June 5, 2023

Ms. Cory-Ann Wind
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RE: Response to Workshop Discussion of Proposed Alternative Estimation Methodology for Forklift Truck Electricity Usage

Dear Ms. Cory-Ann Wind and the CFP Team,

Thank you very much for holding the discussion workshop on the proposed alternative estimation methodology for forklift truck electricity usage on May 30, 2023. As requested, please find below our response to the various discussion points raised during the workshop.

1- Proposed Estimation Methodology

The DEQ proposed the following formula for estimating the kWhrs per forklift per charge cycle:

$$kWhr\ per\ FL\ per\ Charge\ Cycle = DOD \times Batt\ kWh\ Cap. \times Ch.\ Eff \times CRF.$$

where:

- DOD: % Depth of Discharge of the battery
- Battery kWHr Capacity: Battery Nameplate kWhr rating
- Charger Efficiency: Charger efficiency
- CRF: Charge return factor

We have two main concerns with the above proposed formula:

i. The formula doesn't calculate the kWhrs per forklift per **charge cycle** but rather the **discharge kWhrs per shift**. This can be shown from the fact that the product of $Ch.\ Eff \times CRF \cong 1$. The typical Charger Efficiency and Charge Return factors for different charger technologies and their product is shown in the table below:

Typical Charger Efficiencies and Charge Return Factor for the Various Charger Technologies[1]

	SCR	Ferro Resonant	High Frequency
Charger Efficiency	85%	87.5%	90%
Charge Return Factor (CRF)	1.2	1.15	1.1
$Ch.\ Eff \times CRF$	**1.02**	**1.00**	**0.99**

As such, the proposed estimation formula can be approximated by:

$$kWhr\ per\ FL\ per\ Charge\ Cycle \cong DOD \times Batt\ kWh\ Cap.$$

[1] https://www.pge.com/includes/docs/pdfs/mybusiness/energysavingsrebates/moneybacksolutions/grocery/fb_ib/forklift_battery_charger_fs.pdf

This is simply the discharge kWhrs by the battery and NOT the charge cycle kWhrs**.**

The correct formulation of kWhrs per forklift per charge cycle is:

$$kWhr\ per\ FL\ per\ Charge\ Cycle = \frac{DOD \times Batt\ kWh\ Cap. \times CRF}{Charger\ Efficiency}$$

Please refer to the Electric Power Research Institute Research Technical Note on Non-Road Electric Transportation[2].

Note that one needs to divide by the Charger Efficiency to obtain the kWhrs delivered by the charger to the battery.

In summary, the proposed formula only accounts for the discharge kWhrs (kWhrs supplied by the battery to the truck) and not the charge kWhrs. In fact, the DEQ proposed formula already reduces the kWhrs delivered by the charger by more than 25% compared to the corrected formula and as such the proposed DEQ formula already corrects for over reporting.

ii. The DEQ proposed using a 20% for the Depth of Discharge as an adjustment for overreporting actual charge kWhrs. The DEQ indicated that the 20% is not based on any data and requested feedback on the proposed figure.

a) We strongly disagree with the 20% figure as it doesn't reflect actual battery and truck usage based on our extensive experience in industrial battery charging and data gathered from over ~50,000 industrial batteries and chargers. In fact, end users use the 80% DOD figure to size their batteries for a single shift operation. In addition, all truck and battery manufacturers recommend the 80% figure as the optimum figure to size batteries (see Enersys Service Manual[3] and EastPenn/Deka Service Manual[4]). End users have no interest in placing larger batteries than needed nor paying for battery power that is not used. In fact, end users that run more than one shift typically purchase additional batteries per truck as a single battery is not sized for multiple shift operation.

b) Many users use opportunity and fast charging regimen, where the batteries are continuously charged at every break. In these applications, the battery usage is higher than 80% per shift[5]. This is especially the case for the newly introduced Li-Ion batteries, which are charged at much higher rates and discharged even down to 0% (or 100% DOD).

[2] https://www.psoklahoma.com/lib/docs/savings/business/newsletter/1016963_ClassIElectricIndustrialForklifts.pdf
[3] https://allenenergy.com/wp-content/uploads/2020/05/EnerSys-Lead-Acid-Operations-Manual.pdf
[4] https://www.eastpennmanufacturing.com/wp-content/uploads/0656-Service-Manual.pdf
[5] https://www.mhi.org/media/members/17127/130197613453828886.pdf

c) As mentioned above, the DEQ proposed formula already discounts the kWhrs of charge as it only accounts for discharge kWhrs. As such, the formula reflects an effective DOD of less than 65%.

d) The actual depth of discharge varies depending on the class of trucks. Class I Trucks (electric motor rider trucks) and Class II trucks (electric motor narrow aisle trucks) are typically heavily used trucks as they are continuously used to lift and move pallets through facilities. As such, their actual DOD per shift is very close to 80%. Class III trucks (electric motor hand trucks or hand/rider trucks) tend to be less used since there is no lift action and as such their actual DOD per shift would be less than 80% (sometimes as low as 40%). However, the contribution of Class III trucks to the overall electricity consumption is much lower since Class III trucks utilize much smaller size batteries.

e) Below is a table showing the typical battery size and consumption per hour for the three types of trucks.

Typical Battery Sizes for the Different Forklift Truck Classes[6]

	Typical Battery Voltage	**Typical Battery Ahrs**	**Typical Battery kWhrs**
Class I (Sitdowns)	36	1190	42.84
Class II (Reach trucks)	48	1000	48.0
Class III (Pallet Jacks)	24	510	12.24

As shown in the table above, the kWhrs battery rating of Class III trucks is approximately 26-28% of that of Class I and Class II trucks, respectively. As such, and while their actual usage may be less than Class I and Class II, their contribution to the total electricity used by all trucks will be less than 28%.

f) EPRI (The Electric Power Research Institute) has published a number of studies on electric forklifts. In one publication on Class I forklifts (electric motor rider trucks), EPRI points the fact that these trucks are typically 36V and 48V and have an average battery amp-hour capacity of 938Ahrs with an average kWhr rating of 40.8kWhrs to 55.4kWhrs[7]. EPRI states clearly that such trucks use a single charge to run an 8-hour shift and show that for a single shift operation, these tucks consume 48.3kWhrs to 49.7kWhrs. This represents an 80% DOD for such trucks. The same holds for Class II trucks (electric motor narrow aisle and reach trucks).

[6] This data is compiled from ~40,000 battery sizes registered with SCT in CA and OR

[7] https://www.psoklahoma.com/lib/docs/savings/business/newsletter/1016963_ClassIElectricIndustrialForklifts.pdf

g) One option to come up with an average DOD is to calculate a weighted average of the DOD of all trucks at a given facility. One of the large sites we have been managing has 107 forklifts, of which 28 are Class III pallet jacks and 79 Class I sit downs. The table below summarizes the battery size for each type of truck. We assumed an average of 75% DOD for Class I trucks and 45% for Class III trucks to represent the lower utilization of Class III trucks.

Typical Battery Sizes for the Different Forklift Truck Classes

	# of Trucks	**Battery Voltage**	**Battery Ahrs**	**Battery kWhrs**	**Average % DOD**	**# of Trucks × kWhrs × % DOD**
Class I (Sitdown)	79	36	1120	40.32	75%	2,388,960
Class III (Pallet Jacks)	28	24	840	20.16	45%	254,016
					TOTAL	2,643,976

To calculate the effective DOD for the site, one needs to calculate the weighted average kWhr consumption for both types of trucks, namely:

$$Effective\ DOD = \frac{\#\ of\ Class\ I\ Trucks\ \times\ kWhrs\ \times\ \%\ DOD +\ of\ Class\ III\ Trucks\ \times\ kWhrs\ \times\ \%\ DOD}{of\ Class\ I\ Trucks\ \times\ kWhrs +\ of\ Class\ III\ Trucks\ \times\ kWhrs}$$

$$Effective\ DOD = \frac{79\ \times\ 40.32\ \times\ 75\% +\ 28\ \times\ 20.16\ \times\ 45\%}{79\ \times\ 40.32 +\ 28\ \times\ 20.16}$$

$$Effective\ DOD = \frac{2{,}642{,}976}{3{,}749{,}760} \cong 70.5\%$$

As such, the effective DOD for the forklift trucks used at the site is ~70%.

Conclusion:

As we stated, the DEQ formula already reduces the charge kWhrs by more than 20% as it only accounts for the discharge kWhrs. If DEQ agrees to adopt the corrected kWhrs per forklift per charge cycle formula, then we would recommend using an average of 70% DOD for all trucks.

2- **The DEQ proposes that metering of all sites should start by Q3 2023.** As we stated in our previous letter to the DEQ dated on May 15, 2023, there are a number of challenges that remain, including:

    a. The vast majority of the industrial battery chargers in service do not have any built-in metering capabilities to report kWhrs dispensed.

    b. There are no dedicated power meters on the AC panels supplying forklift battery chargers. Most buildings utilize a single power meter and the charger load is a fraction of the total kWhrs used. In addition, forklift charging stations are placed at different locations throughout warehouses and manufacturing facilities. As a result, there is no single point to place a power meter to aggregate energy measurements.

    c. The DEQ need to allow both AC metering (AC panel metering) as well as DC metering (charger output metering) as AC panel metering is impossible to do at many sites.

    d. It would take at least 6 months to deploy meters at the various sites. As such, enforcing metering starting Q3 2023 is almost impossible. We kindly ask DEQ to give end users ample time to install meters once the metering requirements by DEQ are finalized (No sooner than Q1 2024).

3- **Finally, the issue of allocating the metered kWhrs to old and new trucks needs to be addressed.** One proposal is to allocate the metered kWhrs to the ratio of the number of old and new trucks. The problem with that is that the battery kWhr ratings for old and new trucks may not be the same. For example, it may be the case that old trucks use different kWhr size batteries than new trucks. As such, we suggest using a weighted average of the number of old and new trucks along with their respective battery kWhrs ratings.

Thank you for taking our comments into consideration. We look forward to continued participation and discussion.

Respectfully,

/s/

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