Is Hydrogen Energy Storage Ready for Prime Time on the US Grid?

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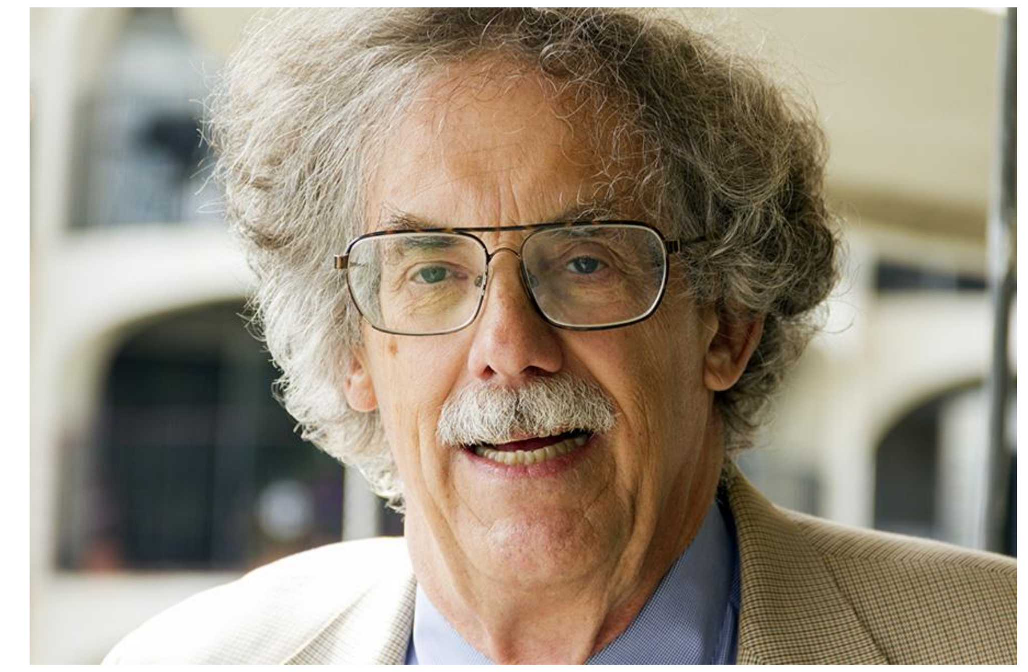


BACKGROUND

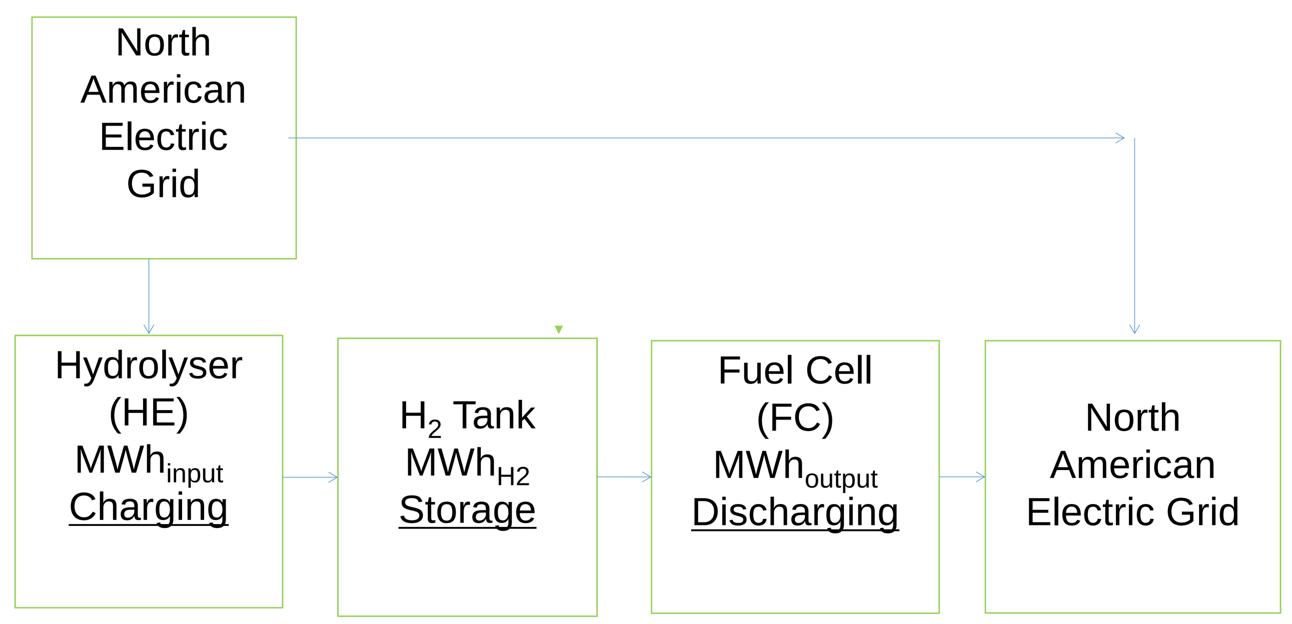
Utility-scale wind plants will soon need energy storage because of their intermittency and because they cannot follow the grid load. Utility-scale wind dispatch depends on the time of day, the wind plant's PPA, the wind plant's instant capacity factor, the current grid load, the wholesale market price and the availability of energy storage on the grid. Pumped hydro storage is the most common commercial grid scale energy storage on the North American gird. Hydrogen (H_2) energy storage has been presented as a commercial alternative to pumped storage.

OBJECTIVE

A bulk electric energy storage plant can be used on the North American electric grid for the daily, weekly or seasonal (180 days) storage of wind electricity (energy) and/or to provide ancillary services (voltage and frequency control and reactive power [var]). The object of this paper is to determine whether H_2 energy storage is ready for prime time (i.e., is commercially viable) on the North American grid.

METHOD

- Author has developed a levelized cost of storage (LCOS) financial algorithm for a model H_2 storage plant (HSP). The model HSP has a daily storage cycle. It does not provide ancillary services The LCOS financial algorithm is used for sensitivity analysis and to confirm published HSP specifications (specs). The algorithm is put in an Excel Workbook for rapid analysis.
- This paper discusses the H_2 storage technology, focusing on the three phases of all HSP; one, the production of the H_2, two, the storage of the H_2, three, the use of the stored H_2 as the fuel to regenerate the wind electricity.
- The LCOS Algorithm uses "project accounting" to compute a separate LCOS for each HSP phase; charging, storage and discharging.
- To compute the LCOS, the paper's HSP LCOS Financial Algorithm requires **22 HSP specifications (specs) [metrics]**. These 22 HSP specs (metrics) [independent variables] are defined using a standard set of H_2 SI units.
- Two of the 22 specs (metrics) specify how many hours a day are used in the daily charging and discharging phases. The remaining 24 hours are automatically assigned to the storage phase. The three phases do not operate at the same time.
- To understand the paper methodology, download (no cost) the paper and the Excel HSP LCOS Workbook at the web address in this poster's lower right corner.



Schematic of a Hydrogen Storage Plant (HSP) on the North American Grid

STANDARD (SI) HYDROGEN UNITS

The 22 HSP specs used in the LCOS algorithm can be presented in MJ_{H2}, $kg_{H2,}$ Nm^3_{H2} or MWh_{H2}. The algorithm uses MWh_{H2}.

$$1\ MWh_{elect} = \grave{}1\ MWh_{H2}$$

In the HSP algorithm energy flows, the MWh_{elect} are first converted into MWh_{H2}. The MWh_{H2} are then converted back into MWh_{elect}. This does not mean that the HSP is 100% efficient (η).

THE THREE PHASES OF THE HSP

The three phases of all HSP are one, the production of the H_2; two the storage of the H_2 and three, the use of the stored H_2 as the fuel to regenerate the wind electricity. H_2 is the energy carrier.

In the paper's model HSP, wind electricity powers a H_2 electrolyzer (HE). When the HE is producing H_2, the HSP is being charged. Currently no HE is the most mature technology. The wind electricity is stored as H_2 in a generic H_2 "Tank". There are various proposed H_2 storage technologies but high pressure and liquefied H_2 storage tanks are the most mature and are currently used for industrial H_2. During discharge, the H_2 is taken out of the H_2 Tank and used as a fuel to power a fuel cell (FC) that regenerates the wind electricity which is then discharged back onto the grid. There are various technologies for using the stored H_2 as a fuel, but the FC is currently the most mature.

THE HSP LCOS ALGORITHM AND ITS EXCEL WORKBOOK

The Excel HSP LCOS Workbook has four worksheets (WS); WS # 1, Charging-H_2 Electrolyzer, WS # 2, Storage-H_2 Storage "Tank", WS # 3, Discharging-FC and WS # 4, the Summary Worksheet. WS # 4 is presented at the bottom of the next column with the 22 complied HSP spec values.

RESULTS

On the summary worksheet below (WS # 4), the cost of the wind energy to be stored is US$50.16/MWh while its LCOS is US$144.88/MWh, a 188% increase.

3,000 MWh/day of wind energy is stored during each 10 hour storage phase; while 2,187 MWh/day of stored wind energy is discharged during each 10 hour discharge phase.

The physical life of the HE, H_2 Tank and FC are each set at 20 years while the weighted average cost of capital (WACC) for the HE, H_2 Tank and FC are each set at 6%.

The HSP round trip η is computed from the phase η for the HE, H_2 Tank and FC are each set at 90%.

The Total HSP CapEx US$684,900,000 is the sum of the HE CapEx, US$171,900,000, plus H_2 Tank CapEx, US$270,000,000 plus FC CapEx, US$243,000,000.

The HSP spec value compilation methodology is discussed in the Cabin Creek Plant Case Study in my Wind Europe 2018 paper [1]

WORKSHEET #4 LCOS ALGORITHM SUMMARY WORKSHEET

US$/€	$1.14610	01/13/19			
	WS # 1	WS # 2	WS # 3		
	HE	H_2 Tank	H2 FC		
Phase→	Charge	Storage	Discharge	HSP-η-%	
HSP Phase-η-%	90%	90%	90%	72.9%	
MWh/day-in	3,000.00	←MWh/day wind energy stored			
MWh/day-out	2,700.00	←MWh/day H_2 produced by HE			
MWh/day-in		2,700.00	←MWh/day H_2 stored		
MWh/day-out		2,430.00	←MWh/day H_2 released		
MWh/day-in			2,430.00	←MWh/day FC H_2 fuel	
MWh/day-out			2,187.00	←MWh/day FC electricity	
			72.9%	←% round trip HSP η	
Phase Operating hrs/day	10	4.00	10	24	
	Only one phase operates at a time; HSP operates 24 hr/day; 365/yr				
$/MWh-in	$50.16	←US$/MWh cost of stored wind energy			
$/MWh-out	$71.28	←US$/MWh HE LC to produce H_2			
$/MWh-in		$71.28	←US$/MWh LC of H_2 stored		
$/MWh-out		$106.14	←US$/MWh LC of H_2 released		
$/MWh-in			106.14	←US$/MWh LC FC H_2 fuel	
$/MWh-out			$144.88	← US$/MWh LCOS wind energy	
			188.8%	←% increase wind energy cost	
				€/MWh ↓	
HE CapEx-US$/$MW_{in}$	$573,000			€ 499,956	
Tank CapEx-US$/MWh		$100,000		€ 87,252	
FC CapEx-US$/$MW_{in}$			$1,000,000	€ 872,524	
CapEx -US$/kWh	$573	$100	$1,000		
CapEx -€/kWh	€ 500	€ 87	€ 873		
				Total HSP CapEx	
HSP CapEx-US$/Phase	$171,900,000	$270,000,000	$243,000,000	$684,900,000	
HSP CapEx-€/Phase	€ 149,986,912	€ 235,581,537	€ 212,023,384	€ 597,591,833	
Fixed O&M Cost-% Phase CapEx	0.05%	0.05%	0.05%		
Variable O & M Cost-US$/MWh	$0.25	$0.25	$0.25		
Physical Life -Years	20	20	20		
Interest/ROE Rate-%	6.00%	6.00%	6.00%		

CONCLUSION

Biased on the following facts, hydrogen energy storage is **not** ready for prime time on the North American grid.

1. There are no commercial HSP on the North American grid.
2. Commercial HSP specs were not found in the literature.
3. The author complied specs for a HSP. The author then computed the LCOS, but LCOS is too high for the current development of a commercial HSP
4. Sensitivity analysis showed that the HSP Round Trip η is not realistically presented by the author. He is too optimistic. HSP Round Trip η should currently be in the 60% range; not the computed 72.9%.
5. Sensitivity analysis showed that the Total HSP CapEx is also not realistically presented by the author. He is again too optimistic. Total HSP CapEx was too high for the LCOS to be less than 20% more than the cost of the wind electricity to be stored, but too low to reflect actual current HSP CapEx values.

ACKNOWLEDGEMENT

I took (1969) the Physical Science Study Committee (PSSC) Course (@ Niles TWP High School, Skokie, IL) where I learned how to do the unit analysis used in this paper. https://tinyurl.com/2awozy

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