

Individual Analytical Analysis

PHS Sustainability Capstone

Efficiency Analysis



Steve Sanghi College of Engineering

Alexandra Miller

ME476C

04/26/2026

I. Introduction

The PHS sustainability project is to analyze and improve the off-grid renewable energy system at the Ponderosa High School (PHS) greenhouse. One way the team will improve the system is by including a human powered generation for an interactive demonstration of renewable energy for students at PHS. After considering client input, the capstone team has decided to design and manufacture a human powered bicycle (HPB) generator. When designing this bike, it is important to understand every component of the bicycle and where there can be performance losses in the design.

This analysis focuses on identifying and calculating performance losses of the human powered bicycle to ensure that optimal efficiency is maintained in the design. The goal of this analysis is to provide sufficient information for the team to improve the design, so the least amount of performance losses is present. The main components of the HPB are,

- Bike (mountain bike with gear shifting)
- Drive belt
- Alternator (12 volt)
- Battery storage (FullRiver DC 400-6)
- Interactive energy display screen (ECM)
- Steel frame stand
- Wooden floor support

In the following sections, the efficiency and possible performance losses will be acknowledged for the components listed above based on the amount of efficiency lost due to the item. These possible losses will be shortened into a list of most importance so the team can effectively prioritize their time to improve efficiency as much as possible.

Results from this analysis will help the team to maintain their goal of providing a durable and efficient human powered bicycle for the PHS greenhouse. Information from this analysis will meet the customer requirements of efficiency energy generation, increased energy generation, and STEAM education for the PHS students.

II. Assumptions and Justifications

Assumptions for the efficiency analysis of the HPB system are shown below with justifications provided.

Assumption 1: the components resulting in performance loss are mechanical, general, electrical, and battery

Justification: other components resulting in performance loss come from manufacturing, material selection, and chemical. However, these components result in a low performance loss and are considered negligible.

Assumption 2: data for bike friction loss is estimated with online data of mountain bikes [1]

Justification: data collected online is a sufficient estimate of the current mountain bikes donated to the PHS capstone team.

Assumption 3: the components for bike performance loss are due to friction at the chain, gear shifting, and tire

Justification: other components resulting in performance loss are due to biological performance, seat to height ratio, and manufacturing of the mountain bike. Since these are very small and vary depending on the rider, they will be considered negligible.

Assumption 4: the components for drive belt performance loss are due to friction with the alternator

Justification: other components resulting in performance are the manufacturing and drive belt slippage between the rear bike wheel and the alternator. These vary between the bike, drive belt, and alternator. Additionally, they result in a small performance loss and therefore are negligible.

Assumption 5: the components for alternator performance loss are due to copper and core losses

Justification: other components that result in performance loss for the alternator are hysteresis and eddy current loss. In comparison to copper and core losses, these other components are negligible.

Assumption 6: the components for battery performance loss are due to heating degradation (charge/discharge cycling) and aging

Justification: other components that result in performance loss for the battery are depth of discharge, wiring, and manufacturing. These components vary and have produced a small performance loss.

Assumption 7: the components for stationary bike stand performance loss are due to tire slipping

Justification: this is the only performance loss for the stationary bike stand. Other components are accounted for in the bike, the alternator, and the drive belt themselves.

Assumption 8: the components for wiring and electrical performance loss are due to voltage regulation and electrical resistance

Justification: other components that result in performance loss for the wiring and electrical are the manufacturing, set up, and varying loads. The other components result in a small performance and therefore are negligible.

III. Methods

Table I
List of Variables

Variable	Description
η_{total}	Total efficiency of HPB system
η_{mech}	Mechanical efficiency
η_{gen}	General efficiency
η_{elect}	Electrical efficiency
η_{bat}	Battery efficiency
η_{bike}	Efficiency of the bike
η_{db}	Efficiency of the drive belt
η_{stand}	Efficiency of the stationary bike stand
η_{wiring}	Efficiency of the wiring
η_{DC}	Efficiency of the FullRiver DC400-6
$\eta_{alternator}$	Efficiency of the alternator
T_1	Tension of tight side (drive belt)
T_2	Tension of slack side (drive belt)
μ	Friction coefficient (drive belt)
β	Contact angle (drive belt)
v_{actual}	Actual velocity of rear bike wheel
$v_{theoretical}$	Theoretical velocity of rear bike wheel
PF	Power factor correction
P_R	Real power
P_a	Apparent Power
η_{cycle}	Efficiency of the battery cycle
η_{charge}	Efficiency of the battery charge reaction
$\eta_{discharge}$	Efficiency of the battery discharge reaction
$W_{delivered}$	Energy delivered to the system
$W_{supplied}$	Energy supplied to the FullRiver DC 400-6
V	Terminal voltage per phase
I_a	Armature current per phase
$\cos(\phi)$	Power factor of the load
R_a	Armature resistance per phase
P_c	Constant losses (alternator)

To begin the efficiency analysis, it is important to identify possible performance losses for each component in the HPB system. These losses are described below in table II.

Table II
Possible Performance Losses for Human Powered Bicycle

Component	Possible Loss	Type of Performance Loss
Bike	Chain belt, gear shifting, tire [2]	Mechanical
Drive Belt	Heat, friction with alternator [3]	Mechanical
Alternator	Copper losses, core losses [3]	Battery
Battery	Heating, charge/discharge, aging	Battery

	[4]	
Stationary Bike Stand	Bike slippage [5]	General
Wiring/Electrical (ECM Display)	Voltage regulation, electrical resistance [6]	Electrical

The losses described above are either possible or definite performance losses. For example, the battery system for the HPB will result in lower efficiency as the battery ages and retains damage from heat during charge/discharge cycles. On the other hand, the stationary bike stand will cause bike slippage if the design does not properly secure the bike stand but that can be resolved through design adjustments.

The total efficiency of the HPB system can be described below,

$$\eta_{total} = \eta_{mech} \cdot \eta_{gen} \cdot \eta_{elect} \cdot \eta_{bat} \quad (1)$$

Each efficiency (mechanical, general, electrical, and battery) can be expanded upon to include the efficiencies from each component in the HPB system. The equations for each efficiency are described below.

Mechanical efficiency

$$\eta_{mech} = \eta_{bike} \cdot \eta_{db} \quad (2)$$

The mechanical efficiency of the HPB system is from the bike and the drive belt. Both items can result in performance loss from friction wear on the bike chain, gear shifting, tire, and the drive belt itself. As previously stated in the assumptions section, the friction losses for the bike will be estimated from data gathered [1]. The friction losses from the drive belt can be quantitatively accounted for in the equation below.

Friction loss due to the drive belt [7]

$$\eta_{db} = \frac{T_1}{T_2} = e^{\mu\beta} \quad (3)$$

General efficiency

$$\eta_{gen} = \eta_{stand} \quad (4)$$

The general efficiency of the HPB system comes from items that can cause performance loss based on the design of the system. In this case, the stationary bike stand is the only part that can cause loss due to tire slippage due to design. The performance loss due to the stationary bike stand can be quantitatively accounted for in the equation below.

Tire slippage [8]

$$\eta_{stand} = \frac{v_{actual}}{v_{theoretical}} \quad (5)$$

Electrical efficiency

$$\eta_{elect} = \eta_{wiring} \quad (6)$$

The electrical for the HPB system is defined by all wiring for the battery and the interactive display. Wiring can cause performance loss due to internal resistance and unexpected voltage drops. To quantify the performance loss due to wiring, the equation below is used.

Power Factor Correction [9]

$$\eta_{wiring} = PF = \frac{P_R}{P_a} \quad (7)$$

Battery efficiency

$$\eta_{bat} = \eta_{DC} \cdot \eta_{alternator} \quad (8)$$

The battery efficiency of the HPB system contains both the DC battery (FullRiver DC 400-6) and the alternator (12 volt) being used to power and store energy from the HPB system. Both the battery and the alternator have predetermined performance loss that occur due to aging and heat damage. The performance loss for the DC battery and alternator is defined by the equations below.

Total losses from the battery [10]

$$\eta_{DC} = \eta_{cycle} = \eta_{charge} \cdot \eta_{discharge} = \frac{W_{delivered}}{W_{supplied}} \quad (9)$$

Total losses from the alternator [3]

$$\eta_{alternator} = \frac{3VI_a \cos(\phi)}{3VI_a \cos(\phi) + 3I_a^2 R_a + P_c} \quad (10)$$

IV. Results

In the methods section, all equations needed to evaluate the total efficiency of the HPB system are established. These equations are defined by the major performance losses such as heat degradation, friction loss, voltage drops, and more. After defining major performance losses, estimates and values from testing and online resources are used to calculate a low, medium, and high efficiency for the system. The table below shows a range of the total efficiency for the HPB system.

Table III

Total Efficiency of the HPB System

Low	0.35
Medium	0.46

High	0.69
-------------	------

Ranges for a HPB system range in between 31%-71% [11], so the values calculated using the mechanical, general, electrical, and battery efficiencies are within acceptable ranges. The higher end of the total efficiency is assuming the stand has minimal slippage, there is little to no friction loss for the bike and drive belt, and the alternator and battery are working at optimal efficiency. Over the course of the time, the HPB system will start to lose efficiency due to heat degradation in the battery (from charge/discharge cycling) and alternator will begin to have significant core and copper loss.

Alongside the total efficiency for the HPB system is the individual calculation for mechanical, general, electrical, and battery. These efficiency ranges can be used to show where the largest performance loss is presented in the HPB system. Below is a table of low, medium, and high ranges for each type of performance loss.

Table IV
Efficiency for Type of Performance Loss

	Mechanical	General	Electrical	Battery
Low	0.81	0.95	0.95	0.47
Medium	0.88	0.96	0.96	0.57
High	0.95	0.97	0.97	0.77

Values for each section are calculated with the respective equations in the methods section and validated with online sources. From these values, most of the performance loss is due to battery efficiency which includes the DC battery and alternator. This makes sense since both the DC battery and alternator usually experience heat degradation with either charge/discharge cycling or rotational friction. To better showcase the percentage of performance loss for each category, pie charts for low, medium, and high stages are shown below.

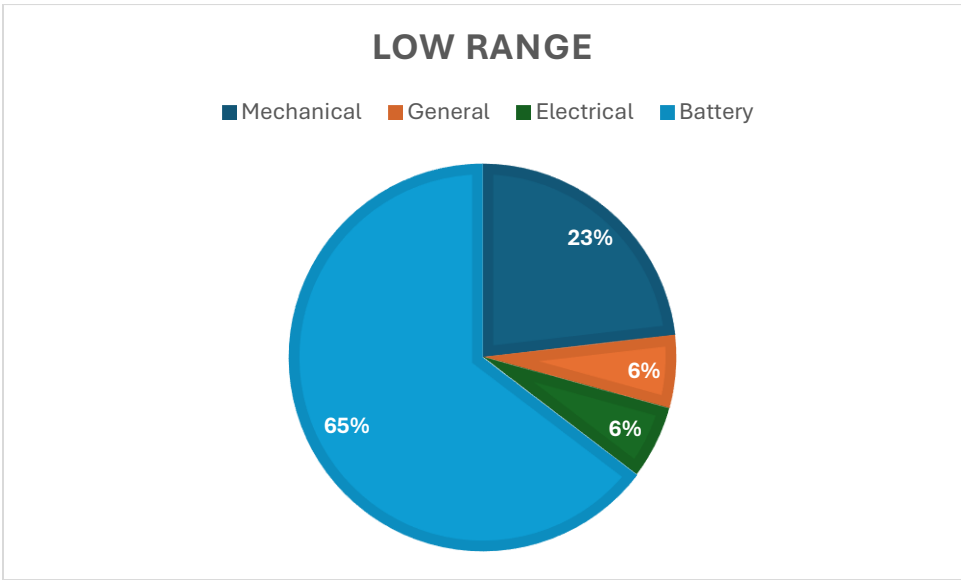


Fig 1. Low Range of Efficiency

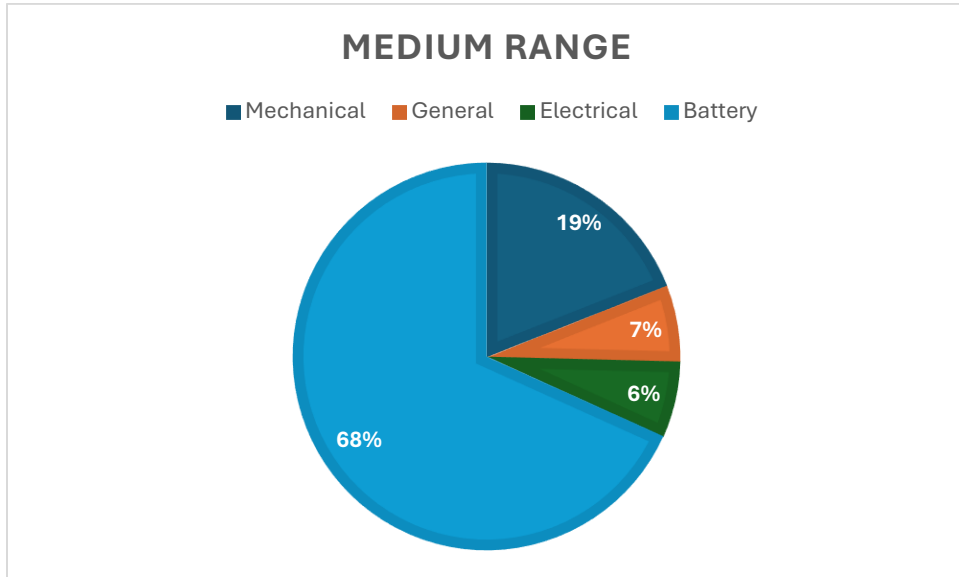


Fig 2. Medium Range of Efficiency

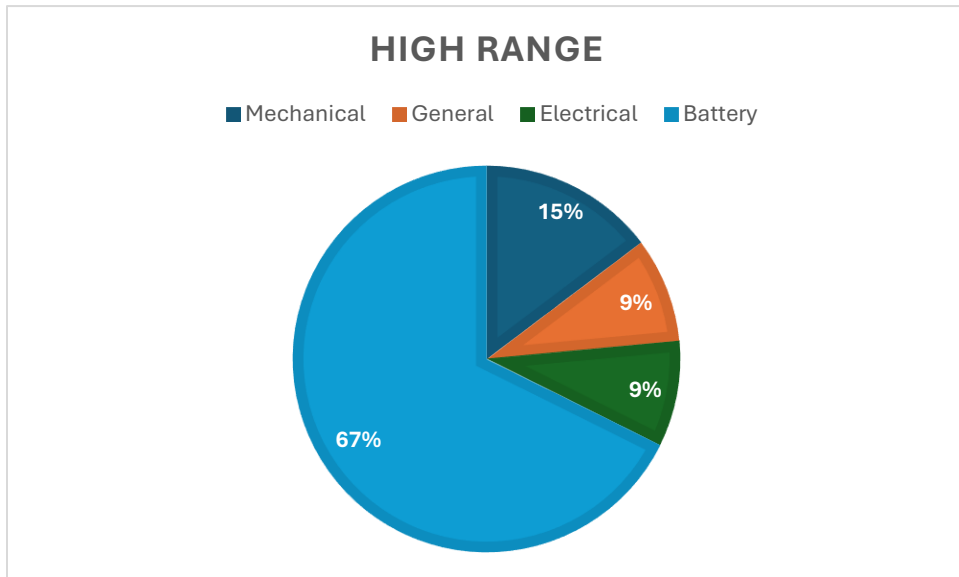


Fig 3. High Range of Efficiency

From these charts, 65-68% of performance loss for the total system comes from the DC battery and the alternator. The rest of the categories only account for about 35% of performance loss of HPB system. This information tells the team that the top priority should be maintaining the health of both the battery and the alternator. Small performance gains can come from design adjustments in the mechanical and general categories.

Current Design for the HPB System



Fig 4. Current Design for the HPB System

Above is the current design for the HPB system in the PHS greenhouse. This design will be used to adequately generate energy for the renewable energy system in the ranges of 35-69%. The team will maintain optimal efficiency with recommendations located in the upcoming section.

V. Conclusion/Recommendations


Current ways to improve the efficiency of the HPB system include making sure the depth of discharge for the battery system stays below 50% and the alternator is pedaled at a consistent rpm to result in less voltage drops. Other changes that can be made to get some performance gain back is confirming the rear bike wheel is securely placed in the bike stand and there is little to no tire slippage, the chain and gear shift are waxed to prevent friction loss, and the drive belt is replaced every couple years to maintain a drive belt with no friction damage.


The analysis shown in this document identifies the low, medium, and high ranges of efficiency for the HPB system at the PHS greenhouse. Using equations to calculate performance loss for the mechanical, general, electrical, and battery systems, estimations for the total efficiency can be found for the total system. This information will be used to revise and produce the best design for the HPB system at the PHS greenhouse.

References

- [1] L. Zinn, "Technical FAQ: Calculating drivetrain friction losses," *Velo*, Jan. 07, 2020. Available: <https://velo.outsideonline.com/road/road-racing/technical-faq-calculating-drivetrain-friction-losses/>. [Accessed: Apr. 25, 2026]
- [2] D. Too, "Factors affecting performance in human powered vehicles: A biomechanical model," *Human Power: Technical Journal of the IHPVA*, 2003. Available: https://www.academia.edu/586339/Factors_affecting_performance_in_human_powered_vehicles_A_biomechanical_model. [Accessed: Apr. 25, 2026]
- [3] "Losses and Efficiency of an Alternator," *Tutorialspoint.com*, 2023. Available: https://www.tutorialspoint.com/electrical_machines/losses_and_efficiency_of_an_alternator.htm
- [4] FullRiver, "Fullriver Battery," *Fullriver Battery*, Sep. 24, 2024. Available: <https://fullriverbattery.com/articles/maximizing-battery-life-some-of-the-most-important-things-to-consider-when-maintaining-your-agm-battery/>. [Accessed: Apr. 25, 2026]
- [5] "Things You Must Know about Bike Trainers | Garmin Singapore Blog," *Garmin Blog*, Jul. 03, 2020. Available: <https://www.garmin.com/en-SG/blog/things-you-must-know-about-bike-trainers/>. [Accessed: Apr. 25, 2026]
- [6] M. SEO, "How Electrical Wiring Affects Energy Efficiency & Savings," *CALIBER ELECTRIC*, Jan. 15, 2026. Available: <https://caliberelectricswfl.com/electrical-wiring-energy-efficiency/>
- [7] "Conveyor Belt Tension & Friction Interactive Calculator — How to Use It," *Firgelli Automations*, Feb. 24, 2026. Available: <https://www.firgelliauto.com/blogs/engineering-calculators/conveyor-belt-tension-friction-calculator>. [Accessed: Apr. 25, 2026]
- [8] "Rolling Resistance in Cycling: Tyre Choice & Efficiency," *Silverstone Sports Engineering Hub*, Apr. 16, 2024. Available: <https://silverstonesportshub.co.uk/2024/04/16/per-rr/>. [Accessed: Apr. 25, 2026]
- [9] PacLights, "Gardnerbender: Electrical Engineers' Must-Know Calculations," *PacLights*, Feb. 19, 2026. Available: <https://www.paclights.com/explore/gardnerbender-electrical-engineers-must-know-calculations/>. [Accessed: Apr. 25, 2026]
- [10] S. Jakovljevic, "Efficiency of a Battery Cycle and its Capacity," *eeSasha Electrical Engineering Courses*, Dec. 25, 2022. Available: <https://eesasha.com/efficiency-of-a-battery-cycle-and-its-capacity/>. [Accessed: Apr. 25, 2026]
- [11] "How Much Electricity Can a Human Generate? - PedalPC," *www.pedalpc.com*. Available: <https://www.pedalpc.com/blog/how-much-electricity-can-human-generate/>

Appendix A: Specifications of the FullRiver DC400-6





DC400-6

DEEP CYCLE

400AH @ 20Hr
6-Volt

Group Size: L16 / 903

Maintenance-Free
Sealed AGM Battery

CYCLING CAPACITY

20 Hour Rate	415 Amp Hours
--------------	----------------------

RESERVE CAPACITY

Reserve @25 AMPS	885 Minutes	Reserve @75 AMPS	229 Minutes
------------------	--------------------	------------------	--------------------

ELECTRICAL SPECIFICATIONS

Nominal Voltage	6 Volt
C100	460AH
C20	415AH
C10	374AH
C5	340AH
CCA	1500
CA or MCA	1800
HPCA	2000 Amps
Internal Resistance	1.6m Ω

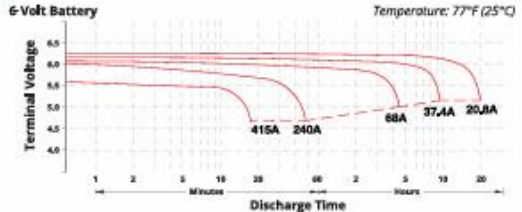
MECHANICAL SPECIFICATIONS

Group Size	L16 / 903	
Terminal Type	DTW	
Terminal Torque	See reverse side	
Height (w/ terminal)	16.69"	424mm
Height (case only)	15.90"	404mm
Width	7.05"	179mm
Length	11.61"	295mm
Weight	123.2 lbs.	56 kg
Case Type	ABS Plastic - Flame Res. Rating UL94-HB	

DISCHARGE TABLE (Constant Current)

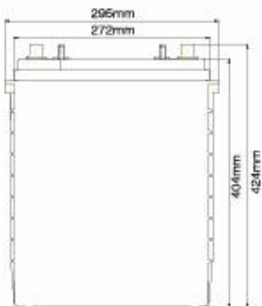
Time	Amps	Rate
20hr	20.8	0.05CA
10hr	37.4	0.10CA
8hr	45.1	0.13CA
5hr	68.0	0.25CA
3hr	93.9	0.33CA
2hr	123	0.50CA
1hr	232	1.00CA


DISCHARGE PROFILE (Constant Current)

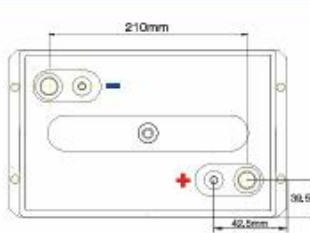


- All listed ratings are @ 100% SoC, T=77°F (25°C), 1.75VPC unless otherwise specified.
 - Specifications listed are for estimation purposes only. Battery performance can vary depending on application. Battery design subject to change.

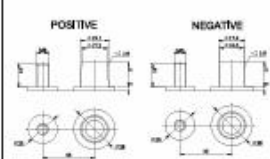
BATTERY & TERMINAL DIMENSIONS (All units shown in mm)







Terminal: DTW (Dual AP & Stud)



Battery bank spacing required, 12.5mm (1/2" inch) minimum

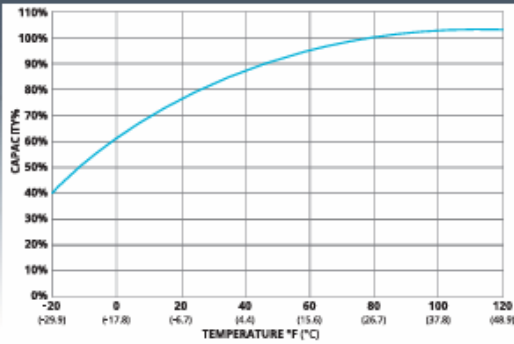
JIN: nrv

Fig A1. Specification of FullRiver DC400-6 (page 1)

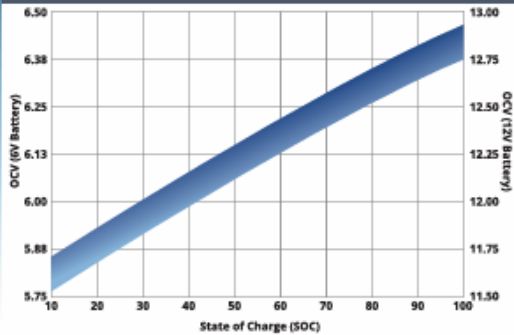


DC400-6 DATA SHEET fullriverbattery.com

TEMPERATURE vs CAPACITY

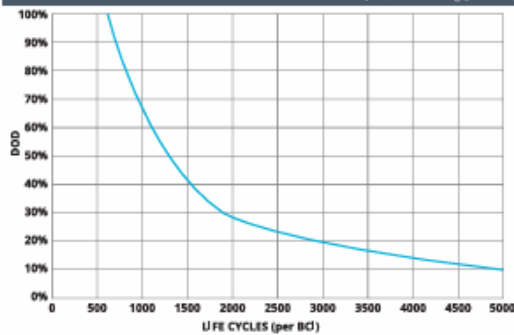


STATE OF CHARGE (SOC) vs OPEN CIRCUIT VOLTAGE (OCV)

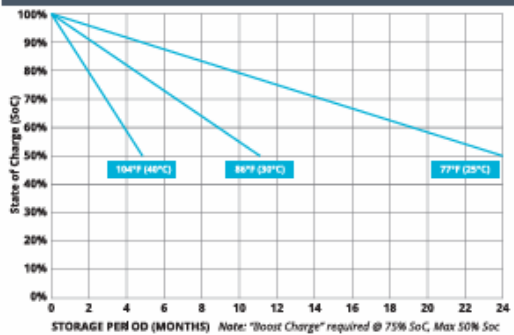


CYCLE LIFE vs DEPTH OF DISCHARGE (DOD)

*(Based on 50 Testing @ 2-yr Rate)



SELF DISCHARGE vs TIME/TEMPERATURE



TEMPERATURE RANGE SPECIFICATIONS

Condition	Recommended		Maximum	
	°F	°C	°F	°C
Storage	5°F to 122°F	-40°F to 160°F	-15°C to 50°C	-40°C to 71°C
Operation	5°F to 104°F	-40°F to 160°F	-15°C to 40°C	-40°C to 71°C
Charge with TC	5°F to 122°F	-40°F to 160°F	-15°C to 50°C	-40°C to 71°C
Charge w/o TC	32°F to 104°F	5°F to 122°F	0°C to 40°C	-15°C to 50°C

*TC= Temperature Compensation

CHARGE VOLTAGES

Charge Stage	Battery Voltages			
	12V	24V	36V	48V
Bulk	14.7V	29.4V	44.1V	58.8V
Absorption	14.7V	29.4V	44.1V	58.8V
Float	13.6V	27.2V	40.8V	54.6V

TC Factor: (-2mV°F/cell) or (-4mV°C/cell)

TERMINAL TORQUE SPECS

Terminal Type	ft-lbs	in-lbs	Nm
AP, DT (AP), M6, M6M (Stud), TP07 (AP), TP08 (AP)	4.2 - 6.0	50-70	5.6 - 7.9
FR4S	6.0 - 7.5	70-90	7.9 - 10.1
M8	7.1 - 8.0	85-95	9.6 - 10.7
DT (Stud), M10M (Stud)	9.2 - 10.4	110-125	12.2 - 14



9001:2008 Quality Management System
 14001:2004 Environmental Management System
 18001:2007 Occupational Health & Safety Management System



DELIVERY APPROVED!
**LAND, SEA
 & AIR**

Fullriver batteries are sealed lead acid batteries made with Absorbed Glass Mat (AGM) technology. The electrolyte is absorbed into the fiberglass separator material rather than in a free-flowing liquid form. Fullriver batteries are non-spillable electric storage batteries. They are exempted from the requirements of DOT's hazardous materials regulations, since they adhere to the requirements of code 49 CFR Section 173.159(D) - (CLASSIFIED APPROVED: DOT, CFR, HMR49, IATA, ICAO67, IMDG27)

Fig A2. Specifications of FullRiver DC400-6 (page 2)