Hydrogen Enabling Renewables Working Group

Update for the HTAC

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Purpose

Examine the various ways in which hydrogen might serve as an enabler for high penetrations *(>50% nationally, on an energy basis)* of variable renewable energy in the United States.

Summarize the opportunities and challenges of using hydrogen as an enabler for renewables in a white paper for DOE executive management.

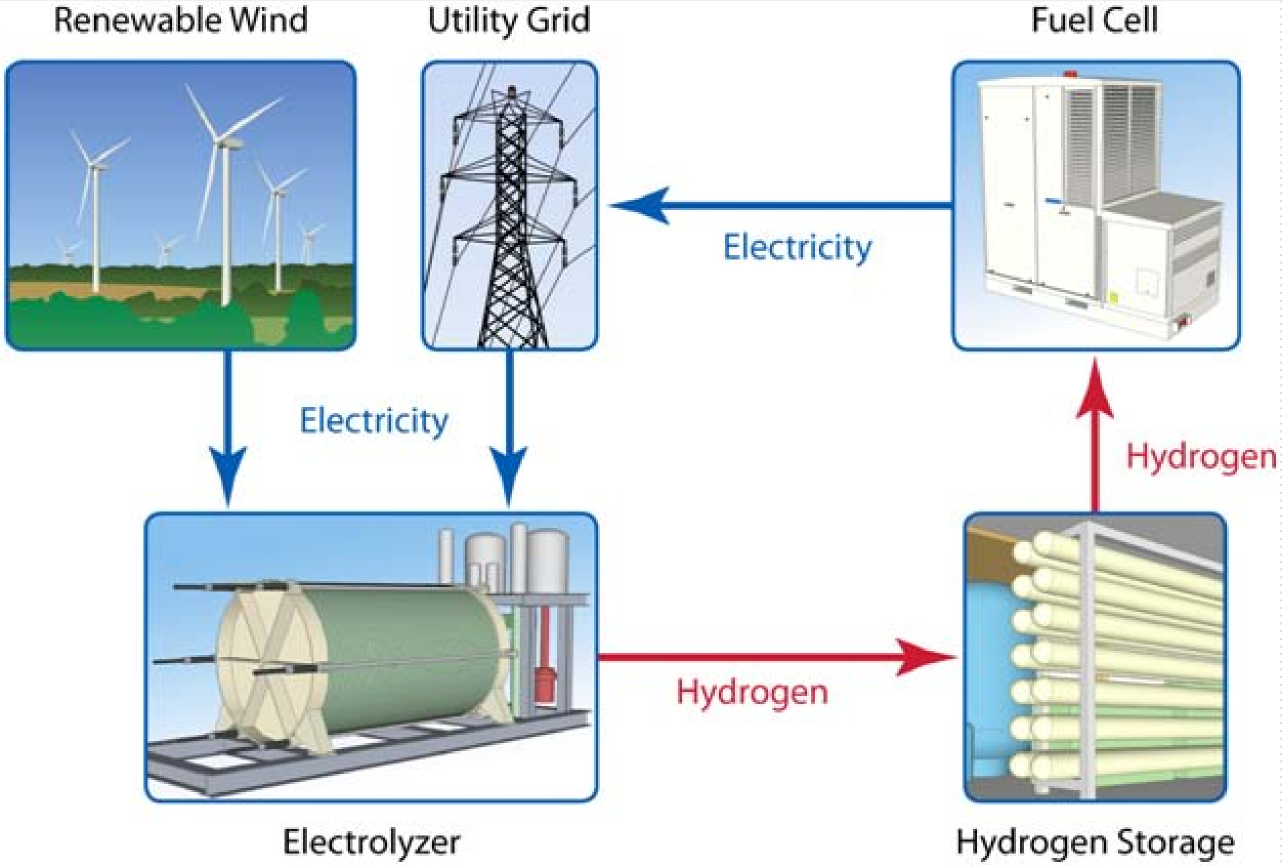
Potential Applications

- Energy storage
- Energy transmission & distribution
- Improved renewable resource utilization via vehicle fuel production
- Supplement to Natural Gas System

Initial Focus Area

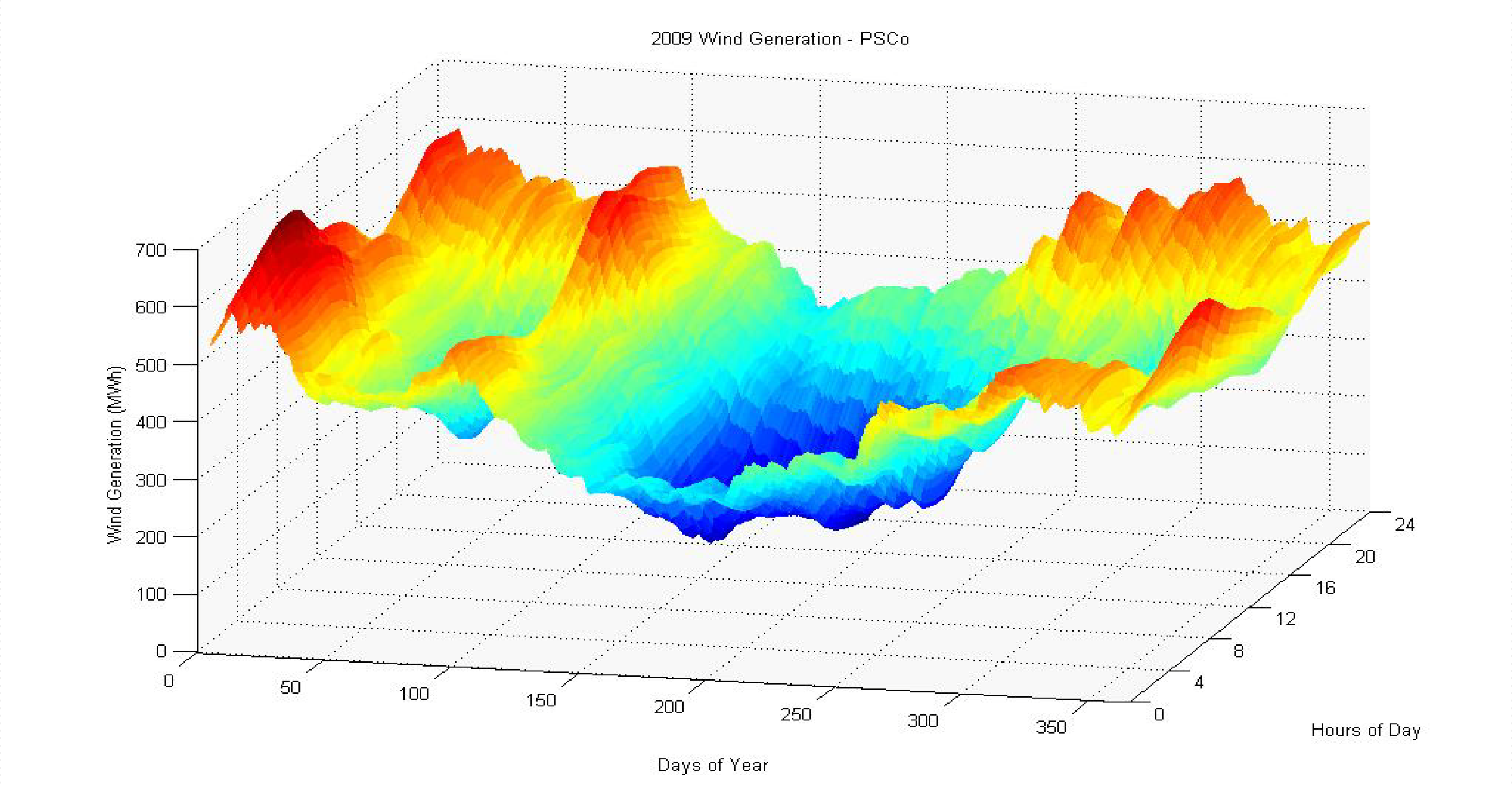
- Grid energy storage application
  - Integration of variable renewable resources (ramp rate controls, time shifting from off-peak to on-peak, reserve margins, etc.)
  - Reduction of variable renewable energy curtailments due to baseload bottoming and/or transmission and distribution system constraints
- Basis
  - Analysis of this application can be leveraged in the analysis of other applications
  - DOE interest in energy storage for integrating renewables

Simple Hydrogen Storage Scheme



Source: Darlene Steward - NREL

Wind Doesn't Always Blow When Needed (Example 2009 Wind Generation)



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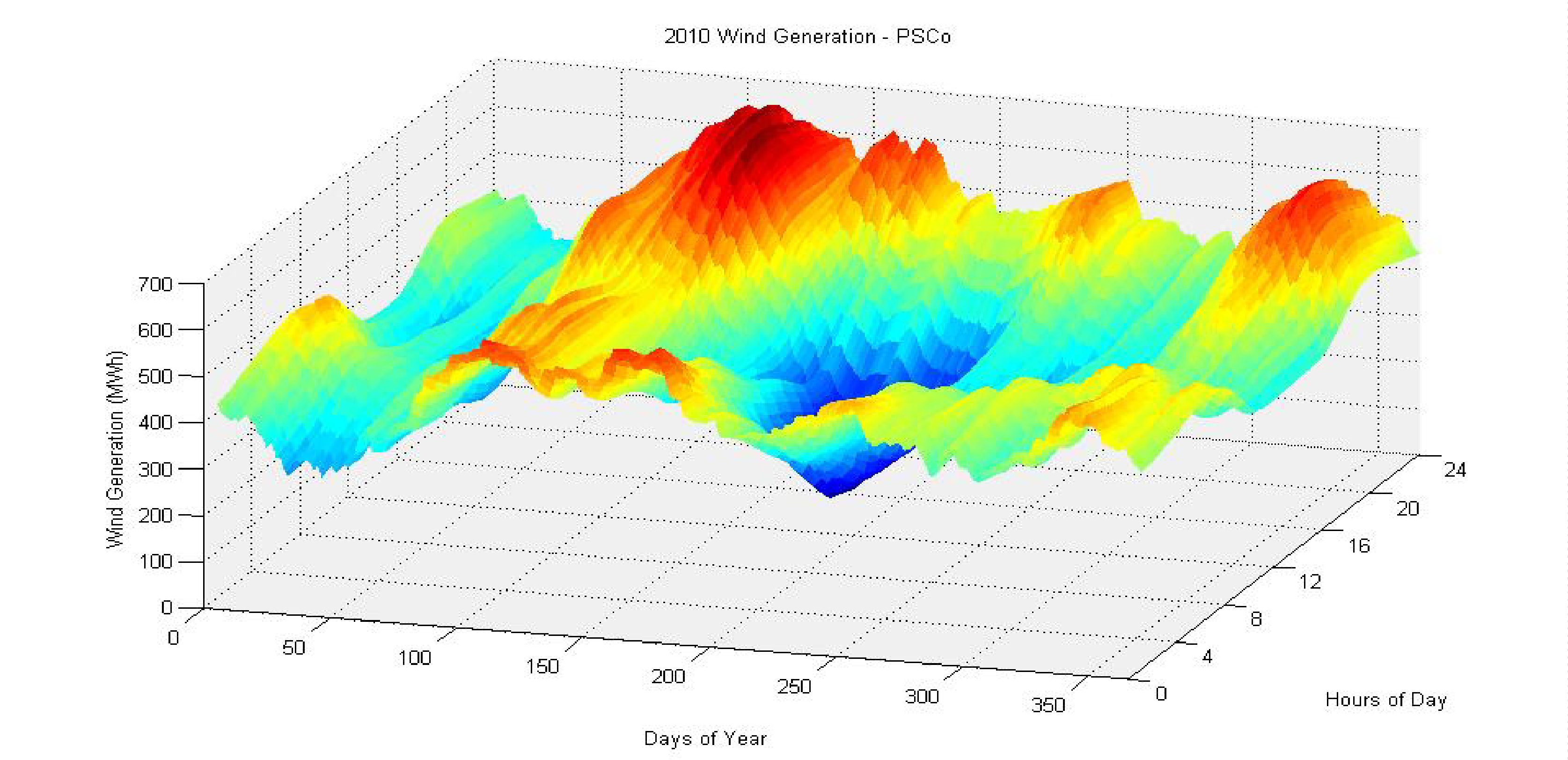
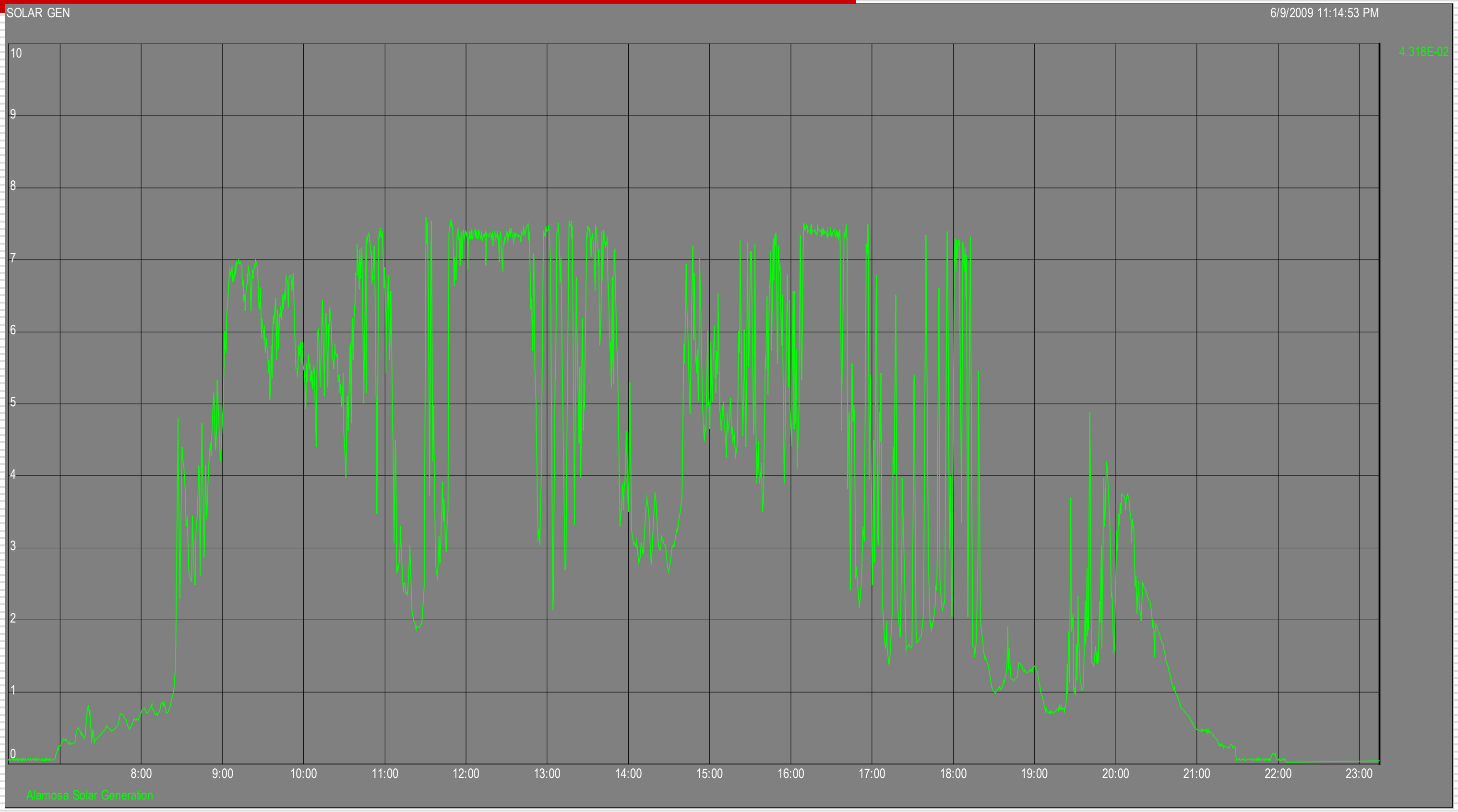


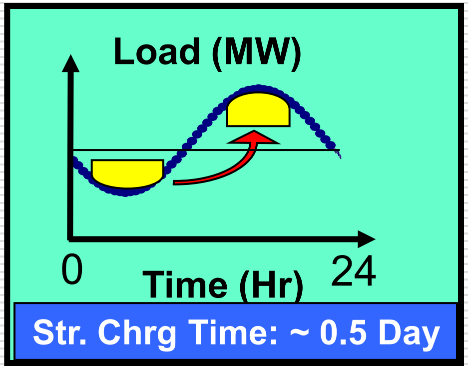
Solar PV Variability



Data from PSCo 8 MW Solar PV Facility in Alamosa, CO

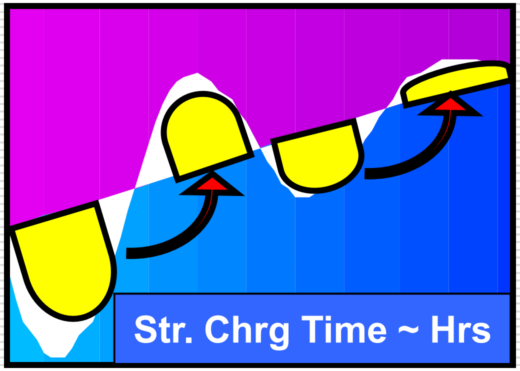
Renewables Integration Value Elements for Energy Storage

Time Shifting



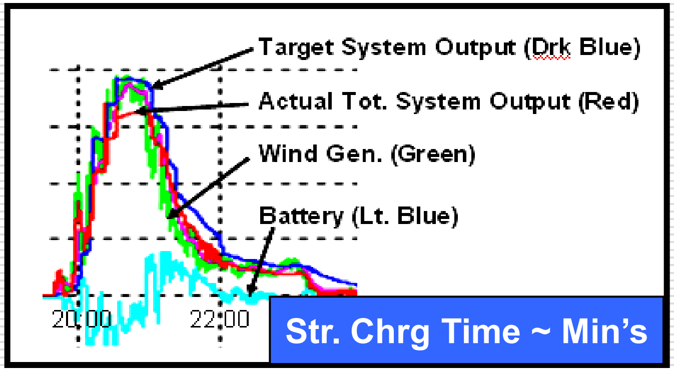
- Arbitrage
- Constraint Relief
- Curtailment Avoidance
- Load/DG Matching
- Peak Shaving

Ramping Control



- Reduced generator cycling
- Reduced reserve requirements (gas & elect)
- Power flow control (distribution)
- Voltage stability (distribution)

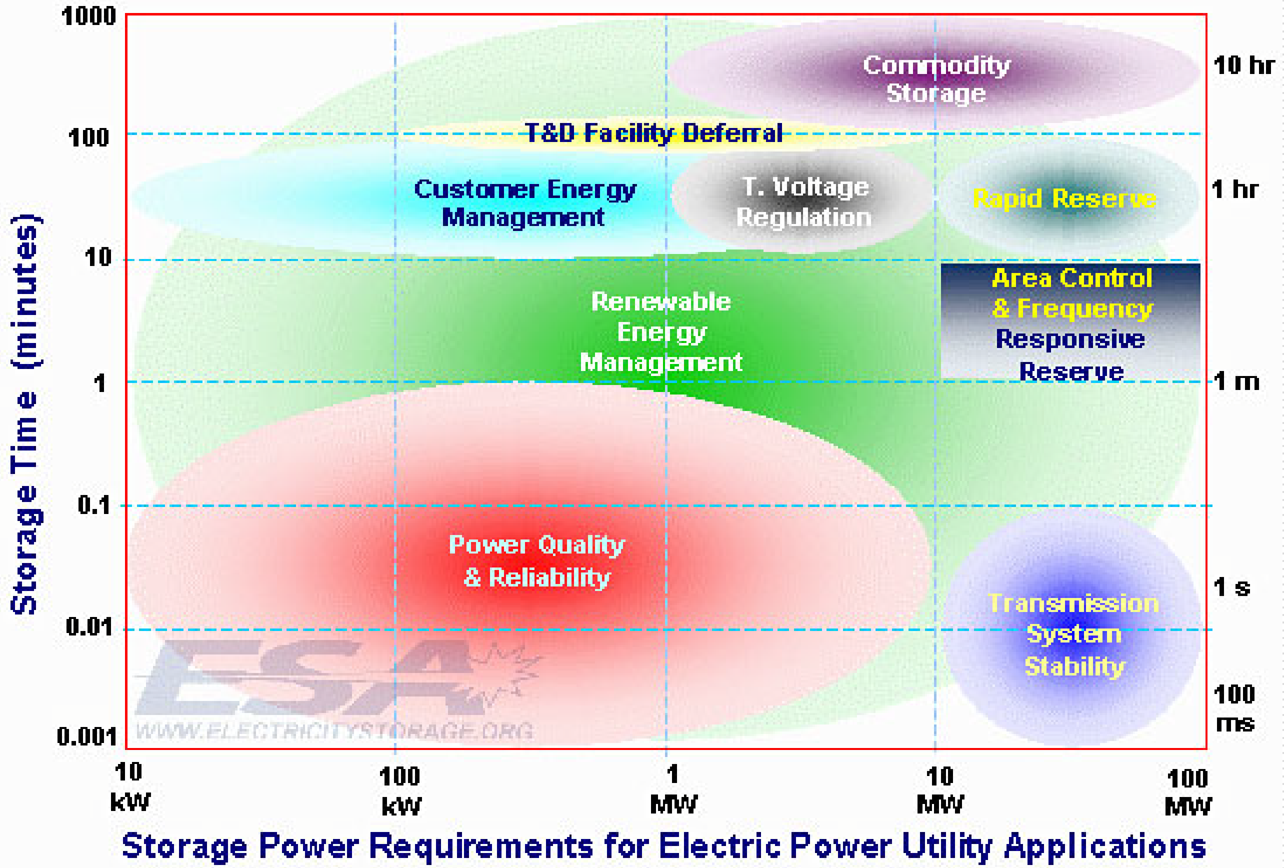
Regulation



- Frequency – "Reg Up/Reg Down"
- Voltage/VAR support
- Fast response to system perturbations

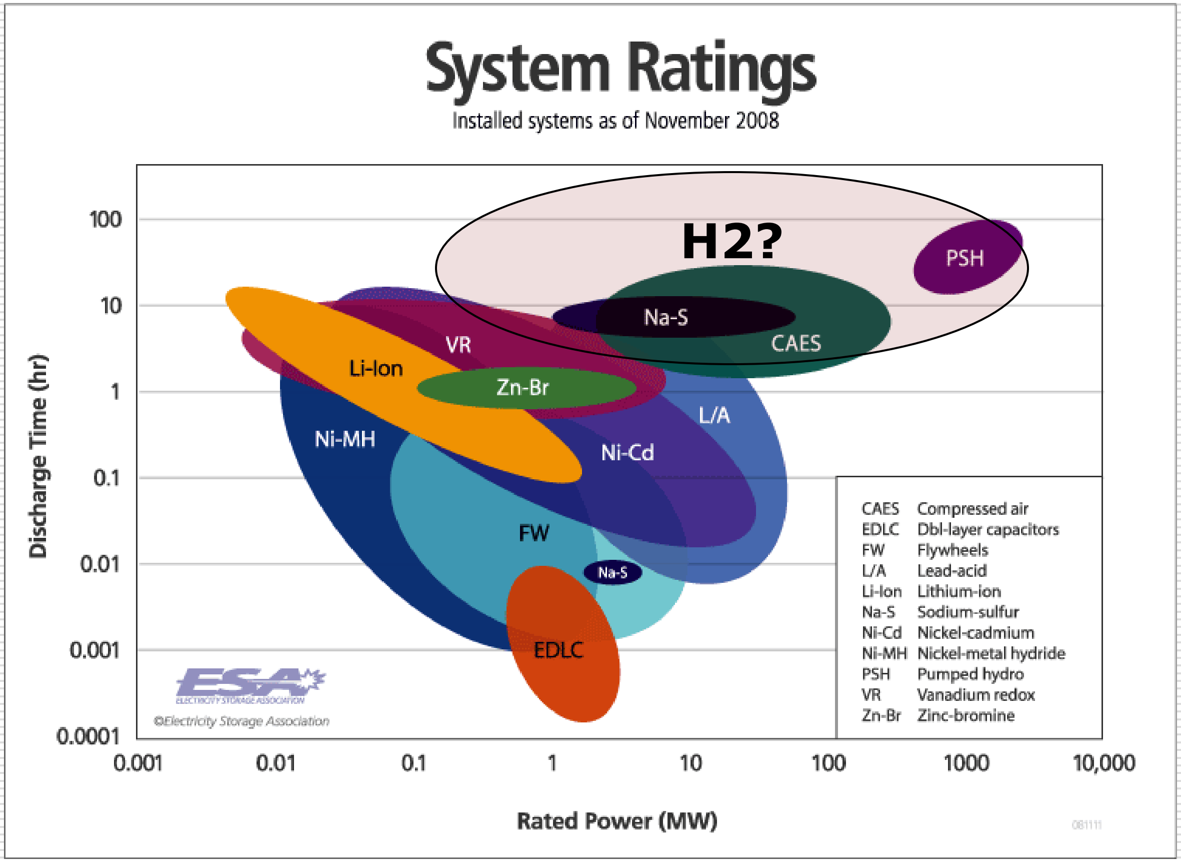
Source: EPRI

Utility Applications for Storage



Data from Sandia Report 2002-1314

Storage Ratings By Technology



WG Tasks - Energy Storage

- Identify and assimilate information needed to evaluate the viability of hydrogen energy storage to:
  - Mitigate the variability of renewable energy
  - To be competitive with other energy storage technologies, including:
    - associated infrastructure requirements and
    - the relative probability of a solution being commercially available in the next 10 years
- ***Progress:***
  - ***Continued assessment of competing technologies***
    - ***Several new technologies hold promise for low cost and high efficiency***
      - ***Lithium flow battery (MIT)***
      - ***Sodium halide battery (Aquion)***
    - ***Interesting new hydrogen energy storage technologies (e.g., Reversible solid oxide fuel cell concept)***
- ***Next Steps: Analyze European hydrogen energy storage economics and rationale for applicability to the US***

WG Tasks - Energy Storage

- Develop simple model for examining the basic economics
- ***Progress:***
  - ***HTAC/NREL Validation of simple model and assumptions for distributed energy storage applications in progress***
  - ***Initial (distributed model) validation results are favorable***
- ***Next steps***
  - ***Summarize economics of distributed energy storage from model runs***
    - ***Costs and efficiencies of hydrogen systems***
  - ***Begin validation of simple model and assumptions for central energy storage applications***

Current Model Validation Assumptions

Model Parameter	Units	Suggested Common Value
PV Electricity Cost to H2 System Owner	cents/kWh	8.6
Electrolyzer Capex	$/kWin	495
Electolyzer Efficiency	%HHV	80%
Fuel Cell Capex	$/kWout	950
Fuel Cell Efficiency	%LHV	59%
Hydrogen Storage System Capex	$/kg	619
Compressor System Cost	$/kg/day	760
Compressor System Efficiency	% HHV	92%
Insurance	% of initial direct capital	2%
Fuel Cell Annual O&M Rate	% of initial direct capital	2%
Electrolyzer Annual O&M Costs	% of initial direct capital	3%
Hydrogen Compressor Annual O&M	% of initial direct capital	5%
Hydrogen Storage Annual O&M	% of initial direct capital	0.020%
Inflation Rate	% of initial direct capital	2%
Total Tax Rate		0%
Reference Dollar Year for Costs		2010
Debt Financing	Debt Financing	100%
Interest Rate on Debt	Interest Rate on Debt	8%
Real, After-Tax Rate of Return Required		0%

Notes & Assumptions:

1. Model parameters are based on a 2020 planning timeframe.
2. Model parameters assume a manufacturing scale of 1,000 systems per year.
3. Annual O&M costs are calculated as a % of initial capital, and include the periodic replacement of components. Compressor system cost is scaled on the hydrogen flow rate in kg/day of flow.
4. The compressor system assumes a 200 psi input pressure and a 3,600 psi output pressure.
5. Renewable electricity to operate the hydrogen storage system is purchased at 8.6 cents/kWh from a PV array.
6. The capital costs associated with construction of the PV array are not included in this analysis.

WG Tasks - Energy Storage

- Apply model to hydrogen and other competing energy storage systems
- Compare results
- Identify key issues for hydrogen system competitiveness
- ***Progress:***
  - ***Accumulating results from relevant economic studies on other energy storage technologies***

Key Variables for 50% Renewables Energy Penetration Scenarios

- Cost of carbon
- Cost of natural gas
- Percent charging with otherwise curtailed renewables (likely wind)
- Amount of storage required to capture optimal amount of otherwise curtailed wind

HTAC Feedback

Appendix

Characteristics of a future US combined electric grid and transportation sector powered with >50% renewables

- Large amounts of variable off-peak renewable energy "spillage"
- Renewables used to power both grid and transportation sectors would count toward total energy produced (denominator) and total renewable energy produced (numerator)
- Reductions in the cost of renewable energy versus traditional energy sources due to high volume production and technological advances
- Baseload power plants with lower turndown capabilities and better load following performance
- Large wind resources will not be near large load centers, requiring significant transmission investments
- Environmental concerns and transmission constraints will limit large scale central solar facilities. This will influence more distributed scale solar, using existing urban and suburban open spaces, including paved lots. This resource will be interconnected to the distribution grids, and will produce more power than is used by the facilities associated with the solar resource.
- Distributed energy such as stationary fuel cells may be more economical and more efficient (both from energy conversion and CO_2 perspectives) than utility scale thermal resources.

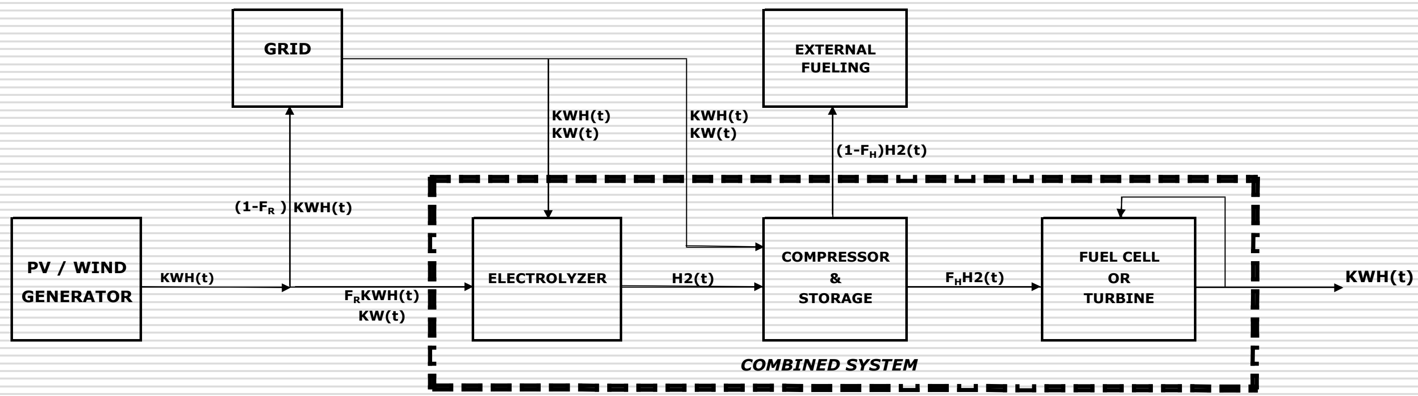
Simple Energy Storage Model Concept (DRAFT)

OUTPUT VARIABLES:

H2 PRODUCED (t)

COST/KG OF H2

COST OF POWER (¢/KWH)
- **OPERATING**
- **CAPITAL**



INPUT VARIABLES:

CAPACITY: KW
HOURS OF OUTPUT/DAY: T_O
CONTRACT PRICE: ¢/KWH

COST OF GRID ENERGY: ¢/KWH(t)

EFFICIENCY: KWH/KG
CAPITAL COST: $/KG
POWER REQUIRED: KW
OUTPUT: KG H2(t)

EFFICIENCY: KWH/KG
CAPITAL COST: $/KG
POWER REQUIRED: KW
OUTPUT: KG H2 stored (t)

EFFICIENCY: KWH/KG
CAPITAL COST: $/KW OUTPUT
POWER REQUIRED: KW (HOTEL LOAD)
OUTPUT: KWH (t)

COST OF CAPITAL

F_R = fraction of kwh to electrolyzer

F_H = fraction of H2 to fuel cell

Assume the *Combined System* runs 24/7 with input either from the Renewable Generator or the Grid.

Note: Model could be run in hourly segments or integrated over a day, week, month, or year.