# Senior Design Project
# Hydrogen Backup System


Presented by
Team 15.1

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# Project Introduction

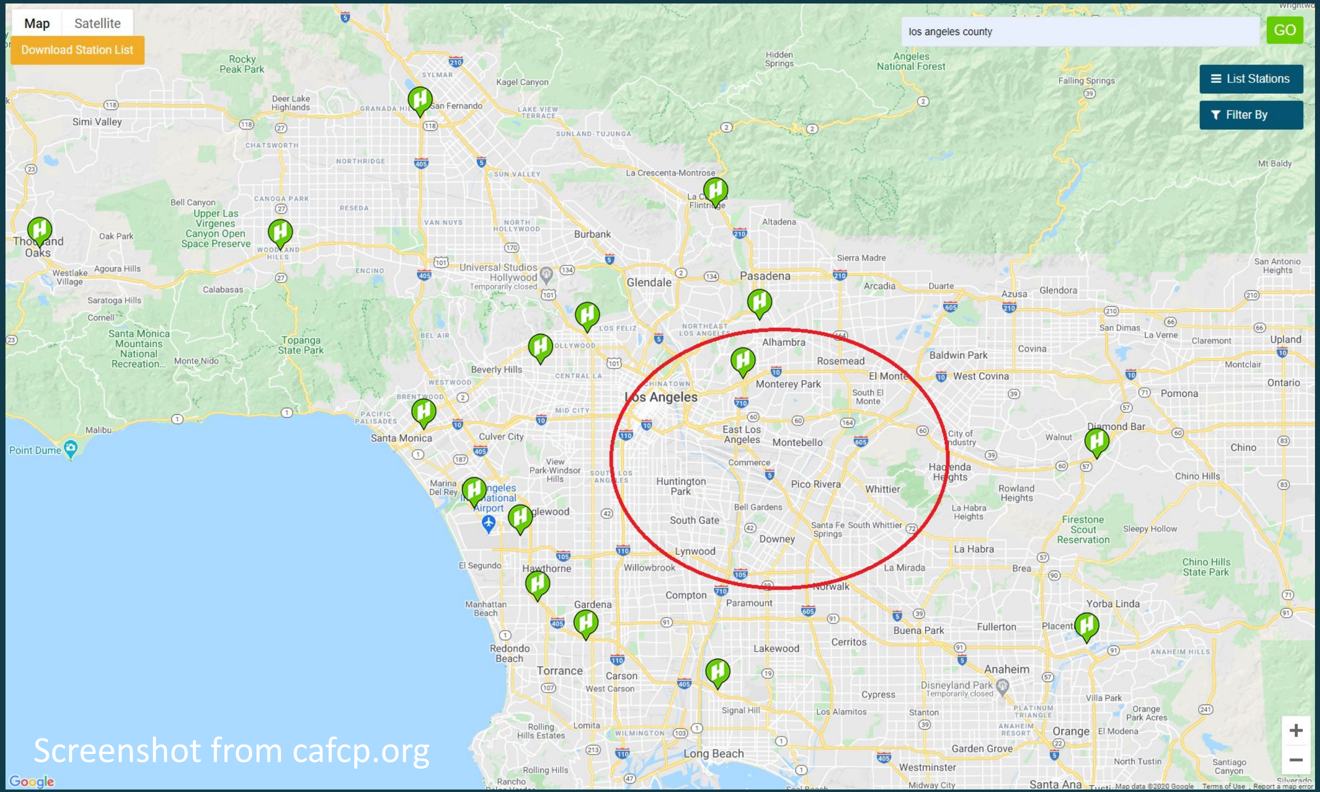
- The primary objective of this work is to focus on providing backup power during an emergency or lack of power to the California State University, Los Angeles' Hydrogen Fueling Station.

- Team 15.1 focused on creating a backup power system utilizing entirely new components chosen specifically to handle the load requirements of the station.
- Team 15.2 focused on creating a backup power system by repurposing the power train found in fuel cell vehicles taken at the end of service life in order to power the hydrogen refueling station during an emergency situation.

# Project Background: The Hydrogen Station

- The hydrogen station makes its own hydrogen to sell through the process of electrolysis. It stores this hydrogen in two 30 kilogram storage tanks. It is the only hydrogen refueling station in the majority of the east Los Angeles area.

Image from calstatela.edu



Screenshot from cafcp.org

# Project Background: The Hydrogen Station

- When a fuel cell vehicle comes to the station for a refuel, the hydrogen gets sent through a set of high pressure compressors after which two parallel chiller units are used to cool the hydrogen before it reaches the dispenser.

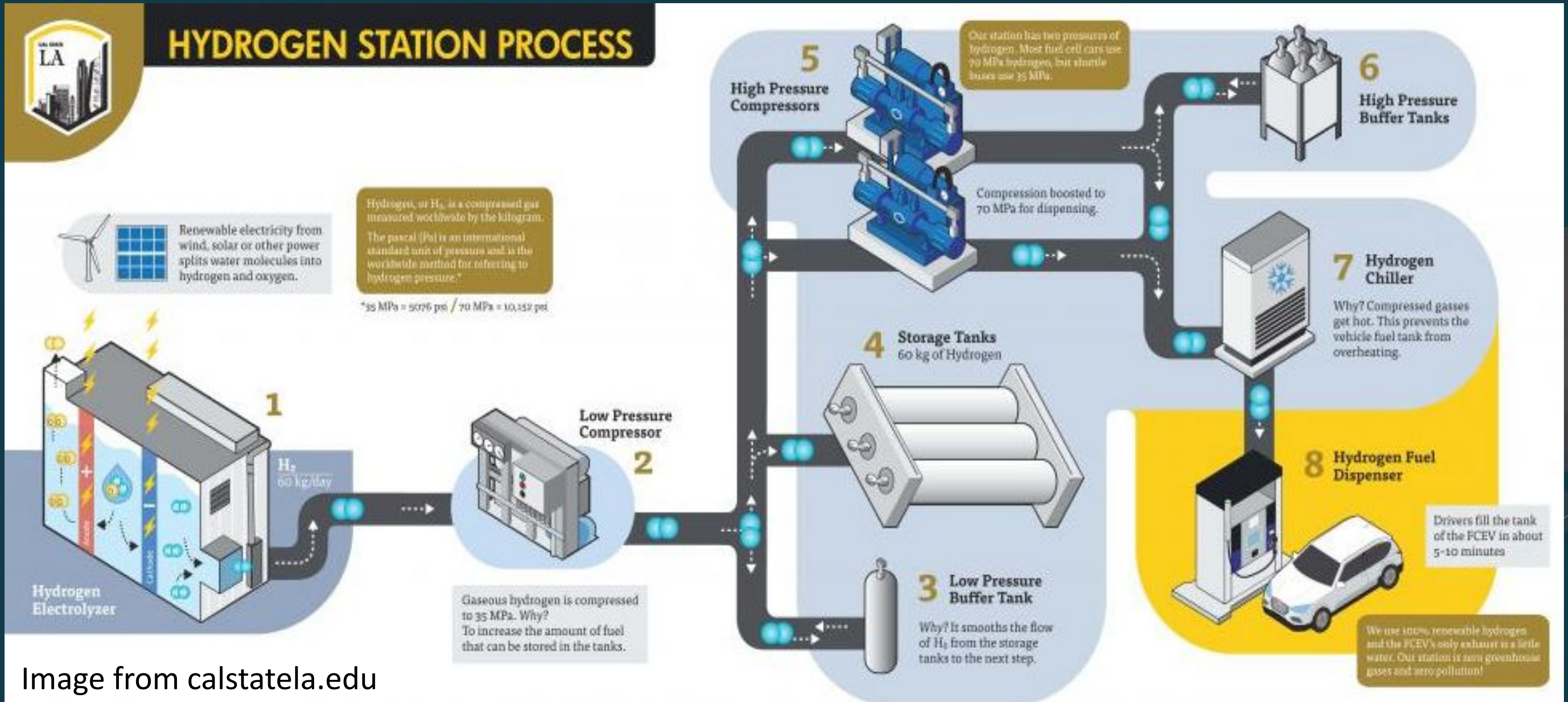



Image from calstatela.edu

# Project Background: PEM Fuel Cells

- Humidified hydrogen is supplied to the anode side of the fuel cell.
- A platinum coated catalyst Ionizes the hydrogen.
- Electrons cannot flow through the membrane so they are forced through a circuit.
- Membrane must be kept moist to aide the transfer of hydrogen ions.
- Hydrogen ions meet with oxygen at the cathode side of the fuel cell where they form water and waste heat.

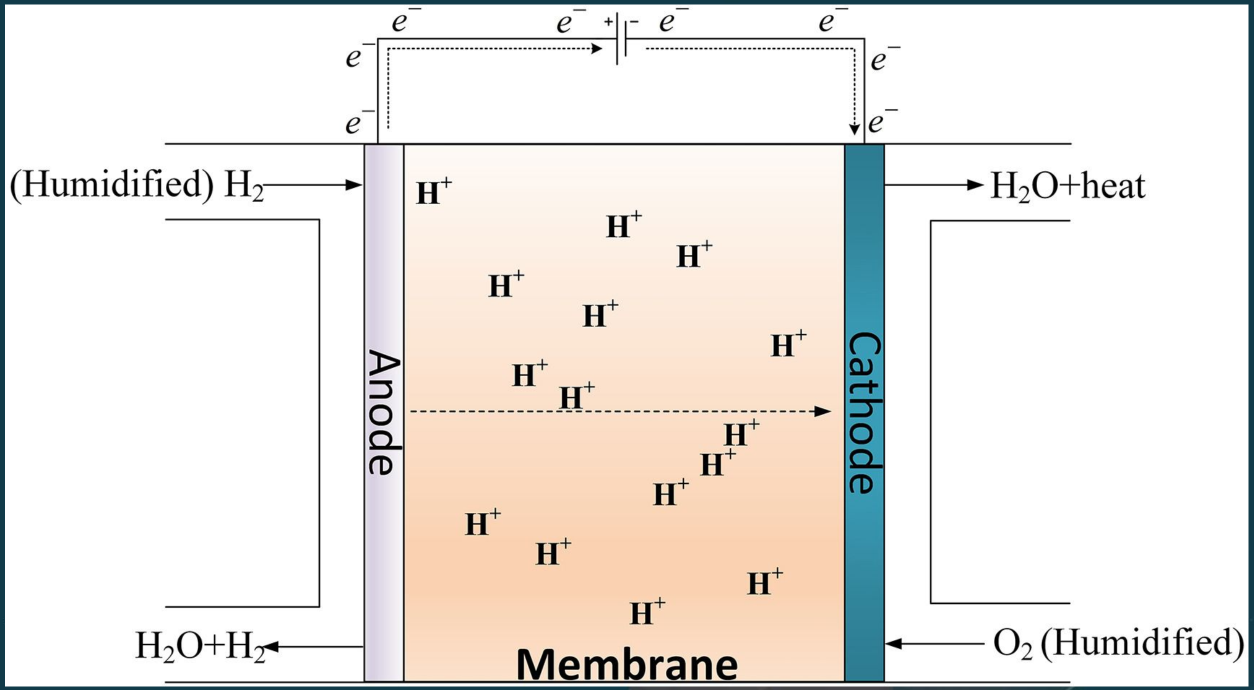



Image from PEM fuel cell model and simulation

# Project Background: PEM Fuel Cells

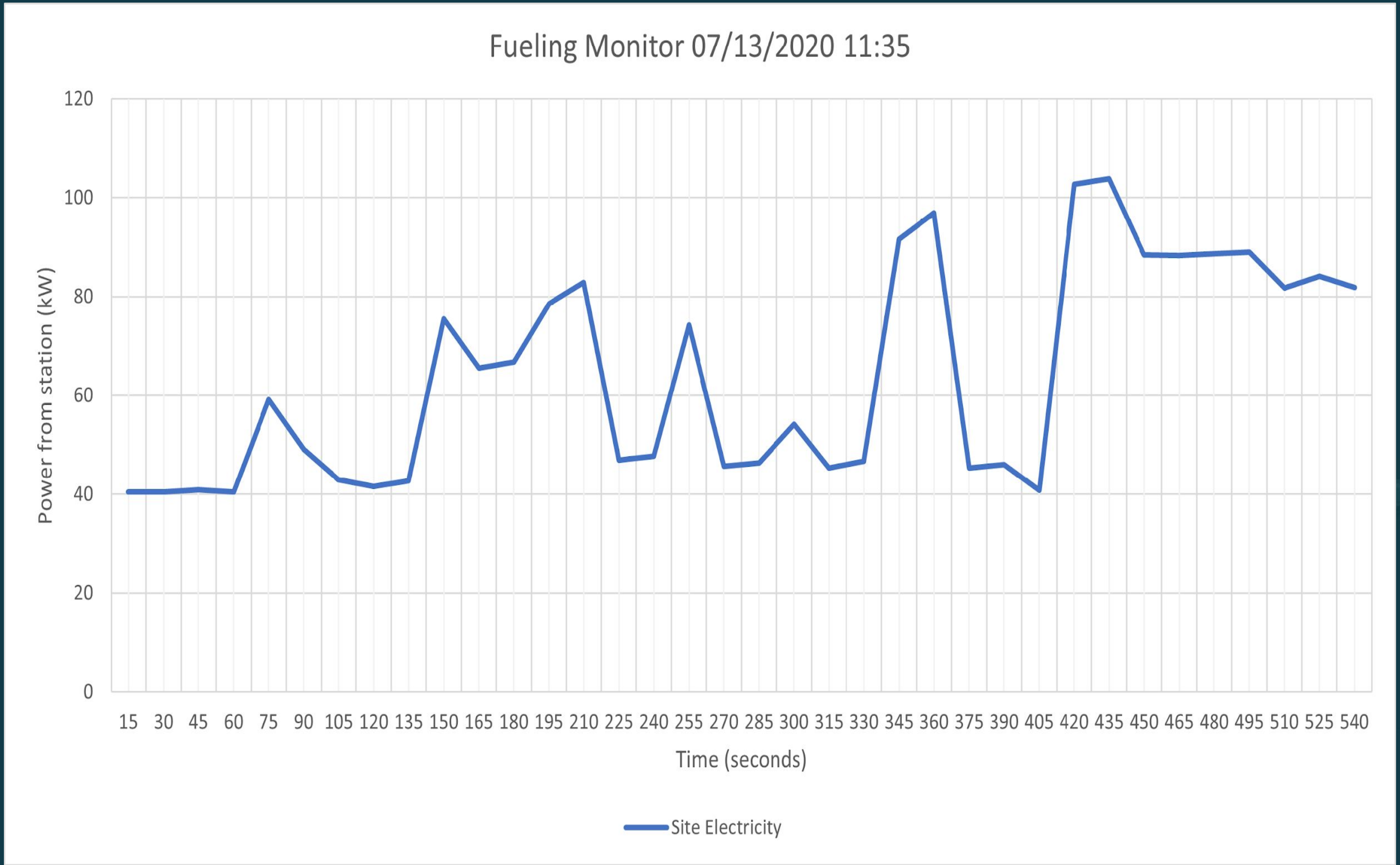
| Brand: | Altergy | Ballard |
|---|---|---|
| Model: | FPS-548 | FCmove- HD |
| Output: | 5 kW | 70 kW |
| Advantages: | Lower output/easier scaling, more publically available specifications, California Based | Less complicated wiring and thermal management loop, More compact than using multiple smaller fuel cells |
| Disadvantages: | More complicated wiring, more complicated thermal management loop | Could prove more difficult to scale, multiple estimations made for specifications, Candian company |

Image from Altergy product brochure

Image from Ballard product brochure

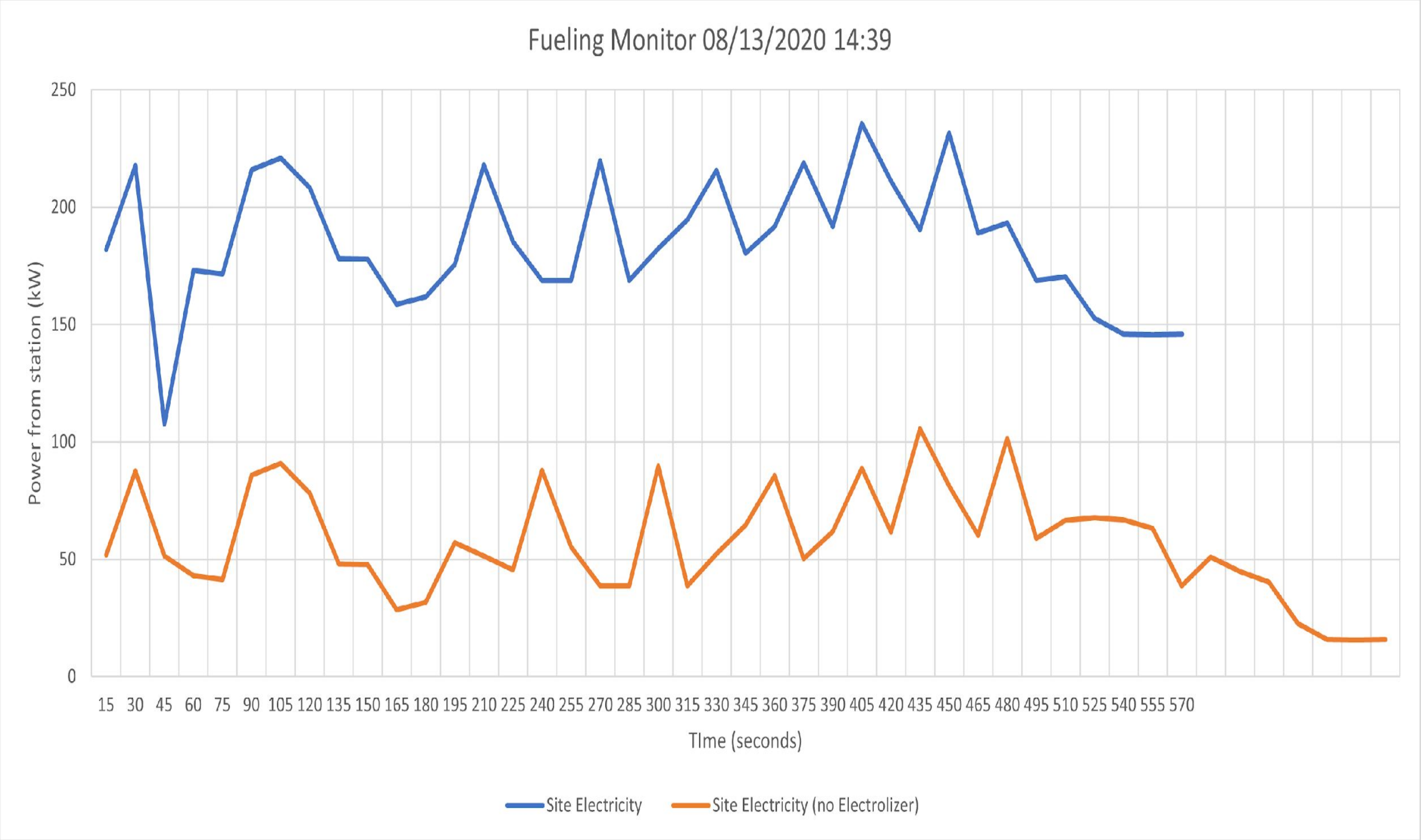
# 3. Hydrogen Station Requirements

- Fueling data taken on 07/13/2020
- This chart does not have the electrolyzer and low-pressure compressor on
- Site electricity ranges from 40kW to 100kW based on 15 second increments
- Estimate power consumption is 5.19kWh in 6 minutes



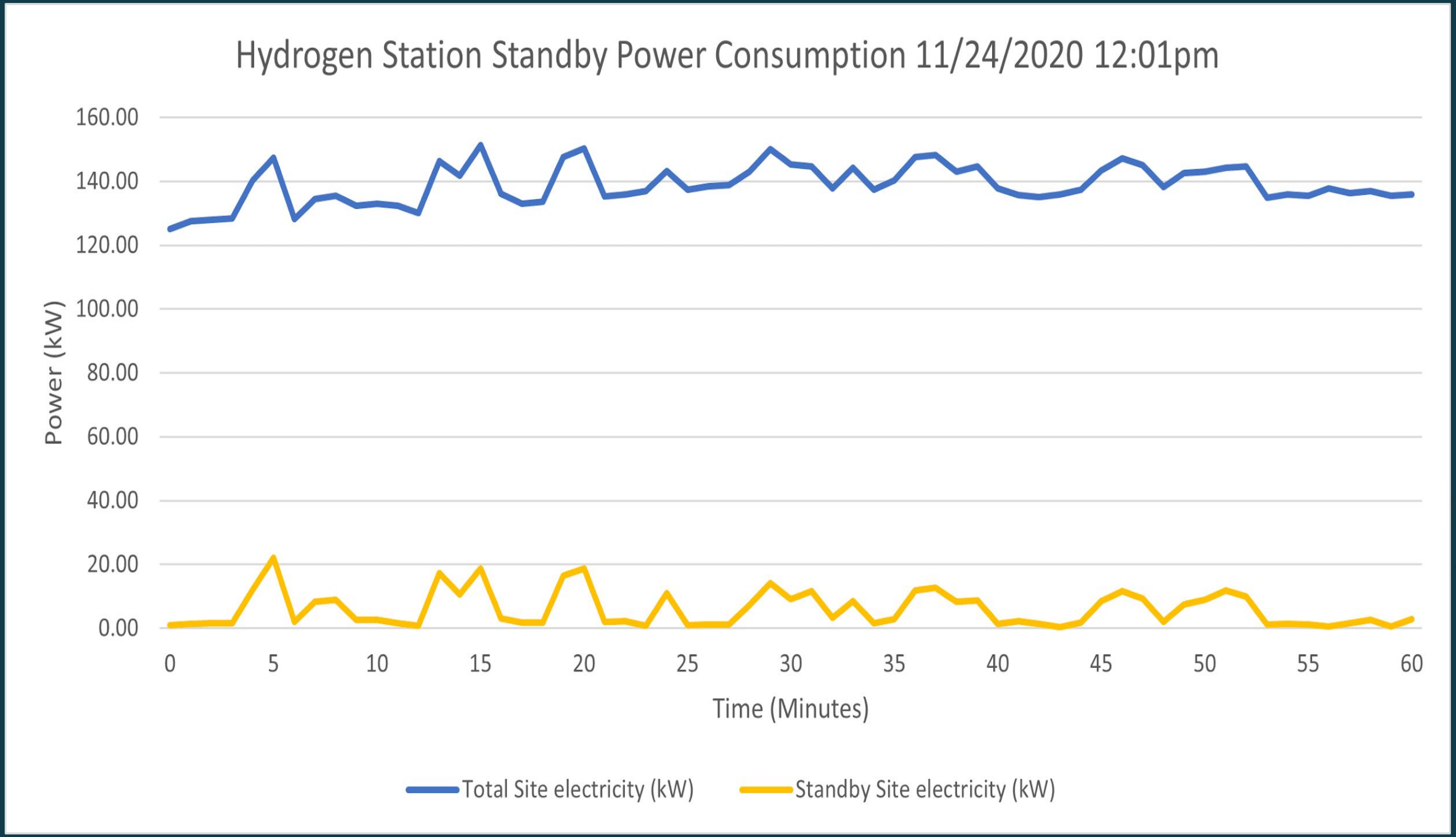
# 3. Hydrogen Station Requirements

- Fueling data on 08/13/2020
- Data includes electolyzer and low-pressure compressor
- Site electricity ranges from50kW to 100kW without electrolyzer (orange)
- Site electricity ranges from 100kW to 230kW with electrolyzer (blue)
- Estimate power consumption without electrolyzer is 10.35kWh in 10 minutes



# 3. Hydrogen Station Requirements

- Standby data taken on 11/24/2020
- Total site electricity (blue) includes the electrolyzer and low-pressure compressor
- Total site electricity ranges from 120kW to 146kW
- The Standby Site electricity (orange) ranges from 1kW to 25kW.
- Estimate power consumption without the electrolyzer is 6.01kWh in 1 hour



# Project Management 15.1

- The first deliverable is Research and Planning.
- It was the focus of the Fall semester.
- It involved finding research we would need to

| TASK | ASSIGNED TO | PROGRESS | START | END |
|---|---|---|---|---|
| ***Research and Planning*** | | | | |
| **Hydrogen Station Operations** | | | | |
| 1.2: Find out Station Power Details | RE, RQ | 100% | 9/7/20 | 9/20/20 |
| 1.3: Find out H2 Storage Details | RE, RQ | 100% | 9/21/20 | 9/27/20 |
| 1.1: Document Video Data | IG, PV | 100% | 10/5/20 | 10/11/20 |
| 1.5: Product Description | All | 100% | 10/26/20 | 11/1/20 |
| **Benchmark Hydrogen Station** | | | | |
| 2.1: Find Backup System Schematics | RE, PV | 100% | 9/7/20 | 11/1/20 |
| 2.2: Find Fuel Cell Manufacturers | IG | 100% | 9/7/20 | 10/11/20 |
| 2.3: Compare Battery Types | RQ | 100% | 9/7/20 | 10/11/20 |
| 2.4: Supplemental Hardware | RE, PV | 100% | 9/7/20 | 10/11/20 |

# Project Management 15.1

- The second deliverable is Design and Modeling.
- It was the focus of the Spring semester.
- The purpose was to create viable models of the backup power system using the Simulink software.

| TASK | ASSIGNED TO | PROGRESS | START | END |
|---|---|---|---|---|
| ***Design and Modeling*** | | | | |
| **Learn to Use Simulink for Station Modeling** | | | | |
| 1.1 Find Resources Teaching Simulink Basics | RE, RQ, PV | 100% | 12/14/20 | 1/1/21 |
| 1.2 Find Relevant Examples on Simulink | RE, RQ, PV | 100% | 1/4/21 | 1/8/21 |
| 1.3 Experiment with Simulink Projects | RE, RQ, PV | 100% | 1/11/21 | 1/29/21 |
| **Create Simulink Model of Hydrogen Station** | | | | |
| 2.1 Search for Compatible Models | All | 100% | 1/29/21 | 2/5/21 |
| 2.2 Choose and Configure Model for Station | All | 100% | 2/8/21 | 3/1/21 |
| 2.3 Test Station Model with Data | RE, RQ, PV | 90% | 2/26/21 | 4/9/21 |
| 2.4 Optimize Model | RE, RQ, PV | 60% | 4/1/21 | 4/23/21 |
| **Update Simulink Model for Cooling System** | | | | |
| 3.1 Search for Compatible Models | SA | 100% | 2/15/21 | 3/1/21 |
| 3.2 Configure to Update with Station | SA | 100% | 3/1/21 | 3/15/21 |
| 3.3 Optimize Model | SA | 100% | 3/15/21 | 4/9/21 |

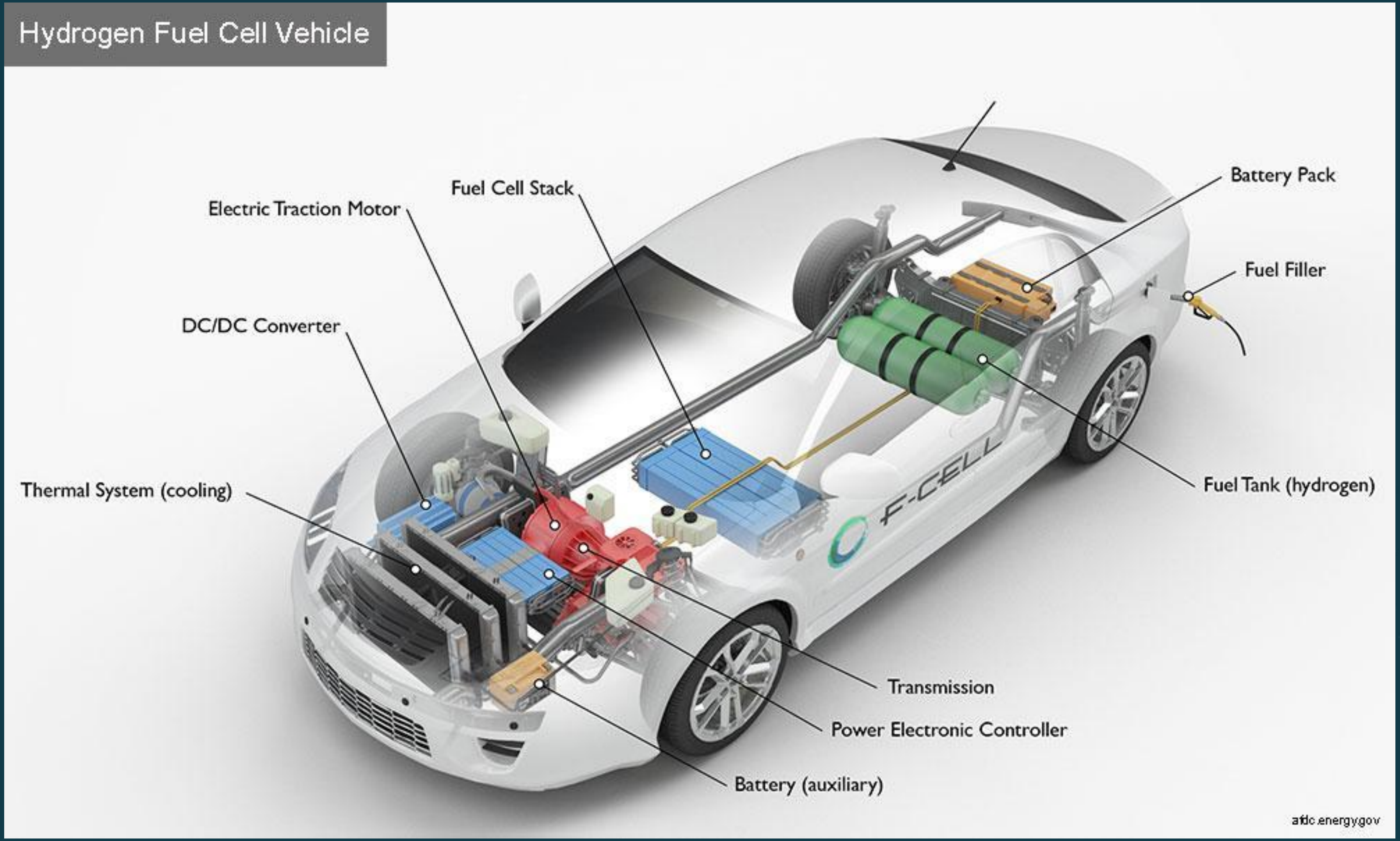
# Project Management 15.1

- The third deliverable is Project Management.
- It includes deadlines for submitting reports to the senior design class, meetings with the team and advisor, filing documents into a shared library, and organizing the team with tools like the Gantt chart.

| TASK | ASSIGNED TO | PROGRESS | START | END |
|---|---|---|---|---|
| *Project Management* | | | | |
| Assign Specialties to Team Members | | | | |
| 1.1 Identify Team Skill Sets | PV | 100% | 8/23/20 | 9/6/20 |
| 1.2 Assign Individuals to Tasks | PV | 100% | 9/6/20 | 9/20/20 |
| Organize Team Tasks | | | | |
| 2.1: Create Work Breakdown Structure | PV | 100% | 8/23/20 | 10/4/20 |
| 2.2: Create Statement of Work | PV | 100% | 8/23/20 | 10/4/20 |
| 2.3: Create Gantt Chart | PV | 95% | 8/23/20 | 4/1/21 |
| Organize Documentation | | | | |
| 3.0 Organize Team Meetings | PV | 90% | 8/23/20 | 5/14/21 |
| 3.1: Compile Research | PV | 100% | 8/23/20 | 12/14/20 |
| 3.2 Document Results from Modeling | RE, RQ, PV | 100% | 2/15/21 | 3/26/21 |
| 3.3 Create Final Report | All | 0% | 4/5/21 | 4/23/21 |
| 3.4 Rehearse for Presentation EXPO | All | 0% | 4/26/21 | 5/7/21 |
| Prepare Reports for the Class | | | | |
| Biweekly Report 1 | All | 100% | 2/15/21 | 2/19/21 |
| Monthly Personal Report 1 | All | 100% | 2/22/21 | 2/26/21 |
| Biweekly Report 2 | All | 100% | 3/1/21 | 3/5/21 |
| Biweekly Report 3 | All | 100% | 3/15/21 | 3/19/21 |
| Monthly Personal Report 2 | All | 100% | 3/22/21 | 3/26/21 |
| Biweekly Report 4 | All | 0% | 4/5/21 | 4/9/21 |
| Biweekly Report 5 | All | 0% | 4/19/21 | 4/23/21 |
| Prepare for EXPO Presentation | All | 0% | 4/26/21 | 5/14/21 |

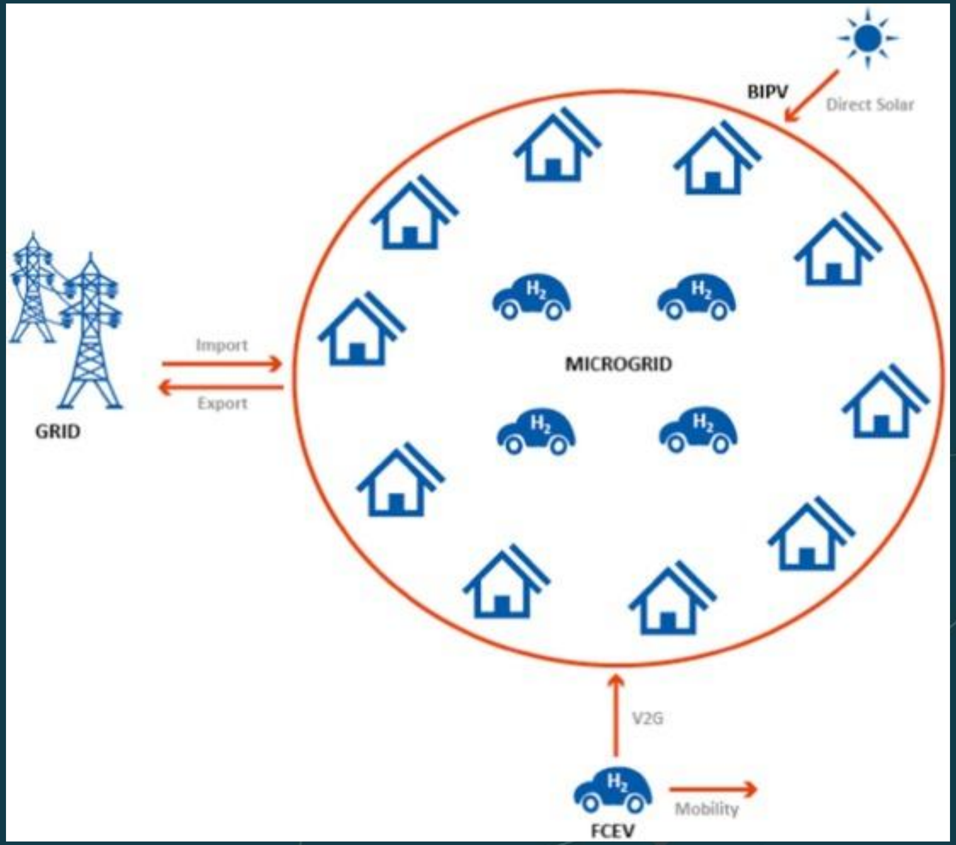
# Approach 15.2: Design Progress

- The group was quick to see similarities After doing research on FCEV we started to see how the power was generated, distributed, and controlled.
- We noticed how every power source related element functioned to give a load to the vehicle.



# Approach 15.2: Design Progress

- The only time that something similar had been done by the time of our research was something called V2G or Vehicle to Grid
- This consists of connecting a FCEV to the grid to give out power to the grid.
- Same principle of power production, but completely different end goal



# Approach 15.2: Organization

-Phase one of the model was "Research".
- The goal of this phase was trying to get a foundation of what we were going to do during the rest of the year.
- We looked to get the details on the final goal.

| Phase 1 - Research | | | | |
|---|---|---|---|---|
| **1.1 Hydrogen Station Details and Specifications** Collect data through the website and videos provided | Martin, Marco, Saud | 100% | 9/4/20 | 9/18/20 |
| **1.1.1** Create charts and tables for analysis | Marco | 100% | 9/13/20 | 9/24/20 |
| **1.2 Similar Projects to Emergency Backup Proposal** Find projects or research like the hydrogen station through databases, journals, or articles | Carlos, Francisco, Marco | 100% | 9/11/20 | 9/24/20 |
| **1.3 Vehicle Transportation** Research Fuel Cell Electric Vehicles operation through companies to understand FCEVs operate during fueling | Carlos, Martin | 100% | 9/11/20 | 10/1/20 |
| **1.4 PEM Fuel Cells** Research applications, schematics, and diagrams on operations of commerically available fuel cells | Martin, Carlos | 100% | 9/25/20 | 10/1/20 |
| **1.5 Benchmarking** Compare similar projects to get the best results | Carlos | 100% | 9/11/20 | 10/23/20 |
| **1.5.1** comparing project details with data of hydrogen station | Carlos | 100% | 10/2/20 | 10/23/20 |

# Approach 15.2: Design Progress

- For Phase 2, we worked on concepts of the project.
- The main goal of this phase was to have a model ready on theory that could be followed and applied in real life.

| Phase 2 - Concepts | | | | |
|---|---|---|---|---|
| **2.1 FCEV Vehicles Specifications and Diagrams**<br>Find diagrams and specifications of commerically available FCEVs | Martin, Carlos | 100% | 10/2/20 | 10/23/20 |
| **2.2 Specifications for Components in Emergency Backup**<br>Find specification and diagram sheets for dc-dc converters, batteries, cooling systems, inverters | Francisco, Saud, Marco | 100% | 10/6/20 | 11/24/20 |
| **2.2.1** Research on FCEV batteries and inverters and possible uses for emegency backup | Francisco | 100% | 11/6/20 | 11/24/20 |
| **2.3 Creating a Black Box**<br>Build a rough draft of the emergency backup system for the hydrogen station based on research and benchmarking | Martin, Saud, Marco, Carlos, Francisco | 100% | 10/9/20 | 11/13/20 |
| 2.3.1 Find the components requirements | Martin | 100% | 11/2/20 | 11/24/20 |
| **2.3.2** Update black box with details of components | Francisco, Saud, Carlos | 100% | 11/6/20 | 12/4/20 |
| **2.4 Project Description (First Draft)**<br>Start a rough draft of the proposal | Marco, Carlos | 100% | 10/9/20 | 10/19/20 |
| **2.5 Perfomance Analysis**<br>Compute values based on results of research | Marco, Carlos, Francisco | 100% | 10/30/20 | 12/12/20 |
| **2.5.1** Get remote access viewing for hydrogen station monitoring | Marco | 100% | 11/11/20 | 11/18/20 |
| **2.5.2** Collect data from hydrogen station during standby hours and high tempertures | Marco | 100% | 11/18/20 | 11/24/20 |
| **2.6 Fall Semester Report**<br>Build a report from our current research, concepts and analysis | Saud, Martin, Marco, Carlos, Francisco | 100% | 11/11/20 | 12/12/20 |
| **2.6.1** Build techincal information based on research and concepts | Martin, Francisco | 100% | 11/20/20 | 12/2/20 |
| **2.6.2** Provide an introduction, summary, WBS, conclusion | Marco, Carlos | | 11/20/20 | 12/2/20 |

# Approach 15.2: Organization

- The third phase of this project was modeling.
- During this phase, a lot of testing, math, and extra research was done.
- We used Simulink as the main platform for our testing and simulation
- we wanted to implement everything we learned in the previous two phases and implement it in simulation.
- At this point, our simulated model worked fine.

| Phase 3 - Modeling | | | | |
|---|---|---|---|---|
| **3.1 Research Modeling Backup System**<br>Begin researching FCEV system modeling | Martin, Marco, Carlos, Francsico | 100% | 1/29/21 | 2/19/21 |
| **3.1.1 Literature review for FCEV modeling in Simulink**<br>research simulink projects and university projects for a typical FCEV | Marco, Francisco | 100% | 1/29/21 | 2/12/21 |
| **3.1.1.1 Fuel Cell, Inverter, and Battery parameters**<br>investigate required parameters used in Simulink taken from commercial FCEVs | Martin, Carlos | 100% | 1/29/21 | 2/12/21 |
| **3.1.1.2 Pre-made FCEV system model for Simulink**<br>investigate for any pre-made simulink FCEV model from databases, journals, or software library to build a standard foundation | Marco, Francisco | 100% | 1/29/21 | 2/12/21 |
| **3.2 Modeling Emergency Back up System**<br>Using the parameters and base model, design the system for the Hydrogen Station | Marco, Francisco, Carlos | 100% | 2/12/21 | 4/11/21 |
| **3.2.1 Implement Base Model Simulation**<br>Modify the base model to a working emergency back up system to power the Hydrogen Station | Marco, Fransisco | 100% | 2/12/21 | 3/21/21 |
| **3.2.1.1 Implement Parameters Simulation**<br>Use parameters from commecial FCEVs and Hydrogen Station with modified | Marco | 100% | 3/21/21 | 4/2/21 |
| **3.2.1.2 Changelog System**<br>Note take modifcations made to the pre-made mode. Establish a collection of changelogs and notes to have a report of the modified model. | Carlos, Francisco, Marco | 80% | 2/12/21 | 4/11/21 |
| **3.3 Optimization of Model**<br>research optimal back up systems in terms of power efficiency or cost efficiency | Marco, Fransisco | 100% | 4/2/21 | 4/11/21 |
| **3.3.1 Scaling of Model** | | | | |

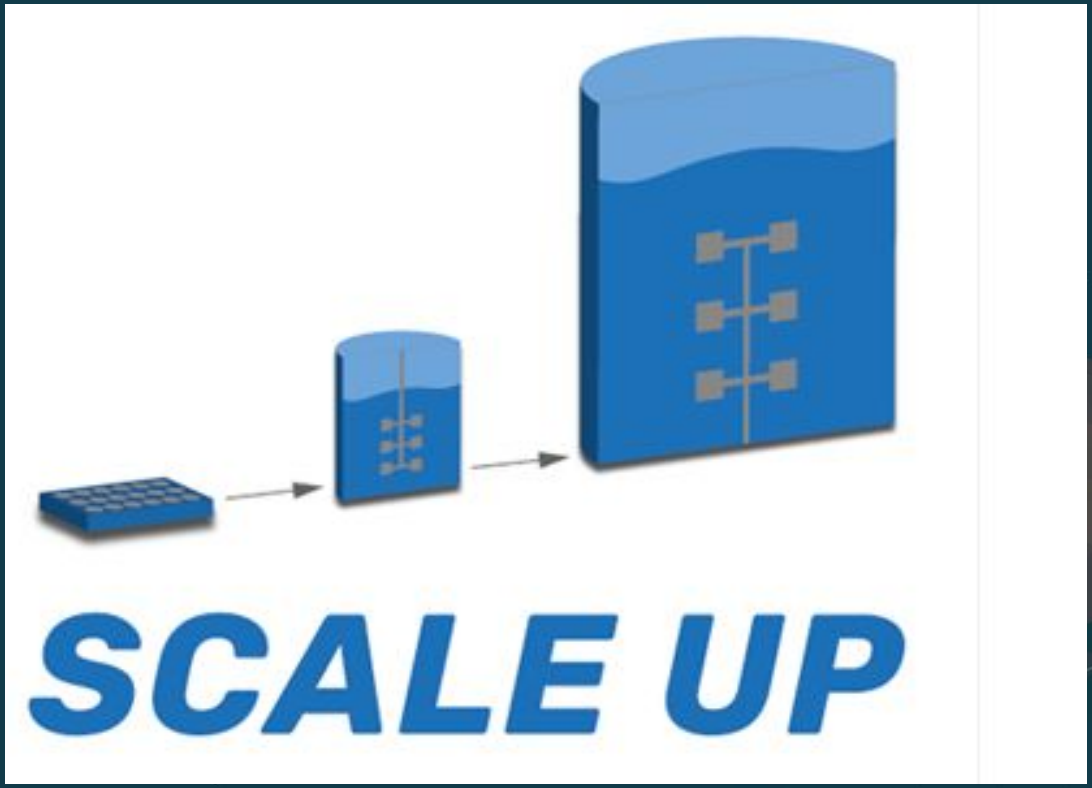
# Approach 15.2: Organization

- The fourth and last phase was about putting everything together for the final report.

| Phase 4 - Final Report | | | |
|---|---|---|---|
| **4.1 Rough Outline for Video Presentation**<br>Create an outline for presentation from previous and current semester | Fransisco, Martin, Marco, Carlos | 3/24/21 | 4/16/21 |
| **4.1.1 Edit and assign presentors for video**<br>Have team members take roles best suited for them to presenting in a Zoom meeting | Carlos, Marco | 3/24/21 | 3/31/21 |
| **4.1.1.1 Record video segments from presentors**<br>have team members record takes for the best perfomance. Then, someone will edit the segments based on the information given by the presentor. | Carlos, Marco, Fransisco | 3/31/21 | 4/16/21 |
| **4.1.1.2 Edit video segements into video presentation**<br>create a structured video based on the outline and the segments and edit anything unrelated or time comsuming out of the video. | Carlos | 3/31/21 | 4/25/21 |
| **4.2 Rough Outline for Final Report**<br>build a rough outline that includes last semester's work into an outline | Martin, Francisco, Marco, Carlos | 3/24/21 | 4/4/21 |
| **4.2.1 Edit Outline for Final Report**<br>edit in new information and old information from the project for the final report. | Martin | 4/4/21 | 4/25/21 |
| **4.2.2 Estimate Costs Analysis**<br>Add a cost analysis to estimate the costs of the system | | | |

# Approach 15.2: Scaling

- An important part of the approach was using the theory of scaling.
- In electric circuits, full scale circuits can be complex to understand at times.
- The system consists of multiple elements that need to be analyzed one by one.

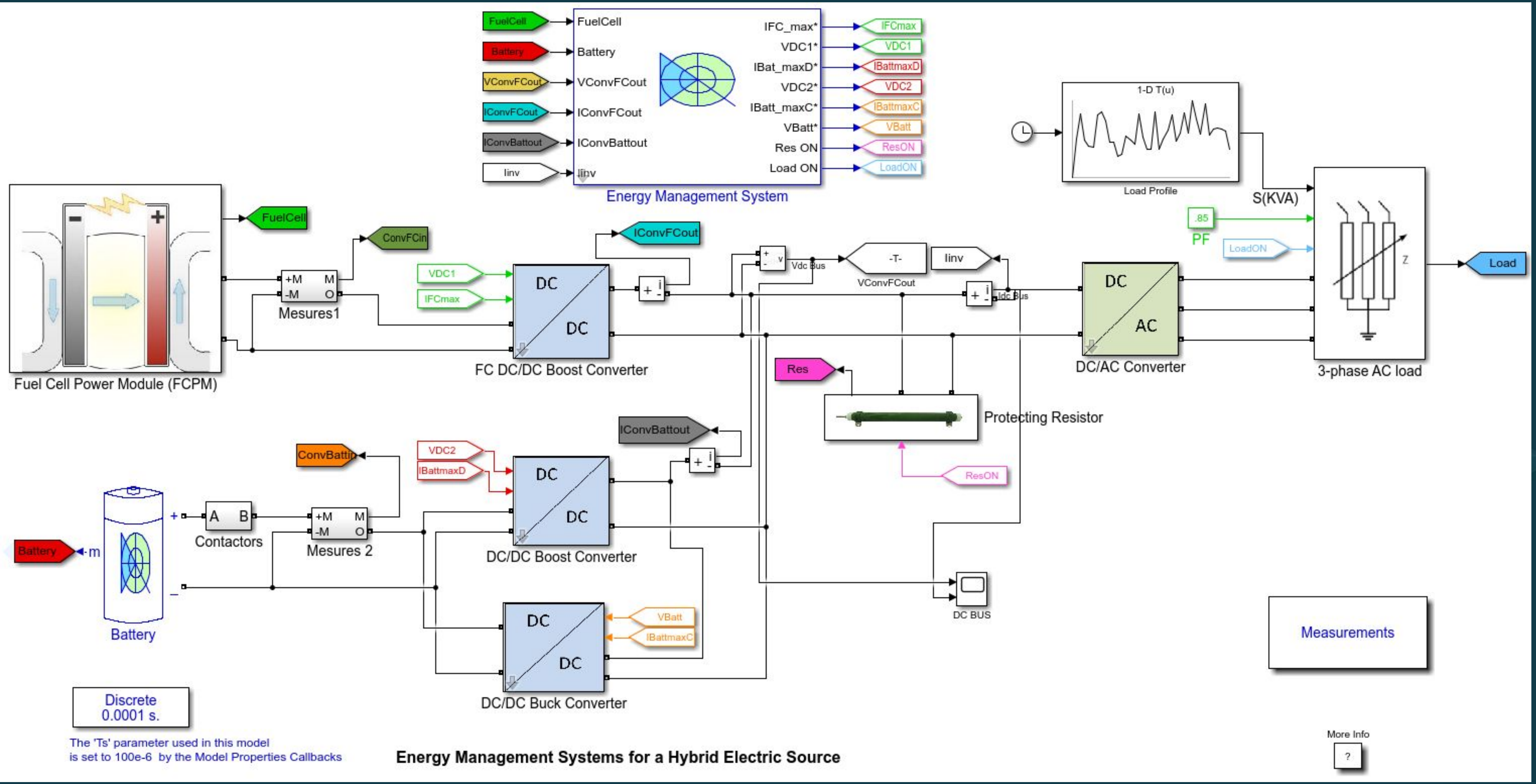


# Simulink Modeling 15.1

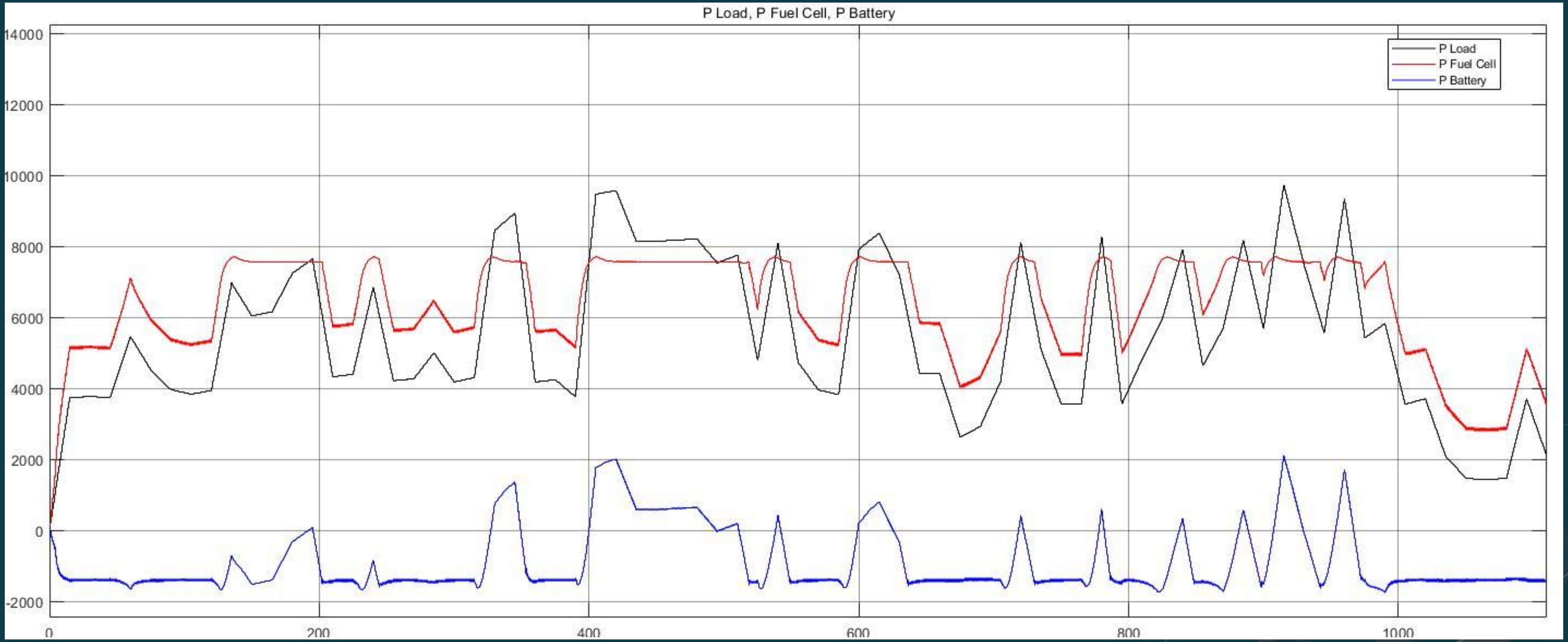
The Simulink model for Team 15.1

It uses an 8kW fuel cell and a 4kWh battery.

It is reduced to 1/10 scale of actual size.

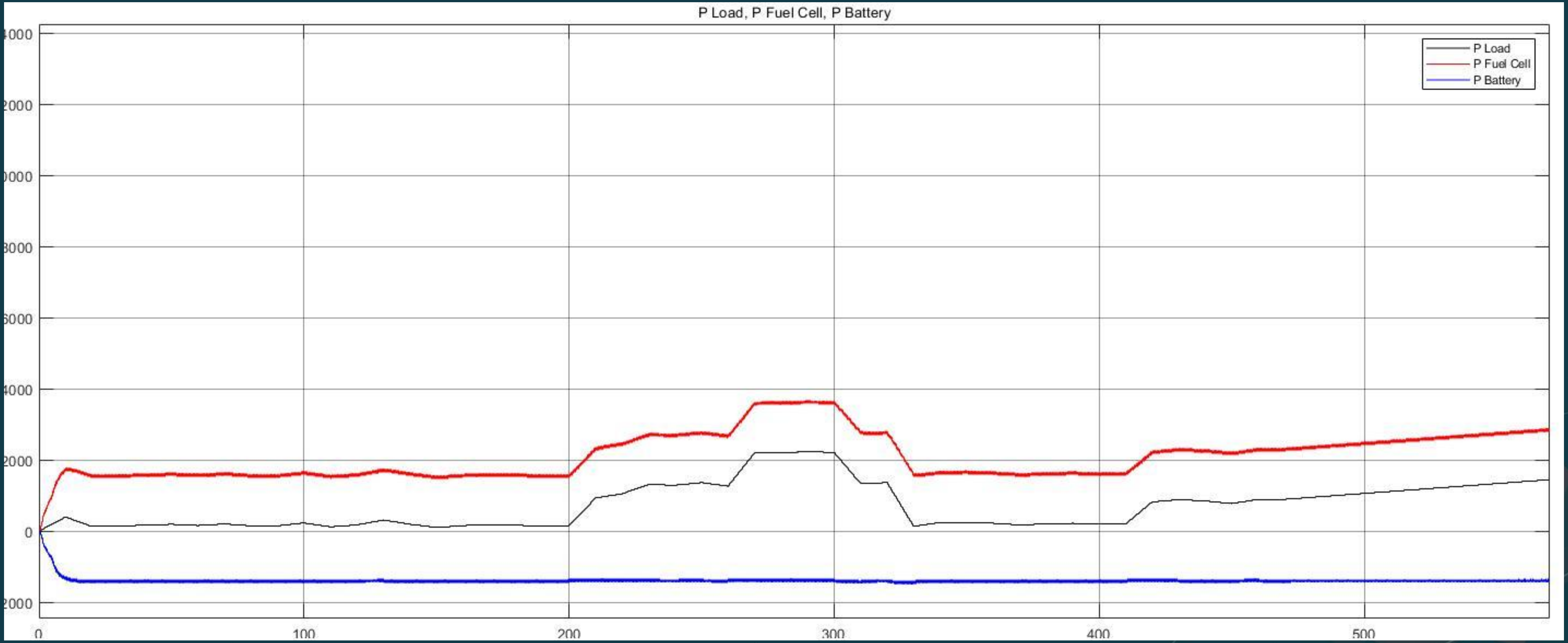


# Simulink Modeling 15.1




An example power output graph for the refueling process of the hydrogen station (black graph) being supplied with power from the fuel cell (red graph) and the battery (blue graph)

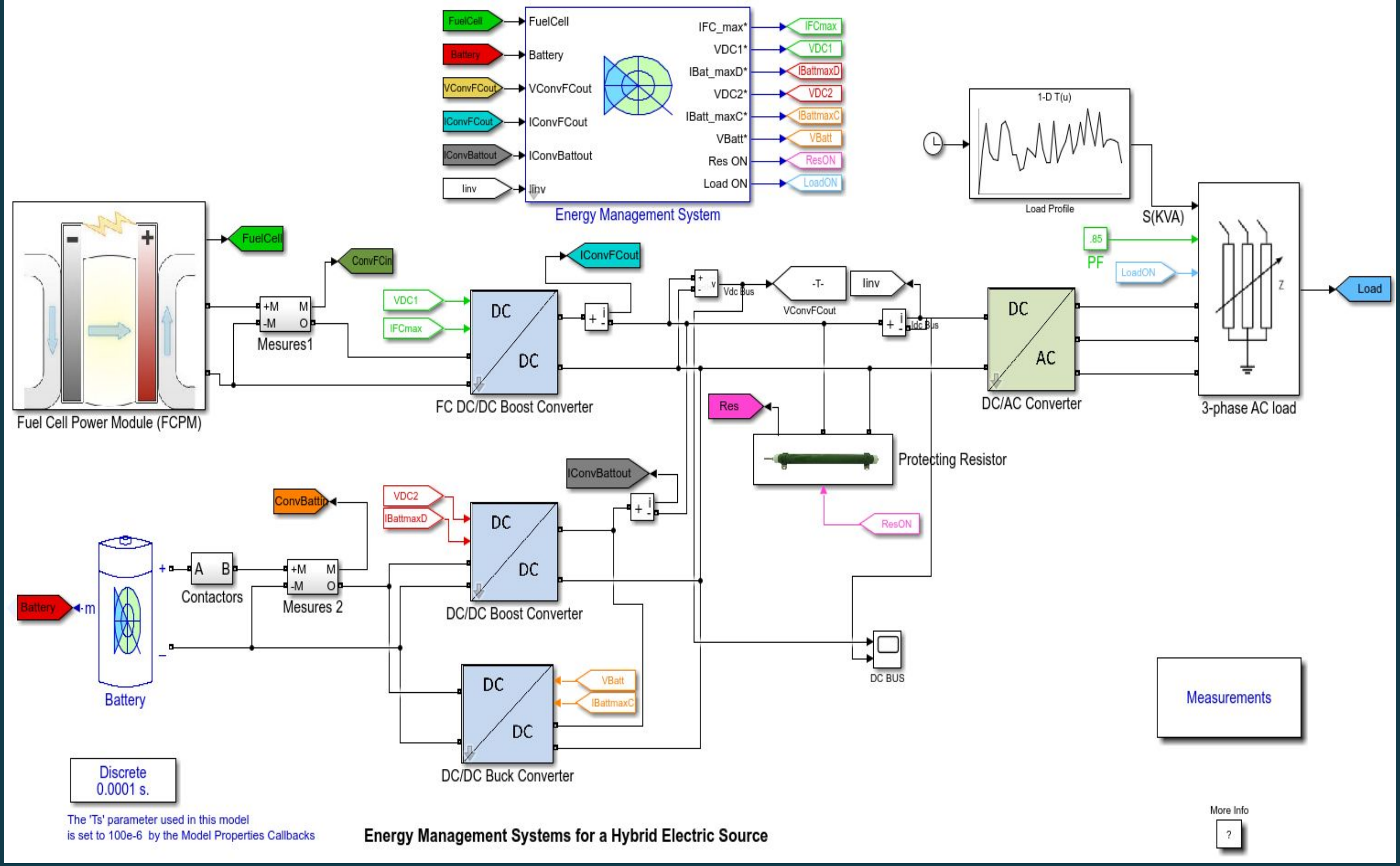
# Simulink Modeling 15.1




An example power output graph of the station on standby power.
The fuel cell is using its excess energy to recharge the battery.

# Simulink Modeling 15.2

- Modified a pre-built model provided by MathWorks, same as 15.1
- Minor differences in parameters in the following: Fuel cell, battery, converters, AC load, and Energy Management System
- The parameters will be based on the 2017 Toyota Mirai



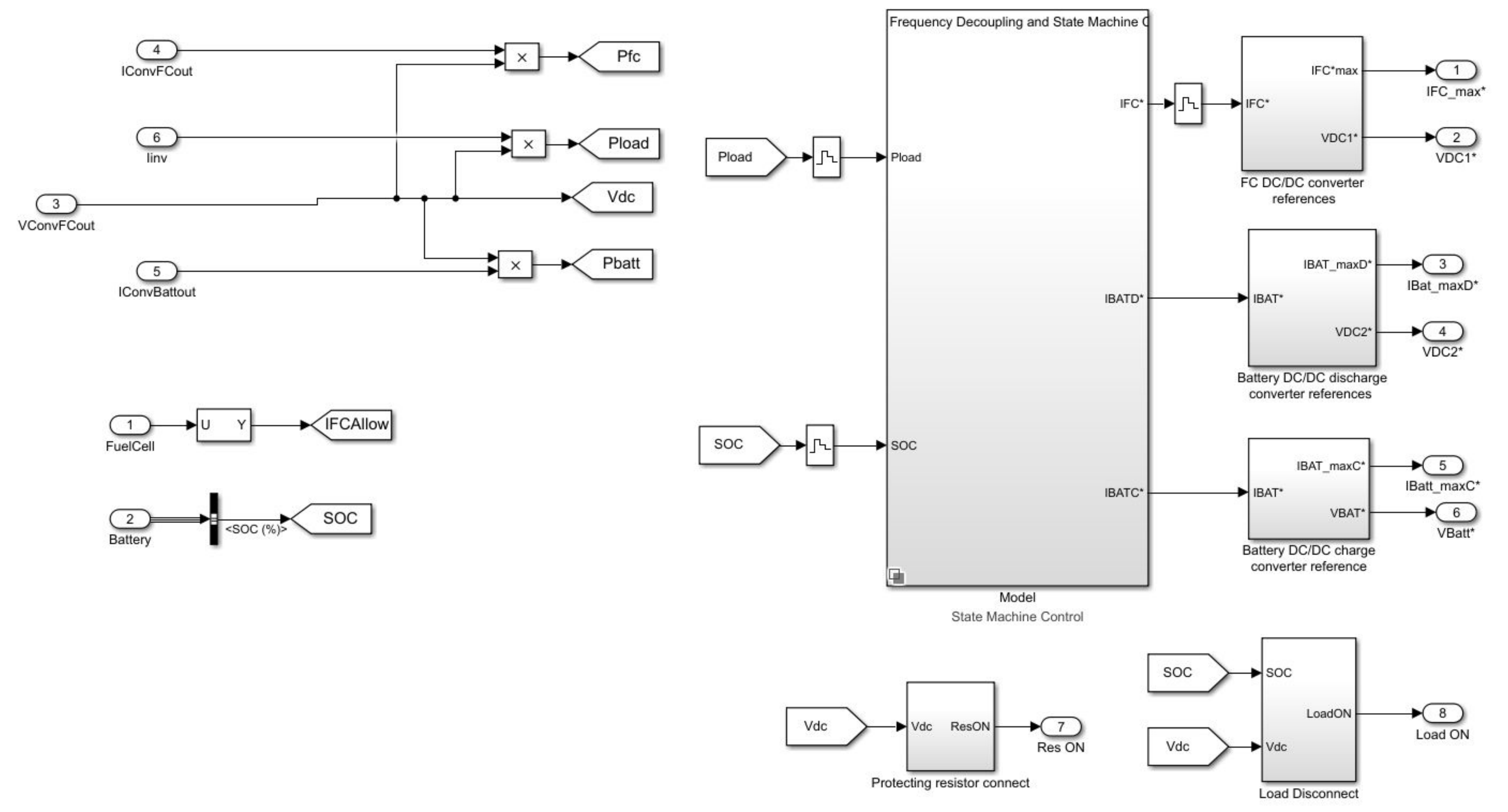
# Simulink Modeling 15.2

- To keep track, established an Engineering Change Log system with 15.1
- Keeps track of versions and people working on model
- Supplied with notes and changes made to the anyone accessing on that version

| | Simulink model name | Person(s) | Date | Changes | Notes |
|---|---|---|---|---|---|
| 1 | power_FCHPS_MEA_Fuelcell_complete_022221 | Carlos/ Marco | 02/22/21 | Uploaded FC values | |
| 2 | Simulink_HStation_0223 | Peter/Francisco | 02/23/21 | Updated Load Profile | |
| 3 | HStation_0224_rev1 | Carlos/Peter | 02/24/21 | Updated Battery, Capacitor, Converters, Inverter | |
| 4 | HStation_0224_rev2 | Peter/Francisco | 02/24/21 | Updated Breakpoints, Capacitor, Inverter | |
| 5 | CoolingSystem_0224 | Saud | 02/24/21 | --- | |
| 6 | HStation_0225_rev1 | Peter/Francisco | 02/25/21 | Updated Capacitor | |
| 7 | HStation_0226_rev1 | Peter/Carlos/Isaiah | 02/26/21 | Updated Fuel Cell, used 50kw preset to use amperage | |
| 8 | HStation_FCtest_50kw_0301_rev1 | Carlos/Marco | 03/01/21 | Experimented with Mirai data on PEM | |
| 9 | HStation_FCtest_50kw_0301_rev2 | Peter/Francisco | 03/01/21 | Updated breakpoints, removed wires to s.c., | |
| 10 | HStation_FCtest_50kw_0302 | Carlos/Marco/Martin | 03/02/21 | Updated fuel cell to create a linear power trend line and inverse volt/current relationship | |
| 11 | HStation_FC50kw_0304 | Francisco/Peter | 03/04021 | Updated breakpoints, updated inverter | |
| 12 | HStattion_0308 | Francisco/Peter | 03/08/21 | Fixed the SC problem. | |
| 13 | HStation_0310_rev1 | Martin/Marco/Carlos | 03/08/21 | Updated Battery parameters: discharge | |
| 14 | HStation_0309 | Carlos/Marco | 03/09/21 | fix the energy management system, more specifically to have power output match physical model | |
| 15 | HStation_0310_rev1 | Peter/ Carlos | 03/10/21 | No changes | |
| 16 | HStation_0310_rev2 | Peter/Francisco | 3/10/21 | Improved the load profile(still needs work) | |
| 17 | HStation_0311_rev1 | Martin/Marco/Carlos | 3/11/21 | revert changes to EMS, Flow rate, and load profile | need converter changes and proper measurement of Vdc |
| 18 | --------- | Carlos/Marco | 3/16/21 | nothing saved | |
| 19 | --------- | Peter/ Fran the Man | 3/16/21 | nothing saved | |
| 20 | HStation_0317 | Peter/ Franciscoolio | 3/17/21 | new file, inverter | Best to leave the EMS alone, leave sc for now, focus on getting the |
| 20 | HStation_0318 | Peter/ Franciscoolio | 3/18/21 | used breakpoints from 8/13 video in apparent power calcs | Time to start messing with the EMS tomorrow! Good luck. |
| 21 | HStation_0321_rev1 | Peter/Isaiah | 3/21/21 | used model from 3/10 and properly input the Vdc measure tool. Reduced breakpoints to 1/10 scale. Probably some other stuff too, but forgot to make a changelog | This seems to work at the size it's running at. If Royer and Franscio |

# Simulink Modeling

- The Energy Management System, EMS, controls load, voltage bus, current, and the SOC.
- Frequency Decoupling and State Machine controls the current and voltage outputs for the DC-DC converters.
- The DC-DC converters decide the voltage and current outputs if the EMS is “on” or “off”
- Load Disconnect controls the EMS and load profile
- Protecting resistor controls the DC voltage going into the inverter

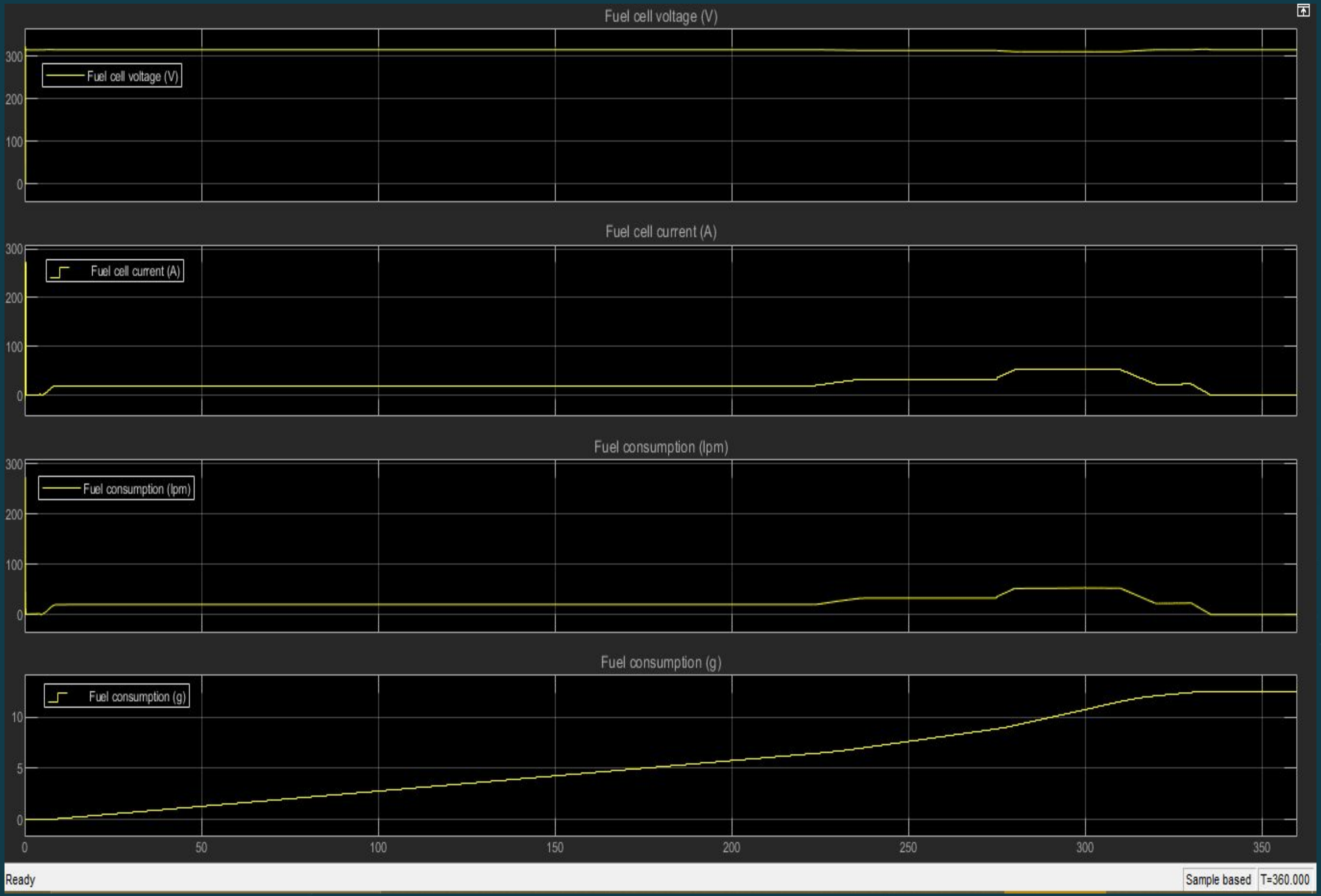


# Simulink Modeling 15.2

- The full-scaled power chart has the Fuel cell (blue), Load (yellow), and Battery (orange)
- Load profile (yellow) is Standby chart at 6 minutes
- Fuel cell is the primary power source, battery helps at certain peaks

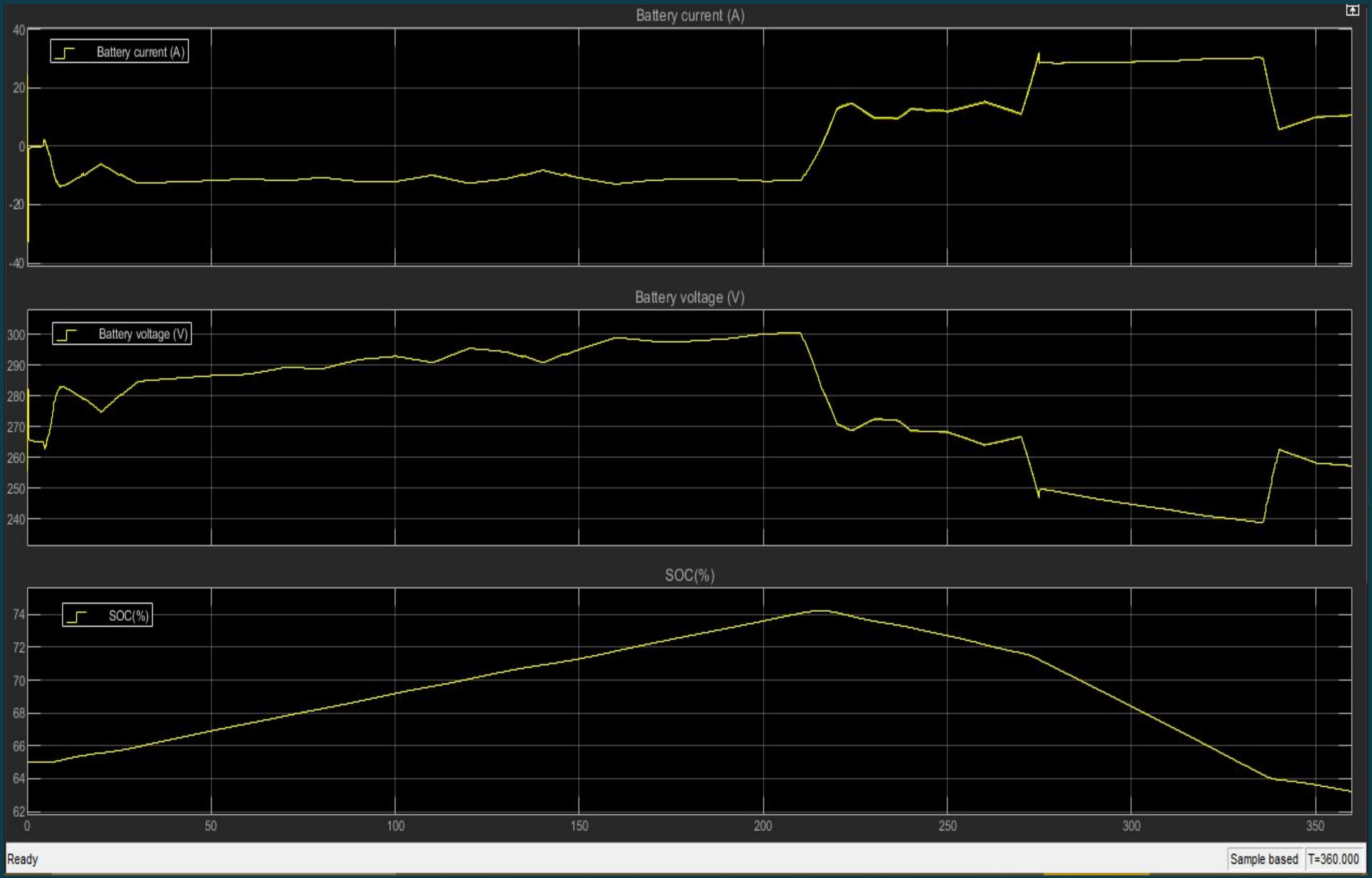
# Simulink Modeling 15.2

- The full-scale fuel cell at Standby is constant high voltage up to 315V and low current at 19A.
- Fuel consumption ranges from 19lpm to 53lpm, at the end consuming 12.48g
- Four separate charts: Fuel cell Voltage (V), Fuel Cell Current (A), Fuel Cell Consumption (lpm), Fuel Cell Consumption (g)



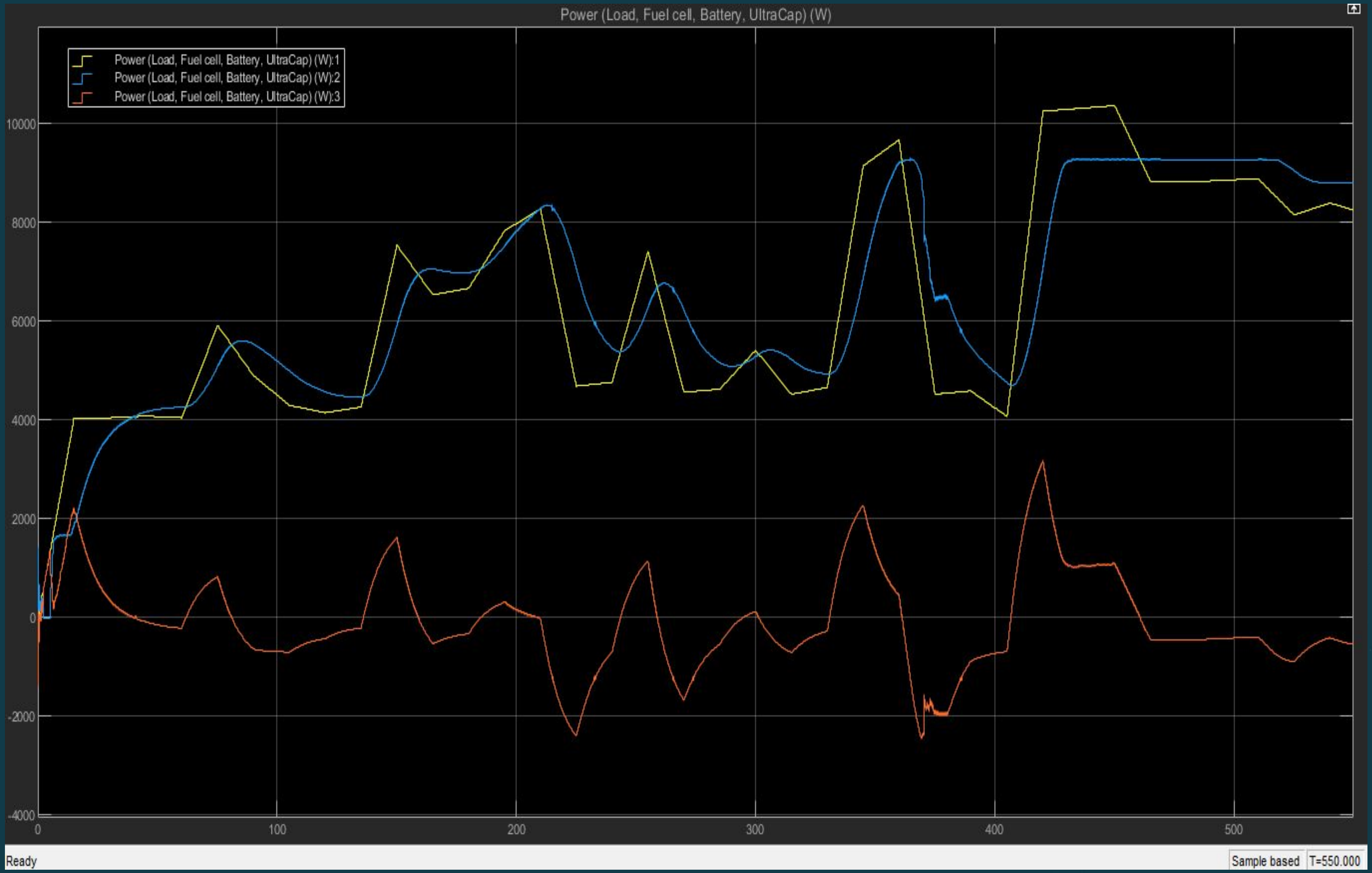
# Simulink Modeling 15.2

- Full-Scale Battery is generally charging for most of the run
- Current is below 0 and Voltage us above 265 V for majority of the run
- SOC reaches up to 74% and ends at 63%
- Three separate charts: Battery Current (A), Battery Voltage (V), Battery SOC (%)



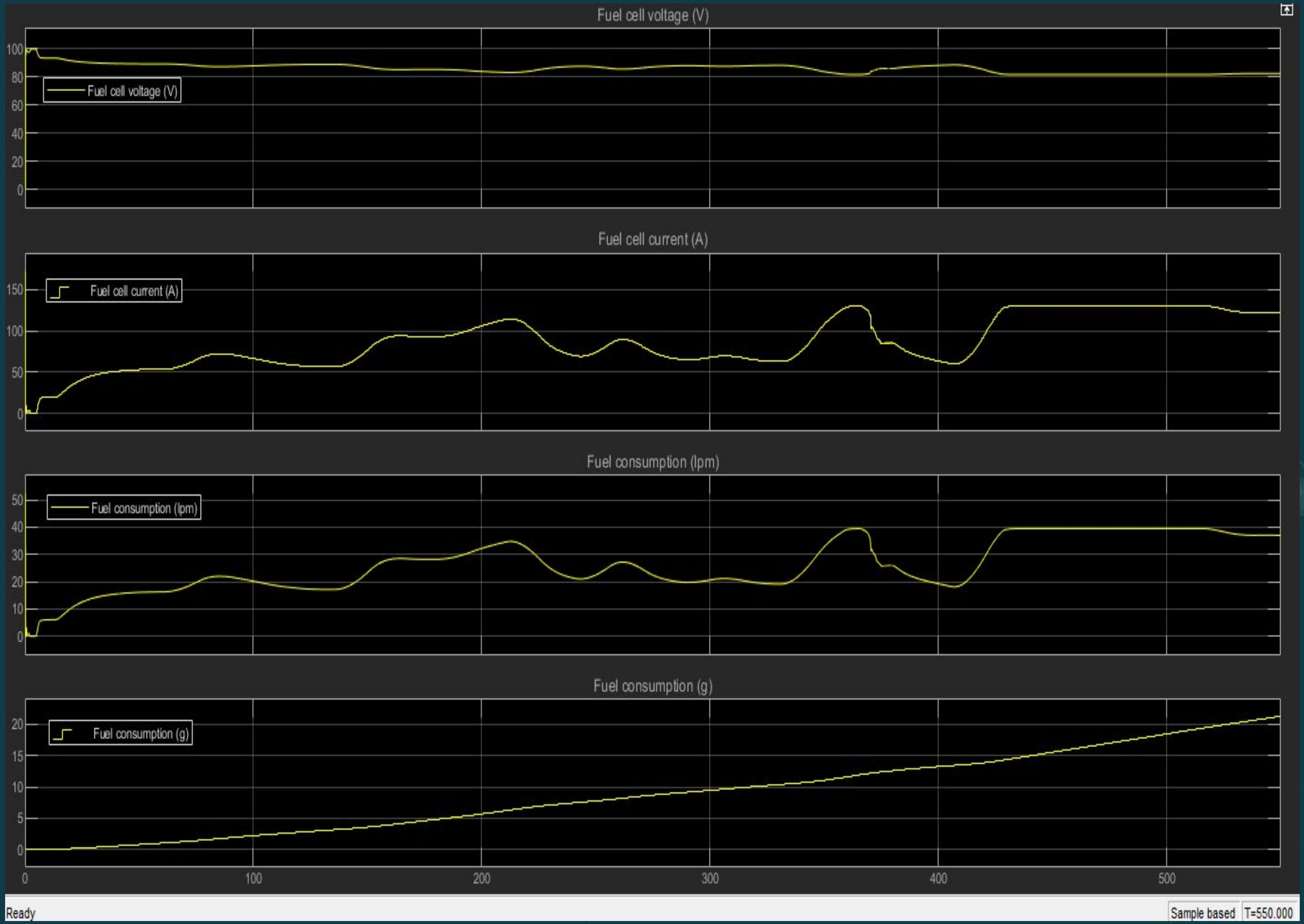
# Simulink Modeling 15.2

- One-tenth version of fueling power chart of the load (yellow), fuel cell (blue), and battery (orange).
- Scaled fuel cell tries to maintain a constant source of power to load but fluctuates
- Scaled battery helps fuel cell in immediate spikes in power



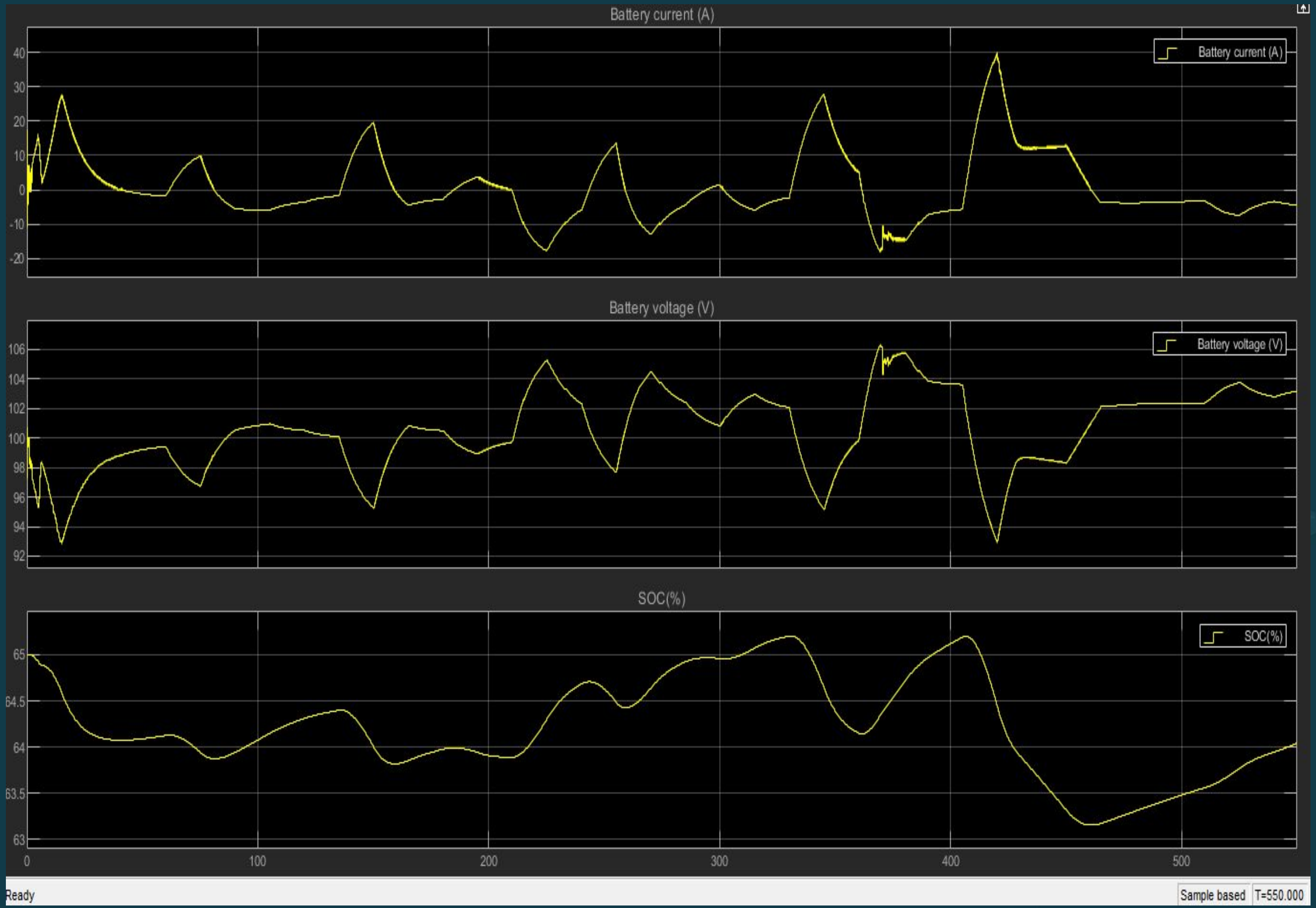
# Simulink Modeling 15.2

- The scaled fuel cell has increased current going up to 127A and the voltage decreasing to 82V
- Voltage oscillates in response to demanding load
- Scaled fuel consumption goes up to 40lpm and ends consumption at 26.3g
- Four Separate charts: Fuel Cell Voltage (V), Fuel Cell Current (A), Fuel Consumption (lpm), Fuel Consumption (g)



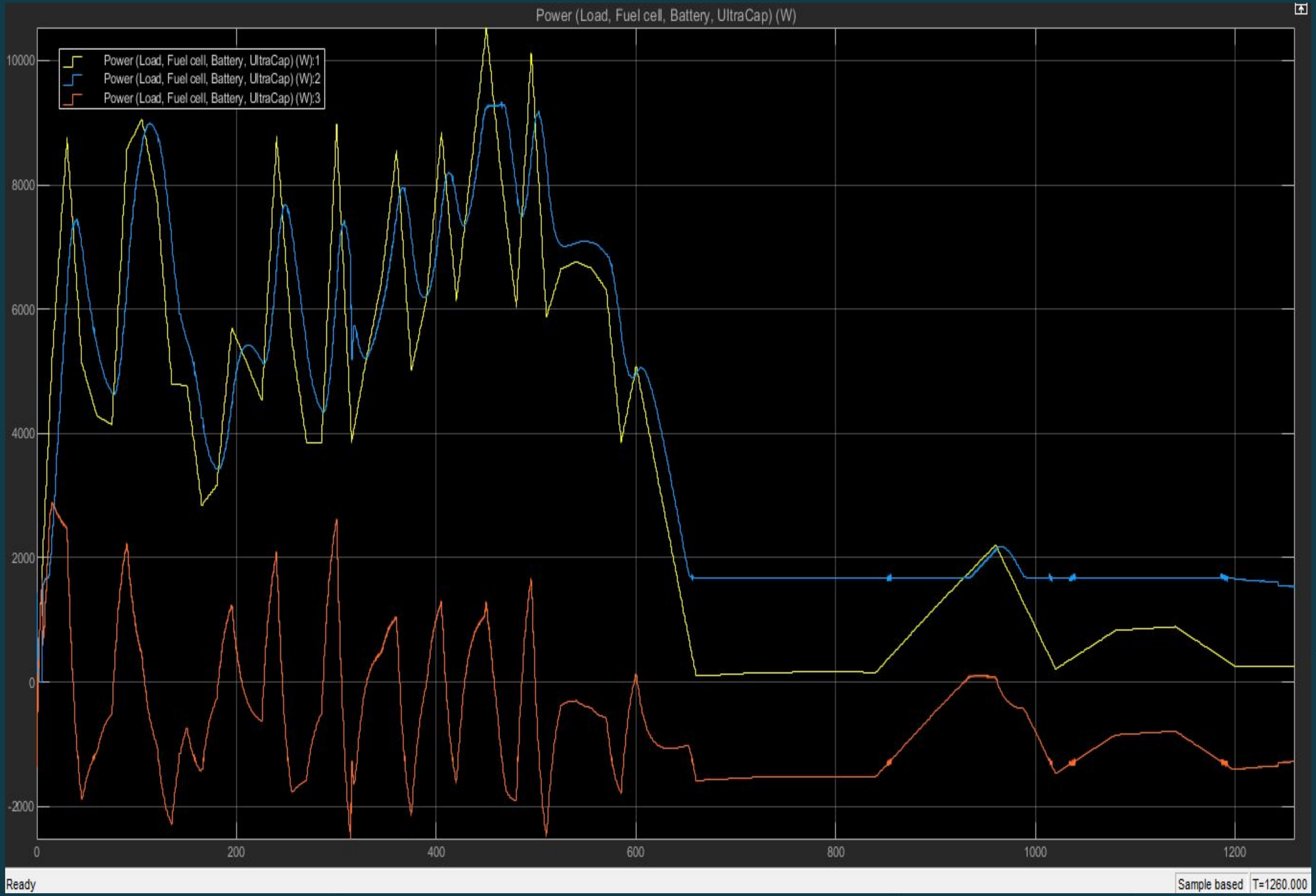
# Simulink Modeling 15.2

- The scaled battery discharges frequently
- Current peaks at 39A and voltage dips to 92V
- SOC peaks at 65.3% and the SOC at the end is at 63.99%
- Three Separate charts: Battery Current (A), Battery Voltage (V), Battery SOC (%)



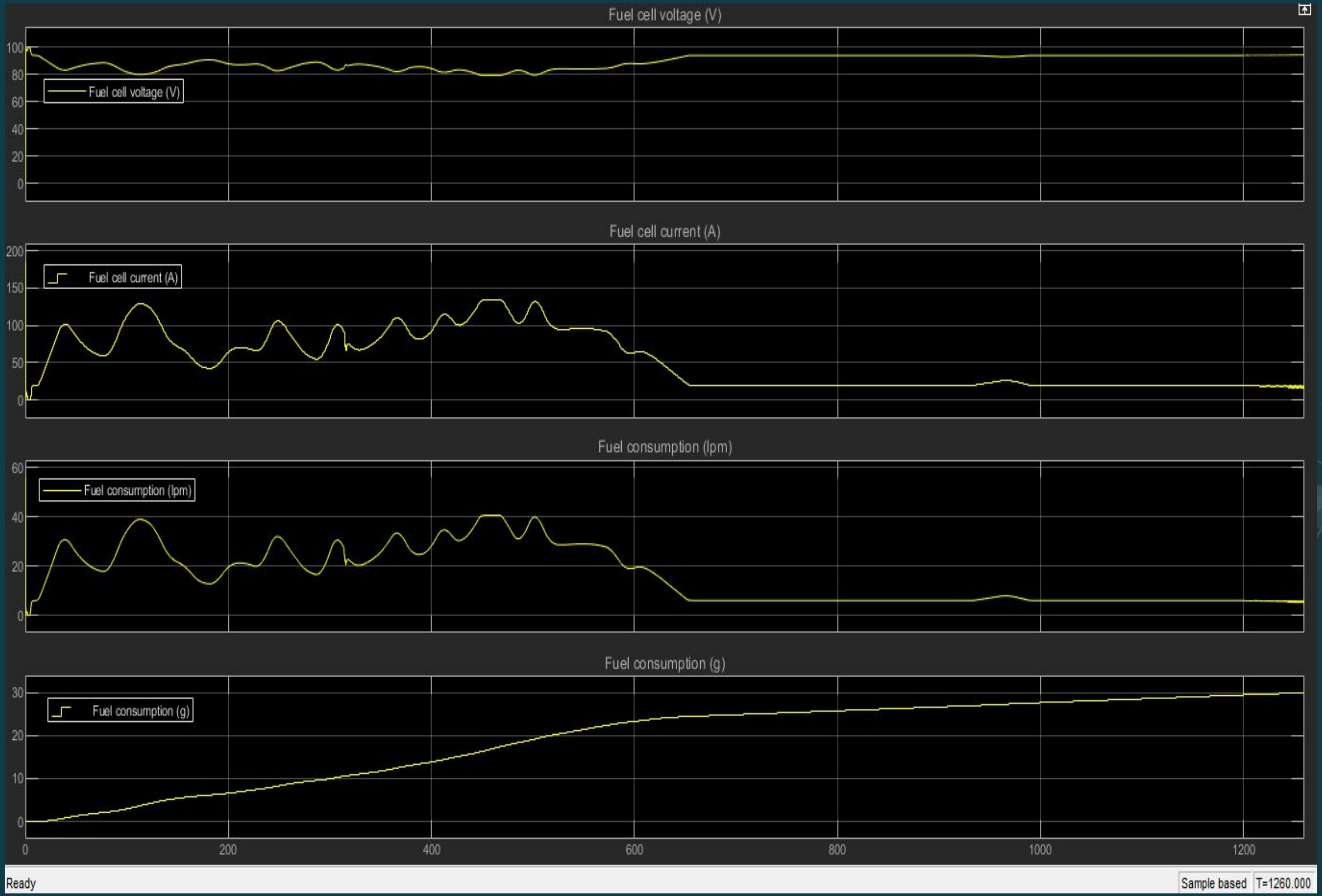
# Simulink Modeling 15.2

- Realistic scenario of fueling two FCVs back-to-back for five minutes each and 10 minutes of standby.
- One-tenth scaled power chart shows the behavior of fueling and standby
- Load (yellow), Fuel Cell (blue), Battery (orange)



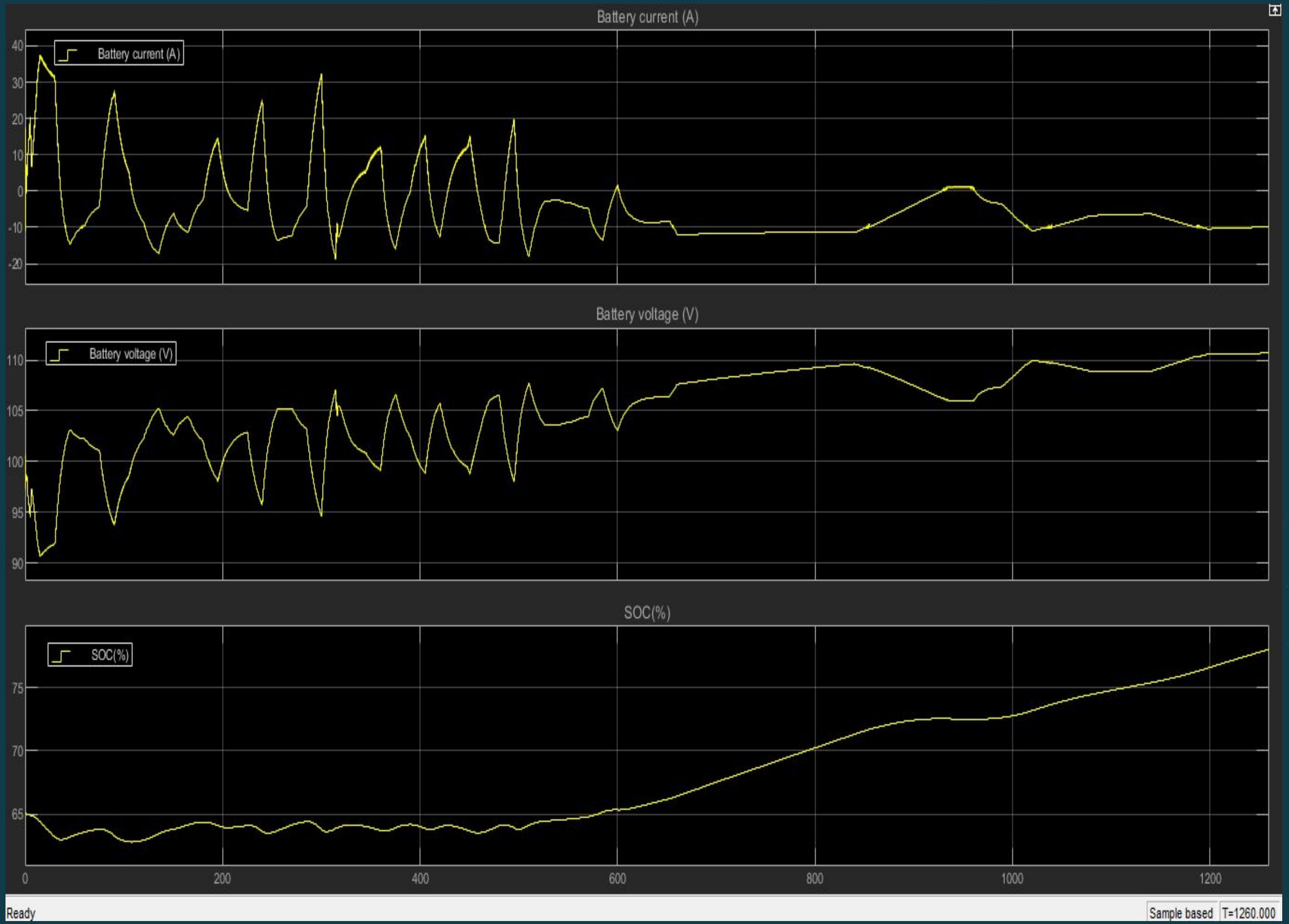
# Simulink Modeling 15.2

- The scaled-down fuel cell shows similar behavior from fueling for the first 10 minutes, current reaches up to 132A and voltage dips to 79V.
- The last ten minutes of standby shows constant high voltage at 94V and low current at 20A.
- Fuel Consumption during fueling ranged between 20lpm to 40lpm. For standby, it drops to a constant 6lpm
- For the entire run, the fuel consumption ends at 29.92g
- Four separate charts: Fuel Cell Voltage (V), Fuel Cell Current (A), Fuel Consumption (lpm), Fuel Consumption (g).



# Simulink Modeling 15.2

- The scaled-down battery shows similar behavior to fueling and standby
- For fueling, current peaks up to 37A and voltage dips to 90V. For standby, current dips to -12A and voltage peaks to 107V.
- The SOC during fueling oscillates between 63% to 65%. For Standby, the SOC reaches to 78.07% at the end of the 20-minute run.
- Three Separate charts: Battery Current (A), Battery Voltage (V), Battery SOC (%)

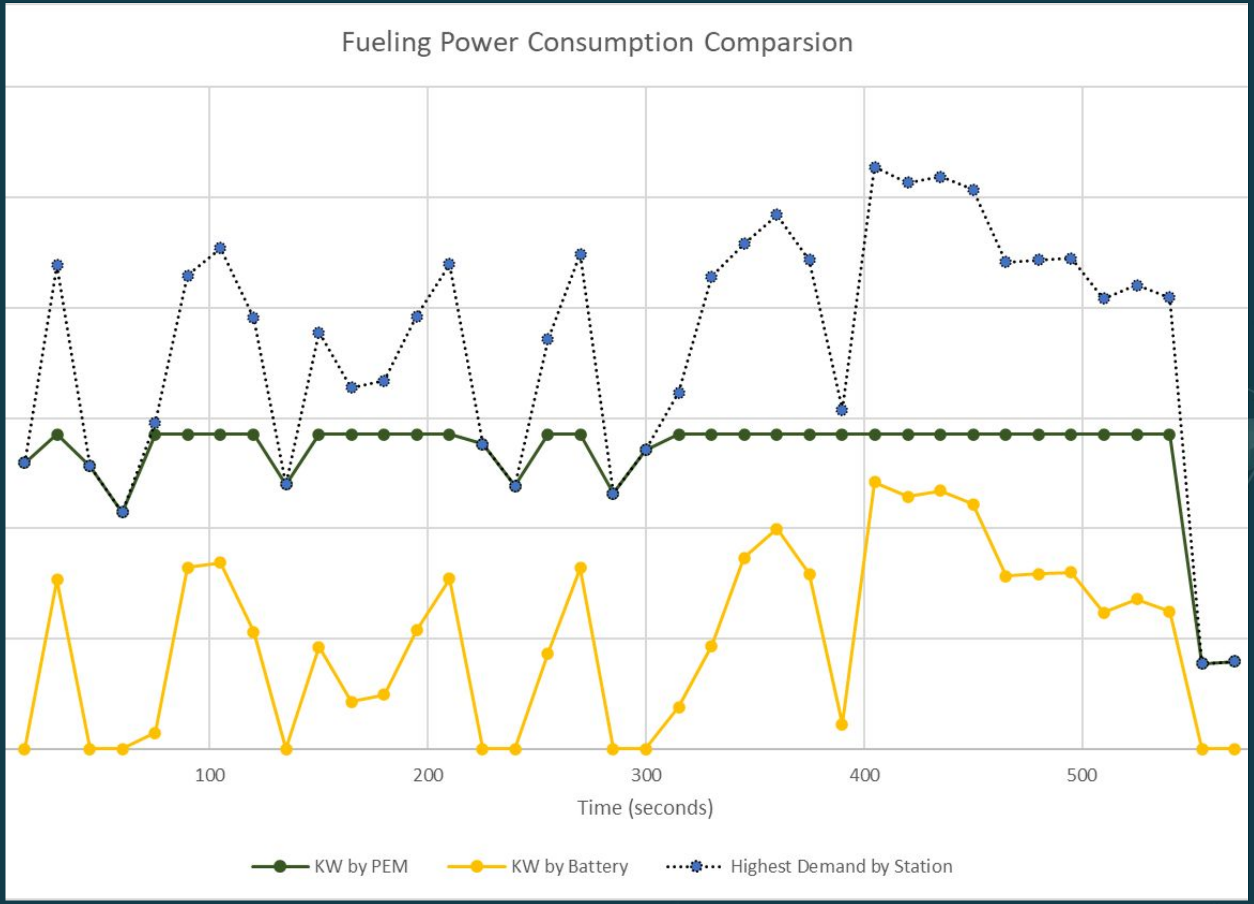


# Product Concept 15.2: Requirements

- The fuel cell system will provide sufficient power to the hydrogen station to support fueling operation for as long as stored hydrogen is available

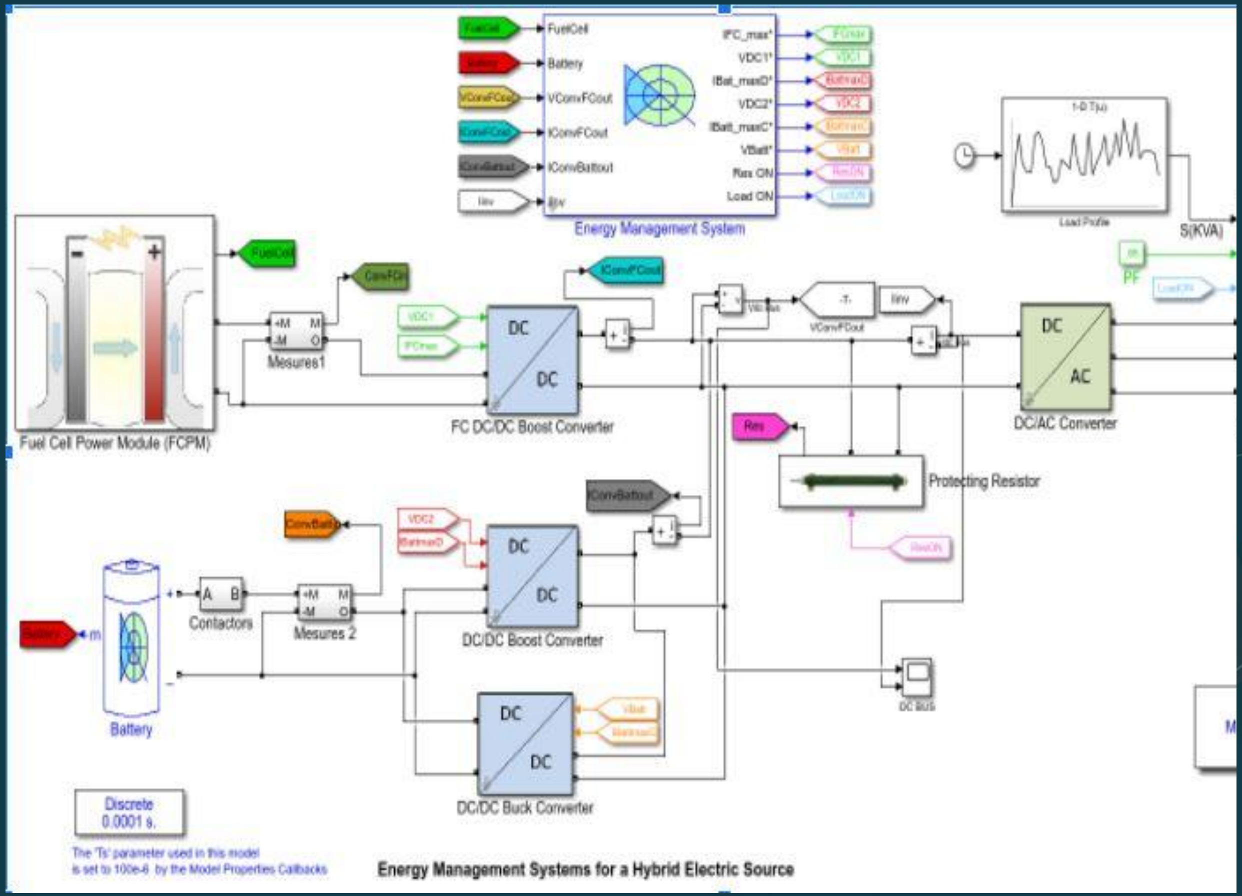
# Product Concept 15.2: Requirements

- The team was able to collect information regarding the power consumption of the Hydrogen Station.
- The demand during fueling in kW by the Hydrogen Station In the blue dots line
- The Fuel Cell will have to be active to its maximum capacity during fueling
- This battery will compensate for whatever load the fuel cell can not output



# Product Concept 15.2: Architecture Overview

- The Back up system consisted of a fuel cell, a battery, two dc to dc boos converters, a buck converter, and a inverter.
- the voltages from both power sources are different
- Which is why we need a DC to DC boost converter.



# Scaling 15.2: Calculations.

$$Peak\ Power = 110kW, Vrms = 480V, \qquad I_{average} = 229.2$$

$$ScaleDownAveragePower = 11.0kW$$

$$P = VI \rightarrow \frac{110}{10}kW = \left(\frac{1}{10}\right)VrmsI_{average} = \frac{Vrms}{\sqrt{10}} \times \frac{I_{average}}{\sqrt{10}}$$

$$V = \frac{480}{\sqrt{10}} = 151.8V \ \leftrightarrow I = \frac{229.2}{\sqrt{10}} = 72.5A$$

$$V_{LL} = \sqrt{3} \times V_{LN}$$

$$V_{LN} = \frac{V_{LN}}{\sqrt{3}} = \frac{151.8}{\sqrt{3}} = 87.07V = V_p$$

$$V_p = V_{ratio}V_{DC} \rightarrow V_{DC} = (V_p/V_{ratio}) = (\frac{87.07}{0.7405}) = 117.6V_{DC}$$

# Scaling 15.2: Calculations.

$$V_{DC} = V_{fc} \times BoostRatio \rightarrow \; V_{fc} = \left(V_{fc}/BoostRatio\right) = \left(\frac{117.6}{1.31}\right) = 89.8V$$

$$V_{Batt} = \frac{V_{dc}}{BoostRatio} \rightarrow \frac{117.6}{1.29} = 91.4V$$

# End-of-Life Economic Sense

- Why repurpose fuel cell technology?
  - The end-of-life economics
  - Challenges facing fuel cell technology
    - Lack of hydrogen infrastructure
    - High manufacturing costs of fuel cell technology
- Vehicle comparison
  - 2017 Toyota Mirai vs. 2017 Toyota Prius
    - Share the high voltage system
    - DO NOT share an estimated $35,000 fuel cell system

# End-of-Life Economic Sense

- Cost Distribution of fuel cell system
  - Based on an article provided by Olivier Bethoux, a Fuel cell system with a net power of 80kW
    - 50% of cost distribution ⟶ Fuel cell stack
  - Compared the Toyota Mirai's fuel cell system with a net power of 114kW
    - similar fuel cell system net power ⟶ 50% of cost distribution ⟶ Fuel cell stack
- Cost Distribution of fuel cell parts
  - Based on the fore-mentioned article, the fuel cell stack has multiple layers creating the actual fuel cell stack
    - 51% of cost distribution ⟶ Active layer, which contains all the needed Platinum [Pt] to complete the chemical reaction

# End-of-Life Economic Sense

- Platinum
  - Supply at risk due to its scarcity and geographically poor distribution
  - Extraction of platinum is difficult has a large environmental footprint, which explains for Platinum’s high prices
    - Emissions of sulfur dioxide
    - Emissions of $CO_2$ equivalent to 13,000 tons per ton of platinum
    - Excessive water & energy consumption
    - Habitat destruction & solid waste
    - Air & water pollution
    - Harsh mining conditions
  - Critical to establish a repurposing and recycling process to satisfy the industry’s needs

# End-of-Life Economic Sense

Repurpose Process:

1. Collection
   a. An end-of-life lease fuel cell vehicle
   b. Salvaged fuel cell vehicle, if all fuel cell components are in good state
   c. Perhaps a used for sale fuel cell vehicle, if the price is right & near its EOL
2. Dismantling
   a. Isolate and de-energize high voltage system
   b. Manually remove all components to prevent any damages to the fuel cell components
   c. Have car on a lift, first the subframe and suspension is removed, then the fuel cell components and needed parts can be easily accessed

# End-of-Life Economic Sense

Repurpose Process:

3. Disassembly, pre-processing, and material recovery
   a. All the needed components from high voltage system to fuel cell components have been removed
   b. What is left over of the fuel cell vehicle is turned over to a junkyard for further disassembly, pre-processing, and material recovery

Recycling Process

- Follow same steps as repurposing
- Requires additional steps in dismantling, in order to acquire the platinum metal groups from the fuel cell stack

# 5. TOYOTA MIRAI

| | | |
|---|---|---|
| **Fuel Cell Stack** | Max Power Output: | 114 kW |
| | Volume Power Density: | 3.1 kW/L |
| | Consumption: | .76 kg/100 km |
| | Number of Cells | 370 |
| **Battery:** | Material: | Nickel Metal Hydride |
| | Energy Capacity: | 1.6 kWh |
| | Nominal Max Voltage: | 250 V |
| | Battery Power: | ~12.3kW |

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