A Financial Algorithm for Computing the Levelized Cost (US$/MWh) of the Bulk Storage of Solar (Wind) Energy (LCOS); An Algorithm for Bankers and Investors

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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 financial algorithm. The algorithm equations are presented. A glossary is presented. For rapid computation, an Excel LC Financial 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 Power/Encore Liquid Air Energy Storage Plant (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 cost; not revenue. Revenue (R) is discussed when reconciling the LCOS with GAAP accounting. The goal of this paper is to present a standard computational financial algorithm for bankers and investors to use. Bankers (investors, financial analyst's) can do a LC computation based on the paper's LCOS algorithm and on the algorithm's nine required ESP specs. The paper's LCOS algorithm gives the reader who has the nine ESP spec values, a quick "back of the envelope" verification of a developer's (manufacturer's; promoter's) value for their EPS' LCOS. A complication arises in using this paper's LC algorithm. The complication is that "published ESP spec values" are limited and that developers (manufacture's, promoter's) spec values must be confirmed by the banker (investor, financial analyst) using this paper's Excel LC Algorithm Workbook to compute the ESP LCOS. The paper has three case studies which discuss how to assemble the nine specs for an ESP when the specs

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are not all publicly available. In finance, having good numbers is always a challenge.

Keywords—levelized cost; algorithm; energy storage plant, ESP; ancillary services, energy storage finance; bulk storage; grid scale energy storage; LAES, LCOS; LCOE; Li-ion, solar energy; wind power; ESP specs; ESP CapEx;

PRECONFERENCE DRAFT VERSION

This is the preconference draft version. The paper's key points are presented.

1. Explaining the LCOS Algorithm to the reader.
2. Explaining to the reader that this paper is concerned with modest goal of developing the LCOS method and not presenting a data base of energy storage plant specs.
3. Reconciling the LCOS with GAAP financial statements.
4. Demonstrating the assembly methodology for nine ESP specs that the LCOS requires.
5. The references are there for place holding although many will be in the final version. They maybe revised for the final version of the paper.
6. The paper's Excel LCOS Algorithm Workbook is correct and can be downloaded right now.

I. A PUBLIC DATA BASE OF ESP SPECS IS NOT PRESENT INSTEAD A LCOS FINANCIAL ALGORITHM AND THREE CASE STUDIES ARE PRESENTED

The actual presentation of a public data base of energy storage plant (ESP) specifications (specs) for ESP with different technologies, technical maturities and functions for use by a banker[1] (investor, financial analyst) is not the primary goal of this paper [1][2] [2][3]. This author has the much more modest goal of first, presenting a recognized standard methodology, an accurate "back of the envelope" LCOS financial algorithm and second, use three case studies to demonstrate to the banker (investor) how the reader, themselves, can assemble the nine required ESP specs.

This paper has three energy storage (ES) plant case[4] studies. The case studies are the same as listed on Table 1 (page 20), This is the same Table 1 that is on the author's Solar and Storage Northeast 2020 Poster. However, the spec values[5] on this paper's Table 1 are not the same as on the poster Table 1.

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[1] banker is this paper's generic term for investor, financial analyst, researcher, etc., etc.,

[2] if the EPRI reference [1] (1) {1} listed this paper's nine required specs for each type of ESP, it would be one such data base. The 2010 EPRI data base is free but it is not up to date.

[3] if the Lazard reference [2] (2) {2} specifically listed this paper's nine required ESP specs, it would be another such data base but Lazard does not clearly state these nine required specs. You should, however, be able to compile the nine required specs for a specific EPS from the disclosed Lazard data. While this paper is only concerned with the LCOS, Lazard also presents the projected revenue for each ESP.

[4] the author earned (1969) his Northwestern (Kellogg) MBA in the full-time program when the case study method was used

[5] more spec assembly work was done by the author after the poster was presented.

The three case studies are the

1. proposed Highview Power/Encore bulk scale Liquid Air Energy Storage Plant (**LAESP**) Plant [50 MW | 400 MWh| 8 hour duration] is to be located in northern Vermont (VT). [3] (3) {xx}
2. upcoming Tesla **Moss Landing** bulk scale Li-ion Battery ESP [182.5 MW | 730 MWh| 4 hour duration] is to be built on the site of the old natural gas power plant in Moss Landing, California. [4] (4) {xx}
3. operating (since 1958) **Cabin Creek** bulk scale Pumped Hydro ESP [324 MW | 1,296 MWh | 4 hour duration] is located in Clear Creek County, Colorado. It is owned by Xcel Energy[6] [5] (5) {7}.

The first case study

1. uses the VT LAESP to demonstrate to the reader[7] how the paper's levelized cost of storage (LCOS) financial algorithm works.
2. uses the LAESP case to demonstrate how to assemble[8] (collect, develop, obtain, compile) the nine ESP specs that the LCOS algorithm requires.
3. discusses the computed results for the LAESP.

The second (Moss Landing) and third (Cabin Creek) case studies

1. again demonstrate how to assemble the nine ESP specs that the LCOS algorithm requires.
2.
3. discuss the computed results[9].

The reader

a. should download[10] this paper's *Excel LCOS Algorithm Workbook*[11],[12]. The reader can better follow this paper's LCOS algorithm by actually entering the nine LAESP spec values on their LCOS Algorithm Worksheet 2[13] and then checking the results.
b. should refer to Worksheet 2 (pages 23, 25 and 27) while reading Case 1 because the paper discusses the ESP LCOS algorithm, the nine ESP specs and the computed values (lines A→√-3) in Worksheet 1 order (there are 29 variables total).

[6] readers should not confuse Xcel, the Colorado Power Company, with Excel, the Microsoft Office Worksheet App

[7] reader is another generic word that this paper uses for banker, investor, financial analyst, researcher

[8] assemble is the paper's generic term for its data collection methodology

[9] the author assumes that after reading Case 1, bankers will know how the LCOS algorithm works

[10] at https://tinyurl.com/Solar-Northeast

[11] this *Excel LCOS Algorithm Workbook currently has four Worksheets; 1.* Poster *Table 1, 2. LOCS Algorithm Worksheet, 3. ESP Comparison* Worksheet and 4. LCOS-GAAP Reconciliation Worksheet

[12] hereafter referred to as the LCOS Algorithm Workbook

[13] hereafter referred to as Worksheet #2

c. who wants to understand the LCOS algorithm's mathematics should refer to Table 2 (page 28), *Equations for Worksheet 2, Excel LCOS Algorithm Worksheet* and Table 3 (page 38) *The E.1 Equations of Workbook 3, ESP Comparison Worksheet.*

The reader can increase their understanding of the paper's LCOS algorithm by entering the nine Moss Landing and Cabin Creek ESP specs on their Excel LCOS Algorithm Worksheet 2.

To help the reader, Worksheet 2 with Case 1 is printed on page 23; Worksheet 2, with Case 2 is on page 25 and Worksheet 2, with Case 3 is on page 27.

Based on what the reader has learned in Case 1, they will be able start to assemble[14] their own datasets for the LAESP, Moss Landing and Cabin Creek ESP. In time, bankers (investors; other readers), will be able to assemble data sets for bulk energy storage projects that they are starting to consider.

II. The LCOS Algorithm: A Uniform Method for Computing the Levelized Cost of Storing Solar (Wind) Energy

For this paper, both "back of the envelope" simplicity and an accurate[15,16] first approximation of the cost (US$/MWh) of storing solar (wind)[17] energy in a bulk (grid-scale) energy storage plant (ESP) are the two criteria for choosing a computational method. This paper's levelized cost (LC) algorithm meets both criteria. The goal of this paper is to present a LCOS algorithm based on generally accepted financial and engineering principles with a recognized uniform set of ESP specifications (specs). Using this paper's LCOS algorithm, bankers with the same nine ESP specs and spec values[18] will always compute the same value for the levelized cost of storage (LCOS)[19]. The reader is encouraged to use Excel LCOS Algorithm Worksheet 2 for understanding and rapid computation.

The paper's LCOS algorithm gives the banker a tool to use with a developer's (promotor's) ESP specs to make a quick "back of the envelope" confirmation of the developer's energy storage cost (LCOS-US$/MWh). Readers can use this algorithm to estimate the LCOS of adding a bulk ESP to a solar (wind) plant or even to the grid

[14] or know the limits of assembling the nine ESP specs from public sources
[15] from technical, mathematical, and financial perspectives
[16] read Section VIII, Results, Conclusions and Complications
[17] when this paper is referring to solar energy, it is also referring to wind power. An ESP does not care if the electricity is from solar, wind or even from thermal electricity
[18] hereafter the spec value is referred to as a spec unless it would be unclear whether the reference is to a specific spec or to its value
[19] there is also the LCOE (the levelized cost of energy). See reference [6] (6) **{8}**

itself (with a PPA or as a merchant ESP). Investors can also use this paper's LCOS algorithm with a researcher's published prototype ESP specs to quickly compute the prototype ESP LCOS.

Whichever ESP technology that is used, the energy storage (ES) cycle is the same (charging, storage, discharging). This paper's LCOS algorithm is, except for CAES[20], ES technology agnostic (e.g. pumped hydro, liquid air, flywheel, capacitor, hydrogen, "batteries of various chemistries" [e.g. Pb-a, NaS, NiMH, Zn-air, Li-ion, etc.]).

Bulk (utility-scale) ESP can be engineered to provide energy storage and/or ancillary grid services (voltage and frequency control and reactive power [var]) behind the fence or on the grid. This paper's algorithm only computes the LC (US$/MWh) for the storage of solar (wind) electricity. It is not designed to compute the LC of an ESP that is designed to primarily provide ancillary services to the grid. The LCOS algorithm must be modified to computer the cost of providing ancillary services.

A bulk ESP can have a daily, weekly or monthly storage cycle. This paper's algorithm only computes the daily storage of solar (wind) electricity.

The emphasis in this paper is on cost, not on ESP revenue (US$/MWh). The revenue (R) is discussed in Section V (page 10) where the author tries to reconcile the LCOS with GAAP project accounting[21]. The reader should note that when the ESP revenue (US$/MWh; US$/ESP/yr[22]) equals the ESP LCOS (US$/MWh; US$/EPS/yr[23]), the ESP is earning its weighted average cost of capital (WACC).

III. Case Study 1- The Highview/Encore VT Liquid Air Energy Storage Plant (LAESP) on Worksheet 2

Worksheet 2, Case 1, (page 23) has one data entry column with 29 lines. Worksheet Lines 1→9 (9 lines) are the nine ESP specs which are the independent variables that the LCOS algorithm requires. Worksheet Lines A→√-3 (20 lines) are the 20 dependent variables that the LCOS algorithm computes using the equations in Table II.

To better understand the LCOS Algorithm, the reader can enter on their downloaded their Excel LCOS Algorithm Worksheet 2, the nine Case 1 specs.

The paper now goes over Worksheet 2, section by section.

A. ESP CapEx[23]

[20] the LCOS algorithm must be modified for the NG used in a CAES. Contact the author concerning this modification.

[21] the author is an Illinois (very inactive) CPA

[22] this is total EPS CapEx

[23] for the reader who prefers the LCOS Algorithm equations, refer to Table 2, The Equations of the Excel LCOS Algorithm Worksheet 2 (page 28)

Since the ESP has a daily cycle[24], the electric storage capacity is measured in MWh/day. ESP power is measured in MW of output (discharge).

The alternative ESP industry energy capacity measurement is hours of storage duration. Duration is number of hours at full power output that the ESP can provide. In this paper's LC algorithm, duration is a derivative spec. A short duration (< 1 hour) is the characteristic spec of an ESP that is designed to primarily supply ancillary services to the grid.

The current industry convention is to price bulk ESP CapEx in terms of energy storage capacity; US$/kWh (US$/MWh). Since the modern ES industry first focused on battery storage, EPS have traditionally been priced in US$/kWh.

Readers may be confused because the current energy storage trade journal convention is to measure bulk ESP CapEx capacity in MW of power output and, not more analytically correct, in MWh of storage capacity plus MW power output. By comparison, a grid sized solar, wind or thermal power plant CapEx is correctly priced in trade journals in terms of the cost of power output; US$/MW.

The ESP CapEx is the result of the cost of manufacturing each component plus the engineering, procurement, construction, and installation of a particular ESP with its specific technology, power output (MW) and energy storage (MWh) specs.

The Highview/Encore VT ESP specs are used on Worksheet 2 to demonstrate the paper's LCOS algorithm.

The Highview/Encore VT LAES ESP [7] (7) {XX} is projected to have 50 MW of power output and 400 MWh of energy storage capacity. The Highview/Encore VT ESP 8 hour daily duration (an 8:1 capacity to power ratio) is very good.

For the LAES and Li-ion battery ES technologies, once the ESP has its charging/discharging powertrain capacity (MW) and control system installed, adding extra energy storage (MWh) [duration] increases the ESP storage to power ratio while reducing the powertrain's CapEx on a US$/MWh basis and, therefore, the Total ESP CapEx (Line B).

Worksheet Line 1, ESP Power Output, is 50 MW. Line 2, ESP-Daily Energy Storage Capacity, is 400 MWh. Line A, ESP-Yearly Energy Storage Capacity, is 146,000 MWh/year. Line A is Line 2 multiplied by 365.

Line 3, ESP CapEx-US$/kWh, is US$135/kWh. On Line √-1, this is converted into ($135,000/MWh). The LAES plant developer stated [8] (8) {XX}that the LCOS (line M) would be US$100/MWh. The author reverse

[24] a daily cycle ESP has a higher inventory turnover (a lower CapEx amortization) than a weekly (monthly, seasonal) cycle ESP

engineered back to US$135/MWh assuming that the other seven LCOS specs would have the values listed on the Worksheet 1 (page 20).

US$/kWh (US$/MWh) is the key CapEx specification for both the ESP and the electric vehicle (EV) battery. Reference [6] reported that EV batteries were in the US$270-US$300/kWh range. Reference [9] (9) {7} reported that the new Tesla Gigafactory will be able to manufacture EV batteries for US$100/kWh. Reference [10] (10) {XX} reported that the Li-ion battery cost fell from US$1,000 in 2010 to US$209/kW in 2017.

Line B, Total ESP Plant CapEx-US$/ESP[25], is US$54,000,000/ESP for the construction of the Highview Power/Encore VT LAESP. Line B is Line 2 multiplied by Line √-1. Line √-1 is US$135,000/MW (US$135/kW). For comparison, this author estimates that the CapEx of a new US on-shore utility-scale wind power plant is in the range of US$1,250,000-US$1,500,000/MW (US$1,250-US$1,500/kW).

B. Cost of the Stored Solar (Wind) Electricity (COSE)

Line 4, ESP Round Trip Efficiency [η], is 70%. The ESP round trip η is reported [11] (11) {XX} by the developer to be 70%. This is a high η value for this type of technology. ESP η is the % of the solar (wind) energy (MWh) put into the ESP (charging) that is later taken out of the ESP (discharging) and then put back on to the grid as stored solar (wind) electricity. The higher the ESP η, the lower the energy loss from storing solar electric energy. Increasing ESP η does not increase the MWh/yr put back on to the grid. It reduces the MWh/yr that has to be put into storage and then taken out of storage to get the specified MWh/yr put back onto the grid. If the reader assumes the impossible, that the ESP η = 100%, the ESP will have no energy loss.

Line 5, Cost of the Solar (Wind) Electricity (COE)-US$/MWh, to be stored, is US$40.00 (US¢4.00/kWh). This is the author's estimate of the cost of solar electricity (COE) currently sold wholesale to load serving entities (utilities) under a long-term contract (PPA) from a utility-scale solar (wind) plant. This is the same value that the author used in Cases 2 and 3. Readers can use the worksheet in [11] (12) {8} to compute their own estimate of the COE.

If fossil electricity[26] is stored in an ESP and if the fossil electricity COE is put on Line 5, the LCOS worksheet will compute the LCOS for the fossil electricity.

Line C, Cost of the Stored Solar (Wind) Electricity (COSE)-US$/MWh, is US$57.11 (US¢5.71/kWh). This is Line 5 divided by Line 4.

[25] when the Total ESP CapEx is the published spec; dividing this value by the energy storage capacity, MWh/day, computes the US$/kWh (US$/MWh) spec. This is an *"off-the-worksheet; back of the envelope"* computation.

[26] Cabin Creek Pumped Hydro ESP originally stored fossil electricity generated at night and then discharged it during the day when the load was greater. At the time, this was cost effective for the utility.

Because of the ESP η loss, the cost of the stored electricity (Line C) discharged from the ESP is always greater than the cost of the electricity that charges the ESP (Line 5).

Line D, Extra Cost of the Stored Solar Electricity-(COSE-COE)-US$/MWh, is US$17.14 (US¢1.67/kWh). Line D is Line C minus Line 5. This is the extra cost of the stored solar electricity because of the ESP η loss. The higher the ESP η, the lower the energy loss from storing solar electricity and, therefore, the less is the extra cost of the stored electricity. If we again assume the impossible, that the ESP η = 100%, the ESP will have no energy loss **and** the COSE will equal COE and Line D will be zero.

Even, if hypothetically, the ESP η = 100%, the LCOS will always be greater than the COE because of the ESP capital amortization, cost of capital and O&M costs.

Line E, % Increase in the Cost of the Stored Solar (Wind) Electricity, is 43%. Line E is Line D divided by Line 5. Line E is the extra cost of the stored the solar (wind) electricity as a % of the original COE.

C. ESP OPEX AND THE COST OF CAPTAL

There are many physical, mechanical, electrical, IT and electronic components in a bulk ESP that must be operated and maintained (O&M). There are also the fixed costs for an ESP project (project administration, maintenance labor, legal, regulatory and accounting fees, insurance, real estate taxes, etc., etc.). Therefore, an ESP has fixed [Lines 6, F & J] and variable [Lines 7 & K] non-electric energy O&M costs. These costs are included in the computation of the LCOS.

The Annual ESP Fixed O&M Cost (Line F) is computed to be a % of Line B. Line 6, Total Annual Fixed O&M Cost-% of Line B, is 1%. This is the author's estimated value. Line F, Annual Fixed O&M Cost-US$/yr, is US$540,000. Line F is Line B multiplied by Line 6.

Line 7, ESP Variable O&M Cost-US$/MWh, is US$1.00. This is the author's estimated value. This is the same value that the author used in Cases 2 and 3.

Line 8, Physical Life of the ESP, is 25 years. This was reported by Highview/Encore VT ESP [12] (13) {XX}.

Line 9, Interest/ROE Rate, is 8%. This is the author's estimated value. This is the same value that the author used in Case 2.

This is the cost (as a %) of the invested capital (Line B) that the ESP plant owner either provides (equity) or borrows (debt) in order to own the ESP plant. This spec is also known as the return on assets[27] (ROA) as the internal rate of return (IRR)[28] or as the weighted average cost of capital (WACC).

[27] not exactly as the project assets usually include working capital in addition to the ESP CapEx

[28] Keynes [xx], the non-monetarist, called this the internal rate of return (IRR)

An ESP has a physical life (Line 8). During its physical life, as the ESP operates by first storing and then by releasing the stored electricity, Line B, Total ESP CapEx, must be recovered (amortization [depreciation]) and the cost of capital (Line 9) for using the invested capital must be paid. If borrowed money is used to construct the ESP, the cost of borrowing the money is called the lender's interest. If the ESP owner uses their own money to construct the ESP, the cost of using the owner's money is called the return on owner's equity (ROE). The cost of capital (Line 9) is a weighted average percent for both the lender's interest and for the owner's ROE. Let us hypothesize that the ESP debt/owner's equity ratio is 1:1; the interest on the debt is 6% and the required ROE is 10%; then the weighted average Interest/ROE Rate is 8%[29].

Line G, the Capital Amortization Factor-CAF, is 0.1019. This is the end of year annual payment computed for a financial annuity[30] having US$1.00 as the principal borrowed, a loan period of 20 years (Line 8) and an interest rate[31] of 8% (Line 9).

Line H, Annual Capital Amortization (ACA)-US$/year, is US$5,058,654. Line H is Line B multiplied by Line G. The levelized cost method uses a financial annuity to compute Line H. The ACA-US$/yr is one constant yearly payment for both the depreciation of Line B and for the payment of Interest/ROE (Line 9) over the physical life of the ESP. This level (constant) capital amortization payment gives the method its name. The first year's payment is almost all Interest/ROE, while the last year's payment is almost all depreciation.

D. Computing the Levelized Cost of the Stored Solar (Wind) Electricity-LCOS

Line M is the worksheet's bottom line. Line M, Levelized Cost of the Stored Solar (Wind) Electricity-LCOS-US$/MWh, is US$96.49 (US¢9.95/kWh).

The LCOS is the sum of Lines I + J + K + L[32].

Line I, Annual Capital Amortization (ACA)-US$/MWh, is US$34.65 (35.9% of the LCOS). Line I is Line H divided by Line A.

Line J, Fixed O&M Cost-US$/MWh is US$3.70 (3.8% of the LCOS). Line J is Line F divided by Line A.

Line K, Variable O&M Cost-US$/MWh, is US$1.00 (1.0% of the LCOS). Line K is the value transferred from Line 7 above.

Line L, Cost of the Stored Solar Electricity-COSE-US$/MWh, is US$57.14 [US¢5.71/kWh]

[29] if the debt/ROE ratio is 2:1, then the weighted average Interest/ROE is 7.33%

[30] a traditional US home mortgage is a financial annuity that is held by the lender.

[31] Some authors would incorrectly call this the discount rate

[32] for the reader who prefers the LCOS Algorithm equations, refer to Table 2, page 28

(59.2% of the LCOS). Line L is the value transferred from Line C.

The algorithm computes the Highview/Encore VT LAESP LCOS to be US$9.49/MWh (US¢9.95/kWh). 9.95¢ is a good price for peak power in many US wholesale energy markets.

E. Computation of the Levelized Extra Cost of the Stored Solar (Wind) Electricity-LECOS

Line N, Levelized Extra Cost (LECOS) of the Stored Solar (wind) Electricity-LECOS-US$/MWh, is US$56.49 (US¢5.65/kWh). Line N (LECOS)[33] is Line M (LCOS) minus Line 5 (COE). Line N is the line "after the bottom line". Line N is the marginal cost (MC) of the energy storage. The marginal revenue (MR) earned storing the solar electricity must be equal to or greater than the MC (Line N).

Line O, % Increase in the Cost of the Stored solar (wind) Electricity, is 149%. Line O is Line N divided by Line 5. Using the Highview/Encore Vermont LAES Plant to store solar electricity adds 149% to its cost or is or 2.4 times (Line √-2) the COE (Line 5).

If, however, a Highview/Encore VT LAES plant is put "behind the fence" by the owners of a utility-scale solar (wind) plant, then, to avoid double counting, only the extra cost (MC) of the energy storage should be considered, that is the LECOS. If a utility-scale solar (wind) plant operates as a merchant plant instead of as a solar (wind) plant under a long term PPA, then the Highview/Encore VT LAES plant can store the solar (wind) energy until the wholesale price of electricity is equal to or greater than Line N, LECOS. Any time that the wholesale price is above its COE, the utility-scale solar plant should sell its power to the grid. It can also delay sales until the wholesale price is above the COE plus the LECOS. Because of the intermittence of solar (wind) electricity, a "behind the fence" LAES plant gives some firm capacity (and perhaps capacity payments) to a utility-scale solar (wind) plant.

E.1 Second Computation of the Levelized Extra Cost of the Stored Solar (Wind) Electricity-LECOS

On Worksheet 3[34], the ESP Comparison Worksheet[35] of the paper's Excel LCOS Algorithm Workbook, readers will find a second computation of Line N, Levelized Extra Cost of the Stored Solar (Wind) Electricity-$LECOS_2$-US$/MWh, with the same computed value US$59.51. This is because the LECOS, can also be computed as the sum of Lines I + J + K + L[36].

Line I, Annual Capital Amortization (ACA)-US$/MWh

Line J, Fixed O & M Cost-US$/MWh

[33] LECOS = LCOS - COE

[34] the second computation is not on Worksheet 2

[35] this a further discussion of the algebraic factors that determine the LECOS

[36] For the reader who prefers the algorithm equations, refer to Table 2 (page 28) where Line N_2 where $LECOS_2$ = $LECOS_1$ and these algebraic factors are shown

Line K, Variable O & M Cost- US$/MWh

Line L, Extra Cost (COSE-COE) of the Stored Solar (Wind) Electricity-US$/MWh[37].

F. Bonus Check Value-Total ESP Annual OpEx

Finally, Worksheet 2 has Line √-3, Check Value, Total ESP Annual OpEx-US$/yr with a check value of $686,000. This is the sum of Lines F plus Line P.

Line F, Annual Fixed O&M Cost-US$/yr- is Line F transferred from above.

Line P, Annual Variable O&M Cost-US$/yr is Line 7 times Line A.

This is a check (√) value for the reader to check against published (or internal) Actual Total ESP Annual OpEx Costs. Will the 50 MW | 400 MWh LAESP only require $686,000 of yearly OpEx? This is what this paper's LCOS algorithm computes. If not, how do the spec values have to be changed?

IV. The Effect on the LCOS From Changing One or Two ESP SpecsWhile Keeping All the Other ESP Spec Values the Same

The paper's LCOS Algorithm Workbook's Worksheet **3**, ESP Comparison, allows the user to compute the effect on the LCOS of changing one or two ESP specs while keeping the other ESP specs the same. For € Zone bankers, the worksheet coverts certain US$ values into € values. The banker should enter their own FX value. This [13] (14) {XX} is the author's FX reference.

The Highview Power/Encore Vermont **LAES** plant with its Table A specs are listed in the Original ESP Column (column **A**).

When the reader assembles[38] their own nine LAES plant specs, they might have found that their value for the LAESP CapEx is US$100/kWh; not the US$135/kWh that the author complied.

In the second ESP Column (column **B**), eight of the nine column A specs are again entered. On line 3, ESP Plant CapEx-US$/kWh is entered as $100. This is US$35 less than the US$135 Table A value or a -25.9% decrease. This causes the LCOS to decrease from US$96.49 to US$86.55 a decrease of US$9.94 (-10.3%).

This worksheet can also be used[39] to compare two different ESP. Put the first ESP nine specs in the First ESP Column and the second ESP specs in the Second ESP Column.

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[37] this shows, that as stated above, even if the ESP η = 0, the LECOS would not equal 0.

[38] using the assembling methodology that the reader learned in Case 1 above and in Cases 2 and 3 below.

[39] contact the author for his assistance

V. Reconciliation of the LCOS with GAAP Project Accounting for an Energy Storage Plant (ESP)

This paper presents a LCOS algorithm and a methodology for assembling the nine specs that the algorithm requires. Case One above demonstrates both the LCOS algorithm and the spec assembly methodology. This section is a brief look at reconciling the LCOS with GAAP project accounting[40]. This is a question that the bankers (investors) have shown an interest in.

Follow this discussion on the paper's LCOS Algorithm Workbook's Worksheet 4, ESP LCOS GAAP Reconciliation.

The ESP revenue (R) (US$/MWh; US$/ESP/yr[41]) is not required to compute the LCOS. It is, however, required to prepare a GAAP income statement. When an ESP R equals its LCOS (R =LCOS), all the ESP costs including the cost of capital are paid. This is because of the way that the LCOS algorithm is constructed. When an ESP R is greater than its LCOS, its net income accrues to the owner's ROE.

There are five sections that Worksheet 4 uses to reconcile the LCOS with GAAP.

First, Worksheet 4 has Worksheet 2 with the nine assembled specs for the Highview/Encore LAESP.

Second, Worksheet 4 has an EPS Capital Amortization Schedule to compute the yearly interest paid to the lender and the yearly ROE paid to the investor. These % are applied to the capital balance at the beginning of the year. The yearly cost of capital is subtracted from ACA, Line H[42], to compute the yearly capital amortization. In year 1, the amortization is subtracted from the beginning of the year-1 capital balance to compute the beginning of year-2 balance. This process is done year after year for the physical life of the ESP (Line 8). This amortization schedule is exactly the same as the amortization schedule for a US home mortgage.

Third, Worksheet 4 has an EPS Yearly MHW_{in} (Cost of Electricity) and MWh_{out} (Revenue) Schedule. Line A, 146,000 MWh are taken from storage and sold to the grid at the LCOS (Line M)[43]. 208,571 MWh are taken from the grid and used to charge the ESP. This is because the ESP η (Line 4) is 70%[44]. The ESP has a COE of $40/MWh.

Fourth, Worksheet 4 has a Yearly Simple Cash Flow Statement. This statement demonstrates that, on a cash basis, when the ESP R = LCOS, all the ESP costs are paid[45].

Fifth, Worksheet 4 has the "GAAP" ESP Project Accounting Statements. For bankers, and investors these maybe simple statements,

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[40] In project accounting, the ESP is a separate entity with its own GAAP financial statements

[41] R and LCOS can be computed per MWh or per ESP per year

[42] of Table A on worksheet 4

[43] here at the LCOS but it could be at a higher price

[44] 208,571 MWh = 146,000 MWh/70%

[45] Either on a MWh or total for the year basis

but they demonstrate the reconciliation between the LCOS and GAAP. To keep it simple there is no working capital (A/R, A/P, inventory).

On the GAAP income statement are the ESP CapEx amortization and the yearly interest expense. The net income is equal to the yearly ROE-$/yr.

On the GAAP cash flow statement in the net cash provided by operations section, the ESP CapEx amortization provides cash. The net cash for investing activities shows the cash used to construct the LAES Plant. The net cash from the financing activities section shows the source of the cash from lenders and investors as well as the start of the repayment of the debt and the return of the owner's equity to the owners.

This reconciliation will require further development in future papers[46]. The ROI-$/yr in the equity section is currently a puzzle to the author. It is zero because the yearly net income is first credited to this account but it is then debited when the cash is paid to the owner.

Another puzzle for the author is that under the LCOS method the owner's equity as well as the debt become zero. So is the repayment of debt. It is a major component of the LCOS. In GAAP accounting, the repayment of debt is not a cost. The interest is a cost but the ROE is not.

VI. Case Study 2—Assembling the Nine Tesla Moss Landing Li-ion Battery ESP-Worksheet 2 Page 25

Getting good ESP spec numbers[47,48] is a challenge for everyone in renewable energy finance. Financial analysts following the digital movie industry have had the same problem that you, the reader, and I, the author, have in this case study. The Wall Street Journal [14] (15) {16} reported that there are (were)[49] "no third parties[50] tracking the digital movie business making exact figures impossible to obtain".

Worksheet Line 1, ESP Power Output, is 182.5 MW. Line 2, ESP-Daily Energy Storage Capacity, is 730 MWh. Pacific Gas and Electric (PGE) [15] (16) {XX} reported the Tesla Li-on Battery power output and duration.

Line 3, ESP CapEx-US$/kWh, is US$125/kWh. On Line √-1, this is converted into ($135,000/MWh). This the author's estimate based on published reports [16] (17) {XX }.

Line 4, ESP Round Trip Efficiency [η], is 88%. This is Tesla's stated value [17] (18) {XX} .

[46] interested bankers, investors and other readers can contact the author to make an appointment to check his progress.
[47] bankers (investors) working with an ESP developer must also decide if spec values found in the developer's documents are sufficient.
[48] Keynes [10], for example see Vol. II, pages 8, 76, 97, 353, etc., also reported that he had difficulty getting the numbers for his *Treatise on Money*.
[49] this is WSJ article is an old reference. The current situation may be different.
[50] Hollywood, like Keynes, had difficulty getting good numbers

Line 5, Cost of the Solar (Wind) Electricity (COE)-US$/MWh, to be stored, is US$40.00 (US¢4.00/kWh). This is the author's estimate of the cost of solar electricity (COE) currently sold wholesale to load serving entities (utilities). This is the same value that the author used in Cases 1 and 3.

Line 6, Total Annual Fixed O&M Cost-% of Line B, is 0.50%. This is the same value that the author used in Case 3. It is the author's estimate.

Line 7, ESP Variable O&M Cost-US$/MWh, is US$1.00. This is the same value that the author used in Cases 1 and 3. It is the author's estimate.

Line 8, Physical Life of the ESP, is 25 years. This was reported by Tesla [18] (19) {XX}.

Line 9, Interest/ROE Rate, is 8%. This is the author's estimated value based on Tesla, a private company having a PPA with PGE, a regulated utility. Bankers (investors) should be able to easily estimate this number. This is the same value used in case 1.

The algorithm computes Tesla Li-ion battery LCOS to be US$80.25/MWh (US¢8.03/kWh). 8.03¢ is a good price for wholesale power in the California wholesale energy market. The battery LCOS is less than both LAESP and Clear Creek Pumped Hydro ESP, yet pumped storage is supposed to be the least cost ES technology.

VII. Case Study 3—Assembling the Nine Cabin Creek Pumped Hydro ESP Specs in Order to Compute Cabin Creek's LCOS-Worksheet 2 Page 25

The purpose of this third case is to again demonstrate to the reader how to assemble the nine ESP specs that the LCOS algorithm requires and to then discuss the computed results. The paper discusses the results because as everybody knows [51] or at least used to know, that pumped hydro is the least cost bulk ES technology. Bankers and investors will see if this is still correct.

The third case is the same Cabin Plant Pumped Hydro Energy Storage Plant Case that the author previously presented in his paper also titled, *A Financial Algorithm for Computing the Levelized Cost (US$/MWh; €/MWh) of the Bulk Storage of Wind Electricity (LCOS)*, WindEurope 2018 Conference, 25-28 September, Hamburg, Germany[52]. The author's WindEurope 2018 paper have been updated to 2020 values.

If the reader wants additional pumped hydro ESP case studies, the author's WindEurope 2018 paper also has "case studies" on the proposed San Vincent Pumped Hydro ESP [xx] {XX} and on very speculative Hoover Dam Pumped Hydro ESP [19] (20) {XX} .

Readers can enter the nine Cabin Creek spec

[51] attributed to Leonard Cohen
[52] download the original paper and worksheet at https://tinyurl.com/y76zkbdm

values that the author assembled in this case on their LCOS Worksheet 2 Case 3[53], and check the results. After finishing this case, the investor should be able to assemble (develop) their own ESP spec values, enter these values on Worksheet 3, *ESP Comparison Worksheet*, and check the comparative results.

Line 1, Cabin Creek Power Output, is 324 MW. This is the value reported [20] (21) {3} by Xcel. Excel Energy owns the Cabin Creek.

Line 2, Cabin Creek-Daily Energy Storage Capacity, is 1,450 MWh. Excel reported [21] (22) {XX}that Cabin Creek has a 4 hour duration.

Line 3, Cabin Creek CapExUS$250/kWh.[54] (US$250,000/MWh) The author used this estimate, even though this is at the low end of the 2010 EPRI [22] (23) {1} pumped hydro data.

Line B, Total Cabin Creek ESP CapEx is computed by the algorithm to be US$324,000,000. This US$ value for a 324MW l 1,296 MWh utility-scale pumped hydro energy storage plant is **not** "in the ball park"[55] number for proposed [23] (24) {18}[56] new US utility-scale pumped storage plants.

Line 4, Cabin Creek Round Trip Efficiency [η], is 80%. In the 2014 EPRI [24] (25) {xx} the pumped storage range was 80-82% AC/AC round trip η. Cotie [25] (26) {18} states that the water turbine efficiency (η) will be increased from 86% to 91%. US [26] (27) {15} did not report an η value.

Line 5, Cost of Solar (Wind) Electricity (COE) to be stored, is US$40.00 (US¢4.00/kWh). This is the same COE value that the author used in Cases 1 and 2.

Line 6, Annual Fixed O & M Cost-% of Total Cabin Creek CapEx, is ½%. This is the same value that the author used in Case 2. It is the author's estimate.

Line 7, Cabin Creek Variable O & M Cost-US$/MWh, is US$1.00. This is the same value that the author used in Cases 1 and 2. It is the author's estimate.

Line 8, Physical Life of Cabin Creek, is 50 years. EPRI [27] (28) {xx} reported a 50 year for pumped storage. According to Xcel [28] (29) {XX}, Cabin Creek started commercial operation in 1967 (53 years ago) and the author can report,

[53] Readers can make their own Worksheet 2, Case 3 by copying Worksheet 2 from their downloaded copy of the paper's Excel LCOS Algorithm Workbook.
[54] One estimate is that the proposed San Vincente pumped storage plant has a US$18250/kWh CapEx.
[55] Total ESP CapEx (US$/ESP) is not a frequently published spec but developer's (IPP's, utility's, OEM, EPC contractor's, FERC, PUC,) internal documents would include this value for bankers and investors.
[56] there are currently many proposed US utility-scale pumped storage plants which readers can search for their specs.

from a visual observation[57], that in 2020, Cabin Creek was pumping along just fine[58].

Line 9, Interest/ROE Rate, is 5%. Xcel Energy is a vertically integrated US investor owned utility (IOU) in Colorado, a regulated state with no retail competition. The author estimates that Xcel should[59] earn 5% on the Cabin Creek Plant asset value. Cabin Creek is a regulated "power generating" asset.

For Cabin Creek, Line M, Levelized Cost of the Stored Solar (wind) Electricity-LCOS, is US$88.45/MWh (US¢8.85/kWh). This is a good price for carbon free electricity.

Xcel is storing its own renewable electricity generation[60] at Cabin Creek. To avoid double counting the cost of the electricity (COE) to be stored, only the levelized extra cost (MC) of storing the electricity (LECOS) should be considered when deciding whether to store solar (wind) energy at Cabin Creek or to directly dispatch it[61]. When the grid load does not need any more energy, the decision to store the energy is easy. When the market price of solar (wind) is below zero[62], the decision to store the energy is easy.

Avoiding double counting is done by using Worksheet 2, Line N, Levelized Extra Cost (LECOS) of the Stored Solar Electricity-US$/MWh. The algorithm computes the LCOS and then subtracts the COE to compute the LECOS for solar electricity.

With the nine spec values listed above, the algorithm computes the Cabin Creek Line N, Levelized Extra Cost (LECOS) of the Stored Solar Electricity to be US$48.45/MWh (US¢4.85/kWh).

Readers should use E.1 Second Computation of LECOS on Excel Worksheet 3, ESP Comparison, to confirm Line N, LECOS value of US$48.85/MWh.

Line N is the sum of

Line I, Annual Capital Amortization (ACA)-US$/MWh, US$37.52 (77.4% of the LECOS).

Line J, Fixed O & M Cost-US$/MWh is US$3.42 (7.1% of the LECOS).

Line K, Variable O & M Cost-US$/MWh, US$1.00 (2.1% of the LECOS).

Line L, the Extra Cost (COSE-COE) of the Stored Solar Electricity-US$/MWh, US$6.51 (13.4% of the LECOS)

[57] the author owns a mountain cabin in Clear Creek County, CO

[58] subject to upgrades., part replacements and refurnishing

[59] until Cabin Creek is completely amortized

[60] mostly wind, but also PV

[61] utility-scale solar (wind) dispatch depends on the time of day, the solar (wind) plant's instant capacity factor, the current grid load and the wholesale price. Solar needs storage because of its intermittency and because it cannot follow the grid load.

[62] or when solar (wind) is being curtailed by the grid

The reader can enter on this paper's Excel Worksheet 2, modifications to the spec values that were presented or they can develop their own values that they have assembled. Readers can change their set of spec values, study the results and compare the results with other ESP.

The three case studies have been presented to explain the paper's LCOS algorithm and to show you how to develop realistic spec values.

This concludes the Cabin Creek case study.

VIII. RESULTS, CONCLUSIONS AND COMPLICATIONS

In Case 1, the Highview/Encore VT LAES plant, the LCOS was computed to be US$96.49/MWh. This was the highest LCOS. The Moss Landing LCOS is 16.8% less.

In Case 2, the Tesla Moss Landing Li-ion Battery ESP, the LCOS was computed to be US$80.25/MWh. This was the lowest LCOS. The Cabin Creek LCOS is 16.3% more.

In Case 3, the Cabin Creek Pumped Hydro ESP, the LCOS was computed to be US$88.45/MWh. This was the middle case even though pumped hydro is supposed to be the lowest ES technology. The Moss Landing LCOS is 14.1% less.[63].

Since everybody knows[64] that pumped storage is the least expensive bulk ES technology, it does not make sense that the Moss Landing LCOS is less than the Cabin Creek LCOS.

This paper's LCOS algorithm does not determine which ESP specs or which computed LCOS makes technical and financial sense and which are nonsense[65]. This is determined by the reader (banker; investor) based on your knowledge of current ESP specs and on your knowledge of which computed ESP LCOS make sense.

Will a US non-carbon restrained wholesale market pay for the LECOS of storing solar (wind) energy? Does the **LAESP** US$56.49/MWh, LECOS, make sense in today's energy market? How about the US$48.45/MWh Cabin Creek LECOS? Before you say NO, you should realize that Cabin Creek, in a non-carbon constrained non-competitive wholesale market, has now been in actual operation for more than 50 years. An explanation of this fact is beyond the scope of this paper.

A nonsensical[65] output can be caused by a nonsensical[65] input or, "heaven forbid dear investor", by this paper's LCOS algorithm having a technical, financial, algebraic or worksheet computational flaw in it. Let us address this second possibility. First, this paper's narrative described how the LCOS algorithm was constructed[66]. If you agree with this paper's

[63] use Worksheet 3, *ESP Comparison Worksheet*, to compute the values for differences and % different.
[64] Lenard Cohen again
[65] that is that these specs are garbage; irrational; not realistic; not factually correct; off base
[66] using a recognized standard methodology

narrative explanation of how the LCOS algorithm was constructed, agreed with the Worksheet 2 equations and if you tested, to your satisfaction, your copy of the Worksheet 2, then there are no flaws in the paper's LCOS algorithm. Second, the reader should know that the paper's LCOS algorithm will accurately[67] compute the LCOS with ESP specs that makes no sense[68]. Logically, therefore, since the paper's LCOS algorithm is correctly constructed, any nonsensical[65] output must be caused by nonsensical[65] input.

The current ESP industry pricing convention, which is not rational[69], is to usually to publicly quote ESP CapEx in terms of energy storage capacity [70] (US$/MWh; US$/kWh) (Line 3) and in terms of energy storage capacity (MWh/day) (Line 2), power output (MW) (Line 1) and Total ESP Plant CapEx (line B). This paper's LCOS algorithm uses this industry pricing convention because this is how ESP specs are presented in the financial press and in publicly available data bases. The reader who works for an ESP developer (IPP, bank, utility, OEM, promotor, EPC contractor, FERC, PUC, angel investor, etc.,) should have access to internal documents that include the cost of energy storage capacity (US$/MWh) and the power output (US$/MW) as well as the Total ESP CapEx (US$/ESP).

This paper did not present a public data base of accurate ESP specs values. This author had the much more modest goal of only presenting, with a recognized standard methodology, an accurate "back of the envelope" LCOS algorithm.

Not discussed[71] in this paper is the reason for the extra market value of stored solar power on a carbon constrained electric grid and how the extra cost of the energy storage is paid for (revenue payments for storage).

One complication in using this paper's financial algorithm is that published (or internal) ESP specs maybe limited or insufficient. The case studies are presented to help the reader overcome this complication.

Another complication is the fact that the actual ESP specs can change. The *Clear Creek Courant*, Clear Creek County's local newspaper, reported [29] (30) {XX} that the Cabin Creek Pumped Storage Plant is going to have a US$ 70 million dollar upgrade that will replace the two electric turbines and add four feet to the top of the upper dam wall. Not mentioned in this article is any increase in the power output (MW), in the round-trip efficiency (η), in the duration (hr/day) or in the energy storage capacity (MWh/day).

Best of luck in using my Excel LCOS algorithm Workbook and this paper in your work in the finances of energy storage! I hope that you have found this paper useful. Contact me if you want some help.

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[67] mathematically; algebraically; financially; technically
[68] garbage in; garbage out
[69] especially for utility-scale
[70] or in duration but duration usually does not have a price dimension
[71] the author is available to clients to discuss these topics

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However, based on the 2016 US Presidential election results, for an American audience it is still necessary to have, in the US, a direct statement of the fact that global warming is occurring and how wind and other renewable energies can help mitigate global warming.

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Glossary

acronym	Definition	page
ESP =	Energy storage plant	1
LAES =	Liquid air energy storage	1
LC =	Levelized cost	1
LCOS =	Levelized cost of storage	1
R =	revenue	1
MWh =	megawatt hour-energy	1
ES =	energy storage	2
VT =	Vermont	2
CAES =	Compressed air energy storage	4
LCOE =	Levelized cost of energy	4
PPA =	Power Purchase Agreement	4
Pb-a =	Lead acid battery	4
NaS =	Sodium sulfur battery	4
NiMH =	Nickel metal hydrate battery	4
Li-ion =	Lithium ion battery	4
NG =	natural gas	4
CapEx =	ESP capital expenditure	5

acronym	Definition	page
COE =	cost of electricity	6
COSE =	cost of stored electricity	7
OpEx =	ESP operating expenses	7
O&M =	operation and maintenance	7
η =	efficiency	7
WACC =	weighted average cost of capital	8
IRR =	internal rate of return	8
ROE =	return on equity	8
ACA =	annual capital amortization	8
CAF =	capital amortization factor	8
ROE =	return on equity	8
LECOS =	levelized extra cost of storage	9
FX =	foreign exchange	10
€ =	euro	11
GAAP =	generally accepted accounting principles	11
PGE =	Pacific Gas and Electric	13

Worksheet # 1, Poster Table 1 Excel LCOS Algorithm Worksheet-With three Columns and the Original Poster Values

Line #			Highview/Encore **LAESP**	Tesla **Moss Landing** ESP	**Cabin Creek** Pumped Hydro ESP
	A. ESP 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	$125	$250
√-1	Computed	ESP Plant CapEx-US$/MWh	$135,000	$125,000	$250,000
B	Computed	Total ESP Plant CapEx-US$/EPS	$54,000,000	$91,250,000	$324,000,000
	B. Cost of the Stored Solar (Wind) Electricity				
4	Enter	ESP Plant Round Trip Efficiency-η-%	70%	88%	86%
5	Enter	Cost of the Solar (Wind) Electricity to be Stored-COE-US$/MWh	$40.00	$40.00	$40.00
C	Computed	Cost of the Stored Solar (Wind) Electricity-COSE-US$/MWh	$57.14	$45.45	$46.51
D	Computed	Extra Cost (COSE-COE) of the Stored Solar (Wind) Electricity-US$/MWh	$17.14	$5.45	$6.51
E	Computed	% Increase in the Cost of the Stored Solar (Wind) Electricity	43%	14%	16%

						COLOR CODE
		C. ESP OpEx and Cost of Capital				
6	Enter	Annual Fixed O&M Cost-% Total ESP CapEx-Line B	1.00%	0.50%	0.50%	
F	Computed	Annual Fixed O&M Cost-US$/yr	$540,000	$456,250	$1,620,000	Spec
7	Enter	Variable O&M Cost-US$/MWh	$1.00	$1.00	$1.00	Computed Value
8	Enter	Physical Life of the ESP-Years	25	25	50	√-Value
9	Enter	Interest/ROE Rate-WACC-%	8%	8%	5%	Transferred Value
G	Computed	Capital Amortization Factor-CAF	0.0937	0.0937	0.0548	
H	Computed	Annual Capital Amortization-ACA-US$/yr	$5,058,654	$8,548,189	$17,747,662	
		D. Computation of the Levelized Cost of the Stored Solar (Wind) Electricity-LCOS-US$/MWh				
I	Computed	Annual Capital Amortization-ACA-US$/MWh	$34.65	$32.08	$27.81	
J	Computed	Fixed O&M Cost-US$/MWh	$3.70	$1.71	$4.38	
K	Transferred	Variable O&M Cost-from Line 7 above-US$/MWh	$1.00	$1.00	$1.00	
L	Transferred	Cost of the Stored Solar (Wind) Electricity-COSE- from Line C above-US$/MWh	$57.14	$45.45	$46.51	
M	Computed	Levelized Cost of the Stored Solar (Wind) Electricity-LCOS-US$/MWh	$96.49	$80.25	$88.45	
N	Computed	Levelized Extra Cost of the Stored Solar (Wind) Electricity-LECOS-US$/MWh	$56.49	$40.25	$48.45	
O	Computed	% Increase in the Levelized Cost of the Stored Solar (Wind) Electricity	141.2%	100.6%	121.1%	
√-2	Computed	LCOS/COE	2.4	2.0	2.2	

F. Check Value-Total Annual O&M

F	Transferred	Annual Fixed O&M Cost-from Line F above-US$/yr	$540,000	$456,250	$2,073,600	
P	Computed	Annual Variable O&M Cost-US$/yr	$146,000	$266,450	$473,040	
√-3	Computed	Check Value--Total O&M US$/yr	$686,000	$722,700	$2,093,040	2/14/2020

Worksheet 2   Case 1; The Highview Power/Encore Vermont LAES Plant
Excel Algorithm Worksheet to Compute the Levelized Cost (US$/MWh)
Of Storing Solar (Wind) Electricity (LCOS).

	ESP CapEx			MWh:MW
1	Enter	ESP-Power Output-MW	50	ratio
2	Enter	ESP-Daily Energy Storage Capacity-MWh/day	400	8:1
A	Computed	ESP-Yearly Energy Storage Capacity-MWh/yr	146,000	
3	Enter	ESP-CapEx-US$/kWh	$135	
√-1	Computed	ESP-CapEx-US$/MWh	$135,000	
B	Computed	Total ESP Plant CapEx-US$/ESP	$54,000,000	
	Cost of the Solar (Wind) Electricity			
4	Enter	ESP-Round Trip Efficiency-η-%	70%	US₵/kWh↓
5	Enter	Cost of the Solar (Wind) Electricity to be Stored-COE-US$/MWh	$40.00	4.00
C	Computed	Cost of the Stored Solar (Wind) Electricity-COSE-US$/MWh	$57.14	5.71
D	Computed	Extra Cost (COSE-COE) of the Stored Solar (Wind) Electricity-US$/MWh	$17.14	1.71
E	Computed	% Increase in the Cost of the Stored Solar (Wind) Electricity	43%	
	ESP OpEx And Capital Costs			
6	Enter	Annual Fixed O&M Cost-% Total ESP Capex, Line B	1.00%	
F	Computed	Annual Fixed O&M Cost-US$/yr	$540,000	US¢/kWh↓
7	Enter	Variable O & M Cost-US$/MWh	$1.00	$0.10
8	Enter	Physical Life of the ES Plant-Years	20	
9	Enter	Interest/ROE Rate-%	8.0%	
G	Computed	Capital Amortization Factor-CAF	0.0937	
H	Computed	Annual Capital Amortization-ACA-US$/yr	$5,058,654	

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√ Checked Value

Worksheet 2 Case 1; The Highview Power/Encore Vermont LAES Plant
Excel Algorithm Worksheet to Compute the Levelized Cost (US$/MWh)
Of Storing Solar (Wind) Electricity (LCOS).

		Computation of the Levelized Cost of the Stored Solar (Wind) Electricity-US$/MWh-LCOS	US$/MWh↓	US¢/kWh↓	%
I	Computed	Annual Capital Amortization-ACA-US$/MWh	$34.65	4.46	38.9%
J	Computed	Fixed O&M Cost-US$/MWh	$3.70	0.22	1.9%
K	Transferred	Variable O&M Cost-US$/MWh-Line 7 transferred	$1.00	0.10	0.9%
L	Transferred	Cost of the Stored Solar (Wind) Electricity-COSE-US$/MWh--Line C transferred	$57.14	6.69	58.3%
M	Computed	Levelized Cost of the Stored Solar (Wind) Electricity-LCOS-US$/MWh	$96.49	11.47	100.0%

		Computation of Levelized Extra (Marginal) Cost of the Stored Solar Electricity-US$/MWh-$LECOS_1$	US$/MWh↓	US¢/kWh↓
N	Computed	Levelized Extra Cost (LCOS-COE) of the Stored Solar Electricity-$LECOS_1$-US$/MWh	$56.49	5.65
O	Computed	% Increase in the Levelized Cost of the Stored Solar Electricity	141%	

		Second Computation of the Levelized Extra Cost of the Stored Solar Electricity-US$/MWh-$LECOS_2$	US$/MWh↓	US¢/kWh↓	%
I	Computed	Annual Capital Amortization-ACA-US$/MWh	$34.65	3.46	35.9%
J	Computed	Fixed O&M Cost-US$/MWh	$3.70	0.37	3.8%
K	Transferred	Variable O&M Cost- US$/MWh-Line 7 transferred	$1.00	0.10	1.0%
D	Transferred	Extra Cost (COSE-COE) of the Stored Solar Electricity -US$/MWh-Line D transferred	$57.14	5.71	59.2%
N	Computed	Levelized Extra Cost (LCOS-COE) of the Stored Solar Electricity-$LECOS_2$-US$/MWh	$96.49	9.65	100.0%

		Bonus-Check (√) Value--Total Annual ESP O&M	US$/yr↓
F	Transferred	Annual Fixed O&M Cost-from Line F above-US$/yr	$540,000
P	Computed	Annual Variable O&M Cost-US$/yr	$146,000
Q	Computed	Check (√) Value--Total Annual ESP O&M US$/yr	$686,000

Worksheet 2 Case 2; The Tesla Moss Landing Li-ion Battery ESP
Excel Algorithm Worksheet to Compute the Levelized Cost (US$/MWh)
Of Storing Solar (Wind) Electricity (LCOS).

		ESP CapEx		MWh:MW
1	Enter	ESP-Power Output-MW	182.5	ratio
2	Enter	ESP-Daily Energy Storage Capacity-MWh/day	730	8:1
A	Computed	ESP-Yearly Energy Storage Capacity-MWh/yr	266,450	
3	Enter	ESP-CapEx-US$/kWh	$125	
√-1	Computed	ESP-CapEx-US$/MWh	$125,000	
B	Computed	Total ESP Plant CapEx-US$/ESP	$91,250,000	
		Cost of the Solar (Wind) Electricity		
4	Enter	ESP-Round Trip Efficiency-η-%	88%	US₵/kWh↓
5	Enter	Cost of the Solar (Wind) Electricity to be Stored-COE-US$/MWh	$40.00	4.00
C	Computed	Cost of the Stored Solar (Wind) Electricity-COSE-US$/MWh	$45.45	45.45
D	Computed	Extra Cost (COSE-COE) of the Stored Solar (Wind) Electricity-US$/MWh	$5.45	0.55
E	Computed	% Increase in the Cost of the Stored Solar (Wind) Electricity	14%	
		ESP OpEx And Capital Costs		
6	Enter	Annual Fixed O&M Cost-% Total ESP Capex, Line B	0.50%	
F	Computed	Annual Fixed O&M Cost-US$/yr	$456,250	US¢/kWh↓
7	Enter	Variable O & M Cost-US$/MWh	$1.00	$0.10
8	Enter	Physical Life of the ES Plant-Years	25	
9	Enter	Interest/ROE Rate-%	8.0%	
G	Computed	Capital Amortization Factor-CAF	0.0937	
H	Computed	Annual Capital Amortization-ACA-US$/yr	$8,548,189	

COLOR CODE
Entry
Result
Side Column Result
Transfer Result
√ Checked Value

Worksheet 2 Case 2; The Tesla Moss Landing Li-ion Battery ESP
Excel Algorithm Worksheet to Compute the Levelized Cost (US$/MWh)
Of Storing Solar (Wind) Electricity (LCOS).

		Computation of the Levelized Cost of the Stored Solar (Wind) Electricity-US$/MWh-LCOS	*US$/MWh↓*	*US¢/kWh↓*	*%*
I	Computed	Annual Capital Amortization-ACA-US$/MWh	$32.08	3.21	40.0%
J	Computed	Fixed O&M Cost-US$/MWh	$1.71	0.17	2.1%
K	Transferred	Variable O&M Cost-US$/MWh-Line 7 transferred	$1.00	0.10	1.2%
L	Transferred	Cost of the Stored Solar (Wind) Electricity-COSE-US$/MWh--Line C transferred	$45.45	4.55	56.6%
M	Computed	Levelized Cost of the Stored Solar (Wind) Electricity-LCOS-US$/MWh	$80.25	8.02	100.0%

		Computation of Levelized Extra (Marginal) Cost of the Stored Solar Electricity-US$/MWh-$LECOS_1$	*US$/MWh↓*	*US¢/kWh↓*
N	Computed	Levelized Extra Cost (LCOS-COE) of the Stored Solar Electricity-$LECOS_1$-US$/MWh	$40.25	4.02
O	Computed	% Increase in the Levelized Cost of the Stored Solar Electricity	101%	

		Second Computation of the Levelized Extra Cost of the Stored Solar Electricity-US$/MWh-$LECOS_2$	*US$/MWh↓*	*US¢/kWh↓*	*%*
I	Computed	Annual Capital Amortization-ACA-US$/MWh	$32.08	3.21	79.7
J	Computed	Fixed O&M Cost-US$/MWh	$1.71	0.17	4.3%
K	Transferred	Variable O&M Cost- US$/MWh-Line 7 transferred	$1.00	0.10	1.5%
D	Transferred	Extra Cost (COSE-COE) of the Stored Solar Electricity -US$/MWh-Line D transferred	$5.45	0.55	13.6%
N	Computed	Levelized Extra Cost (LCOS-COE) of the Stored Solar Electricity-$LECOS_2$-US$/MWh	$40.25	4.02	100.0%

		Bonus-Check (√) Value--Total Annual ESP O&M	*US$/yr↓*
F	Transferred	Annual Fixed O&M Cost-from Line F above-US$/yr	$456,250
P	Computed	Annual Variable O&M Cost-US$/yr	$266,450
Q	Computed	Check (√) Value--Total Annual ESP O&M US$/yr	$722,700

Worksheet 2 Case 3; The Cabin Creek Pumped Hydro ESP
Excel Algorithm Worksheet to Compute the Levelized Cost (US$/MWh)
Of Storing Solar (Wind) Electricity (LCOS).

	ESP CapEx			MWh:MW
1	Enter	ESP-Power Output-MW	324	ratio
2	Enter	ESP-Daily Energy Storage Capacity-MWh/day	1,296	8:1
A	Computed	ESP-Yearly Energy Storage Capacity-MWh/yr	473,040	
3	Enter	ESP-CapEx-US$/kWh	$250	
√-1	Computed	ESP-CapEx-US$/MWh	$250,000	
B	Computed	Total ESP Plant CapEx-US$/ESP	$324,000,000	
	Cost of the Solar (Wind) Electricity			
4	Enter	ESP-Round Trip Efficiency-η-%	86%	US₵/kWh↓
5	Enter	Cost of the Solar (Wind) Electricity to be Stored-COE-US$/MWh	$40.00	4.00
C	Computed	Cost of the Stored Solar (Wind) Electricity-COSE-US$/MWh	$46.51	5.71
D	Computed	Extra Cost (COSE-COE) of the Stored Solar (Wind) Electricity-US$/MWh	$6.51	1.71
E	Computed	% Increase in the Cost of the Stored Solar (Wind) Electricity	16%	
	ESP OpEx And Capital Costs			
6	Enter	Annual Fixed O&M Cost-% Total ESP Capex, Line B	0.50%	
F	Computed	Annual Fixed O&M Cost-US$/yr	$1,620,000	US¢/kWh↓
7	Enter	Variable O & M Cost-US$/MWh	$1.00	$0.10
8	Enter	Physical Life of the ES Plant-Years	50	
9	Enter	Interest/ROE Rate-%	5.0%	
G	Computed	Capital Amortization Factor-CAF	0.0548	
H	Computed	Annual Capital Amortization-ACA-US$/yr	$17,747,662	

COLOR CODE
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Result
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Transfer Result
√ Checked Value

Worksheet 2 Case 3; The Cabin Creek Pumped Hydro ESP
Excel Algorithm Worksheet to Compute the Levelized Cost (US$/MWh) Of Storing Solar (Wind) Electricity (LCOS).

	Computation of the Levelized Cost of the Stored Solar (3ind) Electricity-US$/MWh-LCOS		US$/MWh↓	US¢/kWh↓	%
I	Computed	Annual Capital Amortization-ACA-US$/MWh	$37.52	3.75	42.4%
J	Computed	Fixed O&M Cost-US$/MWh	$3.42	0.34	3.9%
K	Transferred	Variable O&M Cost-US$/MWh-Line 7 transferred	$1.00	0.10	1.1%
L	Transferred	Cost of the Stored Solar (Wind) Electricity-COSE-US$/MWh--Line C transferred	$46.51	4.65	52.6%
M	Computed	Levelized Cost of the Stored Solar (Wind) Electricity-LCOS-US$/MWh	$88.85	8.85	100.0%

	Computation of Levelized Extra (Marginal) Cost of the Stored Solar Electricity-US$/MWh-LECOS$_1$		US$/MWh↓	US¢/kWh↓
N	Computed	Levelized Extra Cost (LCOS-COE) of the Stored Solar Electricity-LECOS$_1$-US$/MWh	$48.45	4.85
O	Computed	% Increase in the Levelized Cost of the Stored Solar Electricity	121%	

	Second Computation of the Levelized Extra Cost of the Stored Solar Electricity-US$/MWh-LECOS$_2$		US$/MWh↓	US¢/kWh↓	%
I	Computed	Annual Capital Amortization-ACA-US$/MWh	$37.52	3.75	77.4%
J	Computed	Fixed O&M Cost-US$/MWh	$3.42	0.34	7.1%
K	Transferred	Variable O&M Cost- US$/MWh-Line 7 transferred	$1.00	0.10	2.1%
D	Transferred	Extra Cost (COSE-COE) of the Stored Solar Electricity -US$/MWh-Line D transferred	$6.51	0.65	13.4%
N	Computed	Levelized Extra Cost (LCOS-COE) of the Stored Solar Electricity-LECOS$_2$-US$/MWh	$48.45	4.85	100.0%

	Bonus-Check (√) Value--Total Annual ESP O&M		US$/yr↓
F	Transferred	Annual Fixed O&M Cost-from Line F above-US$/yr	$1,620,000
P	Computed	Annual Variable O&M Cost-US$/yr	$473,040
Q	Computed	Check (√) Value--Total Annual ESP O&M US$/yr	$2,093,040

Table 2 The Equations of Worksheet 2, the Excel LCOS Algorithm Worksheet

Line #	Description	Algebraic Symbol	Equation
	ESP CapEx		
1	ESP-Power Output-MW	MW_o	ESP spec
2	ESP-Daily Energy Storage Capacity-MWh/day	MWh_d	ESP spec
A	ESP-Yearly Energy Storage Capacity-MWh/yr	MWh_{yr}	$MWh_{yr} = MWh_d \times 365$
3	ESP-CapEx-US$/MWh	$US\$CapEx_{MWh}$	ESP spec
B	Total ESP Plant Capex-US$/ESP	$US\$CapEx_{ESP}$	$US\$CapEx_{ESP} = US\$CapEx_{MWh} \times MWh_d$
	Cost of the Solar Electricity		
4	ESP-Round Trip Efficiency-η-%	η	ESP spec

Table 2 The Equations of Worksheet 2, the Excel LCOS Algorithm Worksheet

Line #	Description	Algebraic Symbol	Equation
5	Cost of the Solar Electricity to be stored-COE-US$/MWh	COE	ESP spec
C	Cost of the Stored Solar Electricity-COSE-US$/MWh	COSE	COSE = COE/η
D	Extra Cost (COSE-COE) of the Stored Solar Electricity-US$/MWh	ECOSE	ECOSE = COSE-COE
E	% Increase in the Cost of the Stored Solar Electricity	ECOSE-%	ECOSE-% = ECOSE/COE
	ESP OpEx and Capital Costs		
6	Annual Fixed O & M Cost-% of Line B, Total ESP Plant CapEx	FOM-%	ESP spec
F	Annual Fixed O & M Cost-US$/yr	FOM-US$$_{yr}$	FOM-US$$_{yr}$ = US$CapEx$_{ESP}$ X FOM-%

Table 2   The Equations of Worksheet 2, the Excel LCOS Algorithm Worksheet

Line #	Description	Algebraic Symbol	Equation
7	Variable O & M Cost-US$/MWh	$VOM\text{-}US\$_{MWh}$	ESP spec
8	Physical Life of the ESP-Years	yr	ESP spec
9	Interest/ROE Rate-%	i	ESP spec
G	Capital Amortization Factor-CAF	CAF	$CAF = US\$1.00\ x\ \frac{i(1+i)^{yr}}{(1+i)^{yr}-1}$
H	Annual Capital Amortization-ACA-US$/yr	ACA_{yr}	$ACA_{yr} = US\$CapEx_{ESP}\ X\ CAF$

Table 2 The Equations of Worksheet 2, the Excel LCOS Algorithm Worksheet

Line #	Description	Algebraic Symbol	Equation
	<u>Computation of the Total Levelized Cost of the Stored Solar Electricity-US$/MWh-LCOS</u>		
I	Annual Capital Amortization -ACA-US$/MWh	ACA_{MWh}	$ACA_{MWh} = ACA_{yr} / MWh_{yr}$
J	*Fixed O & M Cost-US$/MWh*	FOM-$US\$_{MWh}$	FOM-$US\$_{MWh}$ = FOM-$US\$_{yr}$ /MWh_{yr}
K	Variable O & M Cost-from Line 7 above-US$/MWh	VOM-$US\$_{MWh}$	VOM-$US\$_{MWh}$ = Line 7
L	Cost of the Stored Solar Electricity-COSE-from Line C above-US$/MWh	COSE	COSE = Line C
M	Levelized Cost of the Stored Solar Electricity-**LCOS**-US$/MWh	LCOS	LCOS = ACA_{MWh} + FOM-$US\$_{MWh}$ + VOM-$US\$_{MWh}$ + COSE

Table 2   The Equations of Worksheet 2, the Excel LCOS Algorithm Worksheet

Line #	Description	Algebraic Symbol	Equation
	E. Computation of the Extra Cost of the Stored Solar Electricity-US$/MWh[72]		
N_1	Levelized Extra Cost (LCOS-COE) of the Stored Solar Electricity-(LECOS)-US$/MWh	$LECOS_1$-US$	$LECOS_1$-US$ = LCOS- COE
O	% Increase in the cost of the Stored Solar Electricity	LECOS-%	LECOS-% = LECOS-US$/COE

[72] E.1 Second Computation of the Extra Cost of the Stored Solar Electricity-US$/MWh is on Worksheet 3, ESP Comparison Worksheet

Table 3 The E.1 Equations of Worksheet 3, EPS Comparison Worksheet

	E.1 Second Computation of the Levelized Extra Cost of the Stored Solar Electricity-US$/MWh-$LECOS_2$[73]		
I	Annual Capital Amortization -ACA-US$/MWh	ACA_{MWh}	$ACA_{MWh} = ACA_{yr} / MWh_{yr}$
J	*Fixed O & M Cost-US$/MWh*	FOM-$US\$_{MWh}$	FOM-$US\$_{MWh}$ = FOM-$US\$_{yr} / MWh_{yr}$
K	Variable O & M Cost-from Line 7 above-US$/MWh	VOM-$US\$_{MWh}$	VOM-$US\$_{MWh}$ = Line 7
D	Extra Cost (COSE-COE) of the Stored Solar Electricity-ECOS-US$/MWh	ECOSE	ECOSE = COSE-COE
N_2	Levelized Extra Cost (LCOS-COE) of the Stored Solar Electricity-($LECOS_2$)-US$/MWh ($LECOS_2 = LECOS_1$)	$LECOS_2$-US$	$LECOS_2 = ACA_{MWh}$ + FOM-$US\$_{MWh}$ + VOM-$US\$_{MWh}$ + ECOSE

[73] GULP! E.1 is actually only on Worksheet 3, ESP Comparison Worksheet

Table 3 The E.1 Equations of Worksheet 3, EPS Comparison Worksheet

	F. Bonus-Check (√) Value--Total Annual ESP O&M		
F	Annual Fixed O&M Cost-from Line F above-US$/yr	$FOM\text{-}US\$_{yr}$	$FOM\text{-}US\$_{yr} = US\$CapEx_{ES} \times FOM\text{-}\%$
P	Annual Variable O&M Cost-US$/yr	$VOM\text{-}US\$_{yr}$	$VOM\text{-}US\$_{yr} = VOM\text{-}US\$_{MWh} \times MWh_{yr}$
Q	Check (√) Value--Total Annual ESP O&M US$/yr	$TOM\text{-}US\$_{yr}$	$TOM\text{-}US\$_{yr} = FOM\text{-}US\$_{yr} + VOM\text{-}US\$_{yr}$

READER'S COMMENTS

As typos and errors are discovered by the author or pointed out by you kind and gentle readers [bankers (investors)], they will be corrected.

Note #	Reader's Comments	Author's Comments
1.		I defined these terms on page 9.
2.		
3.		
4.		
5.		

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