SWARTHMORE COLLEGE · DEPARTMENT OF ENGINEERING

Hydrogen Fuel Cell Vehicle

Designing, Building, and Racing a Prototype Vehicle for the Shell Eco-Marathon Americas

Alexander Vasquez-Jaffe · Kimaru Boruett

Faculty Advisor: Prof. Carr Everbach

ENGR 090 Final Presentation · Spring 2026

AGENDA

What we'll cover today

01 — **Motivation & Goals**
Why Shell Eco-Marathon, what we set out to do

02 — **Theoretical Background**
PEM fuel cells; longitudinal vehicle dynamics

03 — **Requirements & Constraints**
Drivetrain, Electrical, Telemetry

04 — **Design Methods**
How we built each subsystem

05 — **Testing & Results**
Bench, road, and competition outcomes

06 — **Discussion**
Lessons learned, what to do next

Shell Eco-Marathon: Efficiency over Speed

The challenge

Complete a fixed course within a strict time limit while **minimizing energy use.**

Why this matters

First Swarthmore SEM entry since 2018 · first run with current vehicle

Goal: travel to the competition, pass technical inspection, complete a race.

9.6 miles	**35 min**	**16.4 mph**
Race distance	Time limit	Required avg speed

Pictured left to right: Izzy Hemler, Nora Jiang, Kinley Zangmo, Kimaru Boruett, Jano Vasquez-Jaffe, Mathew Shiley, Eric Chen, and Kaw Moo (students who attended SEM).

How we got to the start line

2018

Last SEM entry

Swarthmore's previous Shell Eco-Marathon appearance

PRE-2026

Groundwork

Carbon Fiber Testing (Justin Chai, Ben Horvat), Chassis, body, suspension (Nora Jiang, Matthew Shiley); steering & brakes (Jasper Mosley)

SPRING 2026

This E90

Full integration: Horizon H-1000XP drivetrain, rebuilt safety circuit, and new race-strategy + telemetry platform.

APR 7–11, 2026

SEM Americas, Indianapolis

Drove the vehicle from Swarthmore to Indianapolis Motor Speedway, passed technical inspection, ran on track.

PROJECT SCOPE

Three Subsystems, One Vehicle

DRIVETRAIN

Hydrogen Fuel Cell

Horizon H-1000XP PEM fuel cell, hydrogen delivery, hub motor & controller.

ELECTRICAL

Power & Safety

High-voltage stack distribution & 12 V accessory bus, safety circuit, sensors.

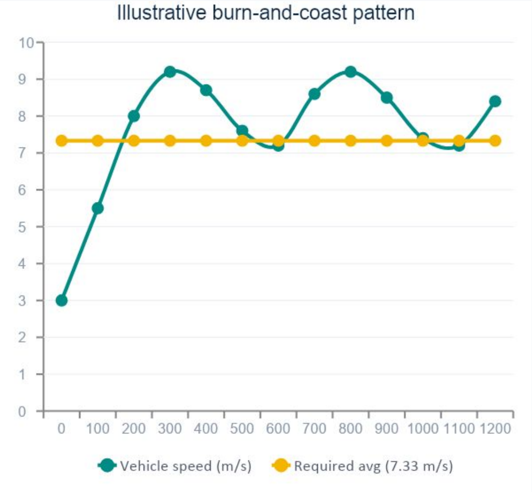
TELEMETRY

Strategy & Data

Burn-and-coast race plan, live dashboard, fuel-cell & IMU monitoring.

Out of scope (developed by other students): carbon-fiber chassis & body, steering & brakes

Race Strategy: Burn-and-Coast Physics



Why not just drive at constant speed?

Holding constant speed wastes energy fighting drag at the upper end, and constantly drawing power from the fuel cell.

Burn-and-Coast minimizes the cell's energy consumption.

Force balance

$ma = F\_drive - F\_aero - F\_roll - F\_grade$

Cornering limit: $v\_corner = \sqrt{(a\_y\_max / \kappa)}$

Hydrogen Drivetrain

Requirement	Description	Status
Hydrogen Delivery System	Cylinder, regulator, solenoid, relief valve, flow meter, tubing — meet SEM rules and feed fuel cell safely.	Met
Fuel Cell Integration	Mount and operate the Horizon H-1000XP; supply power to motor controller.	Met
Electric Drive	Hub motor + controller capable of moving the vehicle reliably under fuel-cell power.	Partially met

Key constraints · SEM Hydrogen Prototype rulebook · weight & packaging on a carbon-fiber chassis · pre-competition timeline.

Electrical System

Requirement	Description	Status
Safety System	Two e-stop buttons, solenoid valve, H2 sensor tuned to 25% LEL (1% H_2 in air)	Met
12 V Accesory System	Powers the safety system, horn, telemetry, and fuel cell controller and independent of the high-voltage stack	Met
Documentation	Clear schematics of all wiring and electrical components (including fuses, relays, controllers, etc)	Met
High Voltage System	Powers the motor controller and hub motor and is electrically isolated from the accessory system	Met

Constraints · variable fuel-cell voltage · parallel mechanical/electrical schedules · instant disqualification on safety circuit failures.

Telemetry System

Requirement	Description	Status
Track processing	Import GPS CSV → uniform-distance grid; estimate grade & curvature.	Met
Burn-and-coast simulation	Longitudinal force balance with cornering & power limits.	Met
Timing constraint check	Verify the 2,100 s event time limit is achievable in simulation.	Met (sim)
Fuel-cell live plotting	Stream stack V/I/P, temperatures, battery voltage to a browser dashboard.	Met
Sensor integration on car	Full GPS, CAN, throttle/brake mapping deployed on the race vehicle.	Partial
Full vehicle validation	End-to-end test of the telemetry stack on the live vehicle.	Not met

Total telemetry cost: $672 (open-source software, Raspberry Pi 5, GPS, 5G hat, CAN boards, batteries, DC-DC converters).

PEM Fuel Cell

Horizon H-1000XP PEM

- Purpose-built for SEM
- Replaces previous H-1000.

Proton Exchange Membrane (PEM)

$$2\ H_2 + O_2 \rightarrow 2\ H_2O + \text{electricity} + \text{heat}$$

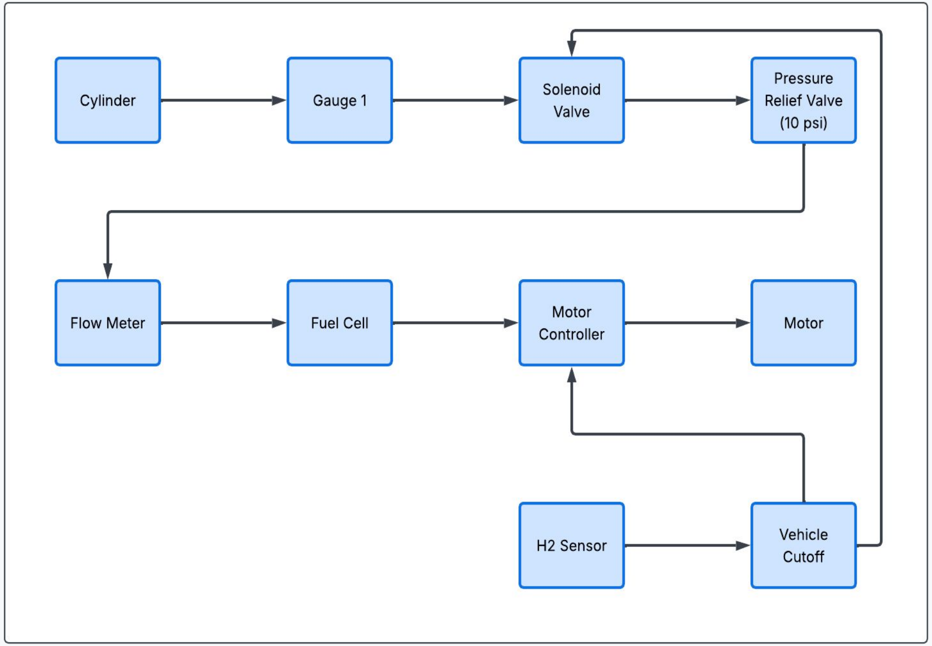
Why PEM for SEM?

- Low operating temperature
- Fast start-up
- High power density with variable voltage output that scales with load
- Well-suited to a lightweight prototype.

Horizon H-1000XP PEM FC

H2 Delivery & Electric Drive

Energy Supply Block Diagram



Energy supply block diagram submitted to SEM.

Hydrogen Delivery

- Gas cylinder → Fuel Cell
- Quarter-inch SS Swagelok tubing, Teflon lines, quick-connect into FC.

Electric Drive

- 1000 W hub motor
- 36 V, 25 A motor controller

H2 Delivery

H2 Sensor

Solenoid Valve

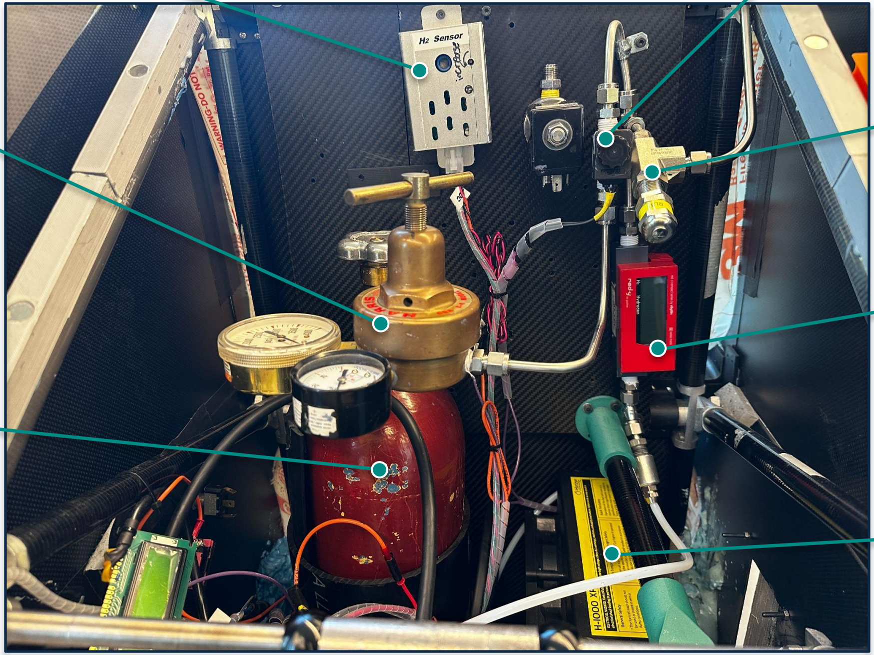
Pressure Regulator/ Gauge

Pressure Relief Valve

Flow Meter

Cylinder

Fuel Cell



Electrical & Safety System

Two-tier architecture

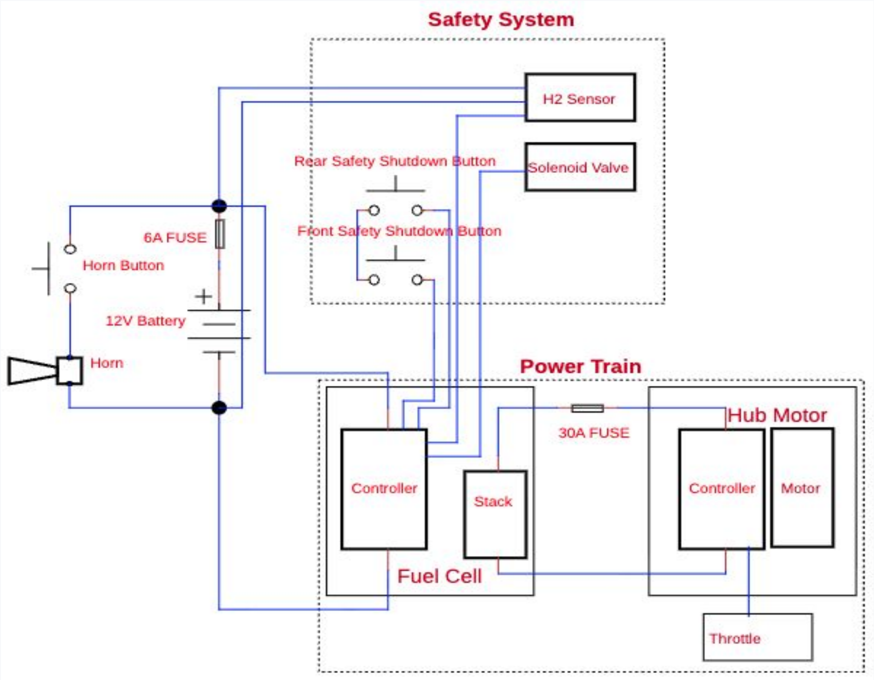
- High-voltage stack drives the hub motor; isolated 12 V bus powers safety, telemetry, horn, and FC controller.

Safety circuit

- Two latching E-stops added to the FC's existing positive/ negative loop.
- Normally-closed solenoid valve is wired directly to the FC controller.

Hydrogen sensor

- Tuned to 25% LEL using a calibrated H_2 test can.



Final vehicle wiring diagram.

Telemetry — Predictive Race Strategy

Pipeline (Python)

- Parse track CSV ⟶ cumulative distance grid ⟶ grade & curvature.
- Step distance-domain solver: integrate $u^2 + 2a \cdot ds$.
- Burn / coast controller switches based on speed thresholds and corner lookahead.

Why distance-domain?

Track features and corner limits are fixed in space, not time therefore solving in s avoids variable-step time errors.

CORE EQUATIONS

$$F_{res} = \tfrac{1}{2}\rho C_d A v^2 + mgC_{rr}\cos\theta + mg\sin\theta$$

$$a = (F_{drive} - F_{res}) / m$$

$$v_{(i+1)} = \sqrt{v_i^2 + 2 a_i \cdot ds_i}$$

$$F_{drive}(v) = \min(F_{max}, P_{drive,max} / \max(v, v_\varepsilon))$$

$$v_{corner}(s) = \sqrt{a_{y,max} / \kappa(s)}$$

$$v_{avg,req} = L_{event} / T_{max} = 15400 / 2100 \approx 7.33 \text{ m/s}$$

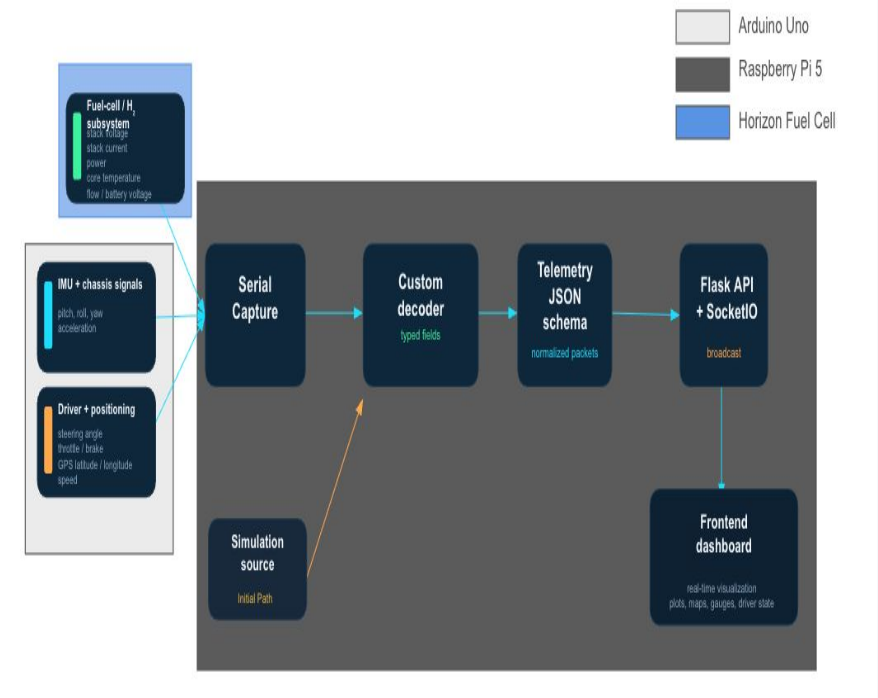
Telemetry — Live Dashboard & Bench Prototype

Software stack

- Flask + Socket.IO server pushes telemetry continuously to a browser dashboard.
- Categories: fuel cell status, vehicle dynamics, driver input, gps, weather (JSON Schema)
- Dual data path: simulator-generated payloads OR data packets from the vehicle

Hardware prototype

- Potentiometer ⟶ steering input; MPU6050 (IMU) ⟶ Vehicle Dynamics; buzzer ⟶ burn / coast cue.
- RS232 (USB) ⟶ stack V, I, P, temperatures, V_battery⟶ fuel cell status.



Telemetry architecture: sensors ⟶ Pi 5 ⟶ Flask/Socket.IO ⟶ live dashboard.

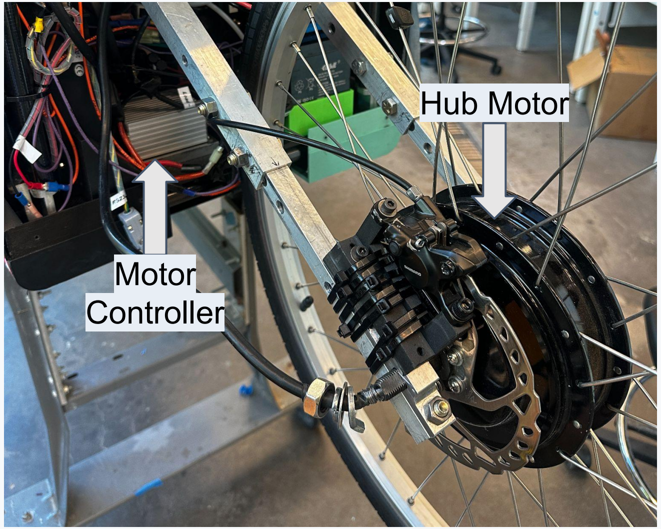
Hydrogen Drivetrain — What We Learned on the Ground

First on-ground test: night before departure

- The vehicle could barely move under its own weight with the original 24 V, 25 A controller.
- Switched to a 36 V controller → vehicle drove, but slowly

Post-competition fix

- Purchased a Grin Tech V6 Phaserunner MT — field-oriented control matched to the FC's variable voltage.
- Smoother torque, quieter operation, fewer current spikes that stress the fuel cell.



Drivetrain status: vehicle drove on track · controller upgrade pending field test

Electrical System & SEM Competition

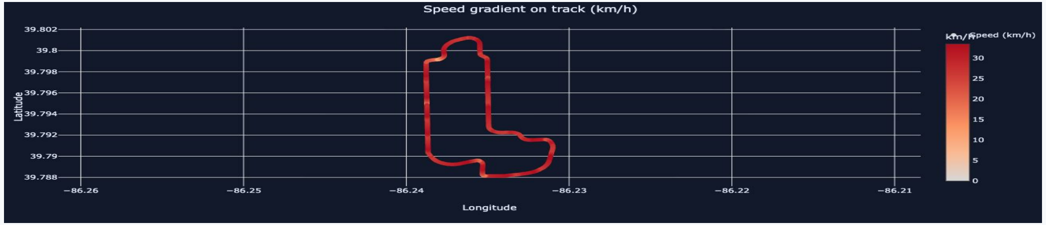
Competition outcome

- Passed technical inspection.
- Vehicle entered the track · ~½ lap before fuel cell shut off (poor error logging).
- 3rd-best record of 5 H_2 Prototype teams; did not place (no completed race).

Vehicle on the Track

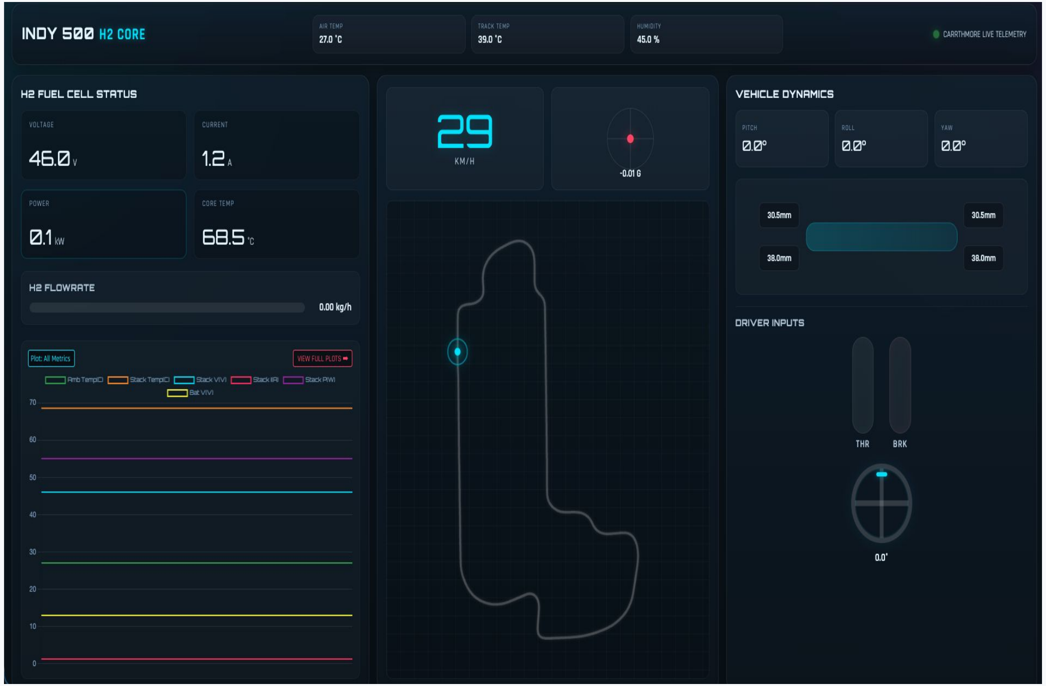
Telemetry — Simulation Outputs

Speed profile vs. curvature-based corner limit (single lap shown).

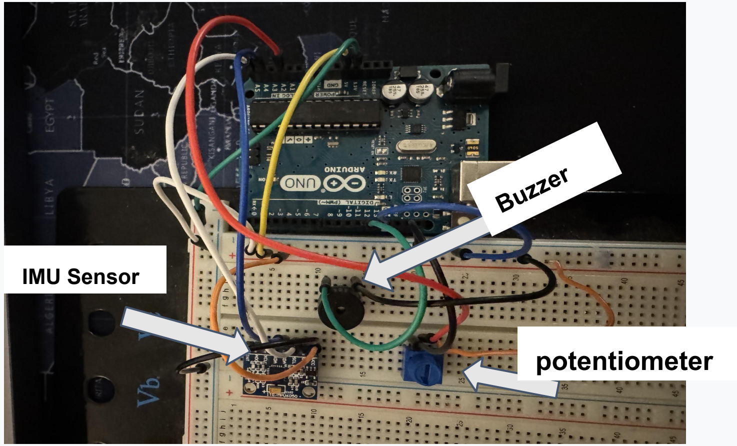


1943.32 s	Total elapsed time (limit 2100 s)
+156.68 s	Finish margin
7.93 m/s	Average speed (req. 7.33 m/s)
Met	SEM timing constraint

Telemetry — Live Dashboard & Bench Validation



Live dashboard: FC status, position, speed, vehicle dynamics



Bench-scale Arduino prototype: validated comms path & burn/coast cue.

EMPIRICAL WINS

- Live FC data over RS232→USB: stack V, I, P, T_stack, T_amb, V_battery.
- Audible burn/coast cue triggered correctly from the simulation layer.

Requirements Met / Not Met

Hydrogen Drivetrain

Fuel cell integration	Met
Hydrogen delivery system	Met
Drive (motor + controller)	Partial

Electrical System

12 V + HV Systems	Met
Safety Systems	Met
Documentation	Met

Telemetry System

Track + sim + timing	Met (sim)
Live dashboard	Partial
Full vehicle validation	Not met

What we learned and what we'd do differently

1

Co-design from day one

Treat mechanical, electrical, and telemetry as a single integrated design and not as bolted-on layers added at the end.

2

Each sub system has experts

There were issues with the braking system that needed correction at the competition, but the team member with expertise on that system was not on the trip.

3

Test the whole stack early

First time the car drove was the night before we left. Earlier on-ground tests would have caught the controller mismatch.

Conclusion

Three takeaways from the first Swarthmore SEM entry since 2018

- **We competed.**

  Passed technical inspection and drove the vehicle on the Indianapolis Motor Speedway track — the first SEM run for Swarthmore in seven years.

- **We adapted in the field.**

  From h2 sensors to motor controllers, every subsystem absorbed last-minute changes and still made it onto the track.

- **We built a software foundation.**

  Predictive race-strategy simulator + live dashboard + bench prototype — a platform ready for next year's full vehicle integration.

Thank You

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J. Johnson
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Jen Parisien
Parts procurement support

Ed Jaoudi
Electronics Support

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Funding for supplies and meals during travel

Countless Others
Additional support throughout the project

Questions?

Alexander Vasquez-Jaffe · Kimaru Boruett

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For Next Year's E90 / SEM Team

DRIVETRAIN

- Replace single-stage with a dual-stage regulator (current unit reads 11 psi at 0).
- Buy spare L-shaped fuel-cell quick connectors (or move to all-stainless tubing).
- Bring a hydrogen sniffer, works much better than leak detector liquid.

ELECTRICAL

- Use the FC's integrated H_2 sensor + safety loop from the start — avoid redundant circuitry.
- Integrate the updated Grin Phaserunner MT motor controller

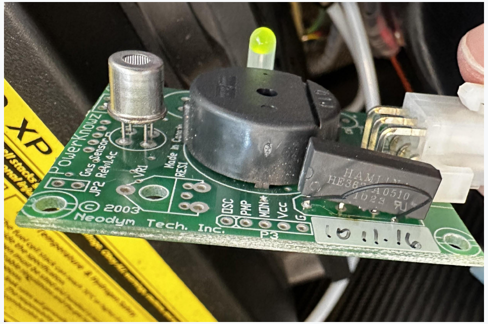
TELEMETRY

- Deploy the Pi 5 + 5G hat early; lock down the JSON schema during the fall.
- Integrate live GPS, throttle, and brake mapping into the dashboard before competition.
- Validate the burn/coast cue (LED + buzzer) end-to-end in the cockpit, not just on bench.

Electrical System & SEM Competition

H_2 sensor failure → field repair

- Burnt trace + faulty relay; bridged trace with 30-gauge wire; replacement Meder relay.
- On-site discovery: the FC's integrated sensor satisfies SEM tech inspection — circuit dramatically simplified.



Original relay with hand-soldered replacement trace.

How a PEM Fuel Cell Works

Reactions

Anode (oxidation)

$2\,H_2 \rightarrow 4\,H^+ + 4\,e^-$

Cathode (reduction)

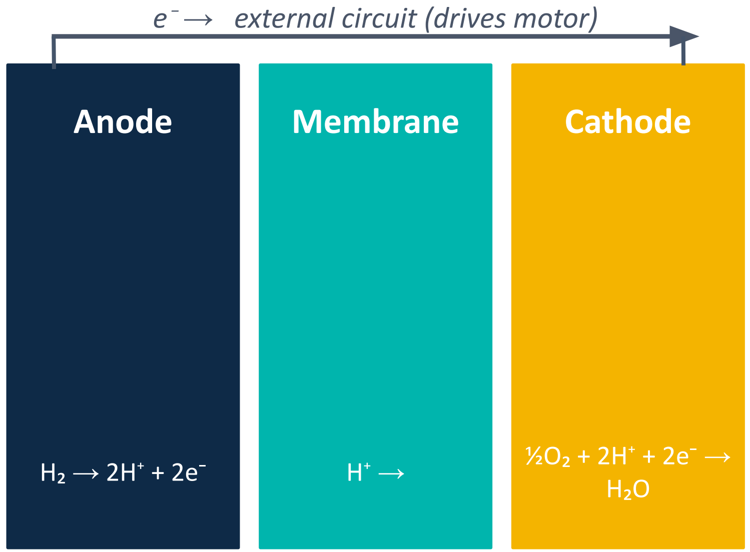
$O_2 + 4\,H^+ + 4\,e^- \rightarrow 2\,H_2O$

Overall

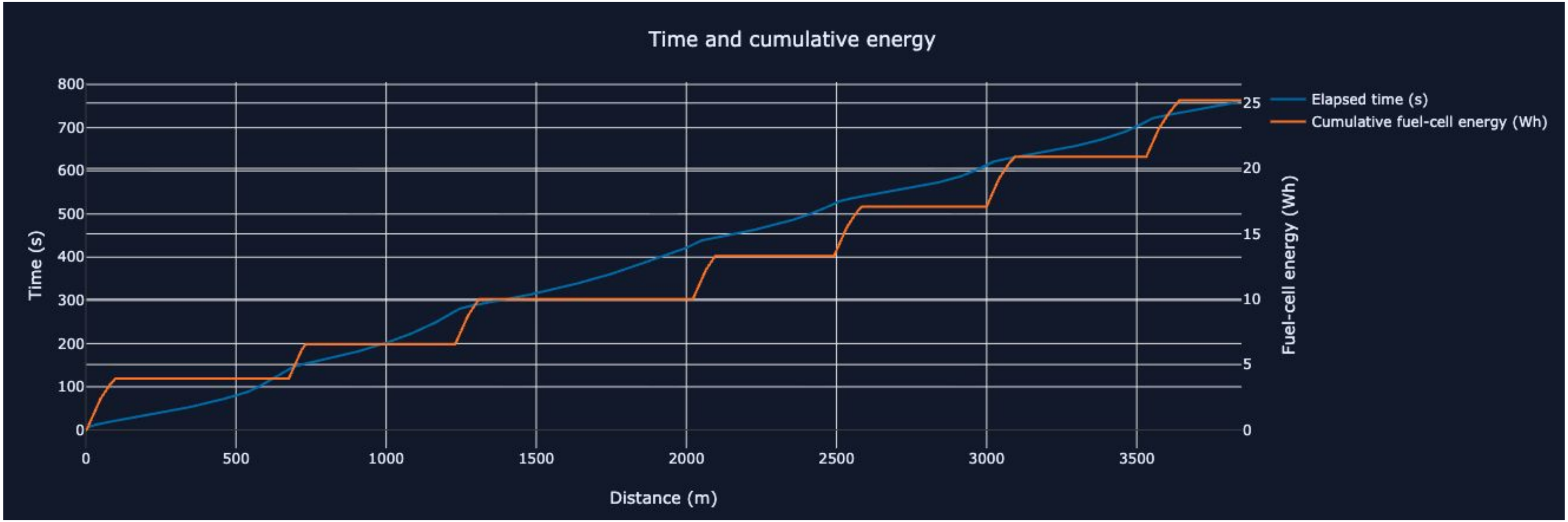
$2\,H_2 + O_2 \rightarrow 2\,H_2O$ + *electricity* + *heat*

What's inside

Bipolar plates · Gas diffusion layers · Pt catalyst · Proton-exchange membrane (Nafion)



Net output: DC electricity at variable voltage with the only emission being water vapor.



Time and cumulative energy
Time (s)
Fuel-cell energy (Wh)
Distance (m)
Elapsed time (s)
Cumulative fuel-cell energy (Wh)
800
700
600
500
400
300
200
100
0
25
20
15
10
5
0
500
1000
1500
2000
2500
3000
3500

Thank you

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- **Jen Parisien:** Coordinator managing parts procurement and supply chain logistics.
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