SPECTRONIK

PROTIUM-450

PROTIUM ECO MARATHON (PEM) PACKAGE

USER GUIDE

VERSION V1.0-1.0 24.04.17

SAFETY, HANDLING & SUPPORT

WARNING: *Read all the safety information below before using PROTIUM-450. Failure to follow these safety instructions could result in fire, electric shock, or other injuries, or damage to PROTIUM-450 Fuel Cell System (PROTIUM-450) or other property.*

Handling Handle PROTIUM-450 with care. It is made of thin sheet metal, graphite, and plastic and has sensitive electrochemical membrane and components inside. PROTIUM-450 is not designed for extreme conditions, rough handling, vibration, shock or drop. Keep PROTIUM-450 away from heat, flame, strong sunlight, water, dust, soil or mud. Do not use a damaged PROTIUM-450.

Repairing PROTIUM-450 is assembled under high compression. Do not disassemble or tamper with PROTIUM-450. Do not troubleshoot, repair or replace any component by yourself.

Hydrogen Use only high purity (99.999%) dry Hydrogen gas with PROTIUM-450. Hydrogen is a colorless, odorless and highly flammable gas. It is non-toxic but can cause asphyxiation. Follow all local rules and regulations for safe handling, storage and usage of Hydrogen gas. Do not smoke when operating PROTIUM-450.

Ventilation Operate PROTIUM-450 in a well ventilated environment. Fresh air intake for the fuel cell oxidant blower, cooling air entry from the front of the protective mask, and hot air exit from the cooling fans shall not be obstructed or restricted.

Purging PROTIUM-450 periodically flushes its anode during operation, releasing Hydrogen gas and water from the Hydrogen gas outlet. Do not block the Hydrogen gas outlet. Do not bring flame or electric spark close to the Hydrogen gas outlet. It is advisable to attach a longer gas tubing to the Hydrogen gas outlet connector and safely guide the purge exhaust far away from the fuel cell.

CAUTION: *Always put the Hydrogen gas outlet tubing behind the cooling fan and never in front of the fuel cell stack. Purged Hydrogen mixed with air intake into the fuel cell's cathode channels may cause fire and irreversible damage to the fuel cell.*

Connectors, ports and buttons Never force a connector into a port or apply excessive pressure to a button. If the connector and port do not join with reasonable ease, they probably do not match. Check for obstructions and ensure that the connector matches the correct port.

Disposal and recycling As PROTIUM-450 contains electronic components, it must be disposed of separately from household waste. When PROTIUM-450 reaches its end of life, follow local laws and regulations for proper disposal and recycling options.

High-consequence activities PROTIUM-450 is a customized system with pending safety tests and certifications. It is not intended for use where the failure of the system could lead to death, personal injury or severe environmental damage.

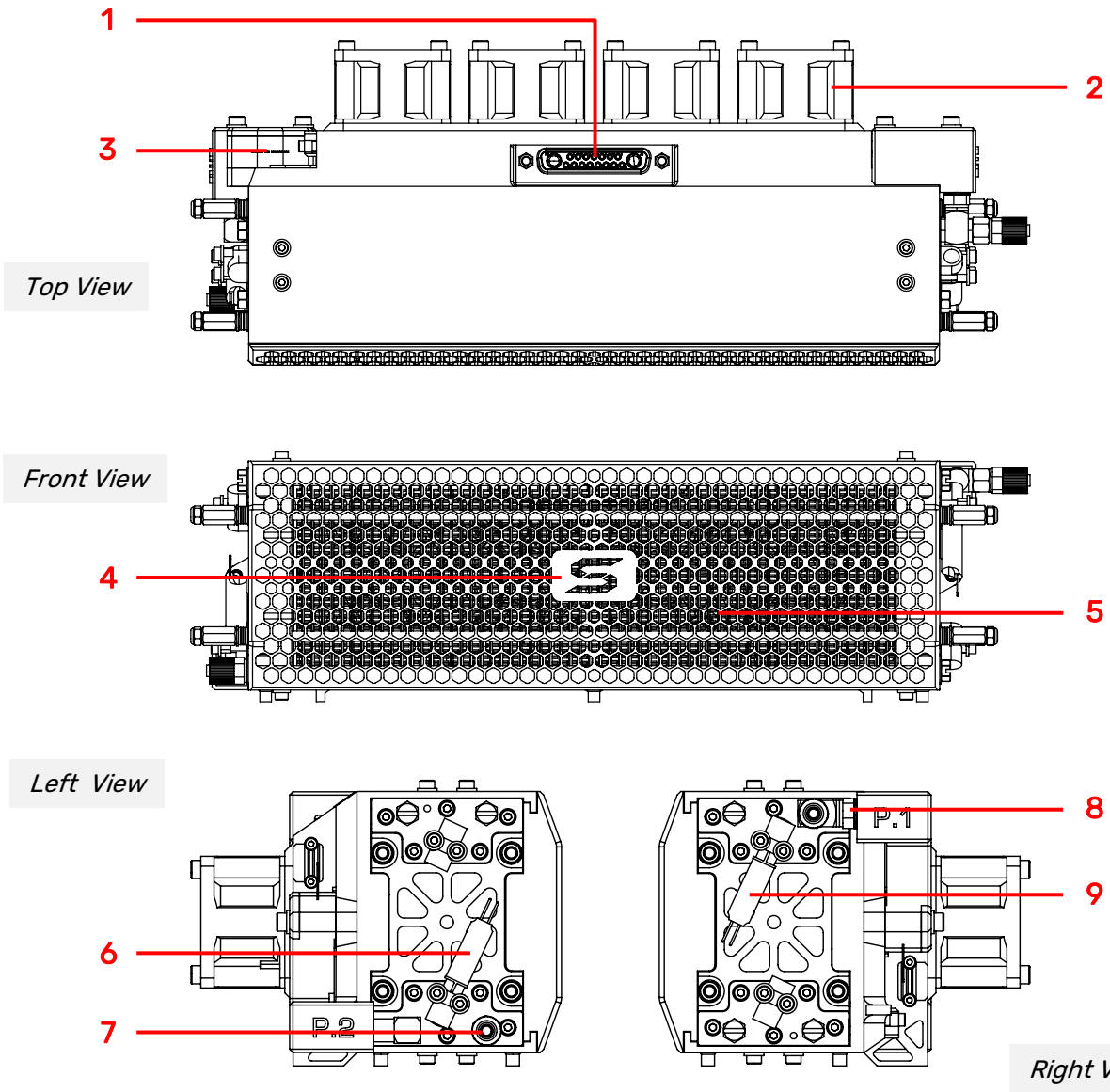
Disclaimer Every effort has been made to ensure that the information in this manual is accurate. This manual serves to adequately recommend safe operating procedures, but shall not be treated as comprehensive. Do not use PROTIUM-450 in any other way than the one recommended in this manual. Spectronik reserves the right to change system specifications, appearance or discontinue the product at any time.

Warranty Spectronik warrants the included hardware product and accessories against defects in materials and workmanship for the first 30 days after delivery. Spectronik does not warrant against normal wear and tear, nor damage caused by accident or abuse.

To obtain service, contact hello@spectronik.com

1 OVERVIEW

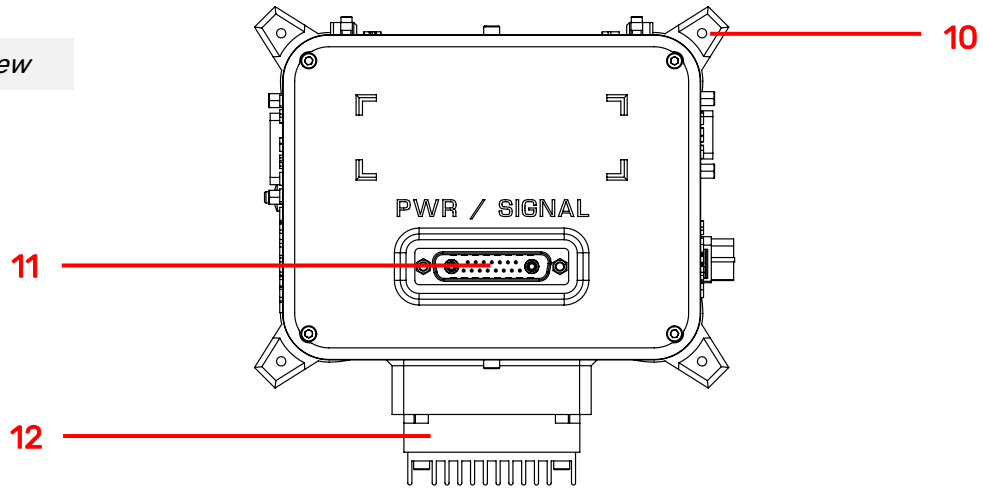
1.1 PROTIUM-450 FUEL CELL OVERVIEW



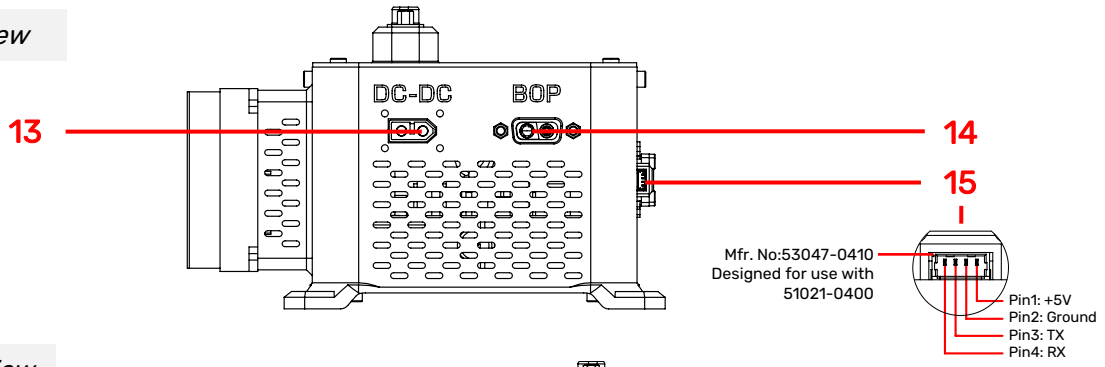
ITEM	DESCRIPTION
1.	Power/Signal receptacle
2.	Cooling fan (x4)
3.	Pressure sensor (x2)
4.	Protective mask
5.	Fuel cell stack
6.	Gas purge solenoid valve
7.	H_2 gas outlet connector
8.	H_2 gas inlet connector
9.	Gas supply solenoid valve

1.2 ELECTRONIC CONTROLLER

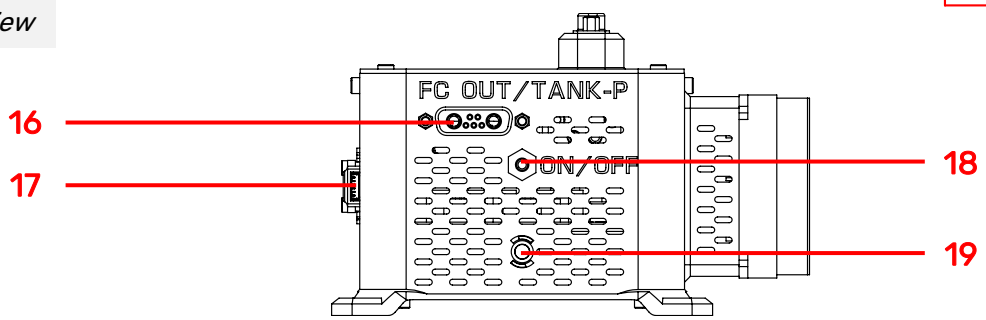
Top View



Left View



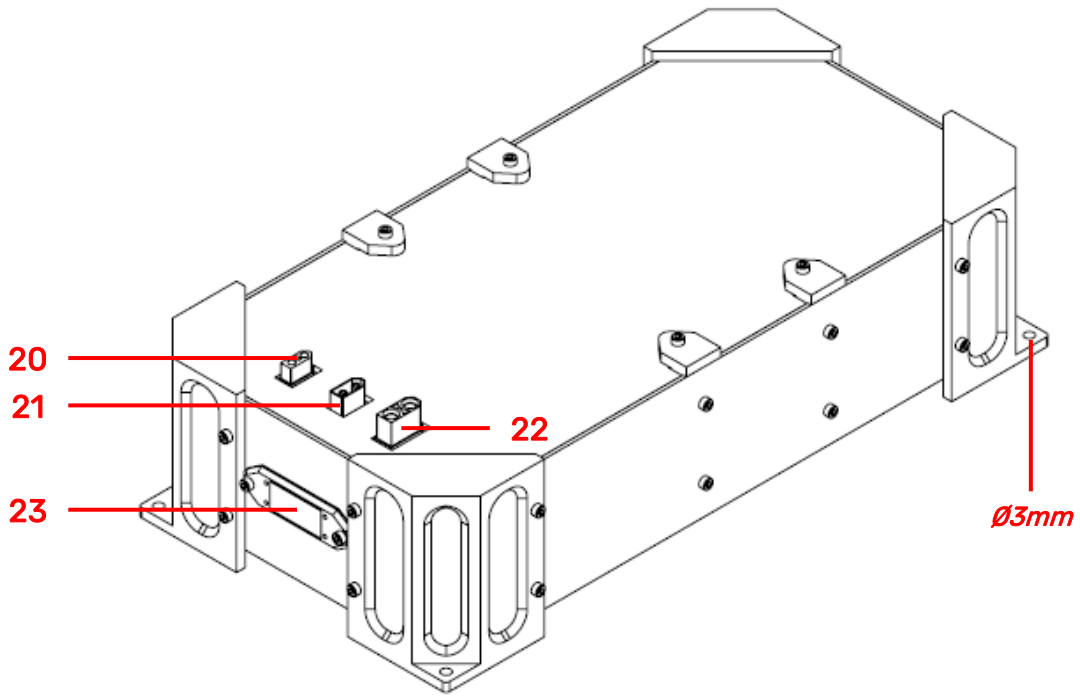
Right View



ITEM DESCRIPTION			
10.	Mounting hole (x4)	**15.**	Data transmission header (4-pin)
11.	Power/Signal header	**16.***	Unregulated stack power out receptacle
12.	DC-DC converter	**17.**	Programming port (6-pin)
13.	DC-DC power out (XT-60 female)	**18.**	On-Off push button
14.	External power supply receptable	**19.**	Status LED

**Also Gas Pressure Transducer data transmission receptacle compatible with Spectronik's Eco-Marathon Pressure Regulator*

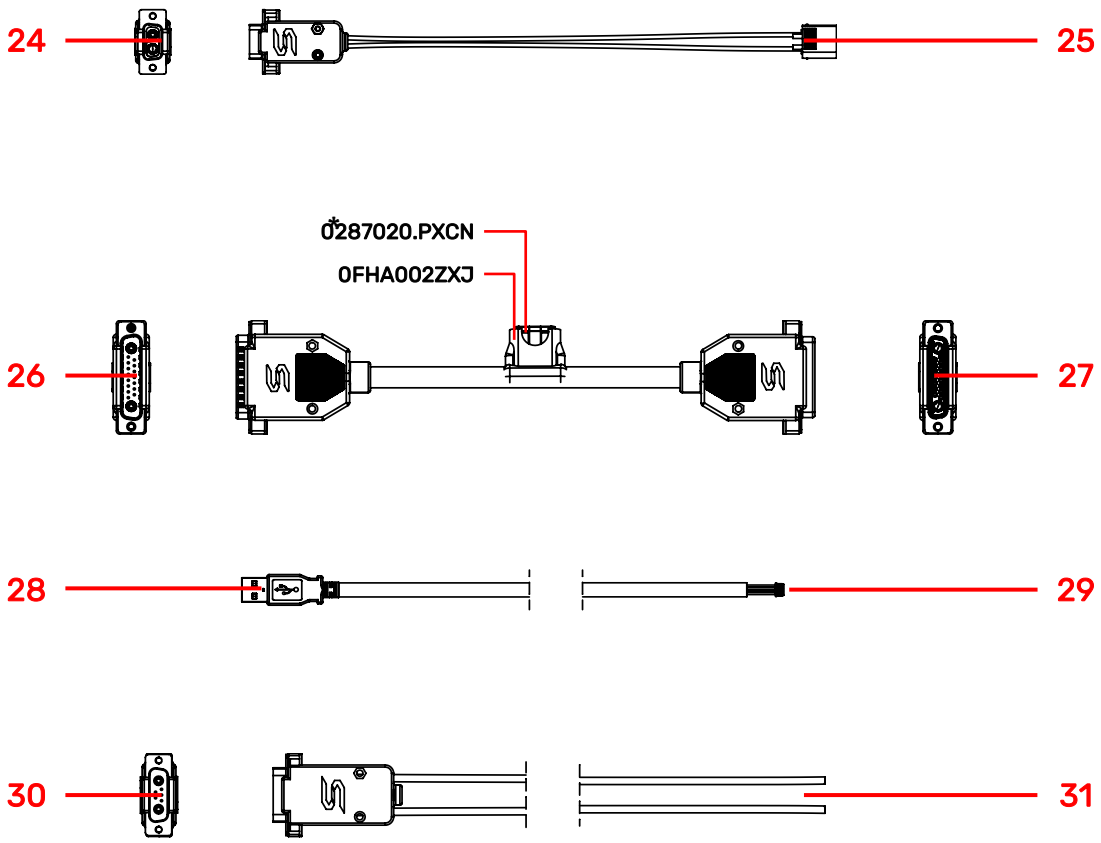
1.3 ULTRACAPACITOR PACK



Ultracapacitor Pack

ITEM	DESCRIPTION
20.	External power supply connector (XT-60 female)
21.	DC-DC power out connector (XT-60 male)
22.	Load connector (XT-90 female)
23.	Digital Voltage Display

1.4 STANDARD ACCESSORIES

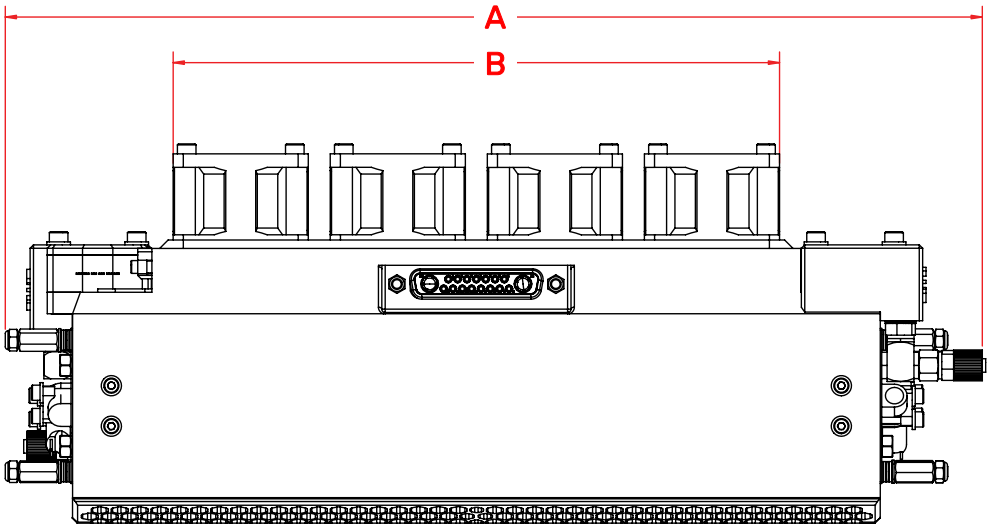


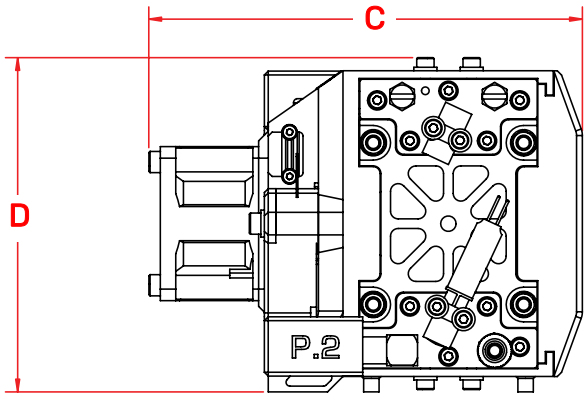
External power supply cable, power/signal extension cable

*In compliance with Shell Eco Marathon competition rules, the fuel cell power output cable comes with ATOF®-series 20A, 32V fast acting Blade Fuse (Part No. 0287020.PXCN) and fuse-holder (Part No. 0FHA0002ZXJ).

ITEM	DESCRIPTION	ITEM	DESCRIPTION
24.	External power supply header	**28.**	USB connector to PC
25.	External power supply connector (XT-60 male)	**29.**	Data transmission receptacle
26.	Power/signal extension cable (header)	**30.**	Unregulated stack power out header
27.	Power/signal extension cable (receptacle)	**31.**	Free-end wires to load

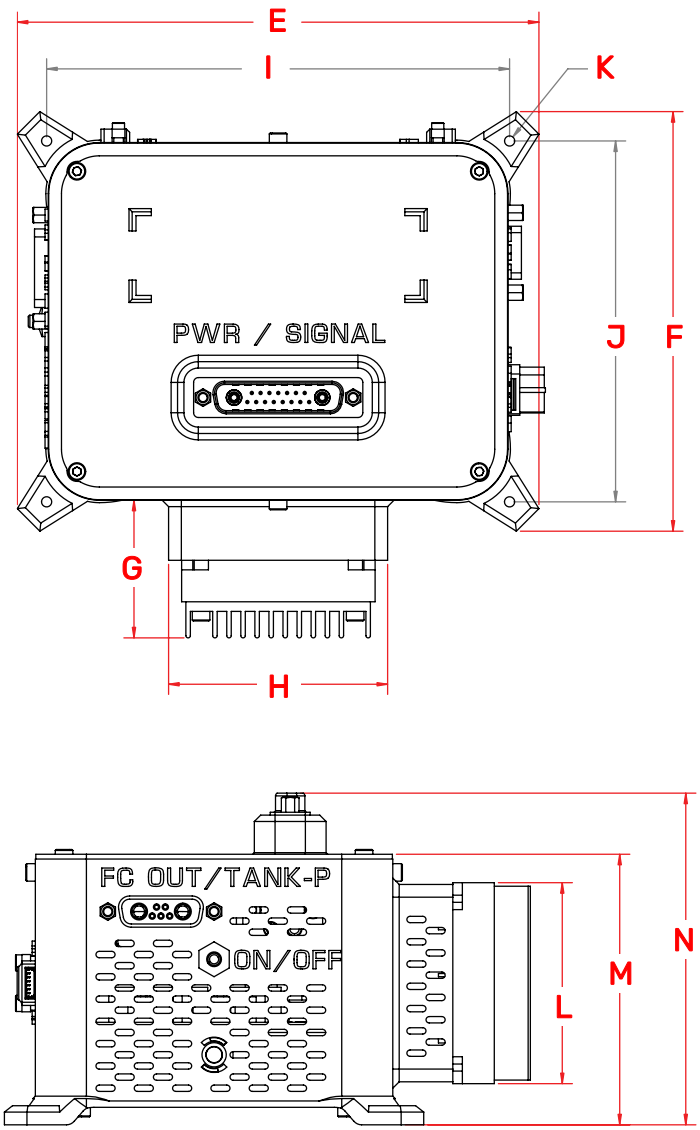
1.5 MECHANICAL DIMENSION – PROTIUM-450





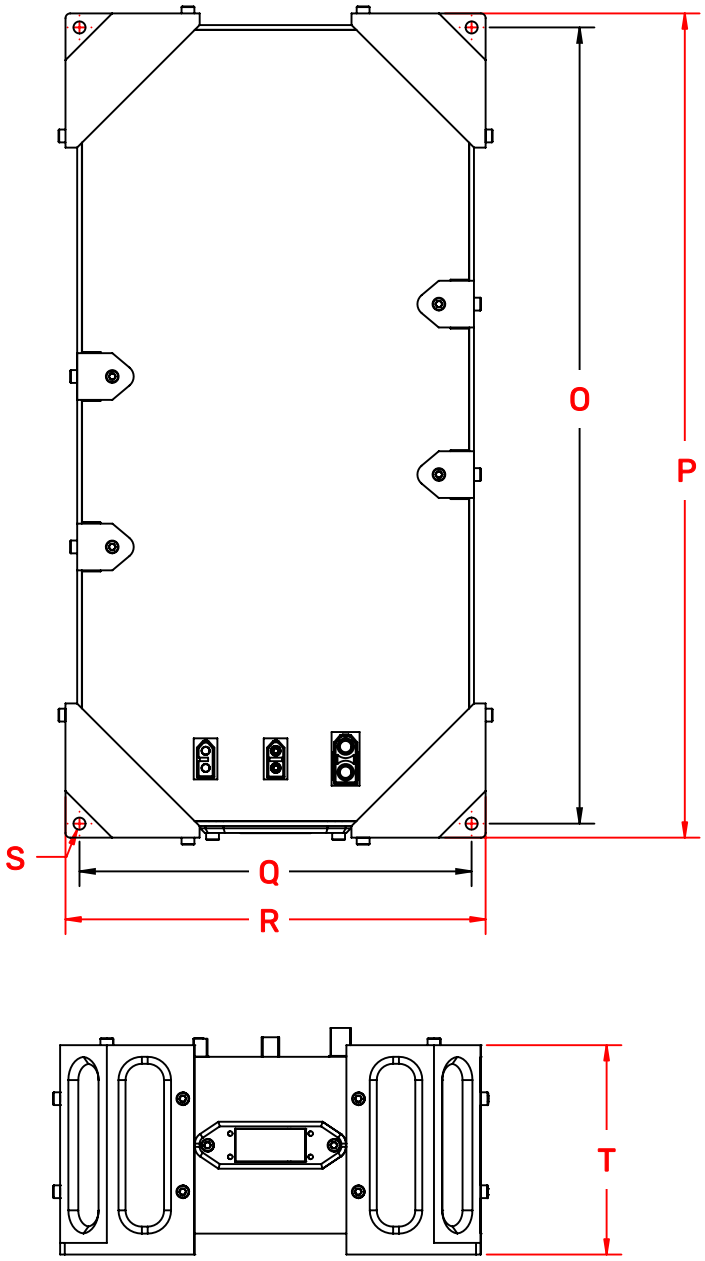
ALL DIMENSIONS IN MM			
A	289.30	**C**	112.50
B	179.50	**D**	86.80

1.6 MECHANICAL DIMENSION – ELECTRONIC CONTROLLER



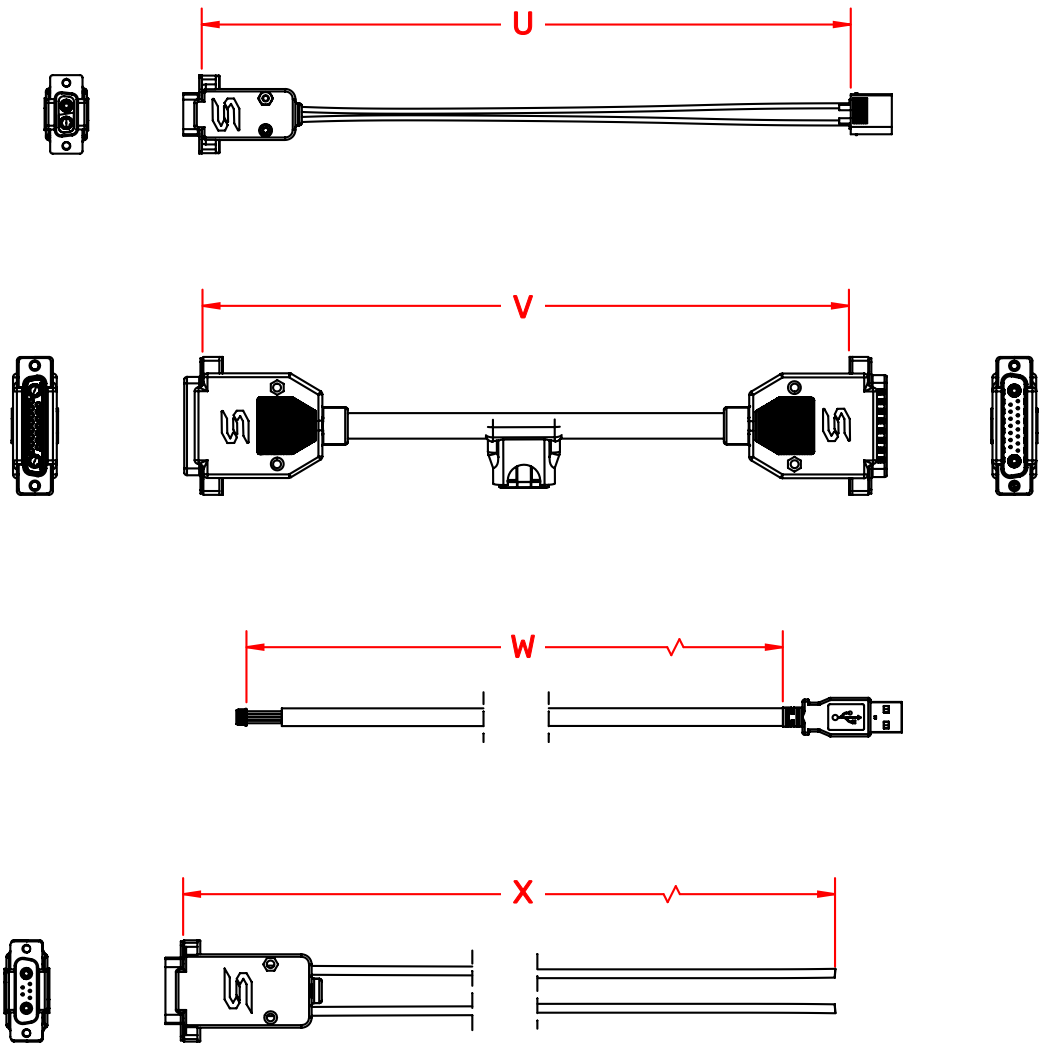
ALL DIMENSIONS IN MM			
E	163.40	**J**	113.00
F	131.40	**K**	∅ 3.20 (4x)
G	43.10	**L**	63.20
H	68.60	**M**	85.00
I	145.00	**N**	104.20

1.7 MECHANICAL DIMENSION – ULTRACAPACITOR PACK



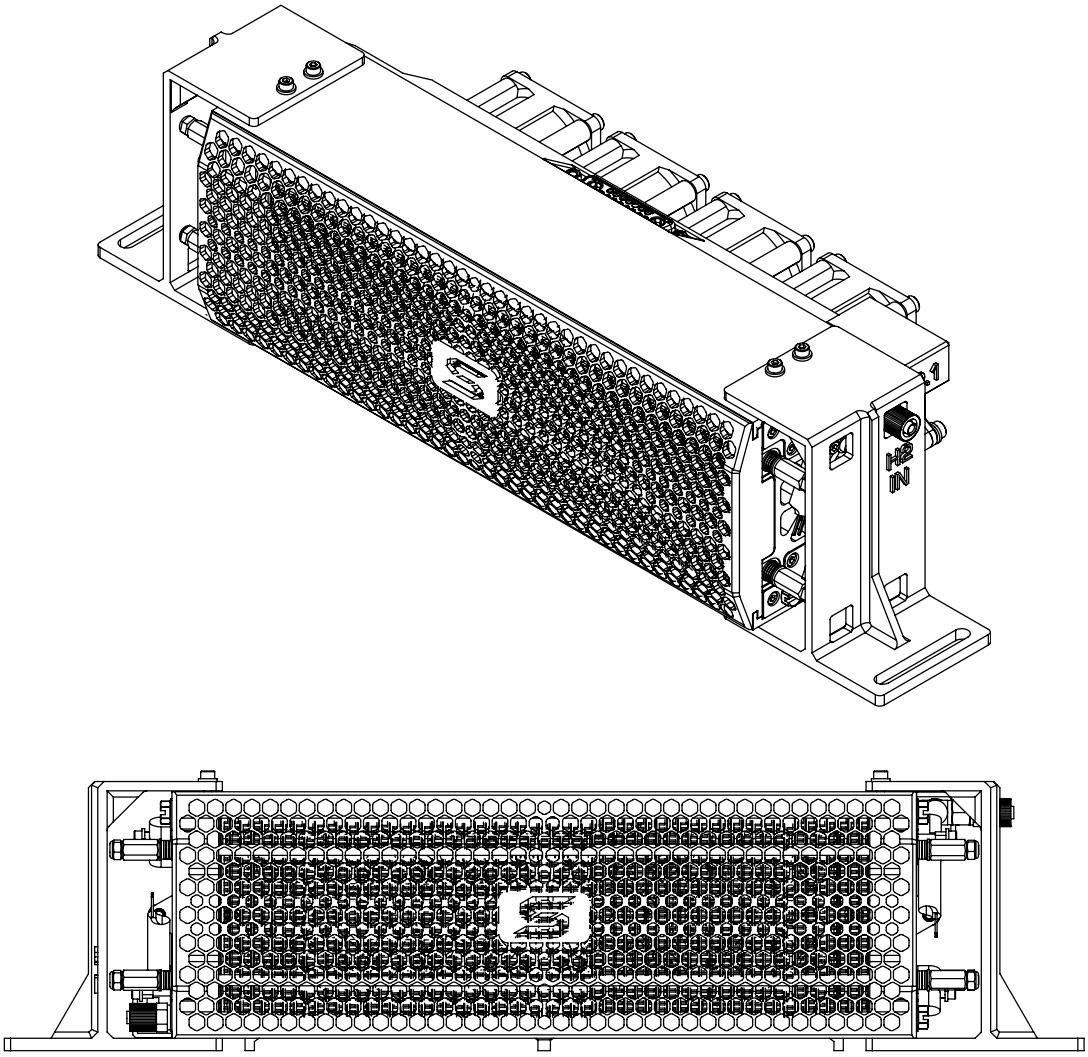
ALL DIMENSIONS IN MM			
O	341.00	R	180.00
P	353.00	S	∅ 5.20 (4X)
Q	168.00	T	90.00

1.8 MECHANICAL DIMENSION – STANDARD ACCESSORIES



ALL DIMENSIONS IN MM			
U	1000	W	1800
V	1000	X	1000

1.9 ORIENTATION, AIR CLEARANCE AND MOUNTING



Recommended Orientation of PROTIUM-450

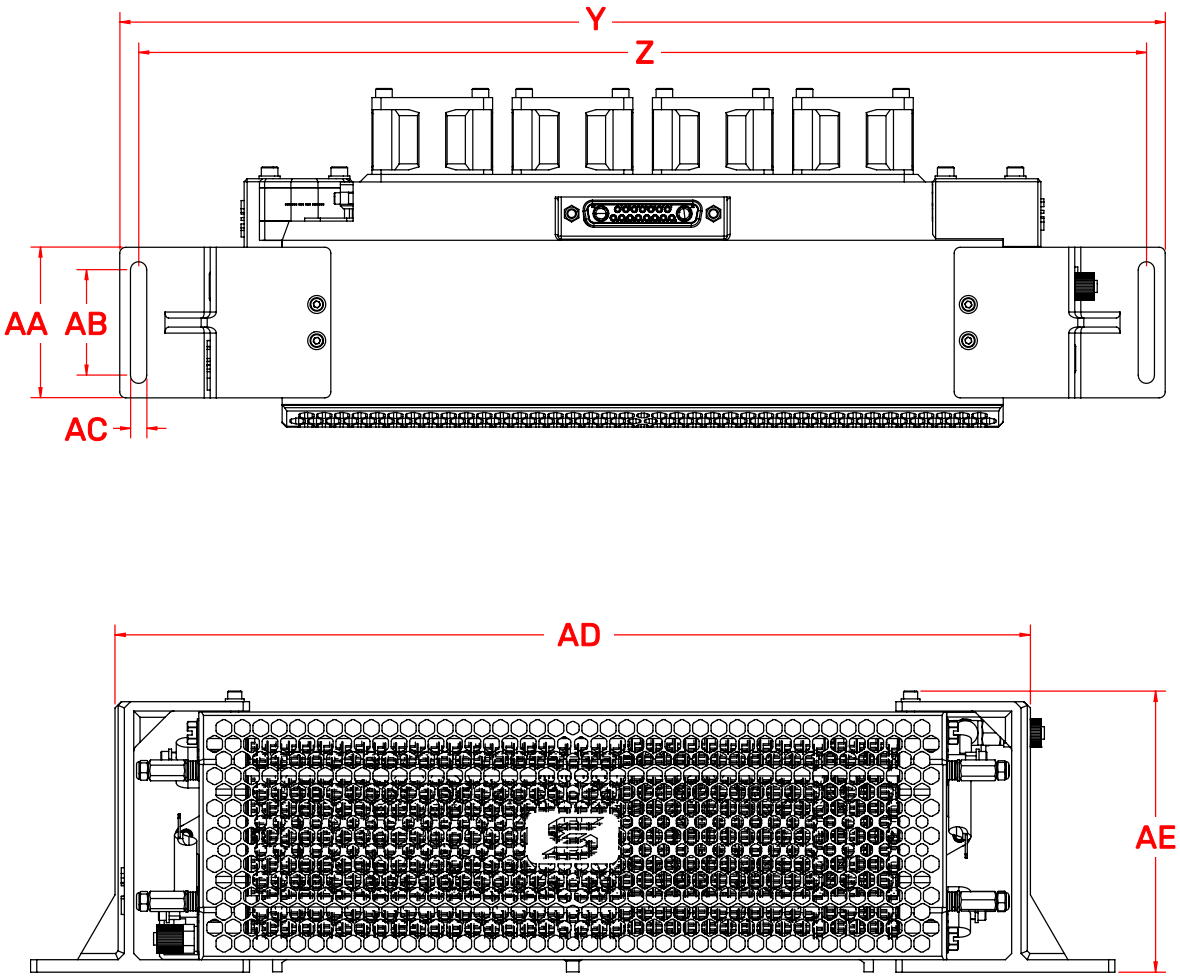
PROTIUM-450 ***cannot*** be mounted in any orientation due to internal routings of the gas streams within the fuel cell stack.

The fuel inlet must always be higher than the fuel outlet. The stack should also be level to ensure water does not get trapped in the gas channels, obstructing the gas flow and causing potential performance drop and cell damage.

Mount PROTIUM-450 in the recommended orientation above, using the mounting brackets provided.

For optimal oxidant and cooling airflows, it is also recommended that there is at least 15cm unobstructed clearance in front of the protective mask and 30cm unobstructed clearance behind the cooling fans' outlet.

1.9 ORIENTATION, AIR CLEARANCE AND MOUNTING



Dimensions of the mounting holes

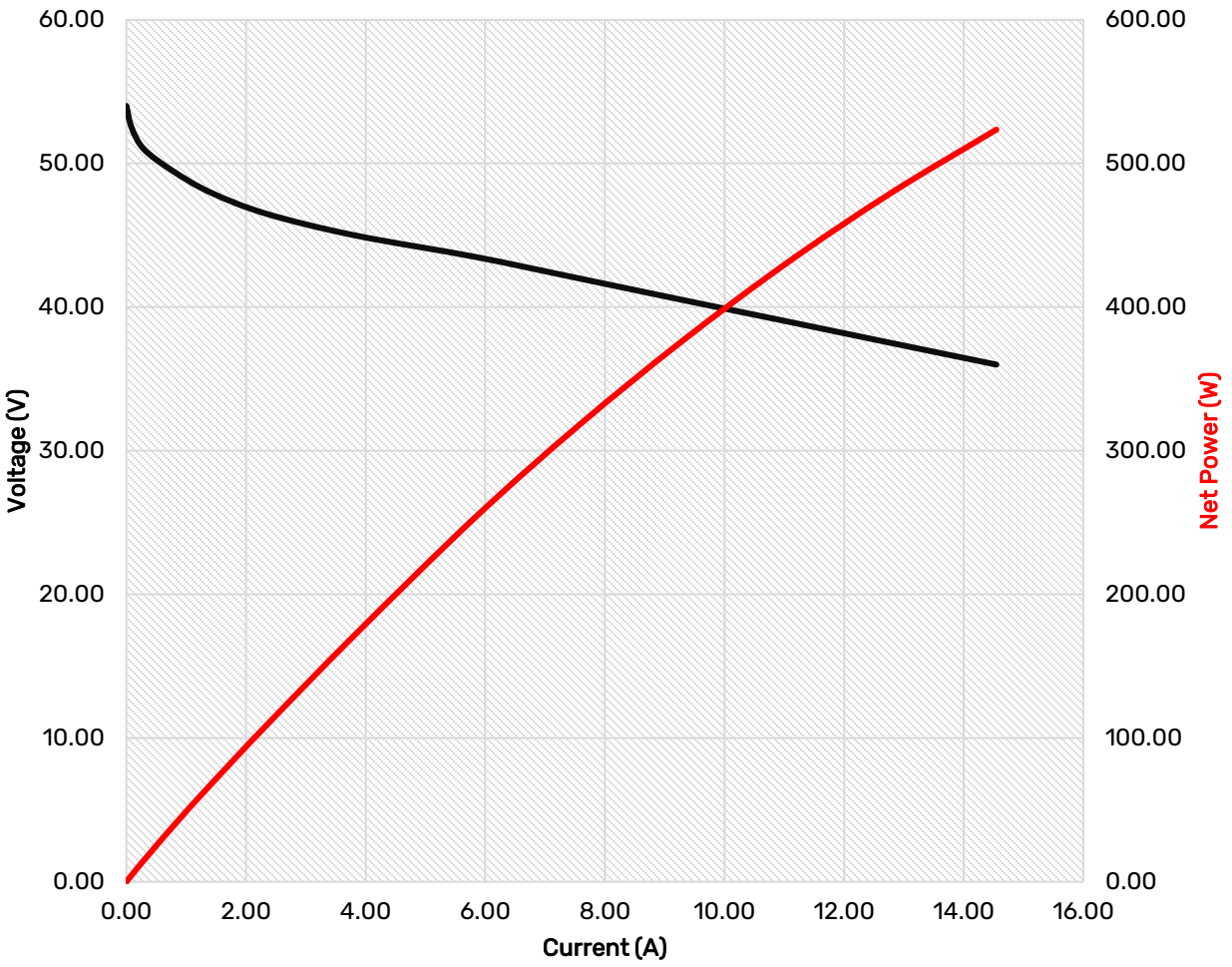
ALL DIMENSIONS IN MM			
Y	346.70	**AC**	5.40
Z	334.20	**AD**	292.70
AA	50.00	**AE**	90.10
AB	35.00		

2 SPECIFICATIONS

2.1 FUEL CELL TECHNICAL DATA SHEET

Fuel Cell	PROTIUM-450
Type	PEM
No. of cells	60
Architecture	Open cathode
Coolant	Air cooled
Rated/gross power	450/540W
Rated/gross current	12.5/15A
Voltage output	36-54VDC
Start-up time	<30s
Operating ambient temperature	[0,35]°C
Operating altitude without power derating	1500m AGL
System weight	1,300g
Max dimension	290 x 113 x 87mm
Cell reaction area	21 sq.cm
Fuse	ATOF®-series 20A, 32V fast acting Blade Fuse Part No. 0287020.PXCN
Fuseholder	Littelfuse Part No. 0FHA0002ZXJ
Fuel Supply	
Hydrogen gas	Dry, 99.999% purity
Delivery pressure	0.4-0.5barg (6-7 psig)
Fuel consumption @ rated power	5.3L/min
Gas tubing	PTFE, 6 x 4
Supply & purge control	Solenoid valves with integrated pressure sensor
Stack leakage checks	Automated via integrated pressure sensors
Electronic Controller	
Processor board	FEATHER V1.2 ESD
External power supply requirement	15-60V, 50W max
Weight (including casing)	680g
Output connector	XT-60 female (DC-DC regulated voltage) Harting D sub DA-7W2 (stack unregulated voltage)
Warning & protections	Low voltage, high/low temperature, high/low pressure, low external power supply, stack leakage
Communication	UART (USB cable for PC connectivity provided)
Data acquisition (DAQ) software GUI	PC app
Remote control	Fan speed, manual purge, remote on-off, stasis on-off

2.2 VI CURVE & HYDROGEN EFFICIENCY CURVE

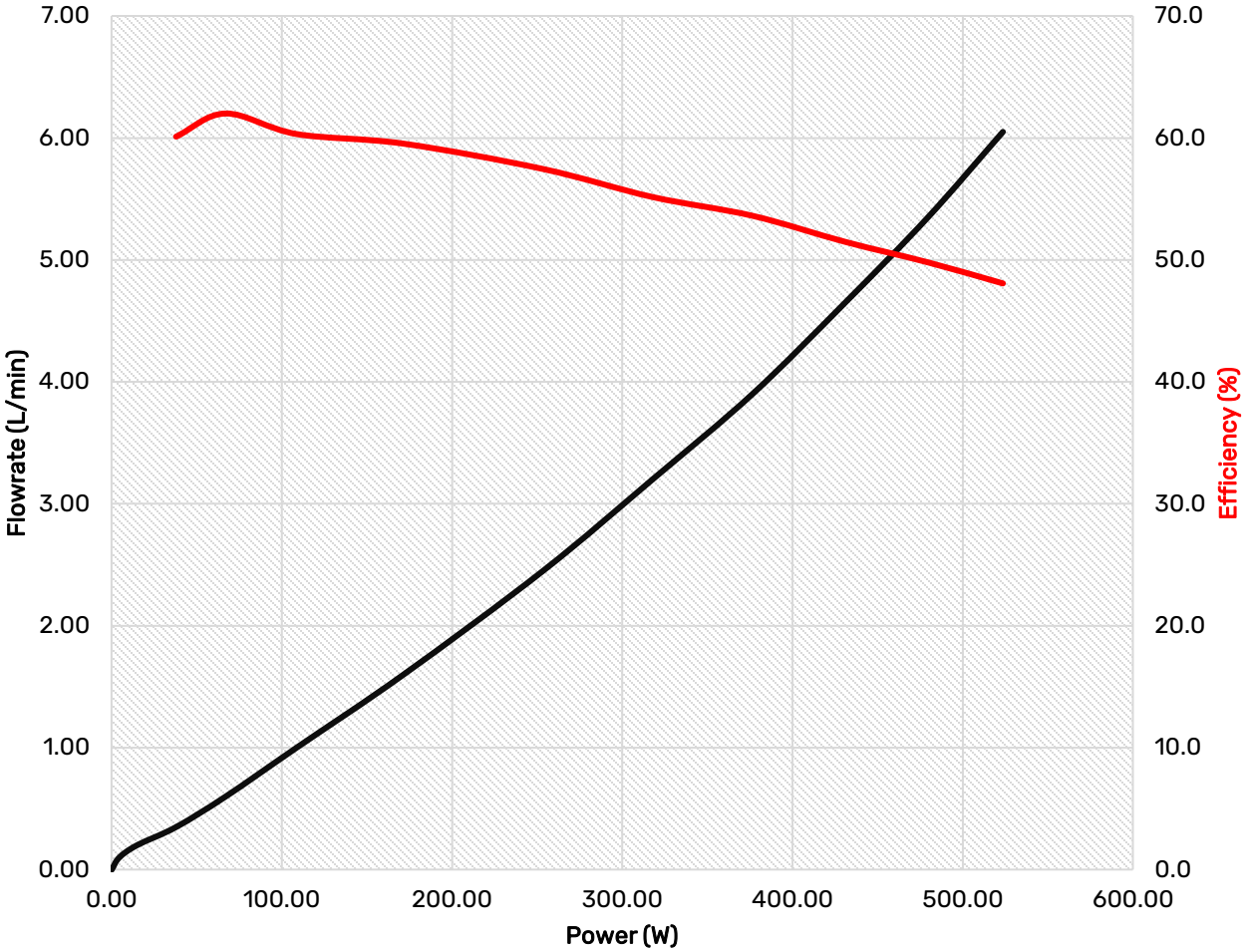


Nominal polarization curve for a fully conditioned PROTIUM-450 at its Beginning-of-Life (BOL).

TEST CONDITIONS

- Ambient temperature: 24°C
- Relative humidity: 60%
- H_2 supply pressure: 10psig
- Dead-ended operation
- Balance-of-plant (BOP) powered by fuel cell
- T_{cell} at 450W: 54°C

2.2 VI CURVE & HYDROGEN EFFICIENCY CURVE



Hydrogen consumption and efficiency for a fully conditioned PROTIUM-450 at BOL.

NOTES

- Hydrogen consumption is instantaneous reading taken from mass flowmeter at STP.
- PROTIUM-450 is most efficient in the 100-300W range which is the typical nominal cruising power of Eco-Marathon vehicles.

2.3 DCDC CONVERTER DATASHEET

DC-DC Converter	
Type	Non-isolated, half-brick, buck-boost
Input voltage	9-60VDC
Output voltage	15-60VDC user configurable
Output current	0-40A user configurable
Dimension	75 x 61 x 13mm
Weight	210g
Efficiency	94~98%
Advised Temperature Threshold	< 80°C
Converter Safety Features	CAN/CSA-C22.2 No.60950-1:2007/A2:2014 UL 60950-1:2007/A2:2014 EN 60950-1:2006/A2:2013 Over-voltage and short-circuit protections in-built

The output voltage (V_set) and output current (I_set) of the DC-DC converter can be changed according to the user's needs. This provides flexibility for PROTIUM-450 to be compatible with various DC motor's voltage input range. To protect against current overdraw or to maintain the fuel cell's output at its most optimum power level, I_set can also be configured to limit the maximum allowable current output.

V_set and I_set can be changed via the Spectronik Protium Eco-Marathon (PEM) GUI PC app.

NOTES

- The integrated DCDC converter has the following user configurable output ranges:

  V_set: 15V to 60V
  I_set: 2A to 30A

- The permutation of V and A must be ≤ fuel cell's maximum power rating (450W).
- To configure V_set and I_set, follow the instructions in Section 5.

2.4 ULTRACAPACITOR PACK DATASHEET

Ultracapacitor Pack	
Pack Max Voltage	60V
Pack Max Capacitance	18.75F
Pack Max Energy @ 60V	9.38Wh
Ultra Capacitor Model	Maxwell BCAP0450 P270 S18
Number of UC cells	24 in series
Pack Weight	3.4kg
Pack dimension	353 x 180 x 90mm

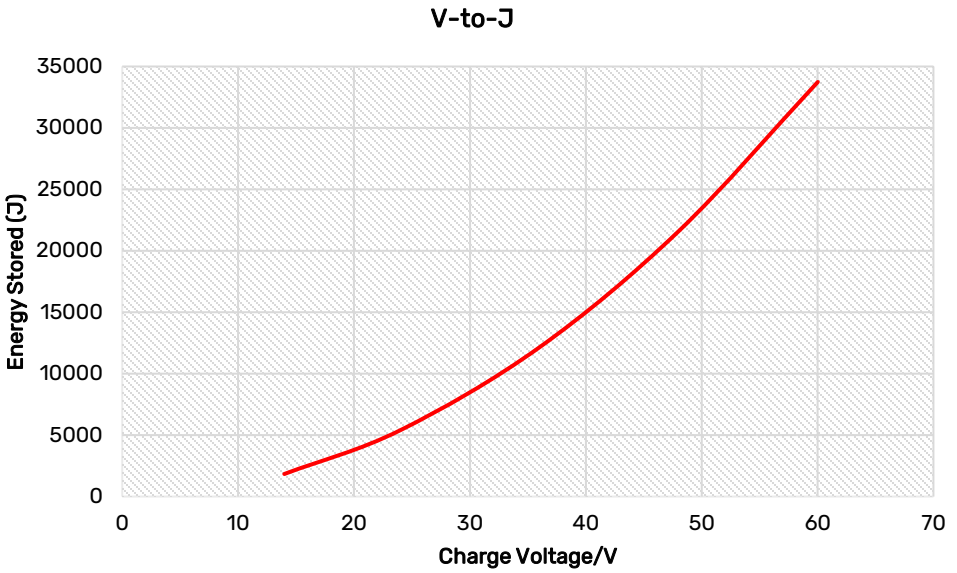
NOTES

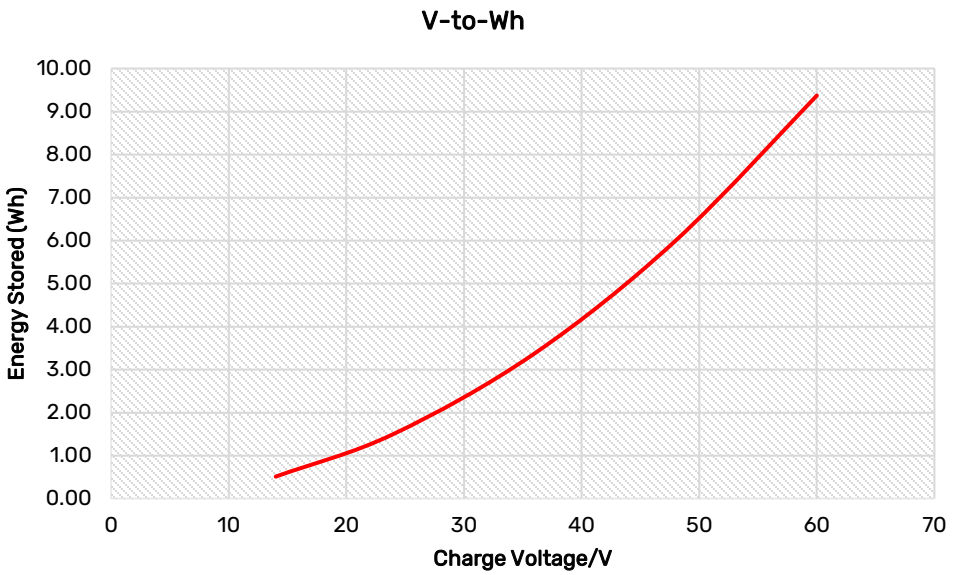
The Ultracapacitors serve several functions:

- To provide external power supply to the Electronic Controller during start-up.
- To provide external power supply to the Electronic Controller and fuel cell's balance-of-plant (BOP) when the fuel cell stack carries out Current Pulsing*.
- To provide additional power output to the motor load during peak acceleration and climbing, in a hybrid parallel configuration to the fuel cell stack output.
- To receive regenerative braking energy.
- To be recharged by the fuel cell when excess power is available during cruising.

*The fuel cell stack performs periodic Current Pulsing (once every 15-30s, for a duration of around 100ms) to rejuvenate its cell hydration and maintain optimal performance. During Current pulsing, power output from fuel cell stack to load is momentarily cutoff for safety.

2.5 ULTRACAPACITOR PACK – VOLTAGE-TO-ENERGY GRAPH





EXAMPLE

Suppose your electric motor can accept 52V to 48V input voltage range.

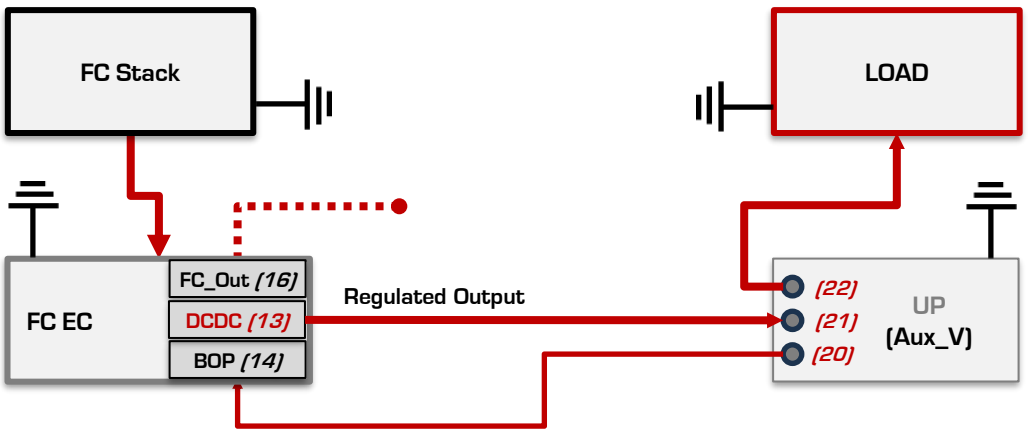
Energy stored at 52V = 0.5 * Capacitance (F) * Voltage $(V)^2$ = 0.5 x (18.75F) x $(52V)^2$ = 25,350J (7.04Wh)

Energy stored at 48V = 0.5 * Capacitance (F) * Voltage $(V)^2$ = 0.5 x (18.75F) x $(48V)^2$ = 21,600J (6.00Wh)

Therefore, while dropping from 52V to 48V, the Ultracapacitor Pack would have contributed 1.04Wh of electrical energy to your load.

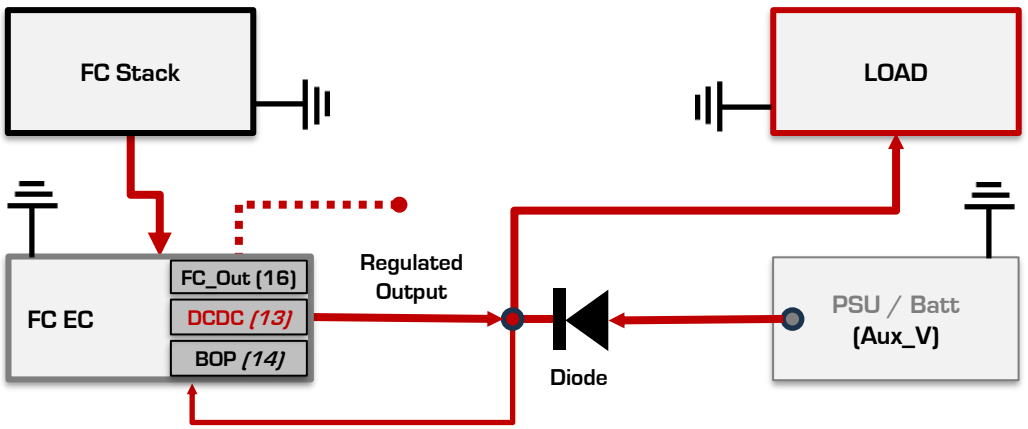
2.6 SYSTEM BLOCK DIAGRAM - PERMUTATIONS

Default Setup: FC (Regulated Output) + Ultracapacitor Pack (UP)

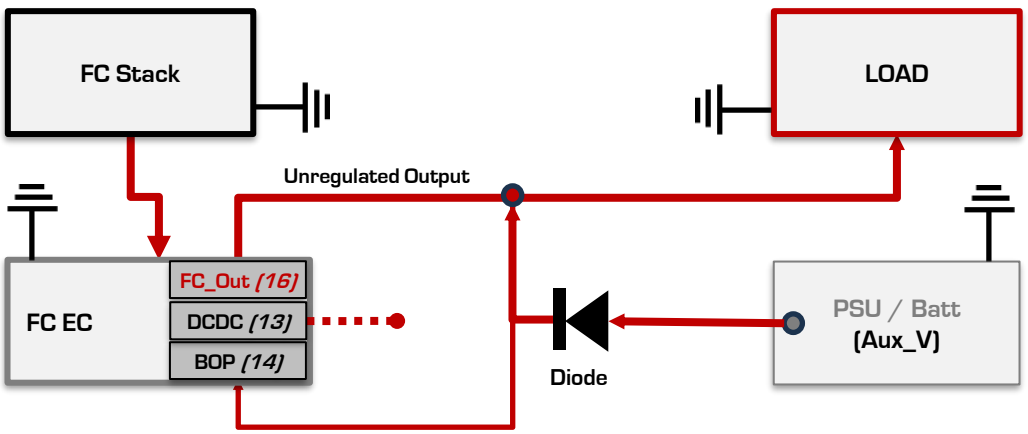


**Default setup*

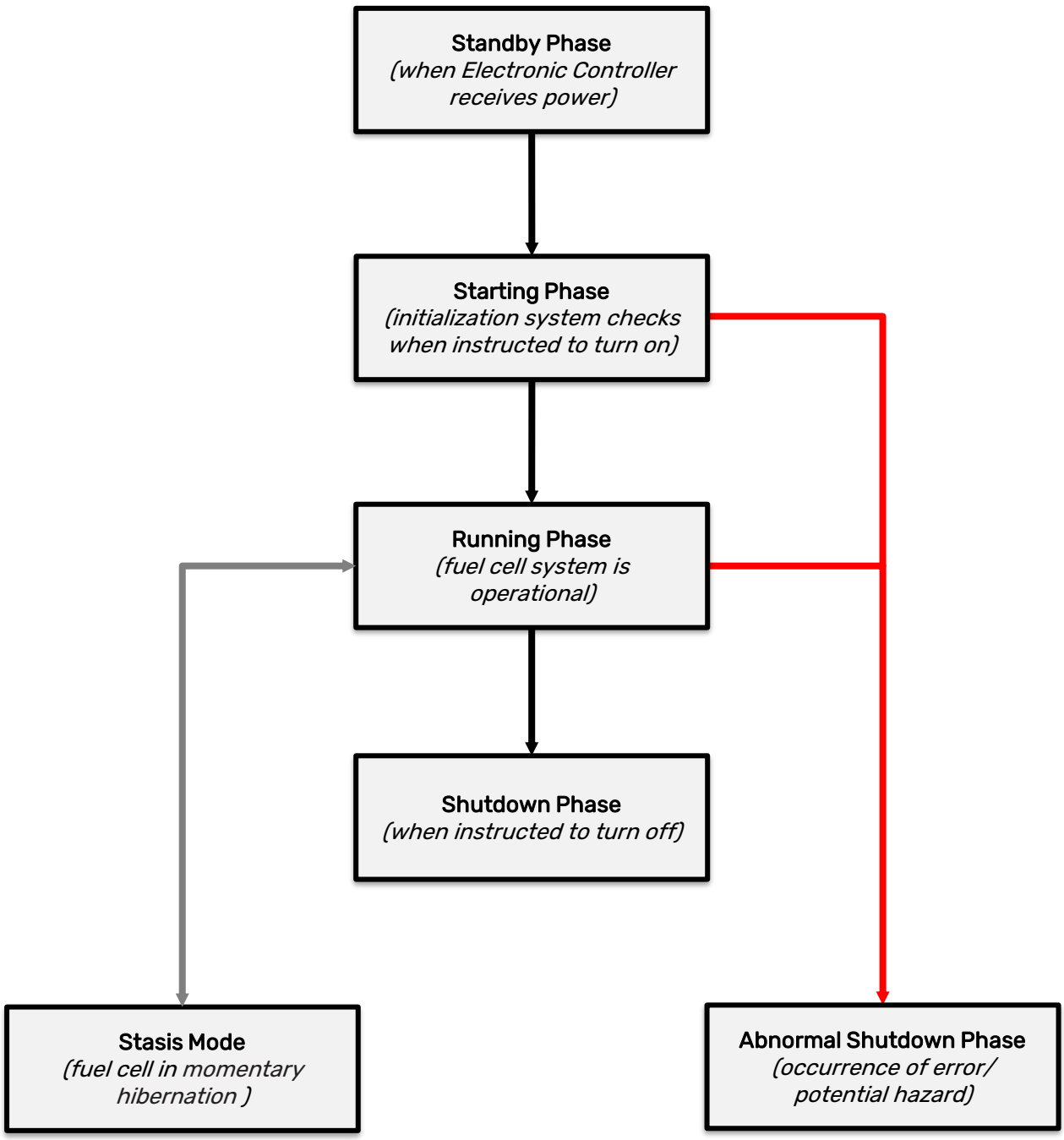
FC (Regulated Output) + Power-Supply-Unit (PSU) / Battery



FC (Unregulated Output) + Power-Supply-Unit (PSU) / Battery



2.7 SYSTEM OPERATION FLOW



3 OPERATING PROCEDURES

3.1 SETTING UP PROTIUM-450

1. Mount PROTIUM-450 securely in the recommended orientation.

2. Connect your Hydrogen gas supply to the *H2 gas inlet connector (8)*. Make sure that your Hydrogen gas supply is OFF at this stage.

3. Connect the purge tubing to the *H2 gas outlet connector (7)*.
   Caution: *Channel the purge tubing to the back of the cooling fans and far away from the front mask of the fuel cell stack.*

4. Connect the *power/signal receptacle (1)* of the PROTIUM-450 to the *power/signal header (11)* of the Electronic Controller, using the *power signal extension cable (26/27).*

5. Connect the *DC-DC power out (13)* of the Electronic Controller to its corresponding *DC-DC power out connector (21)* on the Ultracapacitor Pack.

6. Connect your DC motor load to the *Load connector (22)* on the Ultracapacitor Pack. ***Tip****: check that the polarity is correct. It is also advisable to put an ON/OFF switch at your load and ensure that it is turned OFF at this time.*

7. Connect the *external power supply connector (20)* of the ultracapacitors pack to the *external power supply receptacle (14)* on the Electronic Controller using the external power supply cable (24/25) provided. Once the Electronic Controller receives power, it will enter **Standby Phase**, awaiting instruction to initiate.

8. The PC graphic user interface, Protium Eco-Marathon (PEM) GUI, can be used to turn on/off and interact with the system. Connect the *data transmission receptacle (29)* to the *data transmission header (15)* and the *USB connector (28)* to your PC.

Reminder: *Ensure that all gas tubing and electrical wire connections are firm and secure.*

PROTIUM-450 is now ready to turn on.

NOTES

- This setting up procedure is based on “Default setup” configuration in section 2.6.
- Download the PEM GUI PC app from Protium-450 product webpage and install it on your PC. Follow its instructions in Section 5.
- If you do not wish to use the PEM GUI, you can turn on/off Protium-450 by using the physical *On-off push button (18)*. However, you will not be able to monitor the performance nor access some functions like V_set, I_set, Stasis Mode etc.
- The Ultracapacitor Pack is not charged when you receive it. Connect a DC power supply to **any** of the *Load connector (22), DC-DC power out connector (21), or External power supply connector (20).* Limit the current of the DC power supply to 1-2A and **set the DC power supply voltage to match your eventual motor load voltage.** ***Tip****: this should also be the same voltage as V_set.* Turn on the DC power supply to charge the Ultracapacitor Pack. Charging is completed when the voltage reaches the set voltage and the current output of the DC power supply is almost zero.

3.2 TURNING ON PROTIUM-450

1. If you choose to use the **PEM GUI**, conduct proper link-up and then press the "Start" button. For more detailed instructions, refer to Section 5.
2. Otherwise, press and hold the *On/Off push button (18)* for 3 seconds.
3. The system will enter its **Starting Phase**.
4. Turn on your Hydrogen gas supply. ***Caution:*** *Ensure that the gas delivery pressure is 0.4-0.5barg.*
5. PROTIUM-450 will conduct a series of internal diagnostic checks. If there is something wrong, the *Status LED (19)* will flash and error message will appear in the GUI. Follow the basic troubleshooting guide in section 4.
6. If everything is normal, the fuel cell will enter its **Running Phase** – indicated by the solid white LED on the Electronic Controller, and notification on the GUI.

PROTIUM-450 is now ready to power your application.

NOTES

- After opening the PEM GUI application, select the correct 'Com Port' and select the Baud Rate as '57600'. Then, click on the Spectronik logo button. This will establish communication between the GUI and fuel cell Electronic Controller.
- Insufficient hydrogen gas delivery pressure may cause cell flooding and drop in performance, while excessive pressure may rupture the fuel cell membrane, causing dangerous gas leakage and irreversible cell damage. Ensure that your pressure regulator setting at zero flow rate is ≤0.5barg. Also, ensure that your pressure regulator can maintain ≥0.4barg output pressure while supporting the fuel cell's highest Hydrogen consumption rate.

  Tip: *A good practice is to prepare a gas pressure regulator that can supply 2x Protium-450's maximum Hydrogen consumption, i.e. around 12L/min at ≥0.4barg.*
- Spectronik highly recommend the Eco-Marathon Pressure Regulator which is designed to be compatible with Protium-450.
- Most errors should be rectified once the suggested corrective action has been done and the system restarted.

  If the error persists, contact hello@spectronik.com.

3.3 POWERING YOUR LOAD WITH PROTIUM-450

1. The system is now in **Running Phase**, you may turn ON your load and draw power as per normal. Caution: never draw power beyond 450W.

2. During Running Phase, the following live status of the fuel cell system can be monitored from the GUI. The system continues to monitor the safety aspect and proper running operations. If there is something wrong, the *Status LED (19)* will flash and error message will appear in the GUI. Follow the basic troubleshooting guide in section 4.

Parameters	Description
FC_V	FC voltage (V)
FC_A	FC current (A)
FC_W	FC power (W)
FC_T	FC temperature (˚C)
FAN	Cooling fan duty cycle (%)
ENERGY	Energy delivered by the fuel cell during this operation (Wh)
V_SET	DCDC voltage output setting (V)
I_SET	DCDC current output setting (I)
STASIS	Whether Stasis Mode is selected (toggle on/off)
UCB_V	Ultracapacitor Pack voltage (V)
S.ENTRY	Voltage setting at which FC enters Stasis Mode
H2P1	H_2 supply pressure (Barg)
H2P2	H_2 pressure in FC (Barg)
Tank-P*	Gas tank pressure (Barg)

*with purchase of Spectronik Eco-Marathon Pressure Regulator.

NOTES

- If you are using the Default Setup configuration as per Section 2.6, Protium-450 will deliver a stable voltage output (V_set) though the DCDC. Also, it will not deliver more than the I_set current limit to the load. Excess power required by the load would then be supplied by the Aux_V line (in this case, the Ultracapacitor Pack).

- Most errors should be rectified once the suggested corrective action has been done and the system restarted.

  If the error persists, contact hello@spectronik.com.

3.4 SHUTTING DOWN PROTIUM-450

1. Turn OFF your load. The fuel cell will continue charging the Ultracapacitor Pack until it reaches V_set voltage. The cooling fans will then turn faster to cool down the fuel cell, before returning to their minimum speed.

2. In the GUI, click “end” button. Alternatively, press and hold the *ON/OFF push button (18)* for 3s. The message “Shutdown Initiated” will appear in the GUI and PROTIUM-450 will enter its **Shutdown Phase**. The system is now OFF. LED will blink at 60% on standby awaiting the next start-up command.

3. If you do not intend to restart the system soon, turn OFF your Hydrogen gas supply and remove the Hydrogen gas tubing from the *H_2 gas inlet connector (8).* Caution: some remaining gas in the tubing will be released into the atmosphere.

4. Turn OFF the external auxiliary power supply by plugging out the Ultracapacitor Pack from the Electronic Controller.

PROTIUM-450 is now ready to be kept for storage.

4 SYSTEM MONITORING & PROTECTIONS

4.1 SYSTEM WARNING & PROTECTIONS – STARTING PHASE

Warning messages during "Starting Phase":

Message	Meaning/ Corrective Action
"Gas Tank Not Detected" *	Either the gas tank communication cable is not connected or the tank is empty.
"Gas Tank Pressure Low" *	There is less than 20 Bar remaining in the gas tank.
"Gas Tank Insufficient Pressure" *◉	There is not enough pressure in the gas tank to start.
"Low H2 Supply"	Hydrogen supply pressure is low and the system will wait up to 1min for correction. Please check and correct the delivery pressure.
"Error: Low H2 Supply" ◉	Hydrogen is not correctly supplied within the stipulated time limit. Check and ensure sufficient Hydrogen supply and correct delivery pressure. Restart the system.
"Over Pressure"	Hydrogen supply pressure is too high and the system will wait for 1min. Reduce the delivery pressure.
"Error: Over Pressure" ◉	Hydrogen is not properly supplied within the stipulated time limit. Check and ensure sufficient Hydrogen supply and correct delivery pressure. Restart the system.
"High Temperature"	Stack temperature is too high and the system will wait for 1min.
"Error: High Temperature" ◉	Disconnect everything and wait for system to cool down and restart after 10min. If the problem persists, internal temperature sensor might have been compromised. Contact Spectronik.
"Error: FC Over Cooled" ◉	Stack temperature is too low. Wait for ambient temperature to increase and restart the system.
"FC Sealing Compromised" ◉	Possible stack leakage. Check and ensure all gas tubing and connectors are securely connected.
"Error: Low Voltage" ◉	Stack open circuit voltage is too low. Check and ensure sufficient hydrogen supply and correct delivery pressure. Restart after 1 min.
"Purge Valve Error" *◉	The Purge Valves might not be activating. If the environment is cold, try heating it up.
"Supply Valve Error" *◉	The Supply Valves might not be activating. If the environment is cold, try heating it up.
"Gas Tank Outlet is Leaking" *◉	There has been an unwarranted pressure drop between Gas Tank and Supply Valves. Please verify gas line connections.

◉ *Emergency Shutdown = "**Abnormal Shutdown**" would be activated*

* *with purchase of Spectronik Eco-Marathon Pressure Regulator*

4.2 SYSTEM WARNING & PROTECTIONS – RUNNING PHASE

Warning messages during "Running Phase":

Message	Meaning/ Corrective Action
"High Temperature" ●	Stack temperature is too high. The fuel cell power output to load will be temporarily disconnected for 5s for system to recover. LED will blink. Reduce your load.
"Error: High Temperature" ◉	Stack temperature is too high. Disconnect everything and wait for system to cool down and restart after 10min. If the problem persists, internal temperature sensor might have been compromised. Contact Spectronik.
"Low Temperature" ●	Stack temperature is low. LED will blink.
"Error: FC Over Cooled" ◉	Stack temperature is too low for operation.
"Low Voltage" ●	Stack Voltage at minimum threshold of 0.6V/cell.
"Error: Low Voltage" ◉	Stack Voltage below safety threshold limit.
"Low H2 Supply" ●	Hydrogen supply pressure is low and the fuel cell power output to load will be temporarily disconnected. LED will blink. Check and ensure sufficient Hydrogen supply and correct delivery pressure.
"Error: Low H2 Supply" ◉	Hydrogen supply pressure is too low. Check and ensure sufficient Hydrogen supply and correct delivery pressure. Restart the system.
"High H2 Supply Pressure" ●	Hydrogen supply pressure is too high and the supply valve will be temporarily shut off. LED will blink at 80%. Reduce the delivery pressure.
"Error: High H2 Supply Pressure" ◉	Hydrogen supply pressure is too high. Check and ensure sufficient Hydrogen supply and correct delivery pressure. Restart the system.
"Low Battery" ●	The External Power Supply is at below 15V.
"Gas Tank Running Low" *●	The pressure in the gas tank is below 20 Bar.
"Gas Tank Depleting" *●	The pressure in the gas tank is below 10 Bar.

◉ *Emergency Shutdown = "**Abnormal Shutdown**" would be activated*

● *LED flashing at 80% to alert warning in the running*

* *with purchase of Spectronik Eco-Marathon Pressure Regulator*

4.3 SYSTEM WARNING & PROTECTIONS – LED STATUS & OTHER MESSAGES

LED status:

Phase	Blink % (at 1Hz)	Meaning
Power ON	10%	5s after start-up power is provided into the Electronic Controller, LED will blink at 10%, indicating that the system is ready to receive its “start” command
Starting Phase	40%	Executing “Starting Phase” procedures
Running Phase	100%	System in normal “Running Phase”
Running Phase	80%	System warning during “Running Phase”
After shutdown	60%	System off due to normal shutdown and on standby for the next “start” command
After shutdown	0%	System off due to abnormal shutdown

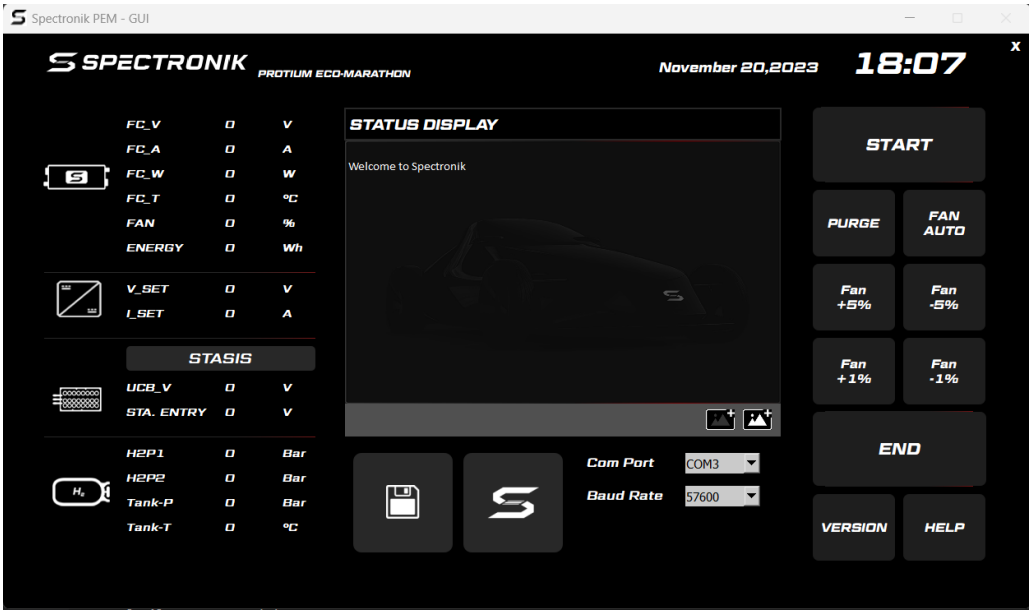
Other messages:

Message	Meaning
Fan PWM auto	Cooling fans control is in auto mode
Mileage	Cumulative Watt-Hour of the system
Shutdown Initiated	Entering “Normal Shutdown Phase”
Abnormal Shutdown Initiated	Entering “Abnormal Shutdown Phase” due to an error
System off	System is turned off and ready to restart at the next command
Entering Stasis Mode	Entering “Stasis Phase”
Running in Stasis Mode	Fuel cell is in “Stasis Phase”

5 PROTIUM ECO-MARATHON (PEM) GRAPHIC USER INTERFACE (GUI)

5.1 PEM GUI – LINK-UP

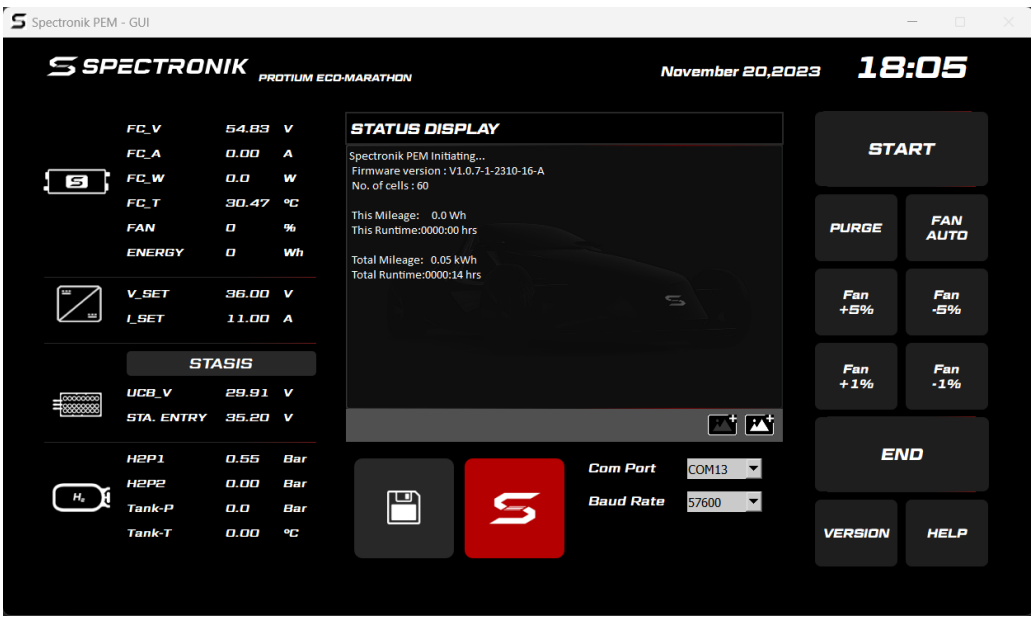
1. Connect the USB cable and open the Spectronik PEM GUI PC app.



2. Select the correct **'Com Port'** and set the Baud Rate as **'57600'.**

3. Click the Spectronik S logo button to connect to the PEM fuel cell Electronic Controller. The S Logo button should light up and a welcome header appears in the 'Status Display' box.

4. PEM will be enter **Standby Phase**, indicated by the message "Spectronik PEM Initializing".

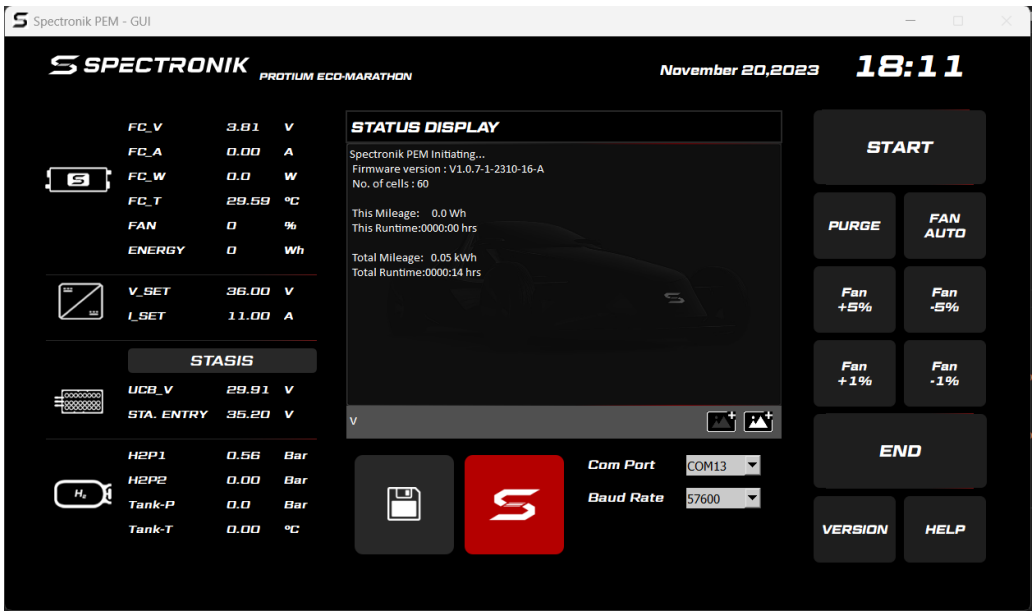


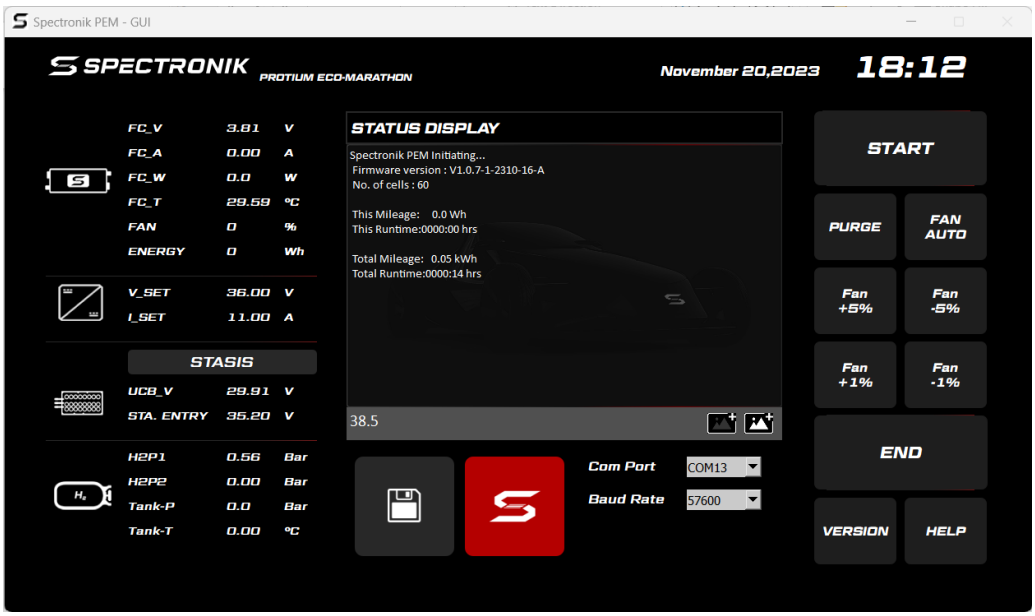
5.2 PEM GUI – CONFIGURE V_set

1. PEM DCDC output voltage “V_set” can be set via PEM GUI only during Standby Phase.
2. Type the following command into the message box:

   ‘v’ <enter> ‘V_set value’ <enter> (V_set value allows one decimal place.)

   For example: ‘v’ <enter> ’38.5’ <enter>



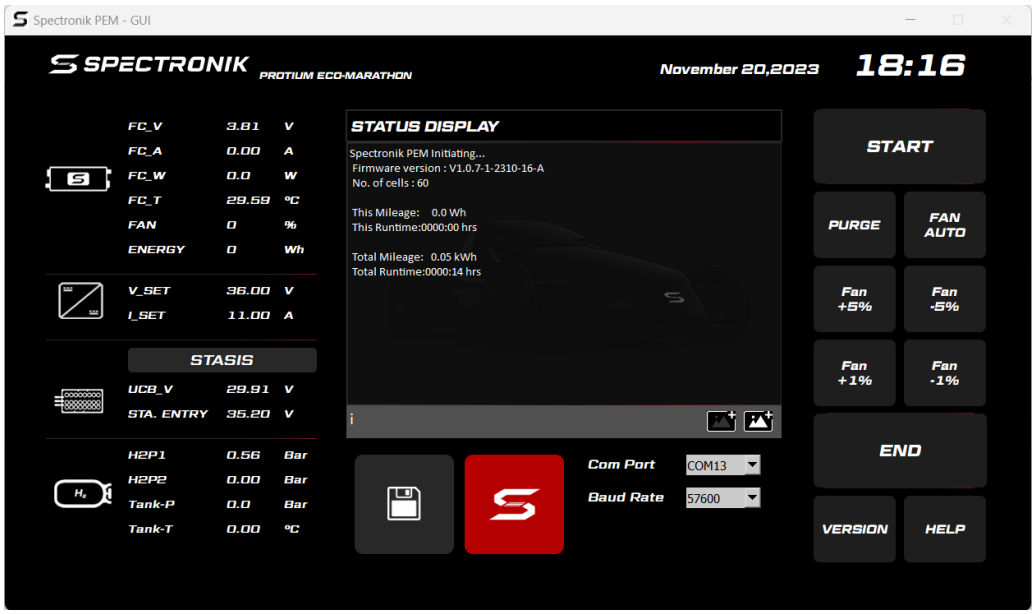


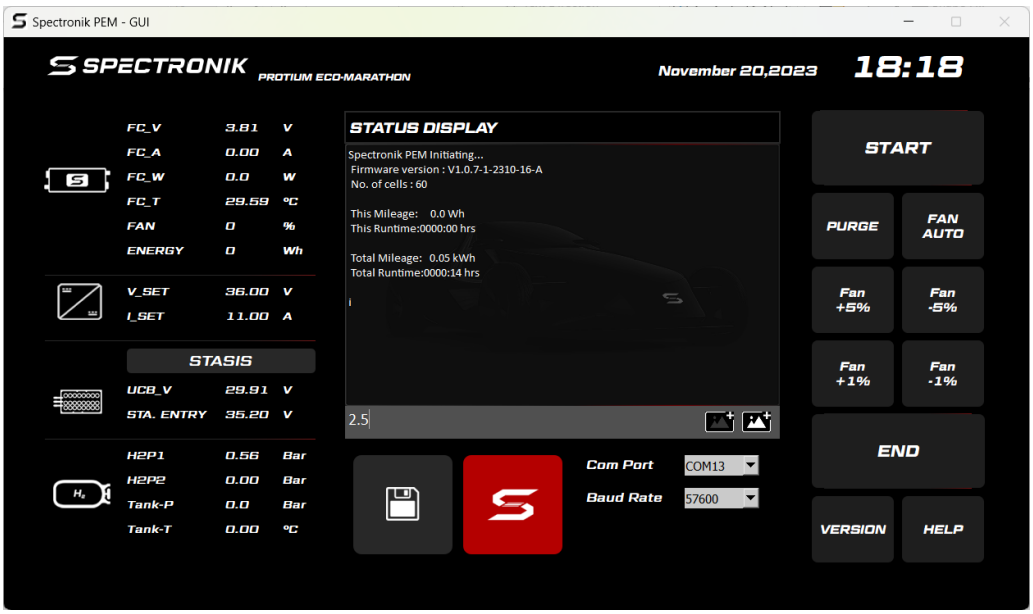
5.3 PEM GUI – CONFIGURE I_set

1. PEM DCDC output current limit "I_set" can be set via PEM GUI only during Standby Phase.
2. Type the following command into the message box:

   'i' <enter> 'I_set value' <enter> (I_set value allows one decimal place.)

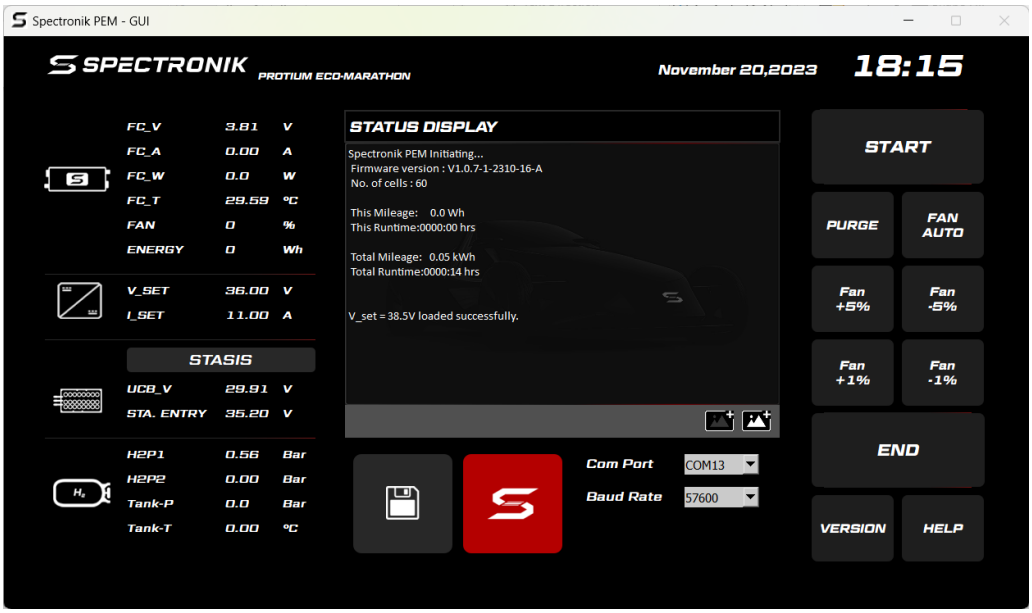
   For example: 'i' <enter> '2.5' <enter>

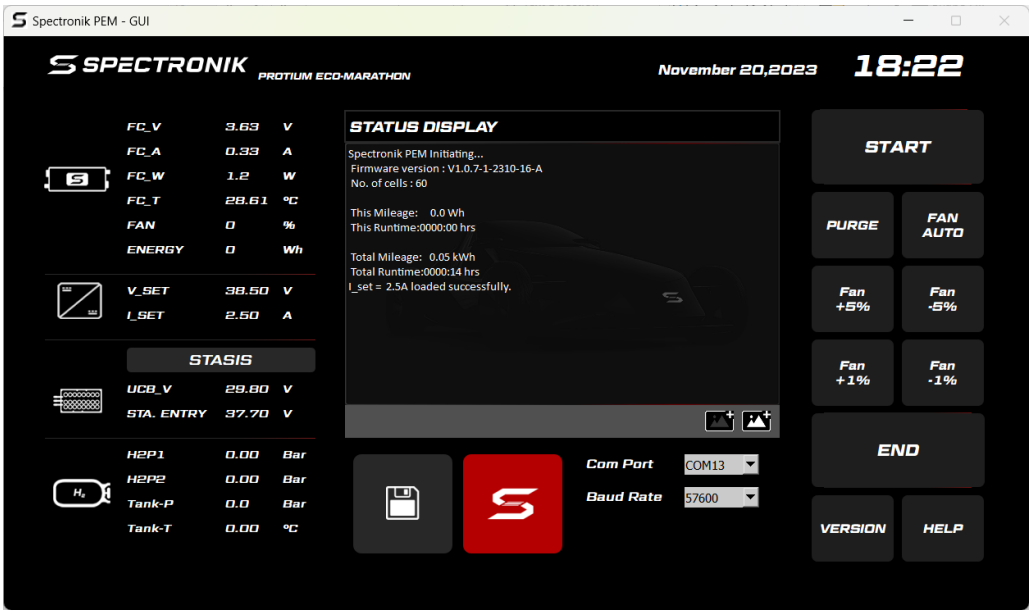




5.4 PEM GUI – V_set & I_set ACKNOWLEDGEMENTS

PROTIUM-450 will check and accept values within the minimum and maximum power, voltage and current limits. Successful entries will get acknowledgements “V_set loaded successfully” and “I_set loaded successfully”.





REMINDER

- The integrated DCDC converter has the following user configurable output ranges:

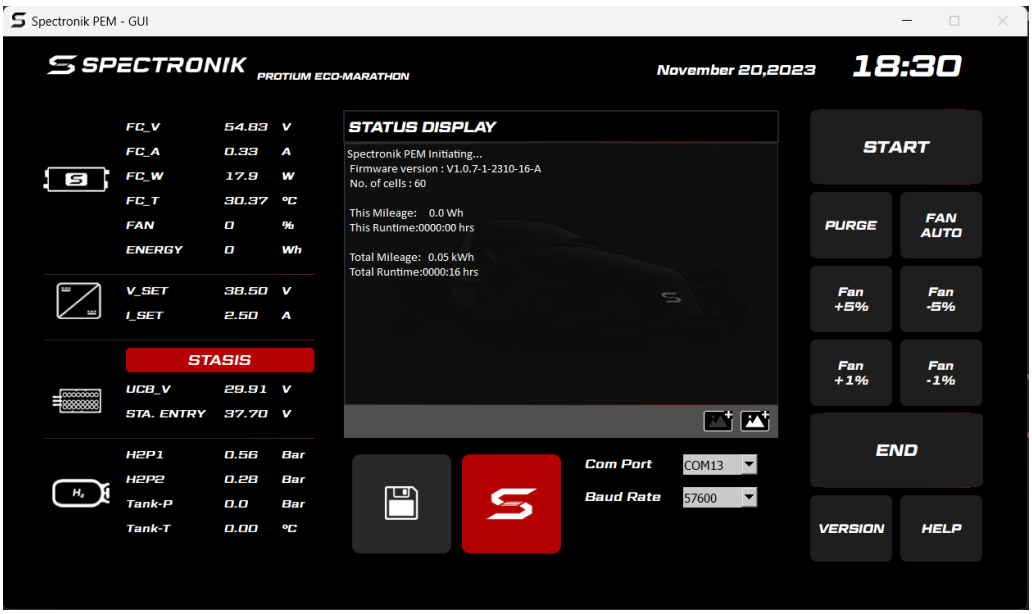
  V_set: 15V to 60V
  I_set: 2A to 30A

- The permutation of V and A must be ≤ fuel cell’s maximum power rating (450W).

5.5 PEM GUI – CONFIGURE STASIS MODE

The Stasis Mode function allows autonomous transition for PROTIUM-450 to enter a temporary hibernation. Stasis Mode helps optimize the use of H2 fuel in applications where power drawn is of an intermittent and fluctuating nature.

Stasis Mode function can be set active/inactive via the PEM GUI only during Standby Phase. Toggle the STASIS button on/off as desired.



NOTES

- Stasis Mode is intended to work only in the Default Setup as per Section 2.6, i.e. with *DCDC output (13)* and Ultracapacitor Pack.
- PROTIUM-450 will autonomously enter hibernation when the auxiliary power source – in this case the Ultracapacitor Pack (UCB_V) is charged to near V_set; It will autonomously exit the Stasis Mode and back to Running Phase when UCB_V has dropped.

  Trigger points reference:

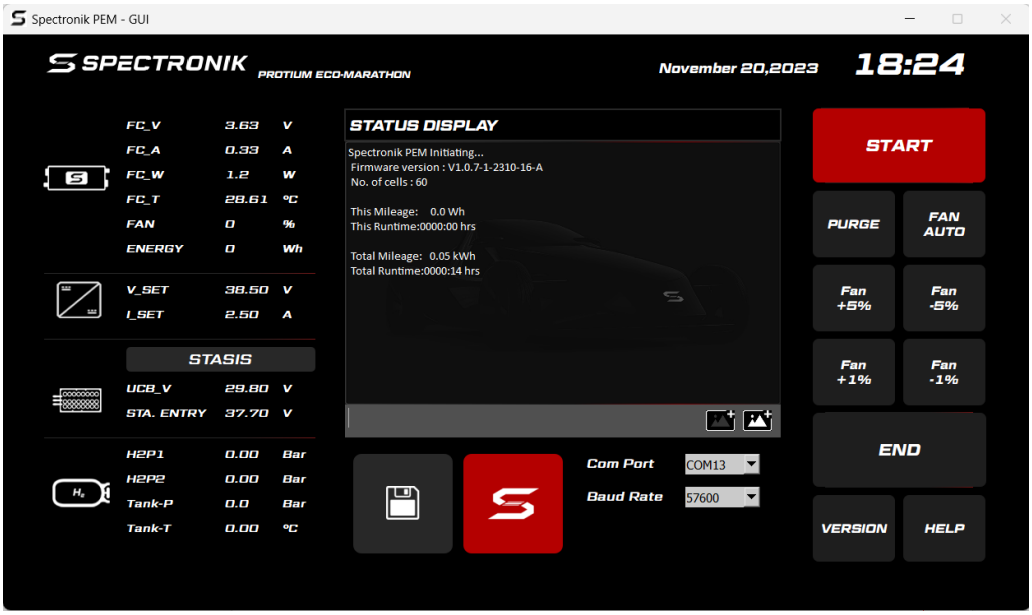
  Enters Stasis Mode when Aux_V is approximately 0.8V below V_set;

  Exits Stasis Mode when Aux_V is approximately 1.5V below V_set.

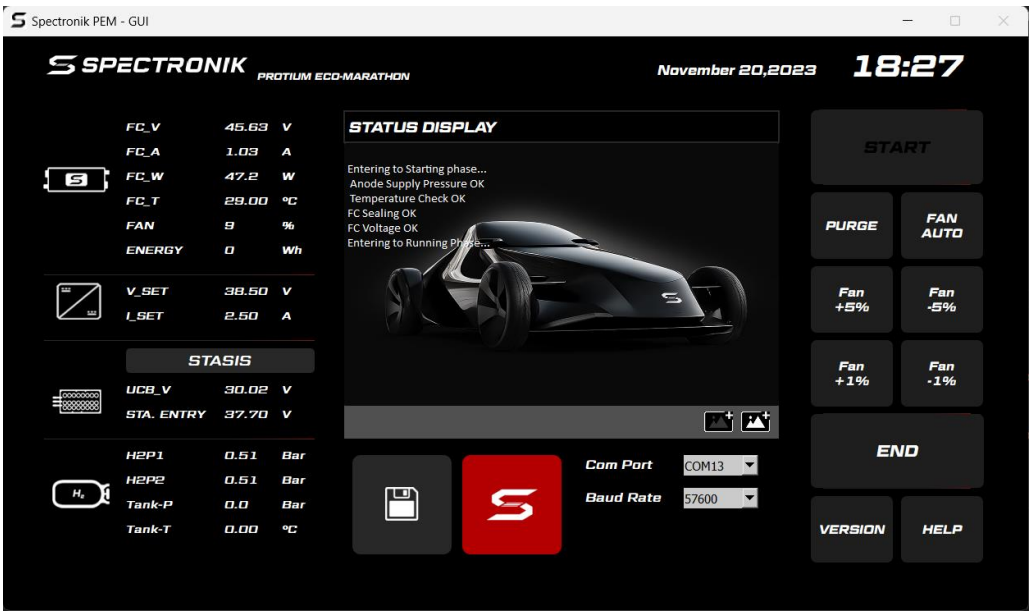
5.6 PEM GUI – SYSTEM STARTING PHASE

1. To start the fuel cell, click the START button on PEM GUI or press and hold the *ON/OFF push button (18)* of the Electronic Controller for 3 seconds.

2. PROTIUM-450 will enter **Starting Phase**. And the START button would fade away.

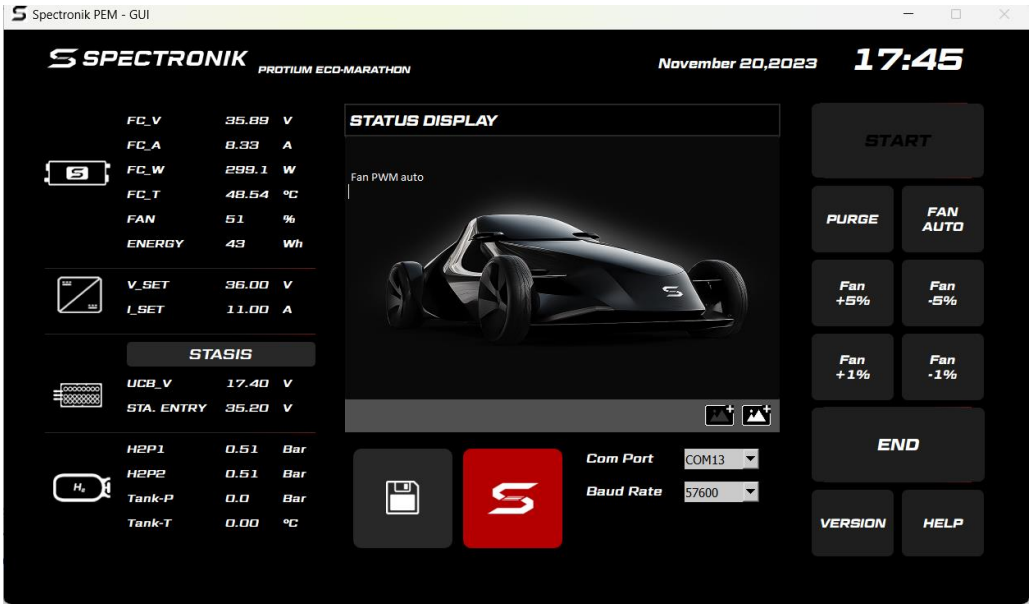


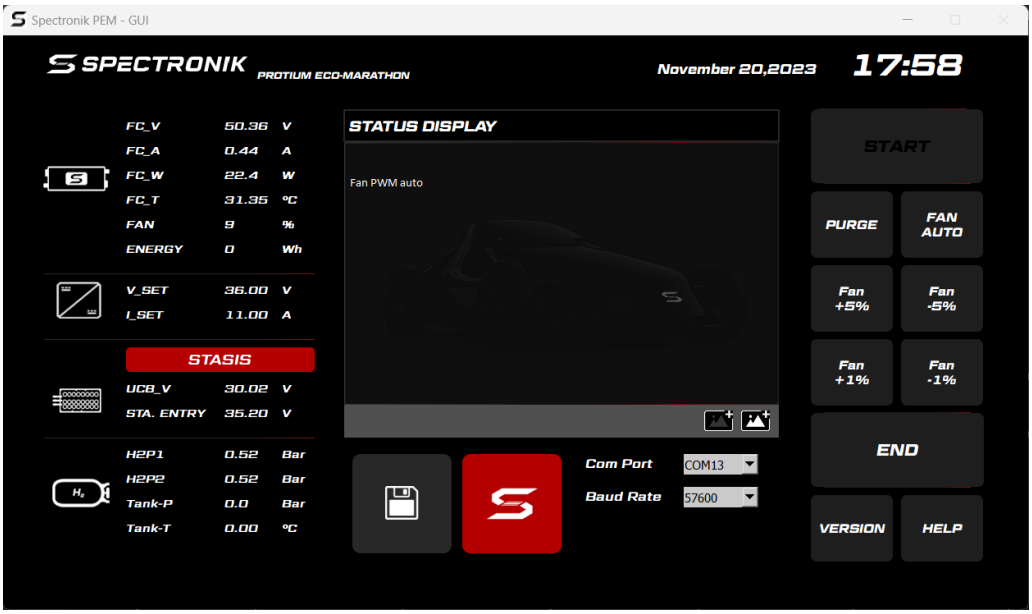
3. During the Starting Phase, PROTIUM-450 will do a series of internal checks to ensure that all parameters are in good working conditions before entering Running Phase.



5.7 PEM GUI – SYSTEM RUNNING PHASE

During the **Running Phase**, all controls are managed by the electronics controller. If Stasis Mode was not selected, its toggle button would be OFF (no color). If Stasis Mode was selected, then the Stasis button would be ON (Red color).





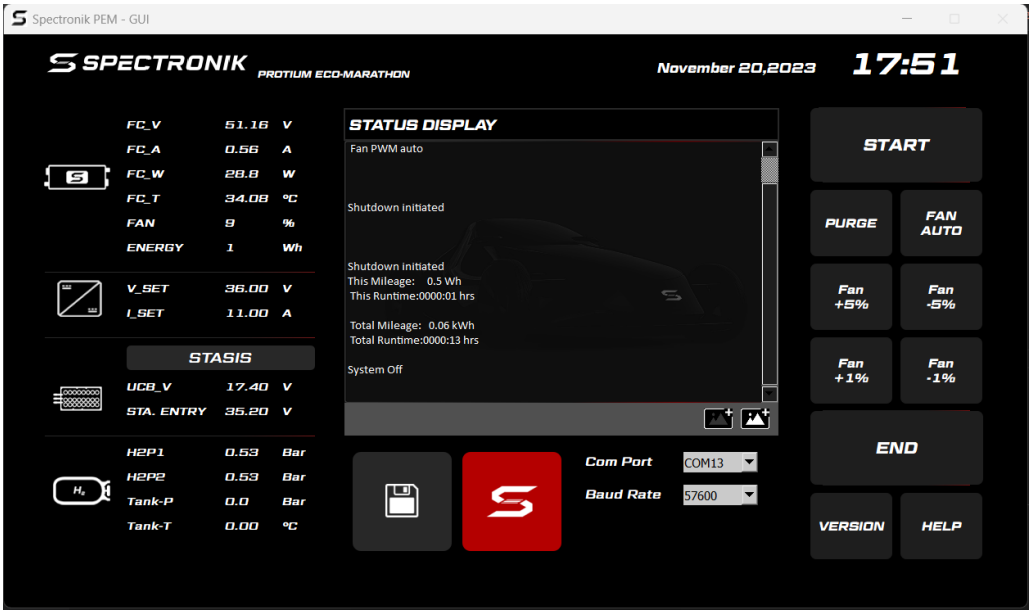
NOTES

- PROTIUM-450 has pre-programmed fan control based on Current output and cell target temperature. Advanced users can manually adjust the cooling fans by pressing the respective Fan buttons at 1% and 5% pwm resolutions. To return to the default program, press FAN AUTO.
- PROTIUM-450 also has pre-programmed purge control based on optimizing fuel saving and cell performance. You can do additional water removal and Hydrogen line flushing by manually pressing the PURGE button.

5.8 PEM GUI – SYSTEM SHUTDOWN PHASE

1. To shutdown the system, click the END button on the GUI or press and hold the *ON/OFF push button (18)* of the Electronic Controller for 3 seconds.

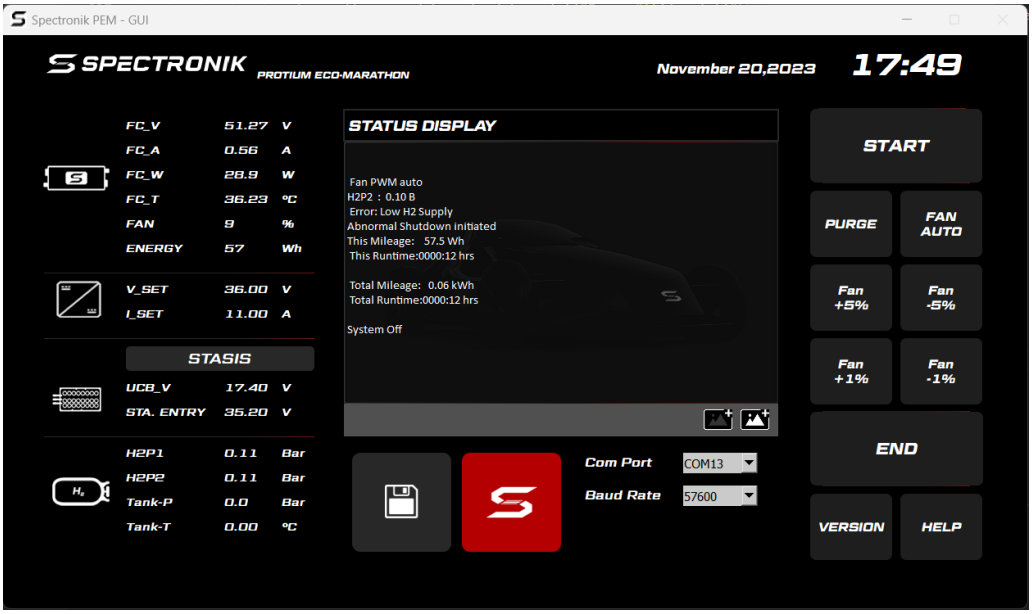
2. The system enters **Shutdown Phase** to properly end the fuel cell system operations. After the complete shutdown, the START button would reappear as it returns to Standby Phase.



5.9 PEM GUI – ABNORMAL SHUTDOWN PHASE

1. During Starting Phase and Running Phase, in case of any serious erroneous conditions, PROTIUM-450 will immediately enter **Abnormal Shutdown Phase**.

2. PROTIUM-450 will return to Standby Phase and can only be restarted after the problem has been resolved. Refer to section 4 for a complete list of possible errors and the recommended corrective actions.

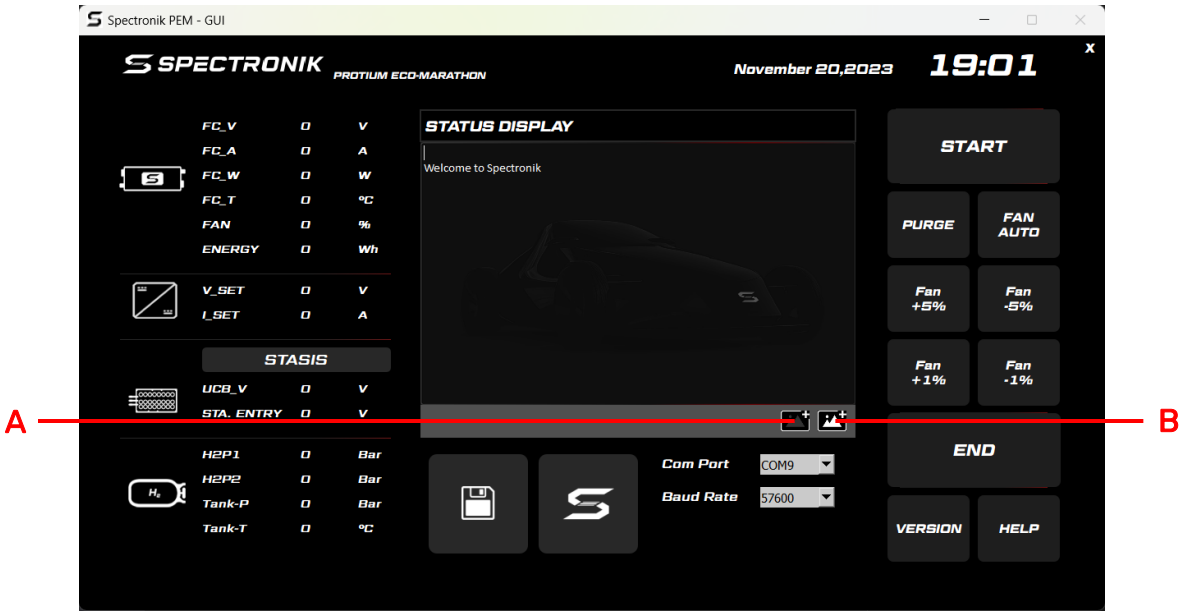


5.10 PEM GUI – BACKGROUND PHOTO

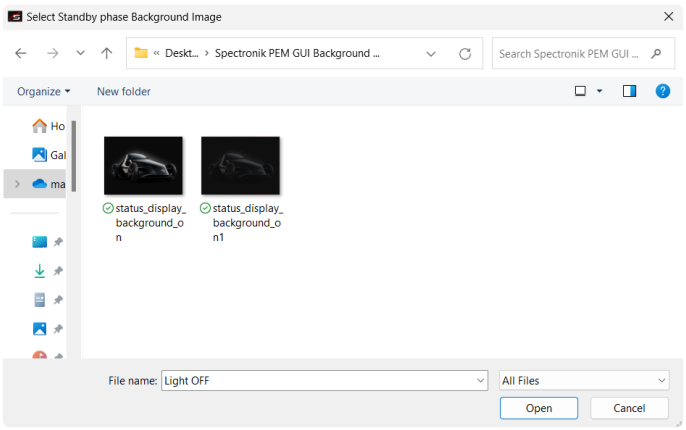
Click on “A” or “B” to change background images.

A: Background image for fuel cell in inactive state. During “Standby Phase”, “Starting Phase”, and “Stasis”.
B: Background image when fuel cell is in active state. During “Running Phase”.

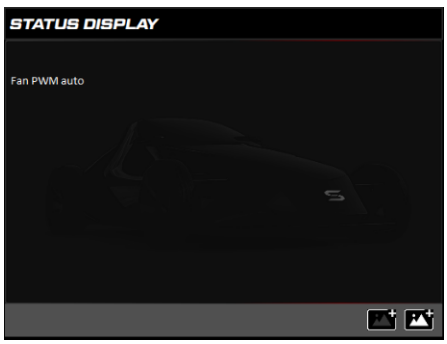
It will prompt for your file location.



Example:



Example:



6 MAINTENANCE AND STORAGE

6.1 MAINTENANCE FOR PROTIUM-450

When not in use, Spectronik recommends that PROTIUM-450 is reconditioned at least once a month.

1. Set up PROTIUM-450 as per instructions in Section 3, taking note of the following differences:

a. Use a DC power supply instead of the Ultracapacitor pack. Set the DC power supply to 36V 2A.

b. Do not use the *DC-DC power out (13)* socket.

c. Connect the *Unregulated stack power out header (30)* to its respective *unregulated stack power out receptacle (16)* on the Electronic Controller. Next, connect the *free-end wires (31)* to a DC electronic load. Caution: ensure that the polarity is correct.

2. After the system enters "Running Phase", set constant voltage (CV) load of 36V and run the system for 1h. The fuel cell should recover to its maximum rated power output.

PROTIUM-450 is now ready for usual operation or can be stored again for future use.

6.2 STORAGE

Keep PROTIUM-450 in an open, cool (standard room temperature of 25°C) and dry place.