DOE Hydrogen Program

IEA Hydrogen Task 18: Evaluation of Integrated Demonstration Systems

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

122 West

Project ID #SCSP3

Overview of IEA Integrated Systems Project (Task 18)

Timeline

- Project start date:
  January 1, 2004
- Project end date:
  December 31, 2009
- Percent complete: ~70%

Barriers Addressed from MYPP

- Tech validation
  - Storage
  - Hydrogen Refueling Infrastructure
  - Codes and Standards
  - Hydrogen from Renewable Sources
  - Hydrogen and Electricity Co-Production
- Safety, codes and standards
  - Conflicts between domestic and international C&S
  - Large Footprint requirements for hydrogen fueling stations
- Systems analysis
  - Lack of consistent data, assumptions and guidelines
  - Lack of consensus on modeling tools

Budget

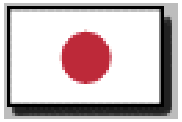
- Total project funding
  - DOE share: $625K
  - Contractor co-share: contributed labor (~$125K)
  - International partners: 42 FTE
- Funding received in FY06: $125K
- Funding for FY07: $170K

Partners / Collaborators

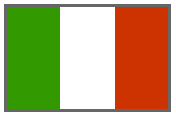
- International Energy Agency, Hydrogen Implementing Agreement
  Task 18 members:
  - Fifteen countries
  - European Commission
- Sandia National Laboratories (Lutz, Stewart)

Participants of IEA Hydrogen Task 18

Canada
Natural Resources Canada

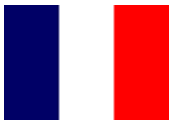


Japan
AIST Laboratory



Italy
ENEA

Greece
CRES



France
CEA

European Commission
Joint Research Center

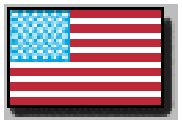
The Netherlands
ECN

Norway
IFE

Spain
INTA

Sweden
EO.N.

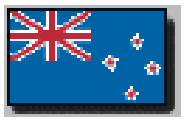
United Kingdom
EA Technology



United States
Department of Energy

Denmark
Gas Technology Center

Germany
Research Center Jülich



New Zealand
Industrial Research

Switzerland
EMPA

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

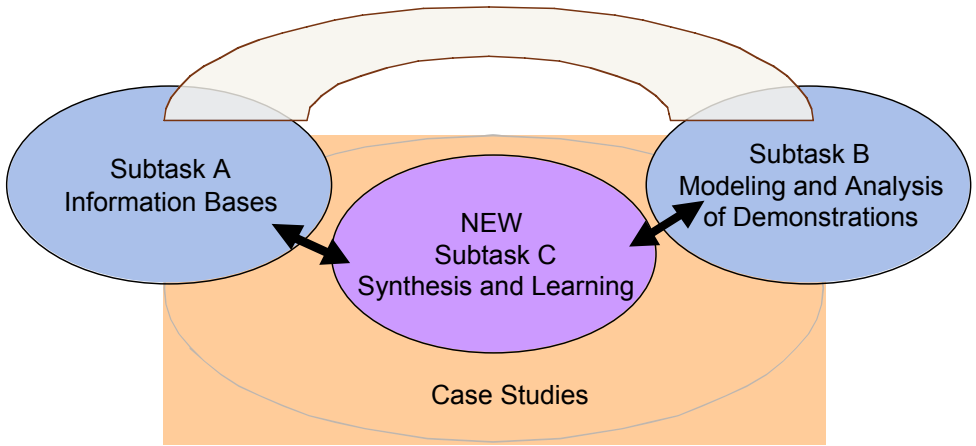
- Meetings:
  - June 2008: Spring Executive Committee Meeting
  - September 2008: Fall Experts Meeting
  - November 2008: Fall Executive Committee Meeting
- Deliverables:
  - May 2008: Semi-annual report
  - October 2008: Semi-annual report
  - January 2009: Annual report
- There are no go-no-go decision 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

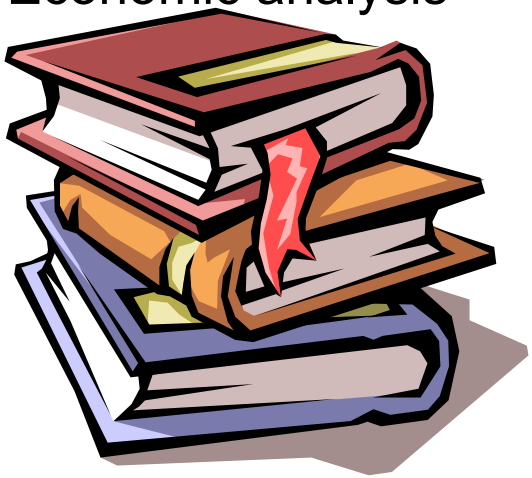


Technical Accomplishments/ Progress/Results

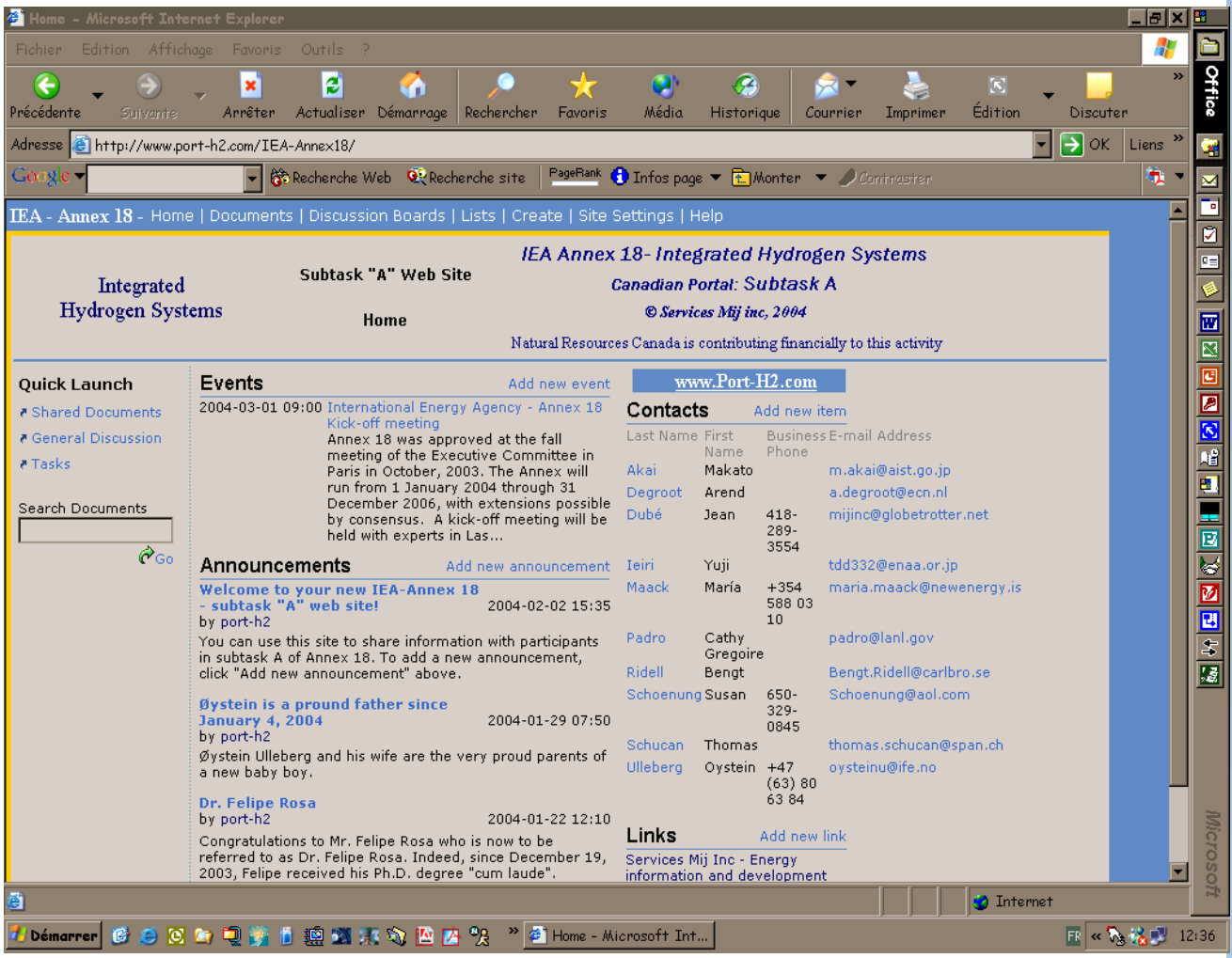
- Subtask A: Database contains over 300 documents (publicly accessible)
  - Includes Hydrogen resources database
- Subtask B: Analysis of 8 new projects underway
  - Spain - Renewables to Hydrogen project (RES2H2)
  - Greece - Center for Renewable Energy Studies
  - Italy - Ecological House
  - Hawaii - 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

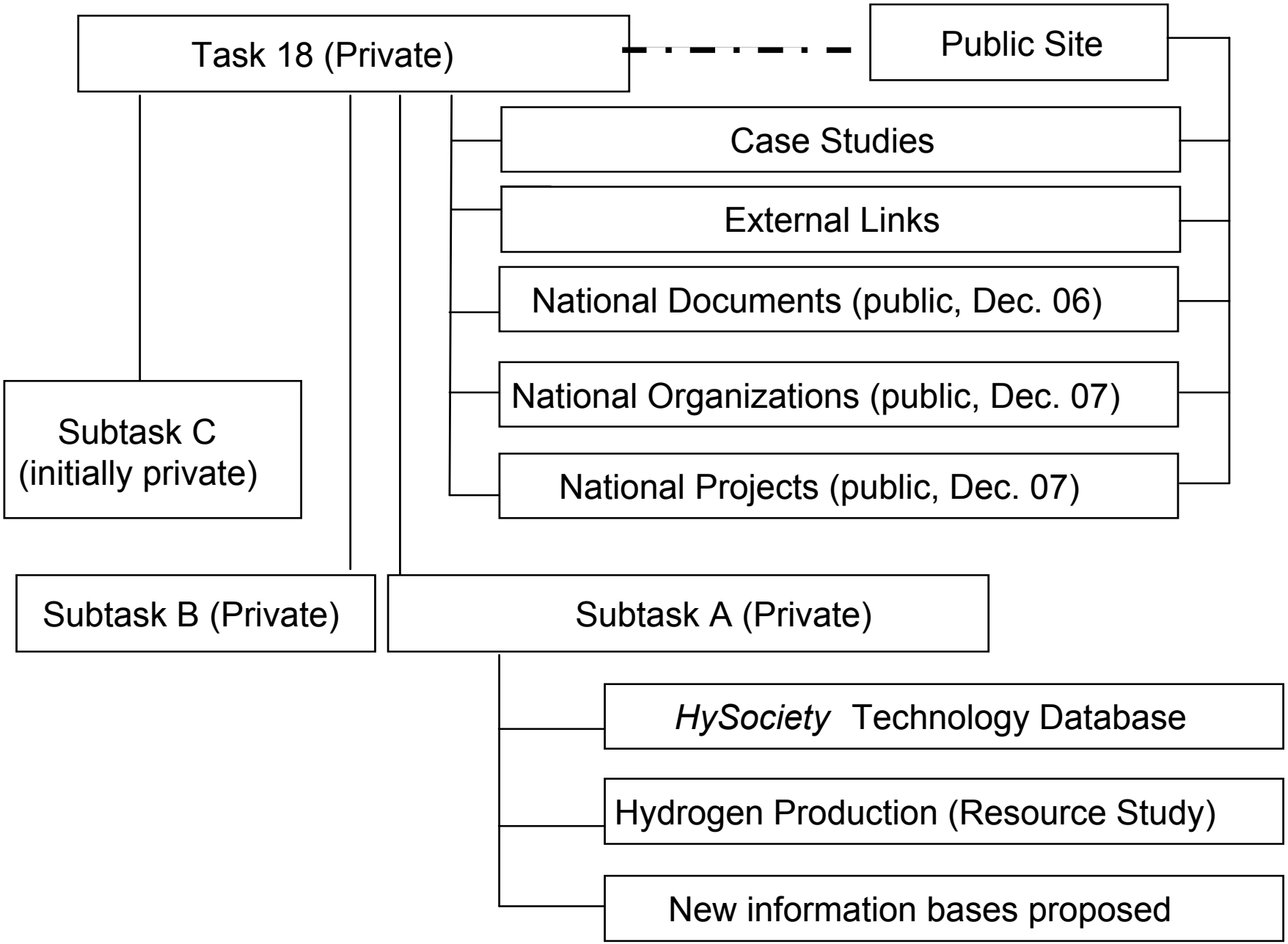
- National plans
- Demonstration progress
- Hydrogen resources
- Vendors
- Utilization rates
- Geographic information
- Refueling projections
- Costs
- Infrastructure
- Codes and Standards
- Economic analysis



Annex 18 website: Searchable portal



Subtask A: Information Bases



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)

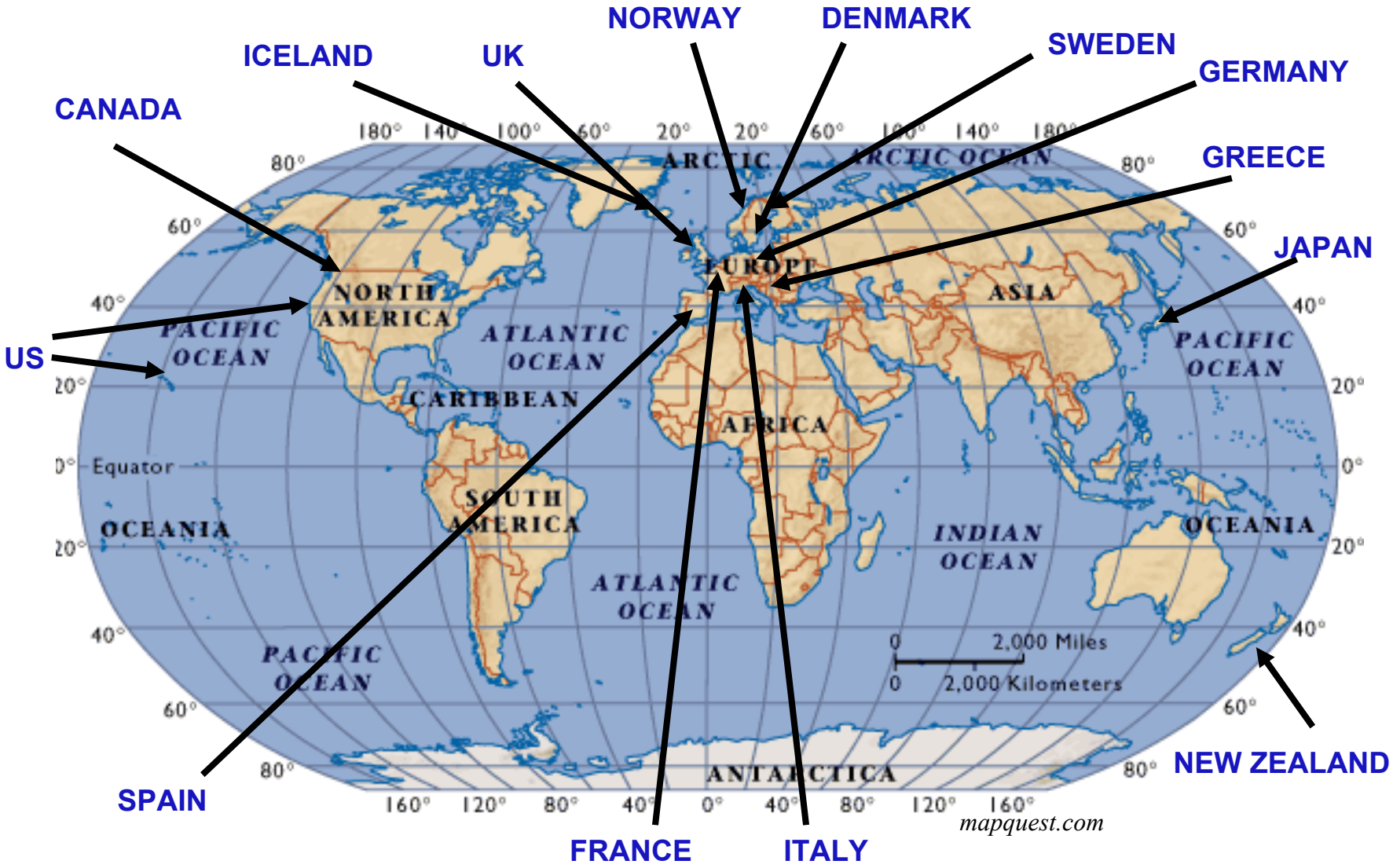
–Overall Performance (user-friendliness, utilization)

Qualitative Analysis

Subtask B Analysis Project Portfolio

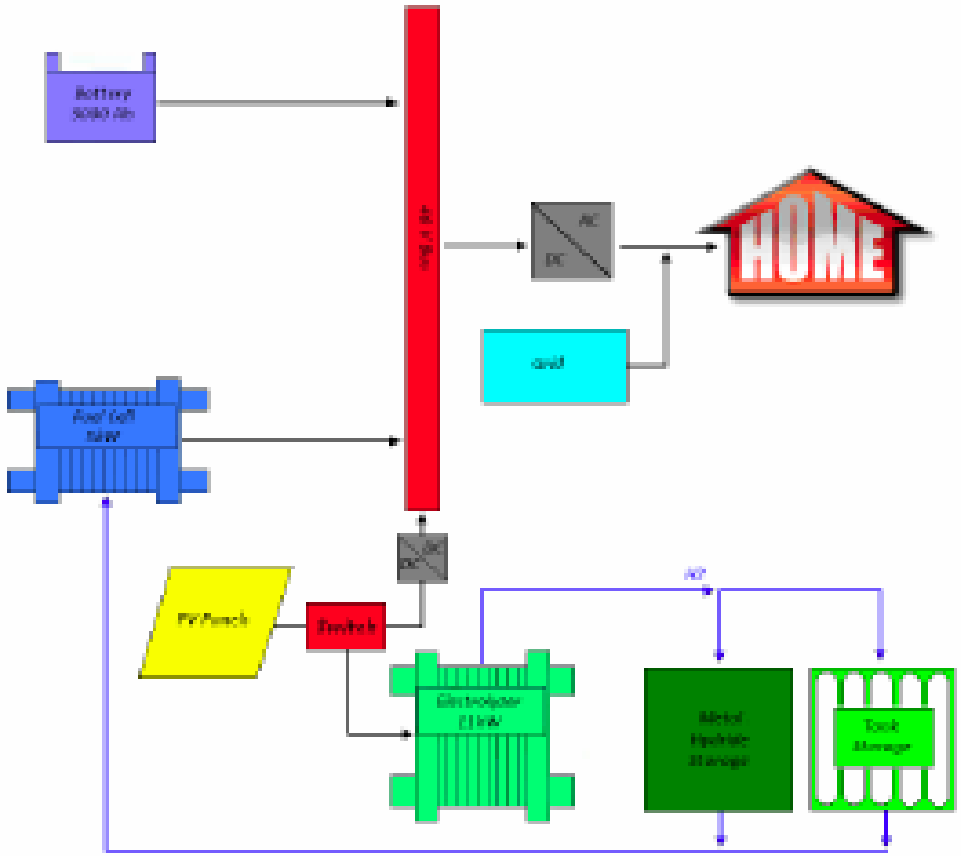
Country	Projects	Location	Modeling focus	Modeling being done by:	Simulation / model in use	Evaluation status	Estimated Completion date
Refueling Stations							
Sweden	Hydrogen filling station (re grid/electrolysis)	Malmö	System sizing	IFE	**Hydrogems**	Expansion in progress	End 2008
Spain	Hydrogen filling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

Project / Member Locations



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 photo-voltaic panels



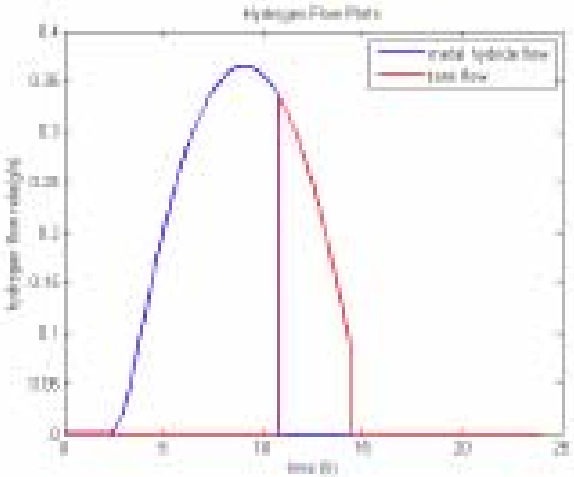
- Main Tasks
  - Control System Development
    - Load Management and Hydrogen Control
    - Event monitoring and control
  - Analysis of demonstration economics

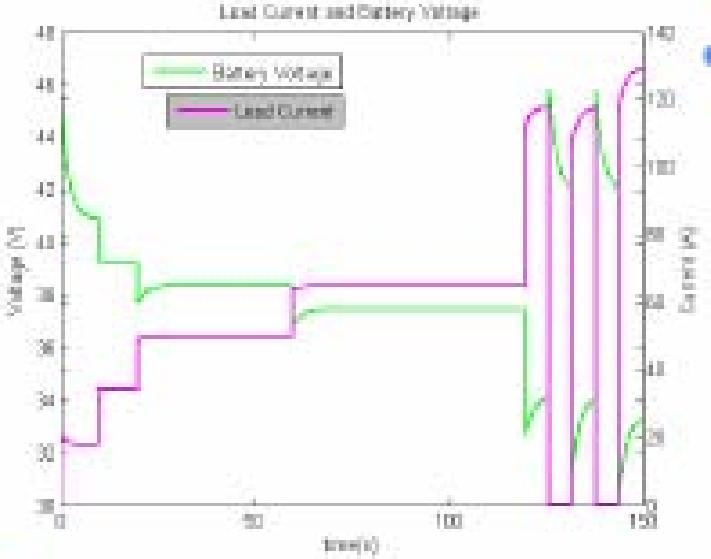
Sandia National Laboratories

CRF

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

Sandia National Laboratories

CRF

System economics show that grid-independent operation affects cost of electricity

Hydrogen Cost:

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

CONTRIBUTION	COH ($/kg-$H_2$)
Capital	2.37
Feedstock (electricity)	6.64
O&M	0.34
TOTAL	9.36

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)**

Sandia National Laboratories

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Technology Assessment – Hawaii H2 Power Park

HNEI: Rick Rocheleau, Mitch Ewan, Severine Busquet

Big Island Hydrogen Sites

1. Kahua Ranch –
PV-Wind-Hydrogen Test Bed
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

Sandia National Laboratories

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

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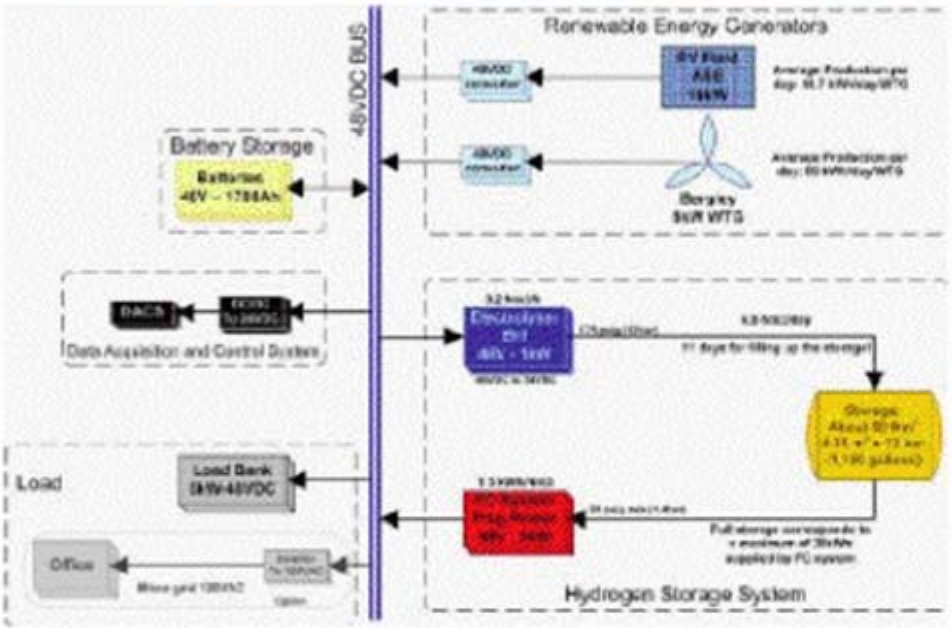
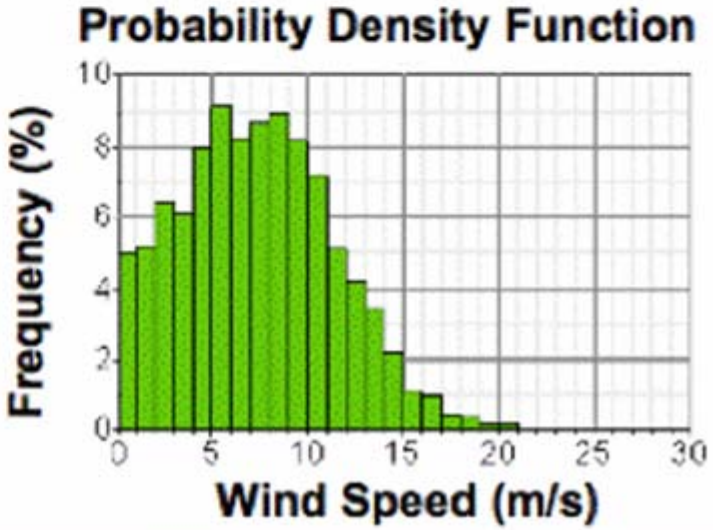
Kahua Ranch PV-Wind-Hydrogen System



- 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



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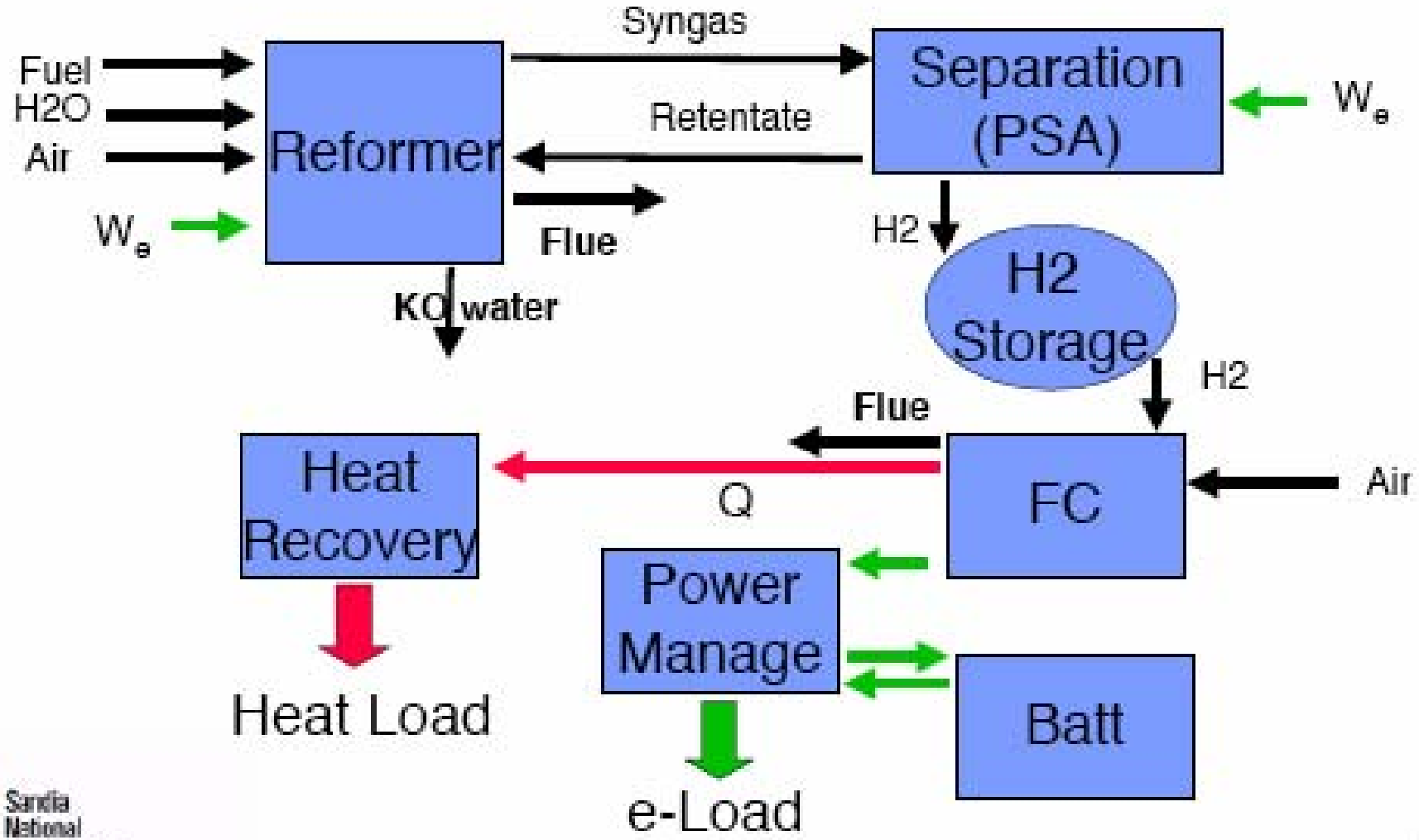
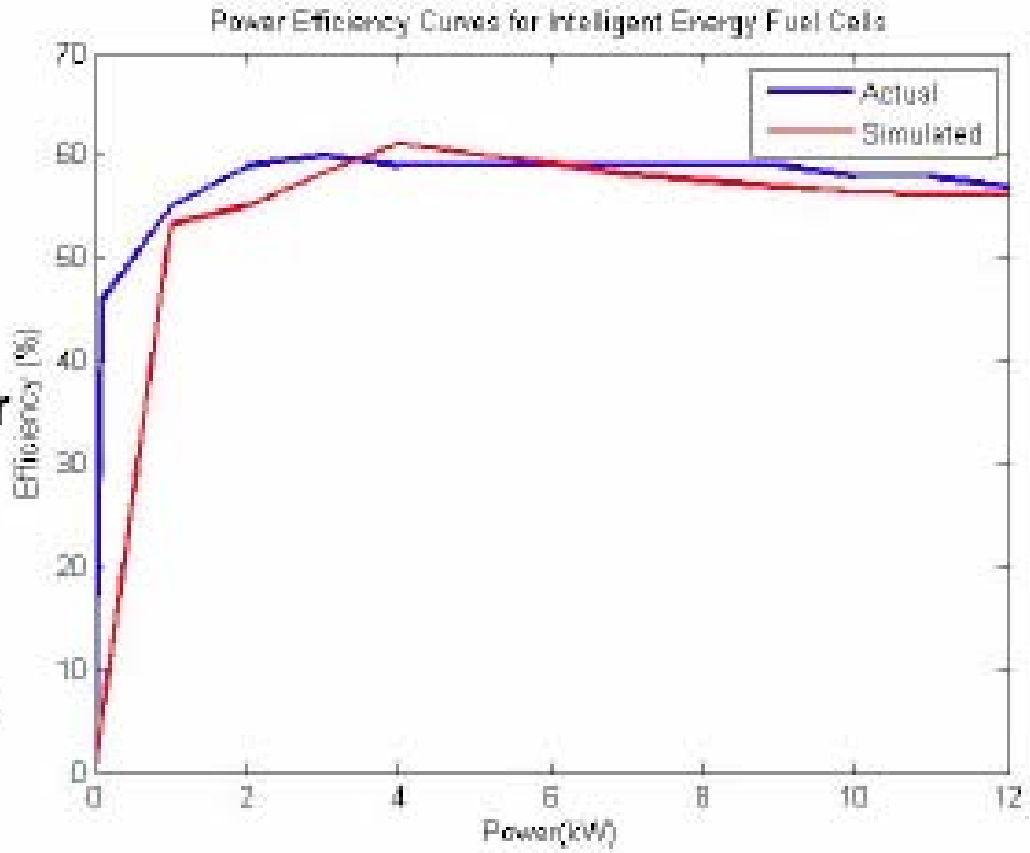
Analysis of Intelligent Energy System

Andy Lutz, Emma Stewart, Sandia National Laboratories



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

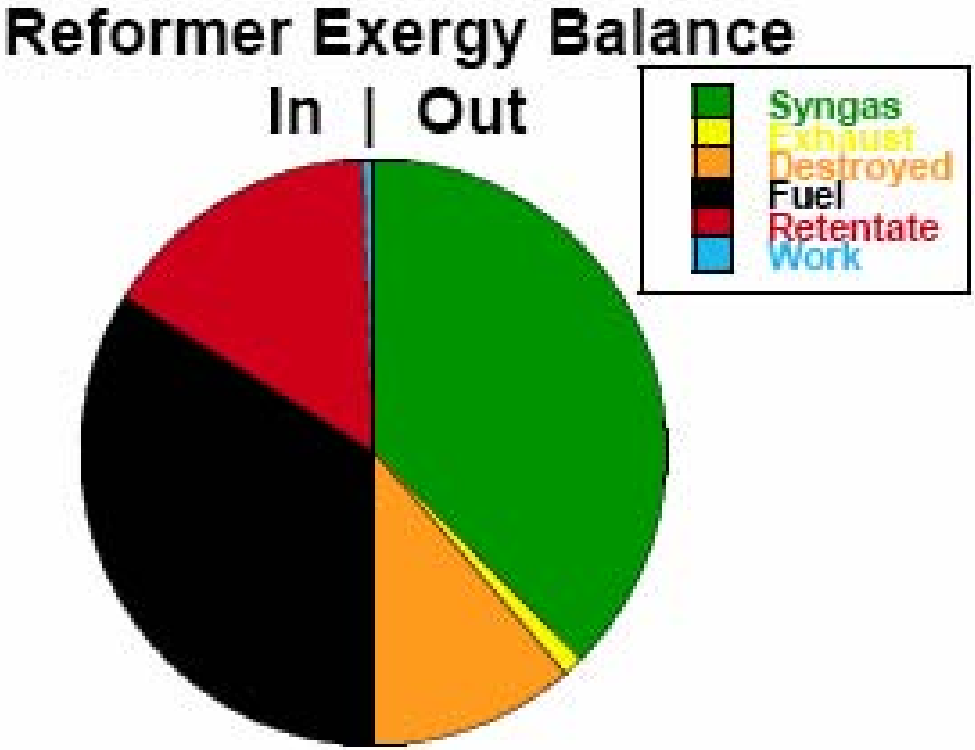


Sandia National Laboratories

CRF

Exergy analysis quantified inefficiency

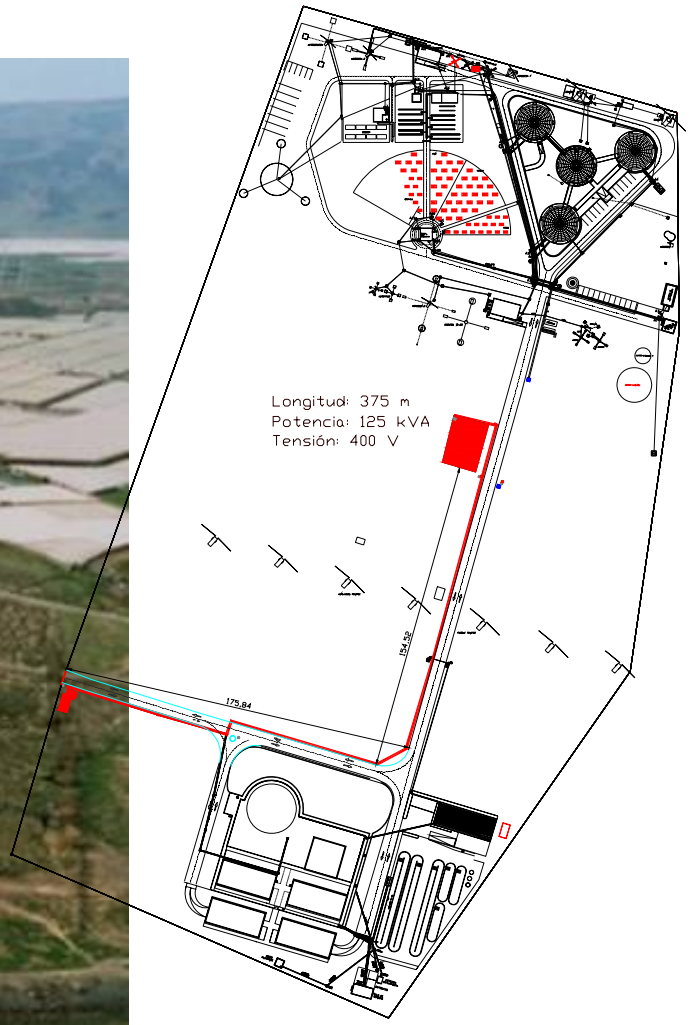
- Exergy balance for reformer shows destruction of useful energy
- Inputs:
  - Fuel, Retentate, Work
- Outputs:
  - Syngas, Exhaust
- Difference is exergy destroyed by irreversible processes



Sandia National Laboratories

CRF

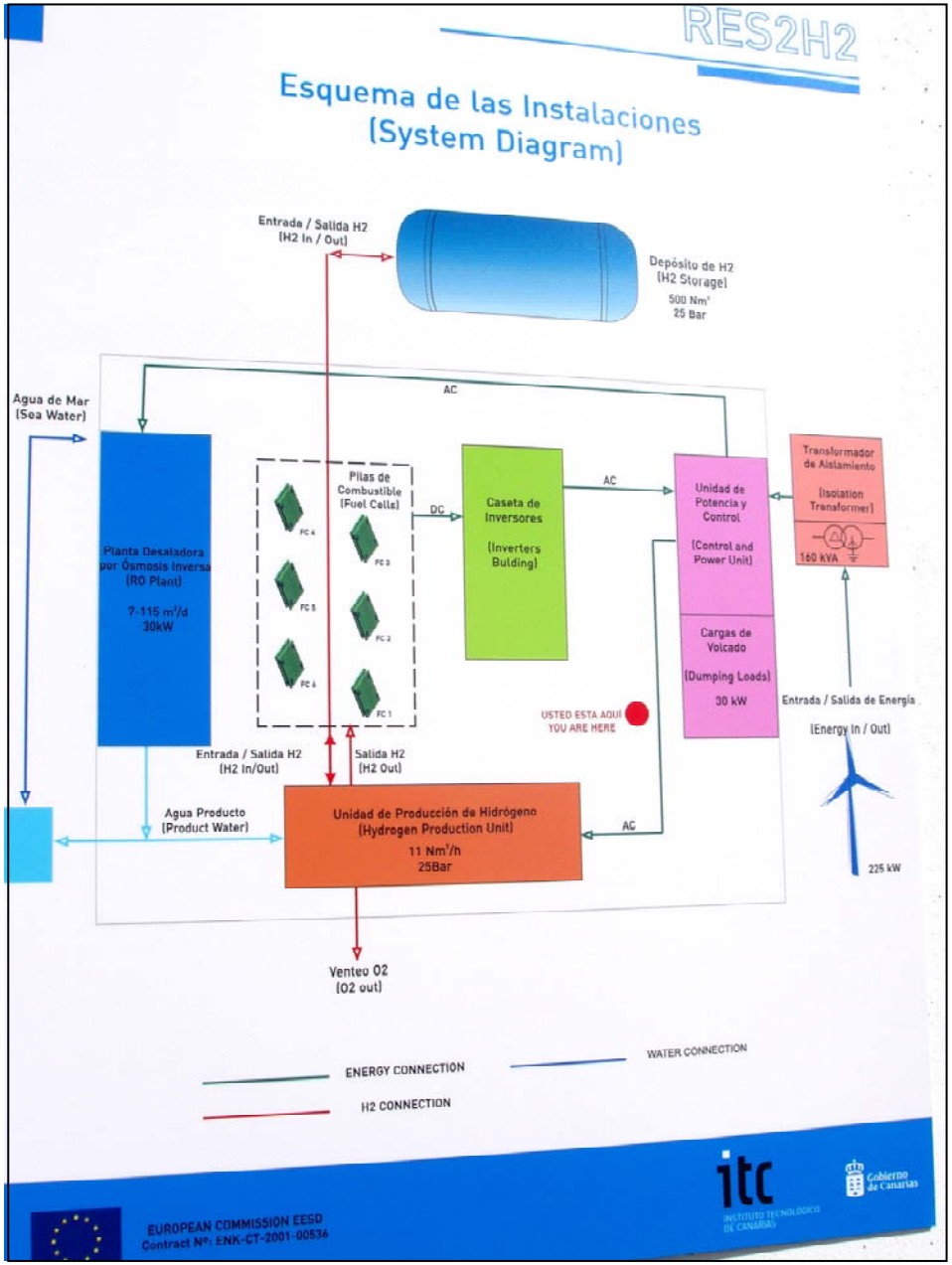
RES2H2 Wind-Hydrogen-Desalination Plant



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

http://task18b.hidrogenoaragon.org/

Phase 1 Subtask B Final Report

System Studies - Optimization for the Future

Hydrogen Demonstration Project Evaluations

FINAL REPORT

for

IEA – International Energy Agency
HIA – Hydrogen Implementing Agreement

Task 18: Integrated Systems Evaluation
Subtask B: Demonstration Project Evaluations

Prepared by:

Øystein Ulleberg*
Subtask B leader
Institute for Energy Technology (IFE), P.O. Box 40, NO-2027 Kjeller, Norway

Hiroshi Ito
National Institute of Advanced Industrial Science and Technology (AIST), Energy Technology Research Institute (ETRI), 1-2 Namiki, Tsukuba 305-8564, Japan

María Hildur Maack
Icelandic New Energy, Borgartun 37, Reykjavik, Iceland

Bengt Ridell
Carl Bro Energikonsult AB, SE-205 09 Malmö, Sweden

Shannon Miles
Natural Resources Canada, 4250 Wesbrook Mall, Vancouver, B.C. V6T 1W5, Canada

Nick Kelly
University of Strathclyde, Department of Mechanical Engineering, Glasgow G1 1XJ, UK

Agostino Iacobazzi
Italian Agency for New Technology (ENEA), C.R. Casaccia, Via Anguillarese 301, 00060 Rome, Italy

Maria del Pilar Argumosa
National Institute for Aerospace Technology (INTA), Renewable Energy Department, Ctra. de Ajalvir, km. 428850, Toorjon de Ardoz, Madrid, Spain

Susan Schoenung
Operating Agent
Longitude 122 West, Inc. Menlo Park, California, USA,

November 2007

Subtask C: Synthesis and Learning

Activity 1: Documenting Experiences/ Practical Lessons Learned/ Guidance

A. Categorization of the project portfolio and case studies
B. Categorize/ outline a guidebook.
C. Complete guidebook

Activity 2: Case Studies

A. Complete draft of new template
B. Complete list of new case studies and completion dates
C. New case studies include:
   i. Spain,
   ii. Greece,
   iii. Netherlands
   iv. Etc

Activity 3: Trend analysis

A. Categorize trend attributes for trend analysis
B. Publish interim trend analysis reports
   i. Interim Report
   ii. Interim Report
   iii. Interim Report
C. Publish final trend analysis report

Activity 4: Comparative & Technical Analysis

A. Comparisons of:
   i. Electrolyzers
   ii. Permitting and Safety Experiences
   iii. Control Systems & Strategies
   iv. Literature Review of Grid Connected Stationary applications
   v. Comparison of Stationary systems

Activity 5: Outreach/ Dissemination Activities

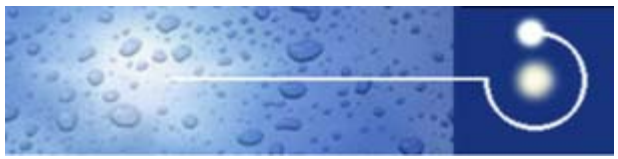
A. Prepare a list of papers, reports and schedule where/when for delivery.
B. Decide on outreach venues for our high level findings
C. Regularly publish on our public site high level findings of our work.

Activity 6: Regional & National Plans

A. Develop and publish comparison of different types of government support initiatives

Activity 7: Economic Analysis

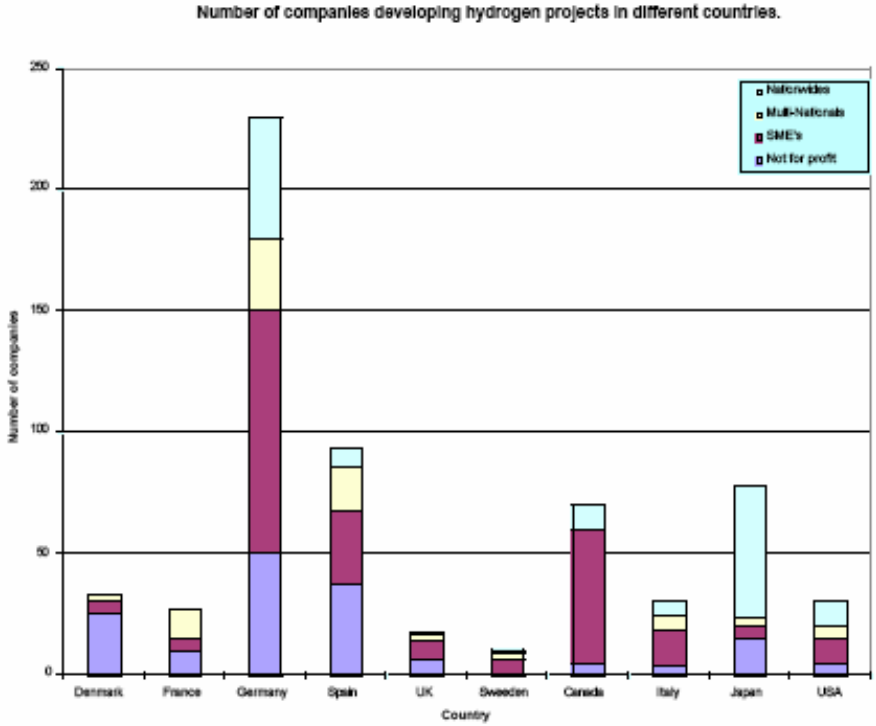
A. Cost saving potential for present & future
B. Niche market opportunities



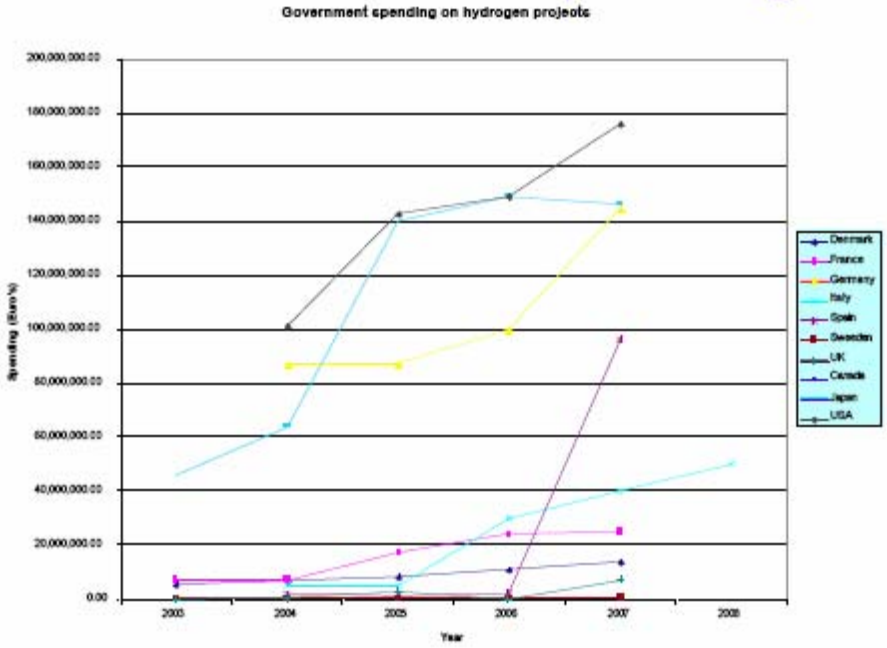
Subtask C: Early Outcomes

Funding and Co-ordination of Projects Survey

Number of Companies



Government spending



Permitting Analysis for new projects - work in progress

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

Future Work: Plans for 2008-2009

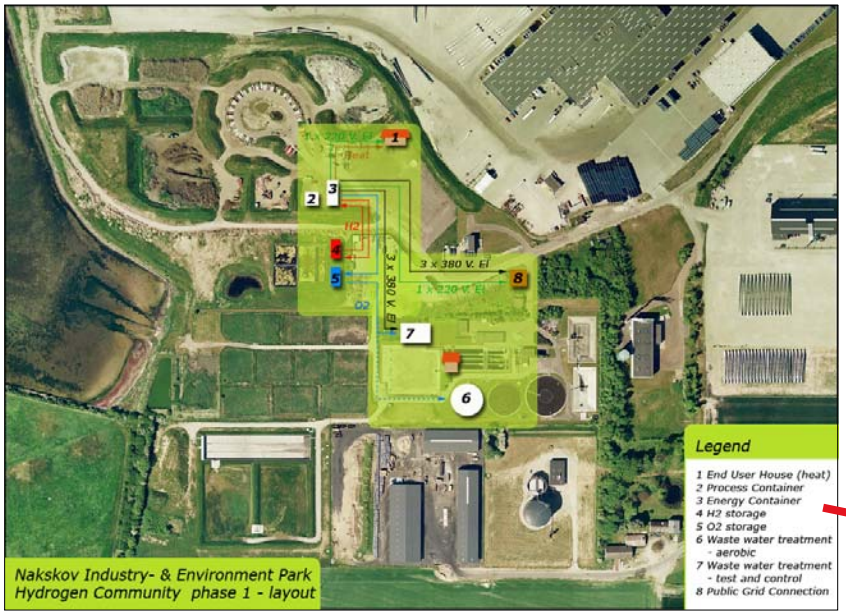
Technical progress plans

- 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

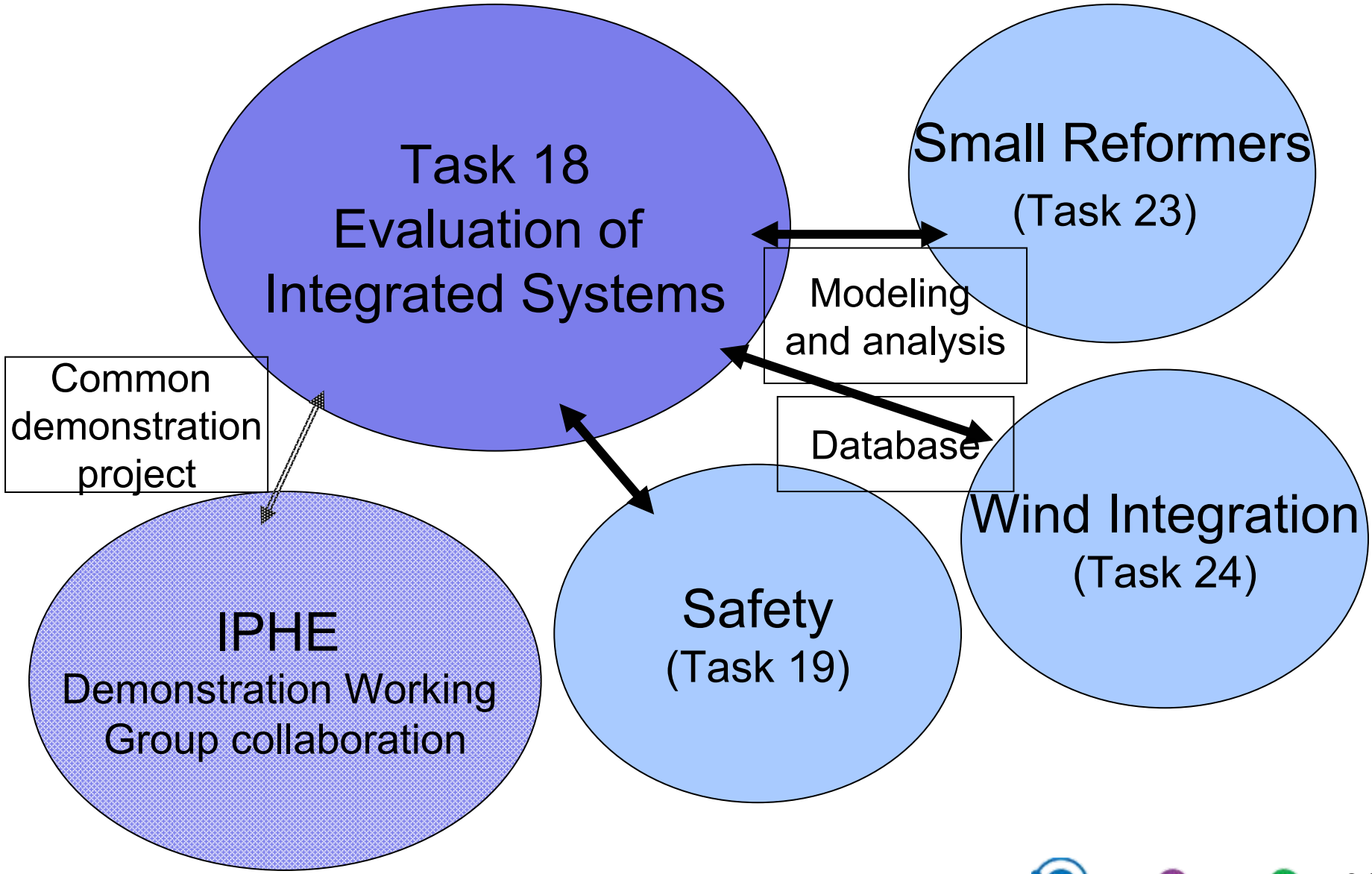
- Task Experts meet twice per year; fall 2008 meeting is scheduled for Copenhagen; spring 2009 meeting is tentatively planned for Germany
- Operating agent meets twice a year with Executive Committee; spring 2008 meeting in Australia; fall 2008 meeting in Greece in November
- Semi-annual reports due 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



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

"Pioneering Experiences by Users of Integrated Hydrogen Systems," by Schoenung, et al.

WHEC 2008 Submittals

- Susan M. Schoenung, Jean Dubé, Ismael Aso, and Shannon Miles, "An Evaluation of Integrated Hydrogen Systems: Overview of IEA Hydrogen Task 18"
- 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"

Case studies (Available on IEA Hydrogen Implementing Agreement: website: http://www.ieahia.org/case_studies.html

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

Task 18 Contact Information

Operating Agent:

Dr. Susan Schoenung, Longitude 122 West, Inc.

schoenung@aol.com +1 650-329-0845

Subtask A: Emma Stewart, Sandia National Laboratories

emstewa@sandia.gov +1 925-294-4814

Subtask B: Ismael Aso, Hidrogen Aragon, Spain

iaso@hidrogenoaragon.org

Subtask C: Shannon Miles, Natural Resources Canada

shannon.miles@nrcan.gc.ca +1 604-221-7373

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

Private website: http://iea-hia-annex18.sharepointsite.net/

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HYDROGEN IMPLEMENTING AGREEMENT