# 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

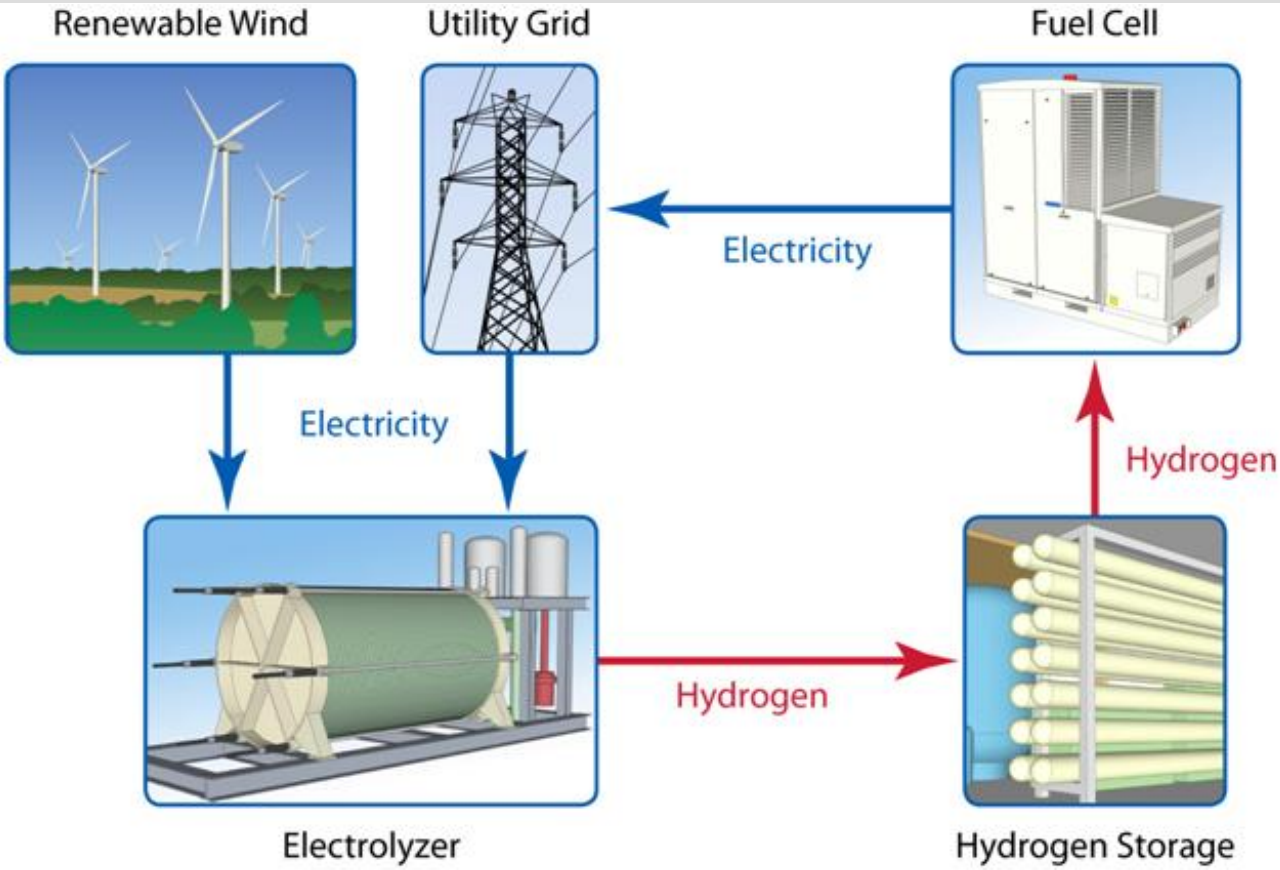
# Initial Focus Area

- 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

# Modeling Progress

- Simple model validated against NREL hydrogen energy storage models
- Using public version of late 2010 EPRI energy storage cost comparison paper for cost comparison figures
- Ran various scenarios

# Simple Hydrogen Storage Scheme



*Source: Darlene Steward - NREL*

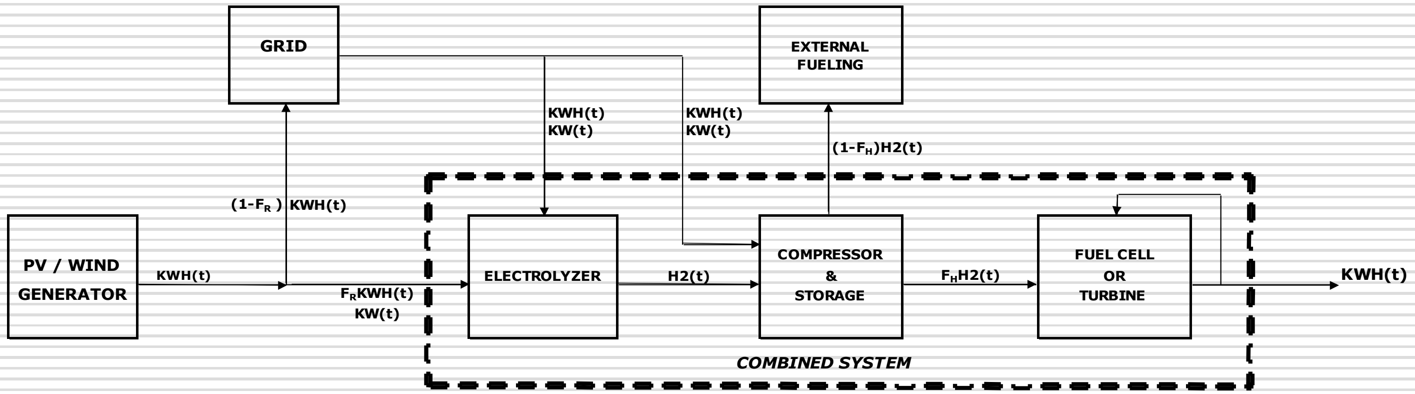
# Simple Energy Storage Model Concept (DRAFT)

**OUTPUT VARIABLES:**

**H2 PRODUCED (t)**

**COST/KG OF H2**

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



**GRID**

**EXTERNAL FUELING**

**PV / WIND GENERATOR**

**KWH(t)**

**(1-$F_R$) KWH(t)**

**$F_R$KWH(t)**
**KW(t)**

**KWH(t)**
**KW(t)**

**KWH(t)**
**KW(t)**

**ELECTROLYZER**

**H2(t)**

**(1-$F_H$)H2(t)**

**COMPRESSOR & STORAGE**

**$F_H$H2(t)**

**FUEL CELL OR TURBINE**

**KWH(t)**

***COMBINED SYSTEM***

**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.

*Source: Bob Shaw & Sandy Thomas*

# Modeling & Analysis Approach

- Focus efforts on “Levelized Cost of Electric Energy in $/kWh”, as was done in the referenced EPRI white paper
- Develop base case & perform sensitivity analyses on the following:
  - **Electrical AC output capacity**: 5 MW, 10 MW, 50 MW and 100 MW
  - **Total duration of storage** (based on full AC electrical output): 4 hours, 24 hours, 1 week, and 1 month
  - **Electrolyzer/compressor charging capacity factors**: 33%, 50%, 75% and 90% (33% represents an 8 hour daily off- peak charging cycle to provide 4 hours of electric generation on peak)
  - **Percentage of free energy available** (e.g. otherwise curtailed wind) for charging: 5%, 10%, 15%, 20%, and 30%
- Additional sensitivity analyses will be considered as we examine the results of the above.

# Preliminary Results

# One Day (4 Hours) Storage

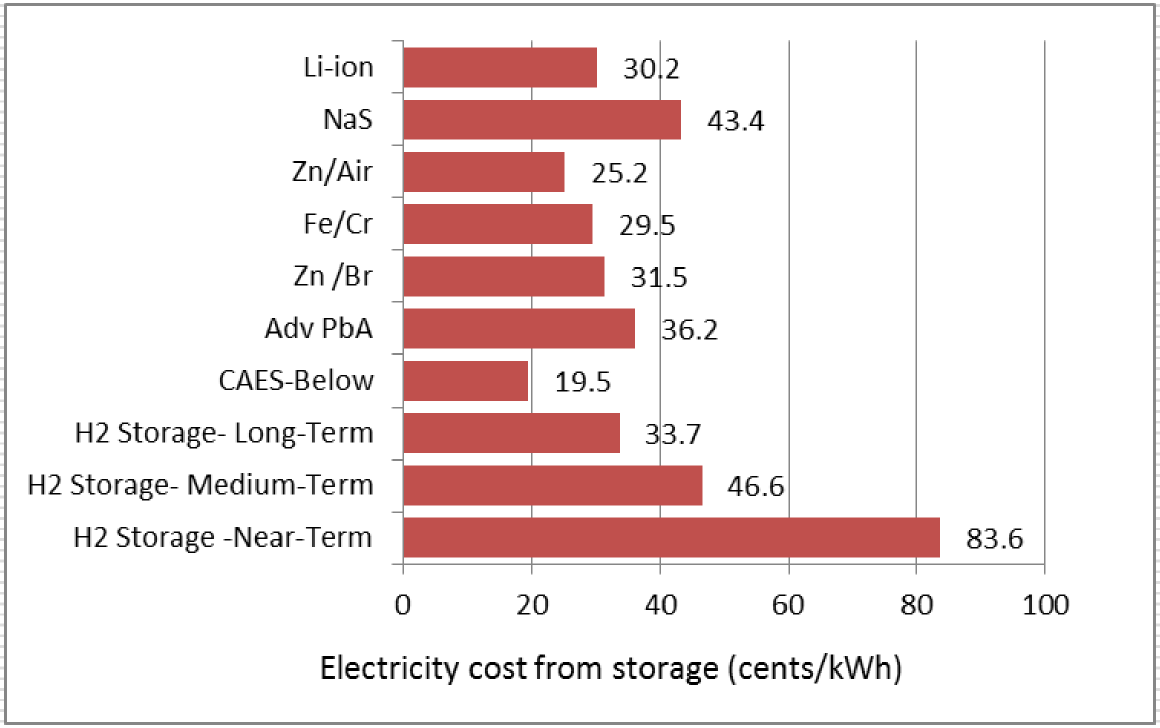


**Figure 1. Price of on-Peak electricity for various below-ground H2 & CAES storage and battery storage options with one-day storage and 10% "free" (stranded) energy for a 10MW output over 4 hours (40MWh/day) & NG = $5/MBTU (for CAES) [All battery & CAES costs are based on the lower EPRI estimates.]**

*Only Long-Term H2 Storage competes in single day cycling*

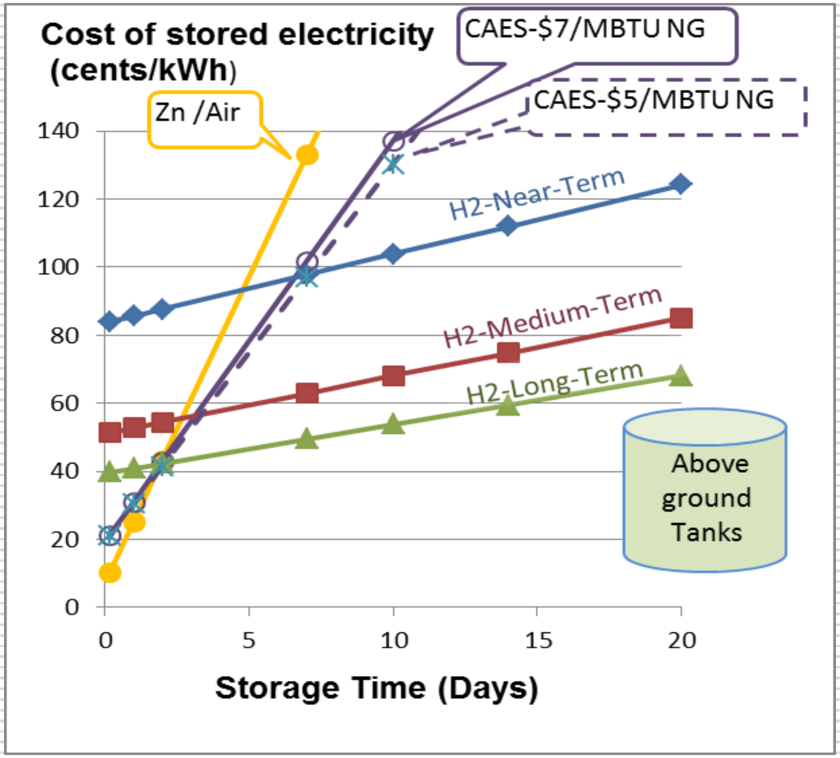
*Source: Sandy Thomas*

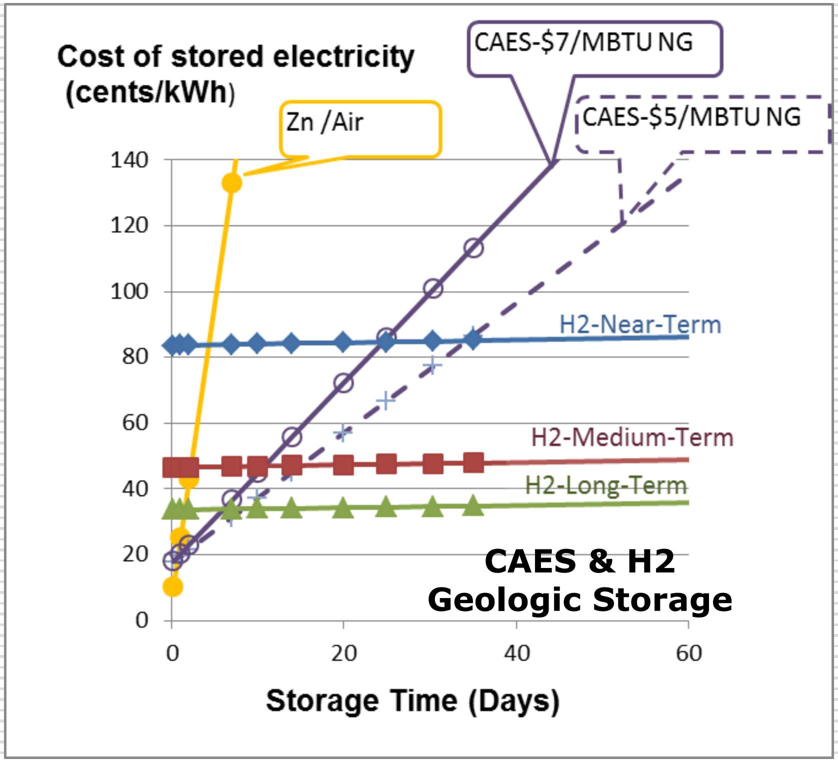
# But …

Multi-day energy storage will likely be necessary in a high renewables penetration scenario, if there is more value placed on otherwise curtailed renewable resources due to:

- Higher Renewable Portfolio Standards
- Carbon Dioxide Emission Controls

# Storage Time Makes a Difference





*Need to understand when there is economic value for longer storage times under high penetration renewables scenarios*

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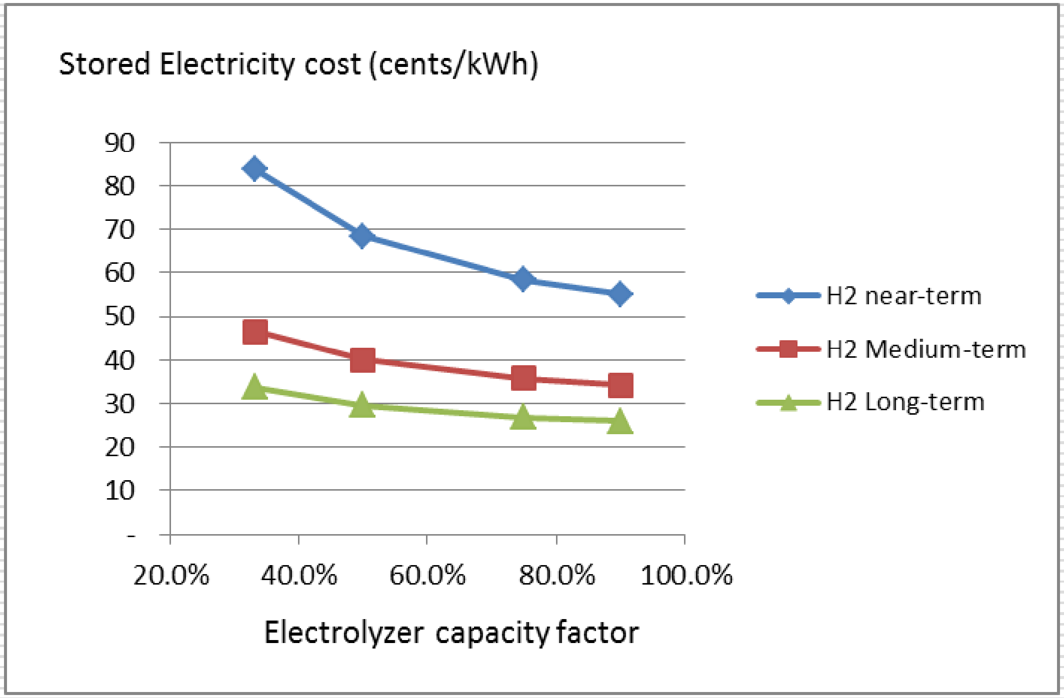
*Source: Sandy Thomas*

# Sensitivity to Electrolyzer Capacity Factor is Low for H2 Medium to Long Term Cases



*Allows more flexibility to charge only during lowest cost off-peak hours (Maximizes Arbitrage Value)*

**Figure 3.On-peak electricity price for a one-day (40MWh) underground hydrogen storage systems with 10% "free" electricity and 90% electricity at 6 cents/kWh**

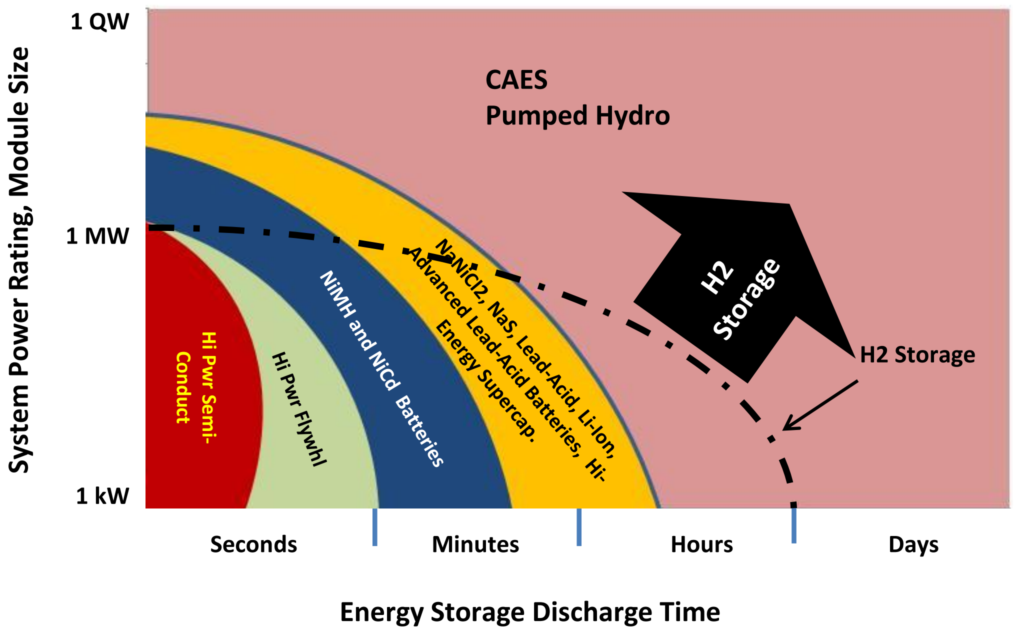
*Source: Sandy Thomas*

# H2 Storage Has Unique Competitive Characteristics That Can Add More Value

- **Scalable** energy storage can be deployed wherever needed (not limited to cavern)
- **Greater flexibility** for discharging stored energy
  - As clean power
  - As low carbon heat
  - As hydrogen fuel for transport
- If hydrogen injected into the natural gas system
  - **Seasonal** storage potential
  - The energy can be **discharged anywhere** on the gas or electric network

# Conceptual Range of Scale For H2 Energy Storage

**Energy Storage Technologies Power Rating and Capacity**



**Source:** The data for the figure was obtained from EPRI's ***Electricity Energy Storage Technology Options*** *A White Paper Primer on Applications, Costs, and Benefits*

*Source: Fred Joseck - DOE*

# Many Thanks To:

- **Sandy Thomas** – Architect and driver of the Simple Model (on personal time!)
- **Darlene Steward** – Hydrogen energy storage subject matter expert and lead for grounding our work in reality
- **Members of the Working Group** – experts and though leaders

**For their interest, input, and commitment to our bi-weekly calls!!**

# HTAC Feedback

# Next Steps

- Complete Energy Storage Application Analysis
- Explore economic drivers for needing greater energy storage capacity in high penetration renewables scenarios
- Begin exploring energy storage in gas pipelines and use of hydrogen for heat

# 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 CO2 perspectives) than utility scale thermal resources.