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A Simplified Method to Evaluate Energy Life Cycle Cost Effectiveness for Electron Ion Collider Infrastructure Design

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Electron-Ion Collider

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A	04/03/23	Initial draft	R Srinivasan	
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1 Introduction

The new DOE Order 436.1A approved on April 25th provides instructions to incorporate principles of sustainability early in the project planning and design process. Integral to the principles of sustainability is life cycle cost effectiveness

Life Cycle Cost (LCC) Analysis is vital to the sustainable energy efficient design and construction of the Electron Ion Collider (EIC). Reducing energy consumption has a direct impact on reducing life cycle operating costs with benefits to the environment.

The early stages of the project are the most influential where design decisions and so life-cycle considerations during this stage can result in significant impacts to the energy footprint of the design.

For example, when comparing between various options, it is necessary to compare the energy savings in $\frac{US\$}{kWh}$ to the capital cost in $US\$$. And although uncertain by nature, it is important to factor in the expected inflation and discount of future spendings to compare with the cost of immediate capital investment

This tech note presents a tool that engineers can readily use to analyze energy operating costs using an incremental life cycle cost method when comparing different design alternatives.

2 Method

Consider selecting between two design options that differ in initial capital investment by $\Delta Capital$, \$ and which differ in energy consumption by $\Delta Energy, kW$. As mentioned previously, we are left with comparing the capital investment in present day \$ compared to future energy cost in $\$/kWh$ which is not a straightforward comparison.

We will therefore proceed by developing the LCC cost of an incremental unit of electricity consumed (kWh). Thisis treated as an annually occurring energy cost that will use discount rates to adjust future cash flows to present value while considering inflation on the costs of electricity.

Using incremental unit energy cost simplifies the comparison method while limiting this method to relatively small differences in energy consumption. Large changes in energy consumption will require a modification of the infrastructure which in turn adds more capital cost. This method is therefore limited to the evaluation of relatively small changes in energy consumption.

To determine the upfront capital cost difference between the two options we start with general formula for Life Cycle present value as defined in reference 1 where:

$$\Delta LCC_{unit} = \sum_{t=0}^{N} \frac{C_t}{(1+d)^t}$$

Where:

$\Delta LCC_{unit}, \$/kW$	=	Incremental unit LCC in present-value dollars of a unit of electricity
C_t , $\$/kWh$	=	One unit energy operating costs treated as uniform annual costs, escalated for energy inflation (see below)
$N, years$	=	Operation period
d, %	=	Discount rate used to adjust cash flows to present value

Note that in the above, the incremental method simplifies the future energy operating costs to be uniform annual costs escalated for energy inflation. So:

$$C_t = C_0(1+e)^t$$

Where:

e, %	=	is the rate of energy escalation
$C_0, \$/kWh$	=	present day energy operating costs

The above is used to develop ΔLCC_{unit} which can be interpreted as the present value cost of an incremental unit of energy consumption when comparing between two options. This is in $\$/kW$ and is in present day \$.

So, revisiting the setup described previously evaluating between two design alternatives that differ in initial capital investment by $\Delta Capital$, \$ and which <u>only</u> differ in energy consumption by $\Delta Energy, kW$

The incremental net present value of the unit energy consumption is:

$$\Delta \mathrm{NPV}_{\mathrm{energy}}, \$ = \Delta Energy \times \Delta LCC_{unit}$$

$$\boxed{\boldsymbol{Design\ Selection = Min\left(\Delta \mathbf{NPV}_{\mathbf{energy}}, \Delta Capital\right)}}$$

Once the ΔLCC_{unit} is developed, it can be used across various projects.

3 Analysis

3.1 Assumptions

For the method described above we make the following assumptions regarding the EIC project:

- Yearly operation : 28 weeks x 24 hrs/day x 7 days/week =4704 hrs/year
- Lifetime of the collider: 20 years
- Expected start of collider operation : 2033
- Discount rate 3% from reference 1
- Escalation rate 2.3% from reference 1
- Electricity Unit Costs from reference 2
  - Expected 0.075 $/kWh
- Energy Costs for Large Deltas

  Add 1% to unit rate above 1MW; Add 6% to unit rate above 5 MW
- For large changes in electrical loads, additional electrical hardware such as new transformers and substations should be accounted for using a different evaluation method and are not included.

4 Results & Conclusion

Using the above we calculate the incremental unit cost of energy consumption ΔLCC_{unit} as

Op. hrs. per year	4704	Unit, kW	1
Number of years	20	Unit Cost, c/kWh	7.5
Discount Rate	3%	Escalation	2.3%
	$ per kW	$\boldsymbol{\Delta LCC_{unit}}$	**$5,921**

		¢/kWh	hrs per year	kW	Annual Cost
Year 1	2033	9.9	4704	1	$ 463
Year 2	2034	10.1	4704	1	$ 474
Year 3	2035	10.3	4704	1	$ 485
Year 4	2036	10.5	4704	1	$ 496
Year 5	2037	10.8	4704	1	$ 508
Year 6	2038	11.0	4704	1	$ 519
Year 7	2039	11.3	4704	1	$ 531
Year 8	2040	11.6	4704	1	$ 543
Year 9	2041	11.8	4704	1	$ 556
Year 10	2042	12.1	4704	1	$ 569
Year 11	2043	12.4	4704	1	$ 582
Year 12	2044	12.7	4704	1	$ 595
Year 13	2045	12.9	4704	1	$ 609
Year 14	2046	13.2	4704	1	$ 623
Year 15	2047	13.5	4704	1	$ 637

		¢/kWh	hrs per year	kW	Annual Cost
Year 16	2048	13.9	4704	1	$ 652
Year 17	2049	14.2	4704	1	$ 667
Year 18	2050	14.5	4704	1	$ 682
Year 19	2051	14.8	4704	1	$ 698
Year 20	2052	15.2	4704	1	$ 714

Both micro- and macro-economic parameters (assumed previously) were varied to determine the sensitivity to the calculated incremental life cycle cost.

Unit Electricity Estimated High: Evaluating the impact of high initial cost of energy.

Escalation Low: Evaluating the impact of varying escalation on future energy prices.

Large Delta Load: Accounting for large electric load increase on purchased electricity cost.

Very Large Delta Load*: Account for very large electric load increases.

Vary Discount Rate: Varying the discount rate at which future costs are converted to present value. See reference 1 for further guidance.

	Base	**Unit Electricity Estimated High**	**Escalation Low**	**Large Delta Load**	**Very Large Delta Load***	**Vary Discount Rate**
Op. hrs. per year	4704	4704	4704	4704	4704	4704
Number of years	20	20	20	20	20	20
Discount Rate	3%	3%	3%	3%	3%	**5%**
Unit, kW	1	1	1	**4000**	**10000**	1
Unit Cost, ¢/kWh	7.5	**10**	7.5	7.5	7.5	7.5
Escalation	2.3%	2.3%	**0.0%**	2.3%	2.3%	2.3%
$ per kW ΔLCC_{unit}	**$5,921**	**$7,894**	**$4,728**	**$5,980**	**$6,276**	**$3,882**

5 Conclusion

The analysis recommends using $5,921 per kW as the basis for evaluating incremental unit energy costs when comparing design alternatives for sustainability and energy life cycle impacts. When utilizing these numbers, consideration should be made to changes in parameters resulting from changed project and economic conditions. These parameters are identified as

1. Operating hours per year
2. Number of years
3. Discount Rate
4. Escalation

Utilizing this method has already resulted in the selection of options that can result in the reduction of electricity consumption, improve sustainability and reduce operating costs. See references 3 and 4.

6 Reference

1. NIST Handbook 135 2020 Edition
2. Verbal conversation with Mark Toscano Energy and Utilities May 2021 for future costs of purchased electricity.
3. Site Ambient Temperatures and Operating Schedules for EIC - Utility CW Considerations BNL-224219-2023-TECH
4. Estimate of the marginal cost of cryogenic heat budget for EIC BNL-224168-2023-TECH