Hydrogen Enabling Renewables Working Group

Update for the HTAC

June 14, 2011

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
  - 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

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:***
  - ***Established shared understanding of grid energy storage systems and their value propositions***
  - ***Developed a set of expected characteristics for an energy system with >50% penetration of renewables (on an energy basis)***

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 that 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.

WG Tasks - Energy Storage

- Develop simple model for examining the basic economics
- ***Progress:***
  - ***Developed simple model***
  - ***Established NREL collaboration to:***
    - ***Validate model and assumptions***
    - ***Build on work previously done by NREL (D. Steward et al)***

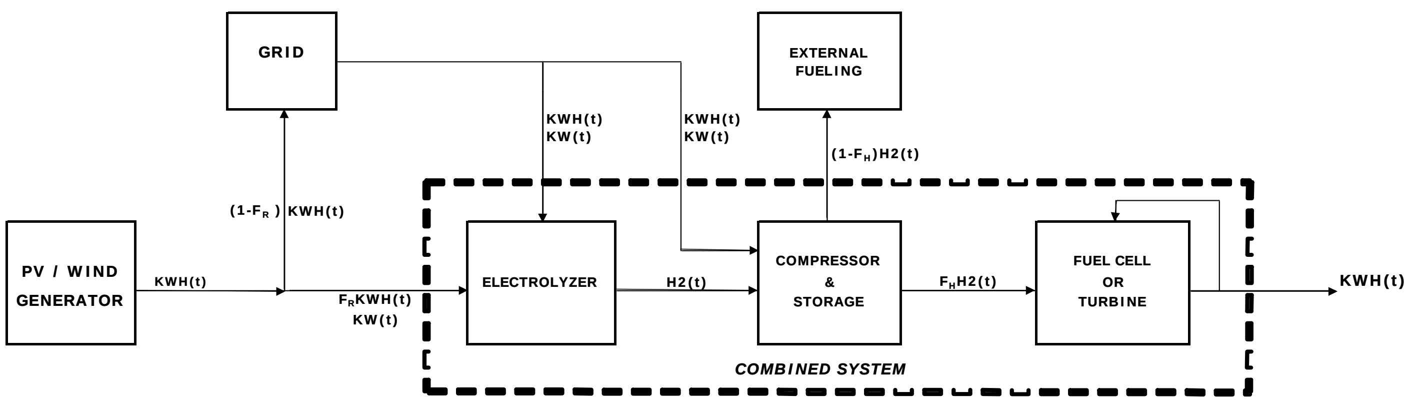
Simple Energy Storage Model Concept (DRAFT)

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

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

COST OF GRID ENERGY: ¢/KWH(t)

F_R = fraction of kwh to electrolyzer

F_H = fraction of H2 to fuel cell

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.

Assume the

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 techologies***

Current model input Assumptions

	Near- term	medium-term	Long-term
Electrolyzer HHV efficiency*	58.0%	79.3%	87.0%
Electrolyzer Capex**	$2000 /kW	$460 /kW	$380 /kW
Compressor efficiency	92%	92%	92%
Compressor Capex ($/kg/day)	826	760	720
FC HHV efficiency	40%	45%	49%
FC capex***	$3000 /kW	$813 /kW	$434 /kW
H2 Dispenser Capex	$ 75,000	$ 60,259	$ 50,216

* Norsk Hydro 50.7 kWh/kg = 77.7% HHV eff.

** NREL Independent Panel Review; (BK-6A1-46676; Sept 2009)

***DOE Targets: $750/kW (2008); $650/kW (2012); $550/kW(2015); $450/kW (2020)

HTAC ERWG simple model.XLS, WS Assumptions D14;5/31/2011

Some Preliminary Results

On-Peak Electricity from off-peak (stranded) wind:

Near-term: 68 to 95 c/kWh

Medium-term: 31 to 39 c/kWh (vs.30 to 34 c/kWh feed-in tariffs in California; see next slide)

Long-term: 26 to 34 cents/kWh

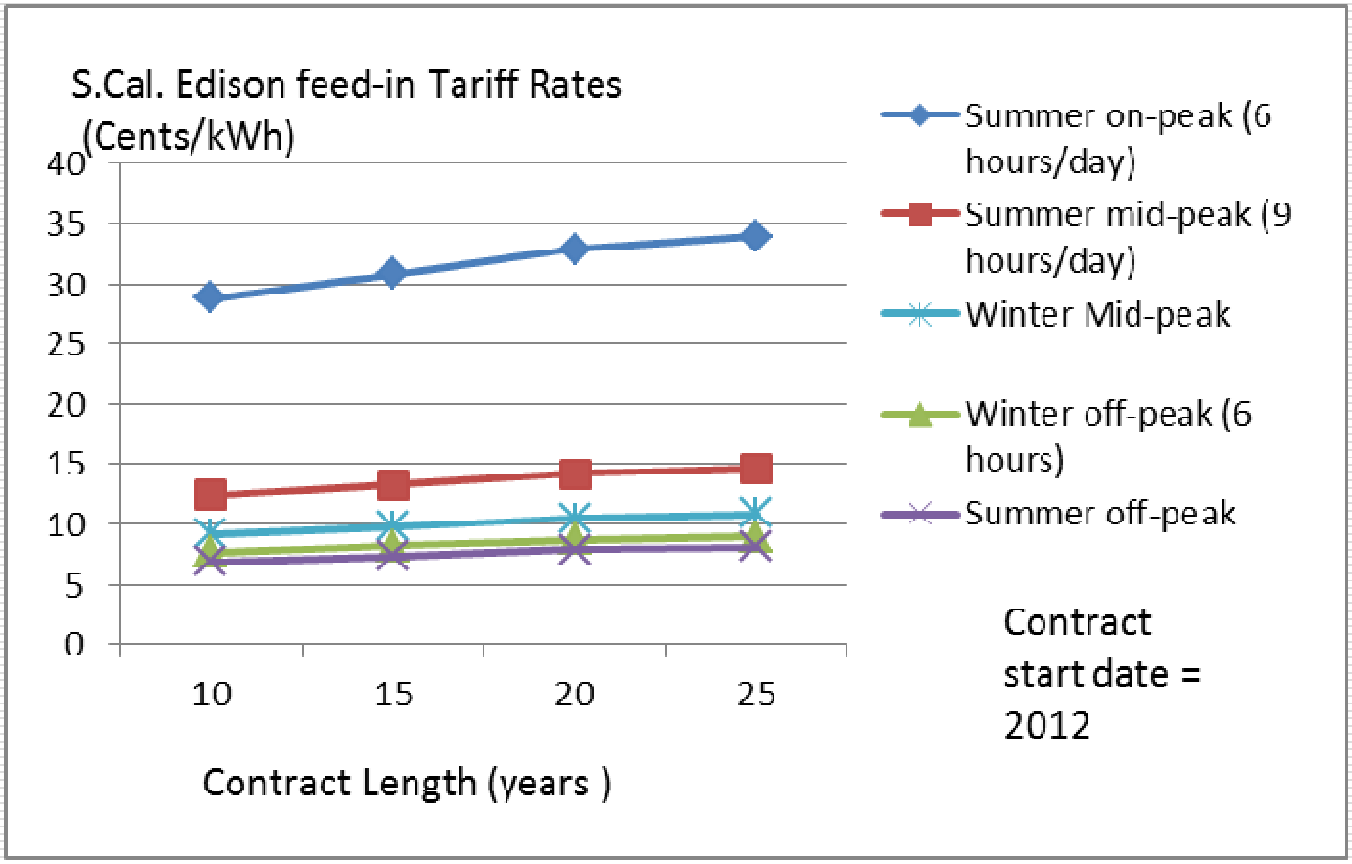
Hydrogen from wind: $5.85/gge near term to $2.57/gge long-term

wind on-peak electricity costs in cents/kWh all 8% Loan or 10% RATROI

		H2-turbine		H2-FC	
		8% Loan	10% RATROI	8% Loan	10% RATROI
Near-Term High cost	Elect	67.9	73.9	80.2	95.1
	H2 $/kg)	9.98	10.45	9.98	10.45
	H2 ($/gge)	5.59	5.85	5.89	5.85
Medium-Term	Elect	31.4	39.1	31.1	37.3
	H2 $/kg)	5.06	5.22	5.06	5.22
	H2 ($/gge)	2.83	2.92	2.83	2.92
Long-Term Low cost	Elect	29.3	34	26.2	28.6
	H2 $/kg)	4.59	4.74	4.59	4.74
	H2 ($/gge)	2.57	2.65	2.57	2.65

HTAC ERWG simple model.XLS, WS Wind-Cost X100;5/31/2011

Wind/hydrogen on-peak costs less than California summer feed-in tariffs



HTAC Feedback