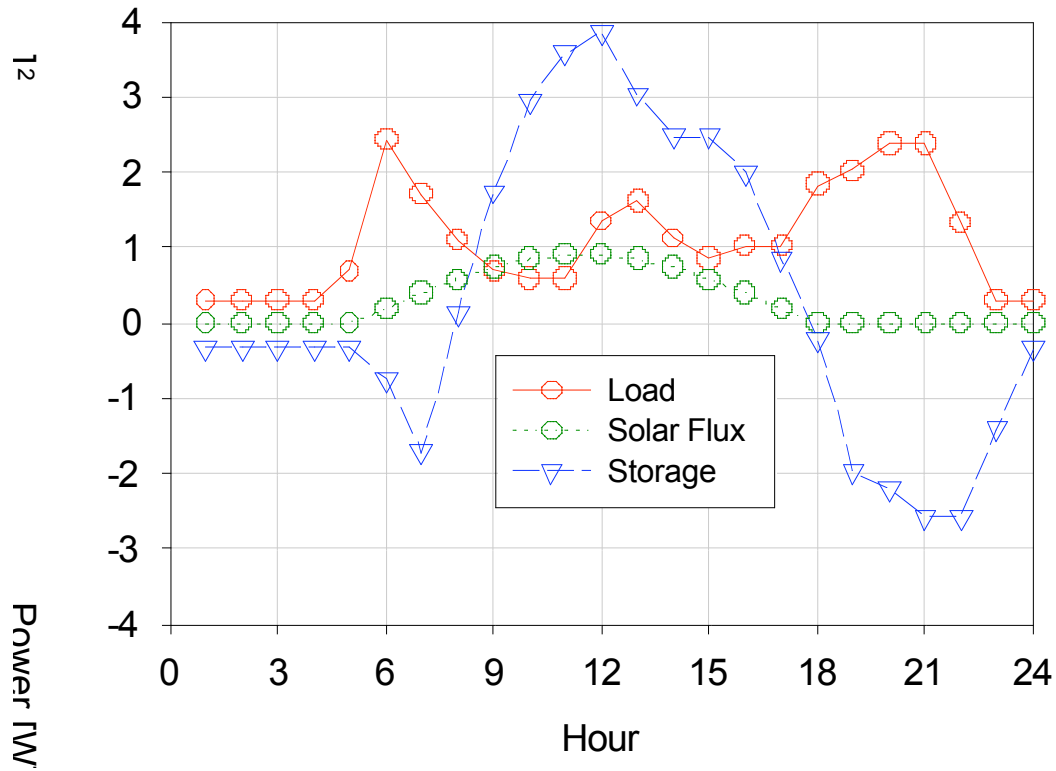
- **Separate Power & Energy**
- **Long term storage**
- **H2 supply**
- **Heat generation**
- **Environmentally friendly**

Remove fossil fuel consumption
Test Facility for Stationary Hydrogen Storage System

HNEI
Hawai'i Natural Energy Institute
University of Hawai'i at Mānoa

Analysis: Community Power - Resource and Load Not in Phase

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



Source: Steven R. Vosen & Jay O. Keller, "Hybrid Energy Storage Systems for Stand-alone Electric Power System: Optimization of System Performance and Cost through Control Strategies," The National Hydrogen Association 1999 Annual Meeting.

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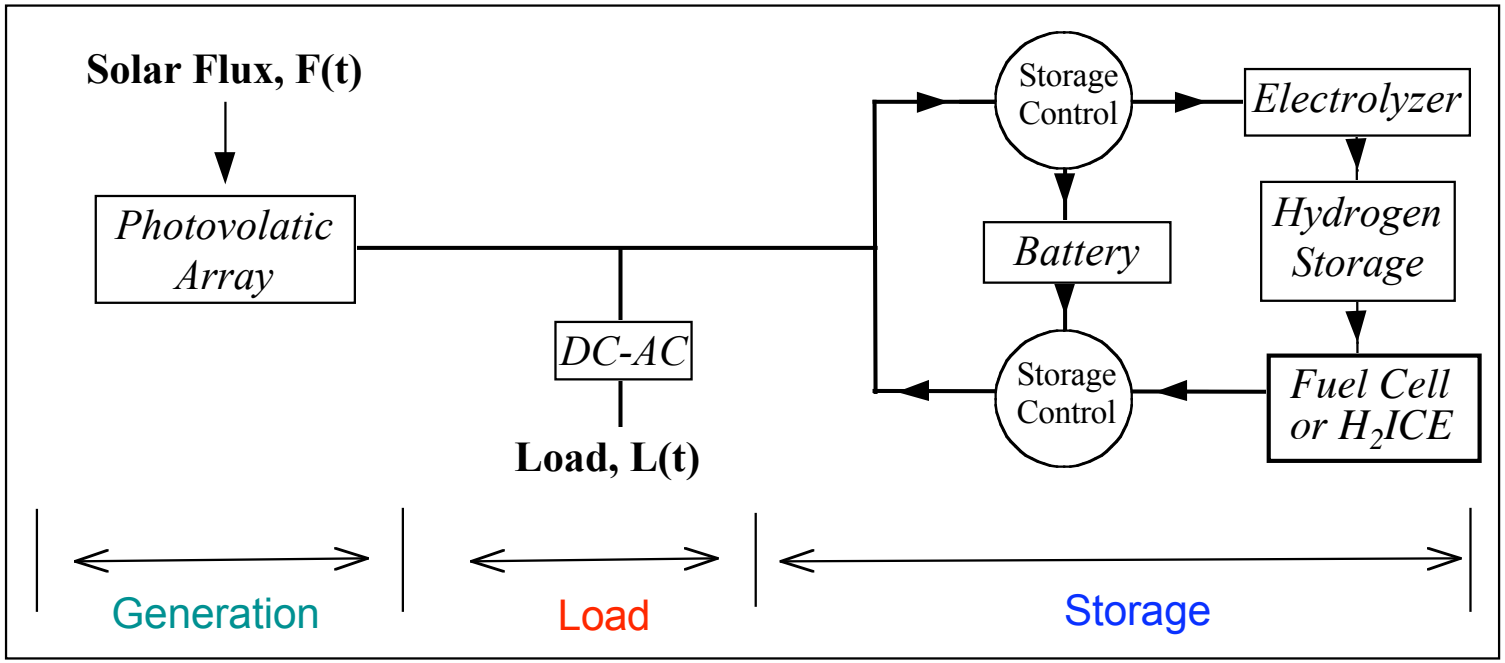
Community Hybrid System Design

- 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.



Source: Steven R. Vosen & Jay O. Keller, "Hybrid Energy Storage Systems for Stand-alone Electric Power System: Optimization of System Performance and Cost through Control Strategies," The National Hydrogen Association 1999 Annual Meeting.

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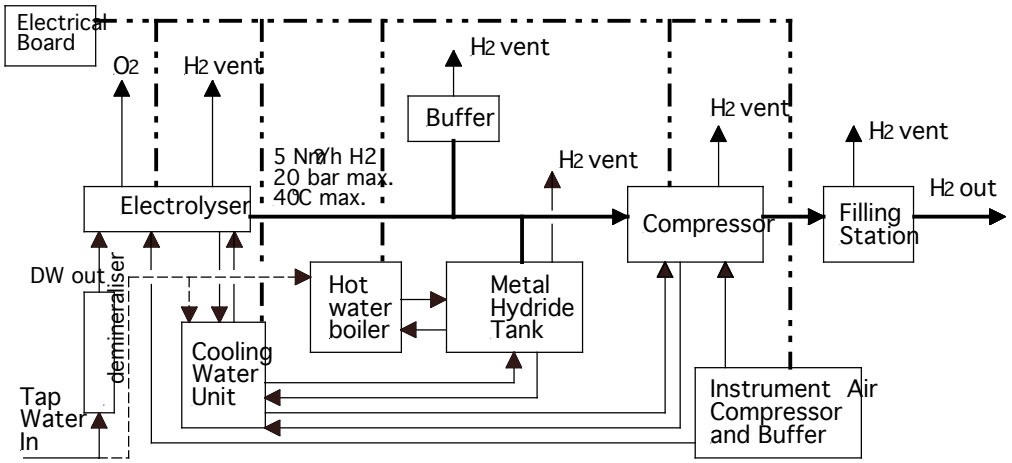
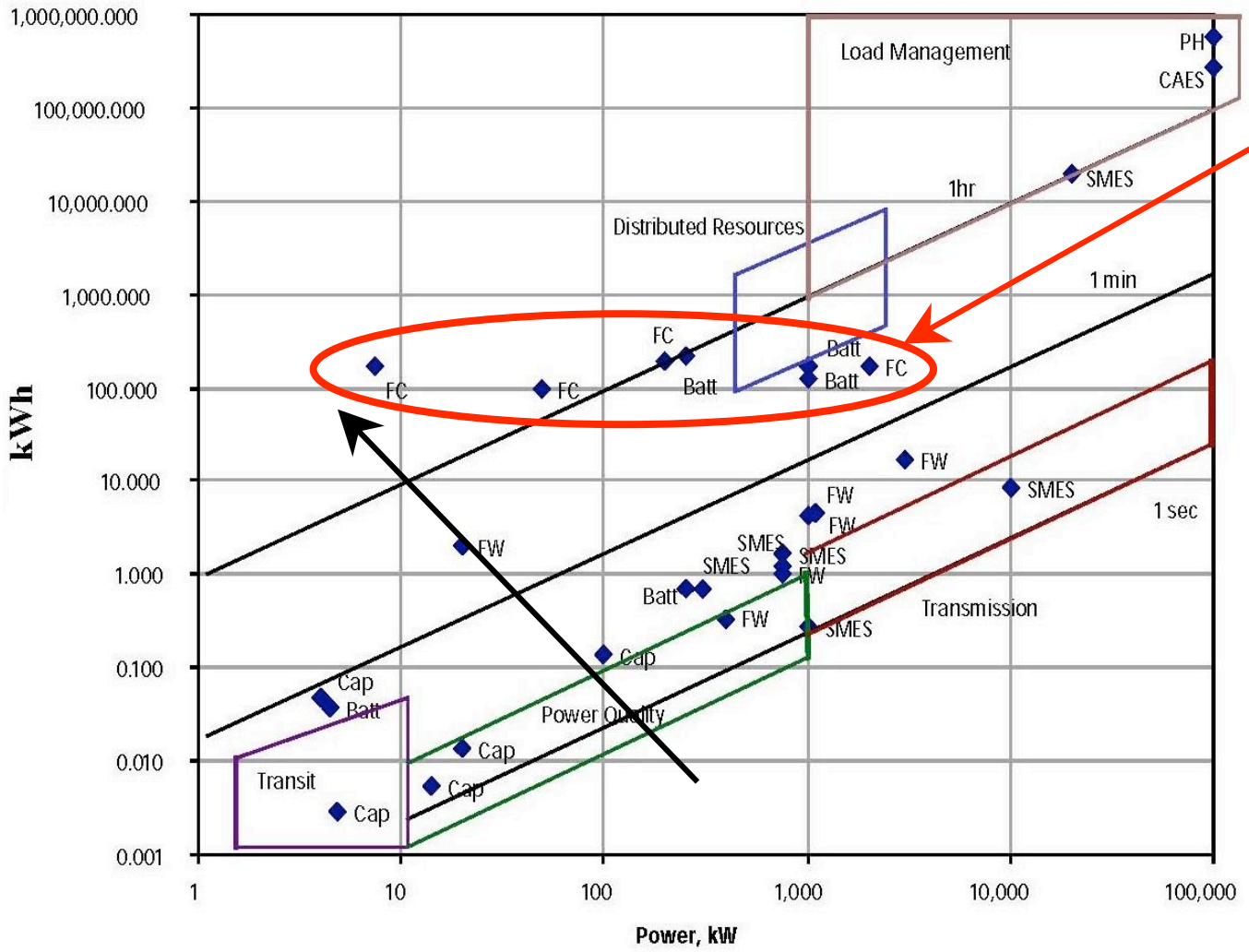
Renewables and Hydrogen Projects (RES2H2 - EU Framework 5)

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

Athens, Greece
CRES Wind farm



Distributed Generation Applications



- **H_2 fuel cell technologies**
- •Peak shaving
- •Distribution upgrade deferral
- •Power quality / frequency regulation

Source: Susan M. Schoenung, "Characteristics and Technologies for Long-vs. Short-Term Energy Storage", SAND2001-0765, March 2001

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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

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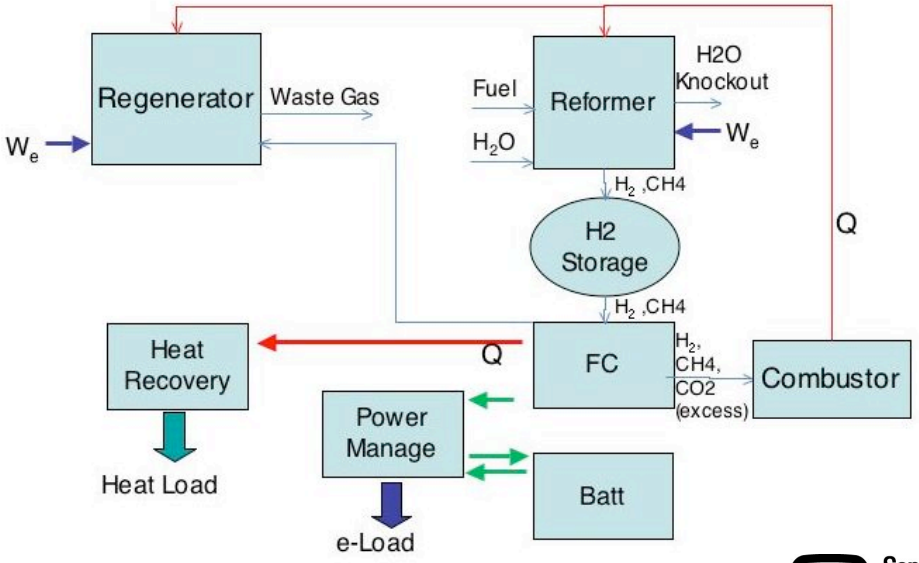
Intelligent Energy Bio-reformer / Fuel cell



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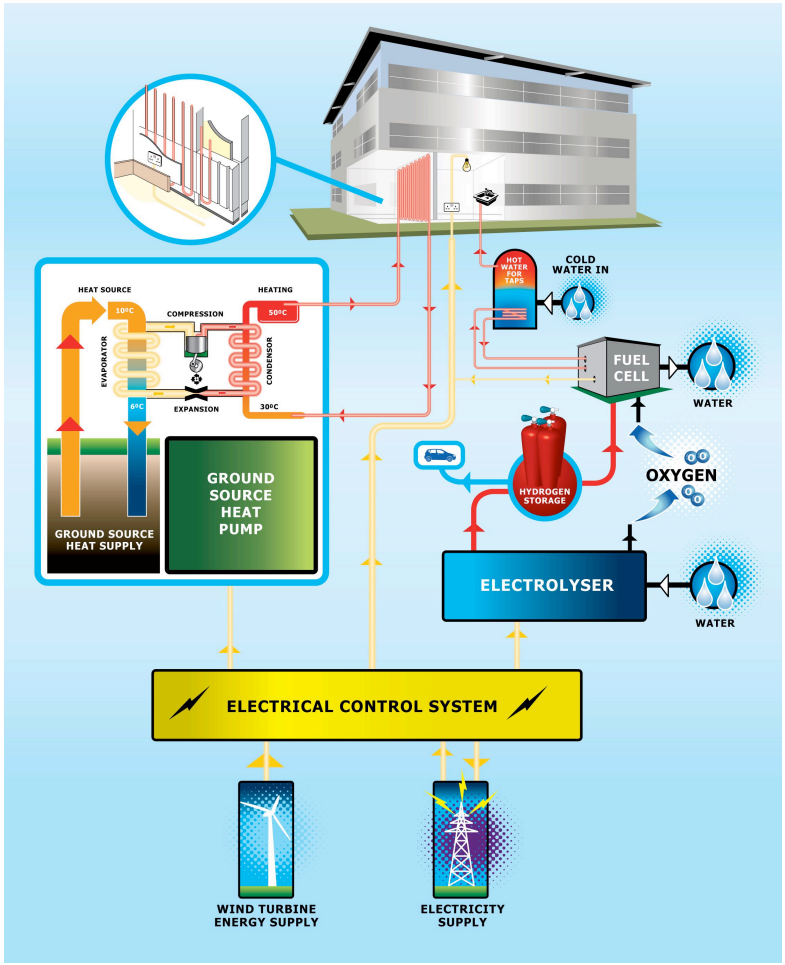
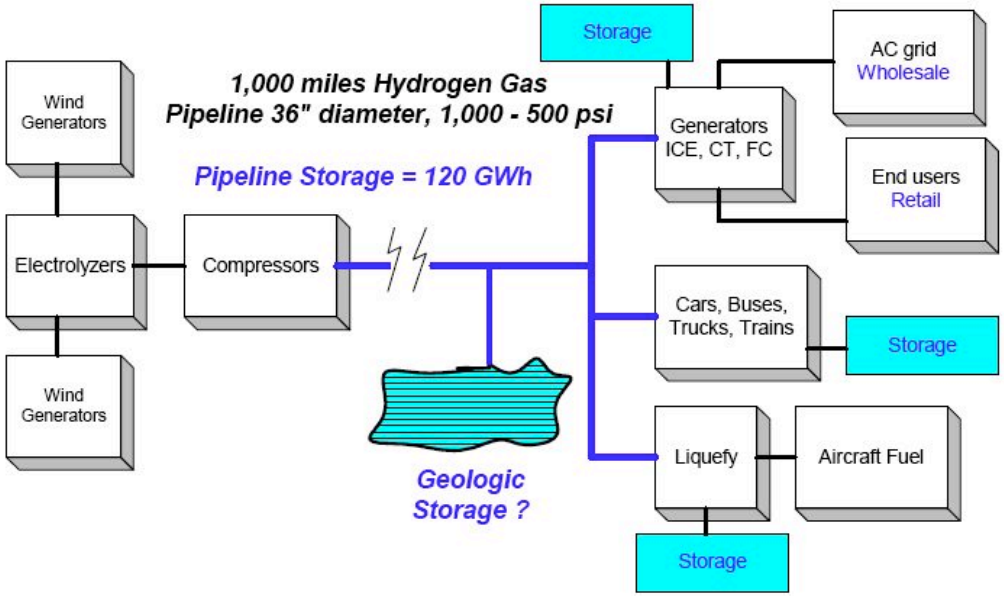
Distributed Nodes for Local and Regional Load-leveling



Hydrogen Office, Scotland

Hydrogen Pipeline, US



Source: W. Leighty, "International Hydrogen Transmission Demonstration Facility," Windpower 2003

Bozcaada H_2 Island, Turkey

20 kW PV panels

30 kW WindTturbine

Local grid 220V

Control strategy

25-40 kW H2-ICE +generator

Governor's House

H_2O

H_2

H_2 storage @15 bar

H_2

25 kW Electrolyzer

15 kW Fuel cell

Compressor

H_2 storage cylinders @220 bar

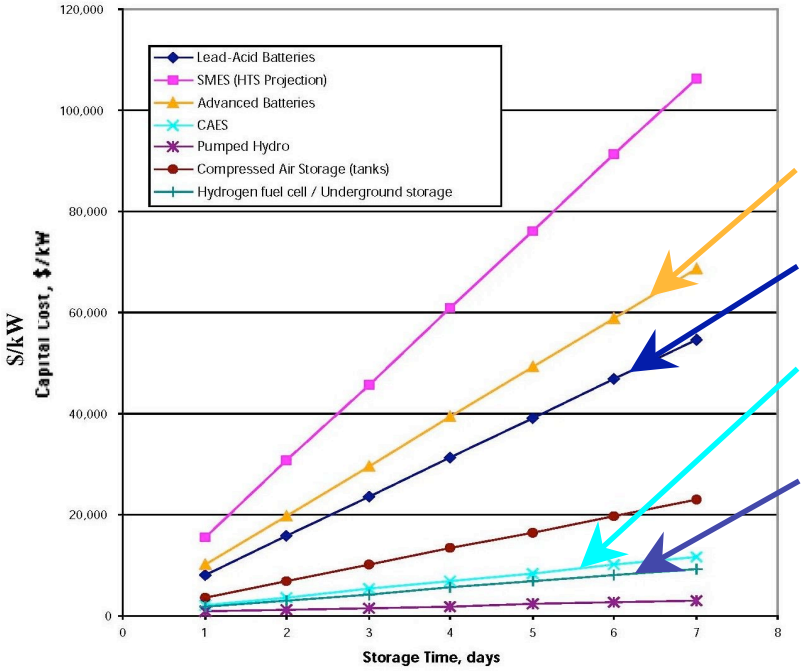
5 kW Fuel Cell Boat

5 kW Fuel Cell Golf-cart

5 kW Fuel Cell UPS

Hospital

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



Advanced Batteries

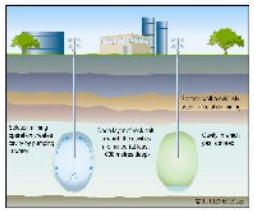
Lead-Acid Batteries

CAES

H_2 Fuel Cell / Underground Storage

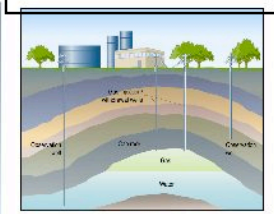
Source: Susan M. Schoenung, "Characteristics and Technologies for Long-vs. Short-Term Energy Storage", SAND2001-0765, March 2001

Source: Anna S. Lord, Peter H. Kobos, and David J. Borns,"Underground Storage of Hydrogen: Assessing Geostorage Options with a Life Cycle Based Systems Approach", 28th USAEE/IAEE North American Conference, New Orleans, Louisiana, SAND2009-7739C. Images source: MJMENERGY.com



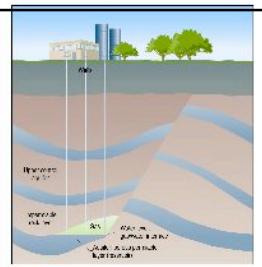
Salt Caverns

- Salt caverns are solution mined cavities within either salt domes or bedded salts that do not match reservoir volume capacity.



Depleted Oil/Gas Reservoirs

- Depleted reservoirs are proven gas reservoirs that are easy to develop and operate due to existing infrastructure.



Aquifers

- Aquifers are similar in geology to depleted reservoirs, but have not been proven to trap gas and must be developed.

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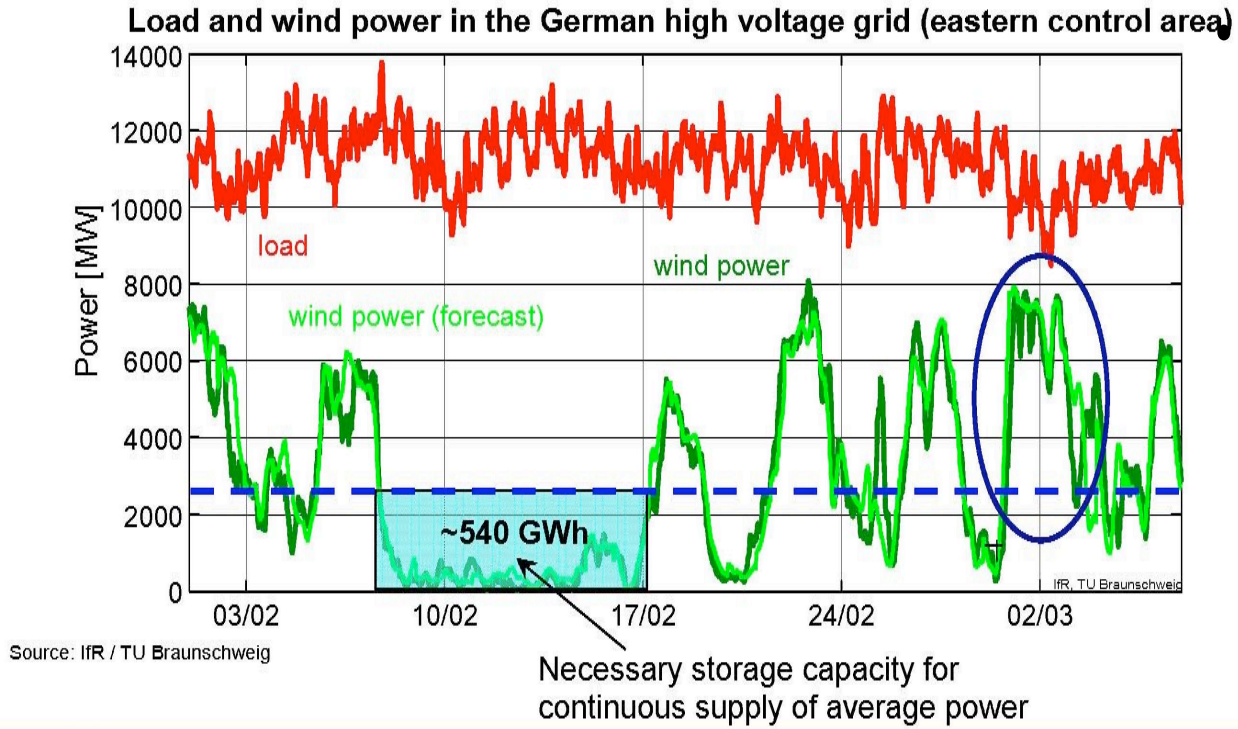
Wind: Supply, Forecast, and Demand Not Matched

RWTH AACHEN ISEA

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



Significant power fluctuations from the mean and from forecasts

- Short term (minutes)
- Long term (days)
- Seasonal (months)

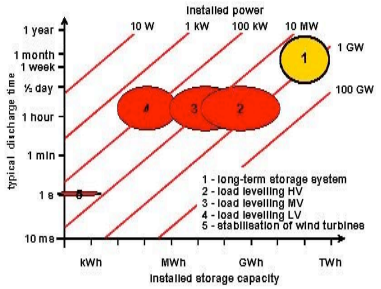
Source: Heide Meiwes, Electrochemical Energy Conversion and Storage Systems Group; Dirk Uwe Sauer, Institute for Power Electronics and Electrical Drives (ISEA), RWTH Aachen University

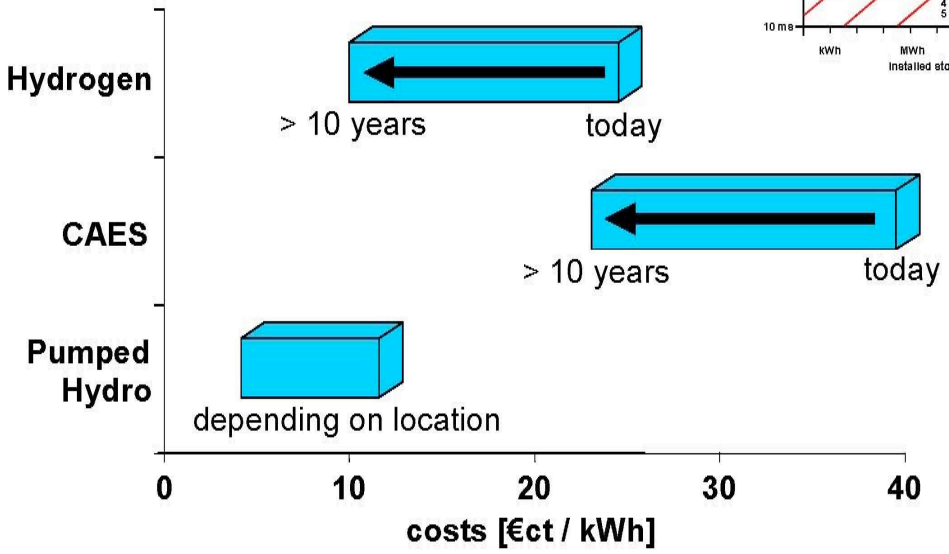
H_2 competes with other large-scale storage technologies

RWTH AACHEN ISEA

Long-term storage system

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





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

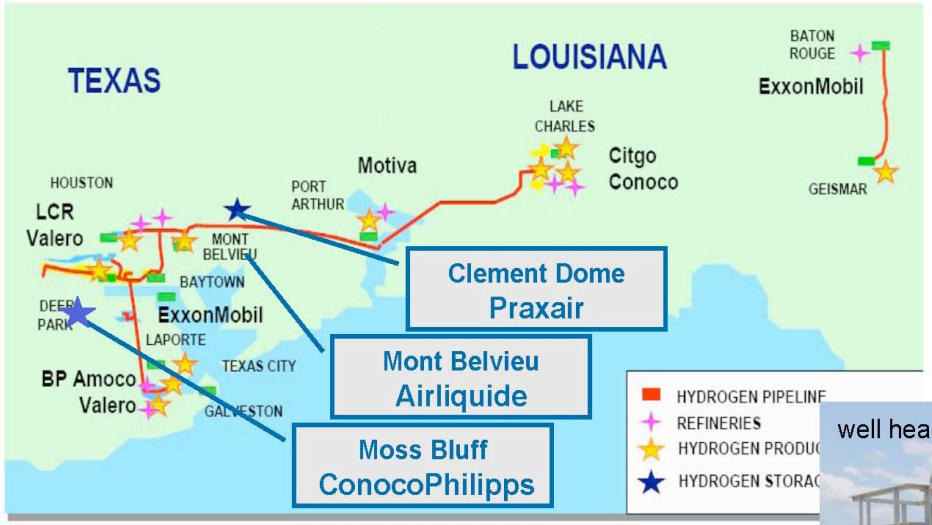
Source: ENERGY STORAGE FOR IMPROVED OPERATION OF FUTURE ENERGY SUPPLY SYSTEMS , M. Kleimaier, et.al., CIGRE 2008

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

Today and tomorrow - Technology

H_2 pipelines und H_2 caverns: Texas, USA



Air Liquide storage under development

well head of a hydrogen cavern

Source: ConocoPhillips

- **In distribution systems**
- **Combined with intermittent and seasonal renewables**
- **H_2 geologic storage, as used in oil refining industry (US, UK)**

Source: Dr. Ulrich Bunger, Hubert Langinger (LBST), Fritz Crotogino (KBB), “Mass Storage of Hydrogen” IEA HIA Task Definition Workshop, “Large-Scale Hydrogen Infrastructure and Mass Storage”, The Netherlands, 12-13 Feb. 2009

Conclusions / Recommendations

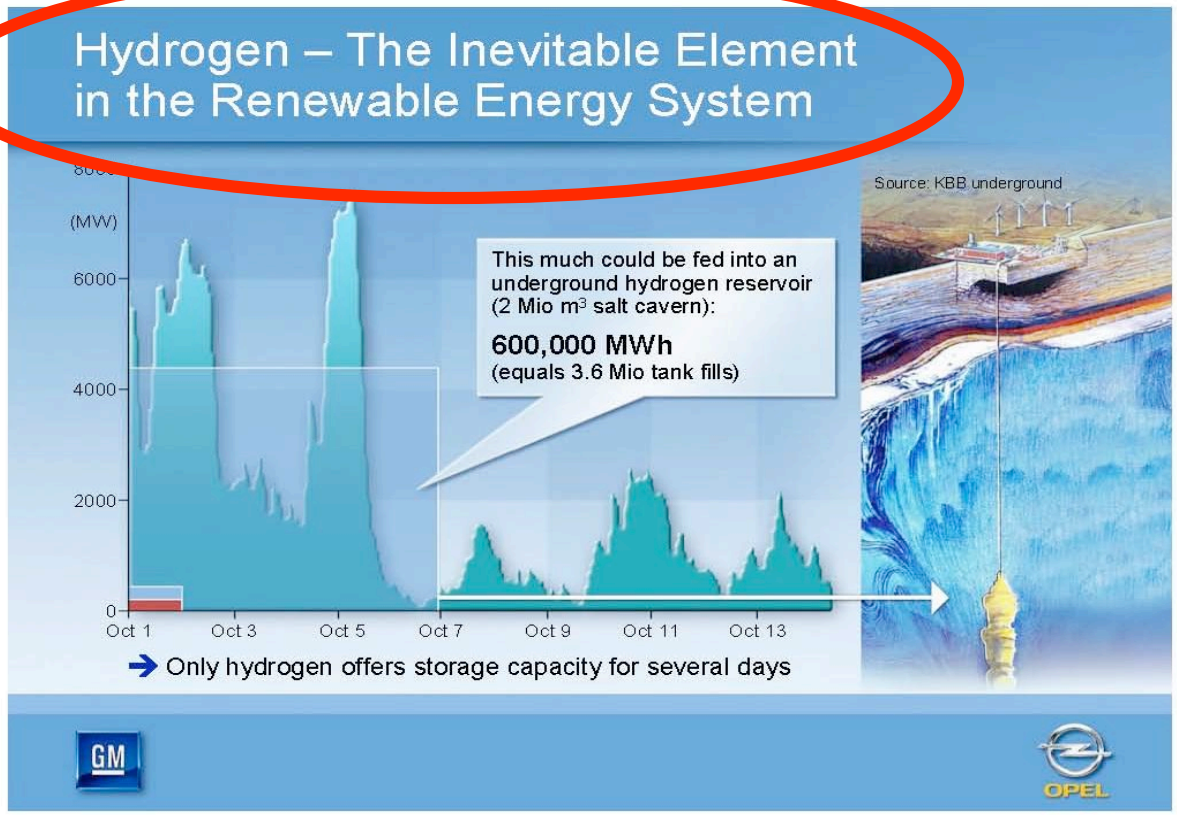
- Stationary hydrogen and fuel cell applications complement the electric system across a spectrum of sizes
  - Residential and communities
  - Distributed generation
  - Load and source - leveling
- An ideal match for renewables of all scales
- H_2 storage can have major impact on H_2 supply for both transportation and power distribution schemes
- Underground storage offers opportunities to store H_2
  - High capacity & Cost competitive

Out-of-the-box analysis of system-optimized H_2 storage installations is needed to fully appreciate the synergies between applications.

Summary – Position Statement

Need and issues for international cooperation

Transport sector



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

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: Dr. Ulrich Bunger, Hubert Langinger (LBST), Fritz Crotogino (KBB), "Mass Storage of Hydrogen" IEA HIA Task Definition