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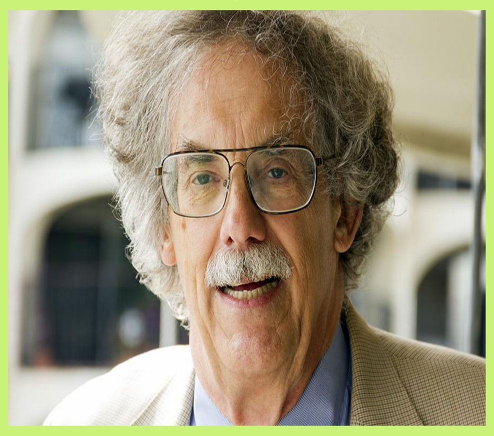

A Financial Algorithm for Computing the Levelized Cost (US$/MWh) of the Bulk Storage of Solar (Wind) Electricity (LCOS)

MICHAEL STAVY[1], Senior Advisor on Renewable Energy Finance

[1]BA-University of Illinois at Chicago (UIC-LAS); MBA–Northwestern (Full-Time Program); CPA-Illinois (Inactive); michael@michaelstavy.com www.michaelstavy.com M: +1-312-523-8328

ENERGY STORAGE FACTS

Bulk solar (wind) electricity is energy and is measured in MWh

Bulk solar (wind) power is measured in MW

Bulk energy storage capacity is measured in MWh

Bulk energy storage power is measured in MW of power output

Bulk energy storage capacity can also be measured in duration time (i.e. hours of storage discharged at full power)

THE LEVELIZED COST (LC) ALGORITHM IS

1. A simple "back of the envelope" method
2. An accurate, first approximation of the cost of bulk energy storage

THE ABSTRACT

This paper discusses the financial and technical principles underlying the levelized cost (LC) method of computing the cost (US$/MWh) of the bulk storage of solar (wind) electricity (LCOS). The paper presents a LC algorithm. The algorithm equations are presented. A glossary is presented. For rapid computation, an Excel LC Algorithm Workbook is presented. The financial algorithm uses nine recognized energy storage plant (ESP) specifications (specs) to compute the levelized cost of the stored solar (wind) electricity. Published (assembled) spec values for the proposed Highview/Encore Liquid Air Energy Storage (LAES) Plant (Vermont), for the upcoming Tesla Moss Landing Li-ion Battery ESP (California) and the actual Cabin Creek Pumped Hydro ESP (Colorado) are used as case studies to demonstrate the algorithm. The emphasis in this paper is on ESP cost; not on ESP revenue, but the revenue is discussed when the paper tries to reconcile the LCOS method with ESP GAAP project accounting. When the revenue (US$/MWh) equals the LCOS, the ESP is earning its weighted average cost of capital (WACC). The goal of this paper is to present a standard computational algorithm (an app in an Excel Workbook) for bankers (investors, financial analysts) to use. Readers can do a LC computation based on the paper's LCOS algorithm and on their own nine assembled ESP specs. The paper's LCOS algorithm gives the reader who has these nine ESP spec values, a quick "back of the envelope" verification of a developer's (manufacturer's; promotor's) value for their ESP LCOS. A complication arises in using this paper's LC algorithm. The complication is that published ESP spec values are limited and that an ESP developer's spec values must be confirmed by the reader before they use this paper's Excel LC Algorithm Workbook to compute the ESP LCOS. The paper has three case studies that discuss how to assemble the nine ESP specs when good specs are not publicly available.

In finance, having good numbers is always a challenge.

THE PAPER'S TABLE 1 WORKSHEET

below has the paper's three case studies: To understand the LCOS algorithm, this poster will first go over the numbers for the proposed Highview/Encore LAES Plant. Then it will examine the Tesla Moss Landing Li-ion Battery ESP. You should read the paper on which this poster is based (take the handout below) in order to study the LCOS Algorithm in depth, to learn how to assemble the nine specs on your own and to review my assembling of the Cabin Creek Pumped Hydro ESP specs listed below.

The LCOS algorithm uses a financial annuity to compute an ESP levelized cost of the stored energy **(LCOS)**. In the LAES Plant Column, the Annual Capital Amortization-ACA-US$/yr (Line H) is one constant end of year financial annuity payment of US$5,500,019. This payment is for an annuity having a principal amount borrowed of US$54,000,000, which is the ESP CapEx-US$/ESP (Line B), a loan period of 20 years (Line 8) and an interest rate (WACC) of 8% (Line 9). The 0.1019 Capital Amortization Factor-CAF (Line G) is the annual end of year payment for a financial annuity having US$1.00 as the principal amount borrowed, a loan period of 20 years and an interest rate of 8%. This yearly level capital amortization payment gives the levelized cost method its name. The first year's payment is almost all interest, while the last year's payment is almost all principal (this is financial amortization not physical depreciation). The other LAES specs are 50 MW of power output (Line 1), 400 MWh/day of energy storage capacity (Line 2), an ESP CapEx of US$135/kWh (Line 3), a round trip efficiency of 70% (Line 4), a US$40.00/MWh cost of the solar (wind) electricity to be stored (Line 5), a Fixed O&M (Line 6) that is 1.0 % of Line B and a Variable O&M of US$1.00/MWh (Line 7). 70% efficiency for a LAES is high, but this is what the developer stated. He also stated that the Line M, LCOS was US$100/MWh, but he did not state the Line 3, CapEx-US$/kWh. Using the Energy Storage Costs spec values that I believed are reasonable on Lines 6, 7, 8 and 9, I thought that it was also reasonable to "reverse engineer" the Line 3, ESP CapEx to be US$135/kWh, by holding Line M, the LCOS, to be at the developer's US$100/MWh spec value.

The Tesla Moss Landing Li-ion Battery ESP will provide bulk energy storage to the California grid. In the Tesla Column, I entered, from the sources cited in my paper, the ESP specs on Lines 1, 2, 5, 7, 8 and 9. The Line 3 value that I used was assembled based on reliable sources, but I did not have a Tesla spec. Line 4, 88% efficiency, is a Tesla spec. 0.50% on Line 6 causes the Line J, Fixed O&M cost-US$/MWh, for the Li-ion battery ESP to be less than for either a LAES plant or for a pumped hydro ESP.

The Cabin Creek Pumped Hydro ESP was completed in 1967. It uses what is now a conventional pumped hydro technology. In the Cabin Creek Column below, are entered my nine assembled Cabin Creek ESP specs.

RESULTS

The LCOS in the three ESP cases below are 2 to 2.5 times (Line √-2) the cost of the electricity being stored. The three ESP are in electric markets that support these LCOS. This paper presents a LCOS algorithm. It does not present datasets of ESP specs. The nine ESP specs are to be assembled by the reader. The methodology used to assemble the spec values is described in the paper. The paper also discusses sources from which published spec values can be assembled.

		Table I Excel LCOS Algorithm Worksheet	Vermont Highview/ Encore **LAES** Plant	California Tesla **Moss Landing** ESP	Colorado **Cabin Creek** Pumped Storage Plant	
	ES Plant CapEx					
1	Enter	ESP-Power Output-MW	50	182.5	324	
2	Enter	ESP Daily Energy Storage Capacity-MWh/day	400	730	1,296	
A	Computed	ESP Yearly Energy Storage Capacity-MWh/yr	146,000	266,450	473,040	
3	Enter	ESP Plant CapEx-US$/kWh	$135	$200	$160	
√-1	Computed	ESP Plant CapEx-US$/MWh	$135,000	$200,000	$160,000	COLOR
B	Computed	Total ESP Plant CapEx-US$/EPS	$54,000,000	$146,000,000	$207,360,000	CODE
	Cost of the Stored Solar (Wind) Electricity					Specification
4	Enter	ESS Plant Round Trip Efficiency-η-%	70%	88%	86%	Computed Value
5	Enter	Cost of the Solar (Wind) Electricity to be Stored-COE-US$/MWh	$40.00	$40.00	$40.00	√ Check Value
C	Computed	Cost of the Stored Solar(Wind) Electricity-COSE-US$/MWh	$57.14	$45.45	$46.51	Transferred Value
D	Computed	Extra Cost (COSE-COE) of the Stored Solar (Wind) Electricity-US$/MW	$17.14	$5.45	$6.51	
E	Computed	% Increase in the Cost of the Stored Solar (Wind) Electricity	43%	14%	16%	
	Energy Storage Costs					
6	Enter	Annual Fixed O&M Cost-% Total ESP CapEx-Line B	1.00%	0.50%	1.00%	
F	Computed	Annual Fixed O&M Cost-US$/yr	$540,000	$730,000	$2,073,600	
7	Enter	Variable O&M Cost-US$/MWh	$1.00	$1.00	$1.00	
8	Enter	Physical Life of the ESP-Years	20	20	50	
9	Enter	Interest/ROE Rate-WACC-%	8%	8%	6%	
G	Computed	Capital Amortization Factor-CAF	0.1019	0.1019	0.0634	
H	Computed	Annual Capital Amortization-ACA-US$/yr	$5,500,019	$14,870,422	$13,155,807	
	Computation of the Levelized Cost of the Stored Solar (Wind) Electricity-US$/MWh					
I	Computed	Annual Capital Amortization-ACA-US$/MWh	$37.67	$55.81	$27.81	
J	Computed	Fixed O&M Cost-US$/MWh	$3.70	$2.74	$4.38	
K	Transferred	Variable O&M Cost-from Line 7 above-US$/MWh	$1.00	$1.00	$1.00	
L	Transferred	Cost of the Stored Solar (Wind) Electricity-COSE- from Line C above-US	$57.14	$45.45	$46.51	
M	Computed	Levelized Cost of the Stored Solar (Wind) Electricity-LCOS-US$/MWh	$99.51	$105.00	$79.71	
N	Computed	Levelized Extra Cost of the Stored Solar (Wind) Electricity-LECOS-US$/	$59.51	$65.00	$39.71	
O	Computed	% Increase in the Levelized Cost of the Stored Solar (Wind) Electricity	148.8%	162.5%	99.3%	
√-2	Computed	LCOS/COE	2.5	2.6	2.0	
	Total Annual O&M					
F	Transferred	Annual Fixed O&M Cost-from Line F above-US$/yr	$540,000	$730,000	$2,073,600	
P	Computed	Annual Variable O&M Cost-US$/yr	$146,000	$266,450	$473,040	
√-3	Computed	Check Value--Total O&M US$/yr	$686,000	$996,450	$2,546,640	1/17/2020

↓↓TAKE my Handout below↓↓ Get my Paper and my Excel LCOS Algorithm Workbook at→ https://tinyurl.com/Solar-NE-20