Optimizing the operational efficiency of a PEM hydrogen fuel cell for applications in a hybrid electric vehicle

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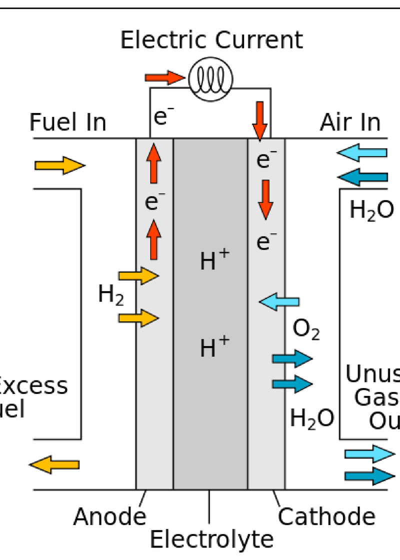
Background

- Duke Electric Vehicles competes in the Shell Eco-Marathon annually
- 1st place Battery-Electric Prototype at 2017 competition
  - 296 mi/kWh
  - Equivalent to 9,976 MPG-e
- Expanding to hydrogen fuel cell category for 2018
- Eco-Marathon is competition for efficiency
  - Previously: optimize aerodynamics, rolling resistance, weight, motor controller, battery management system
- New considerations with hydrogen fuel cell (H2FC) implementation in the electric vehicle

Objective

Goal: optimize H2FC to maximize efficiency
- Variables: humidity, temperature, pressure, purging frequency, fan speed, short circuit
- Change operating conditions of commercial fuel cell by controlling variables

Reduce variability in load to fix operating point
- Vehicle power has significant spikes in load during acceleration or climbing hills, while is constant and low while driving on flat roads



Methods

Optimize H2FC operational efficiency
- Generate IV curve for the fuel
- Derive power curve as a function of load
- Use flowmeter to determine efficiency vs. load
- Change variables, determine impact on efficiency

Setup:
- Compressed hydrogen tank + pressure regulator
- Flowmeter attached between tank and H2FC
- Slide resistors to manually change load
- 2 multimeters to determine voltage and current at each load value (voltmeter connected in parallel with fuel cell, ammeter in series)
- Energy in with flowmeter, energy out by IV curve

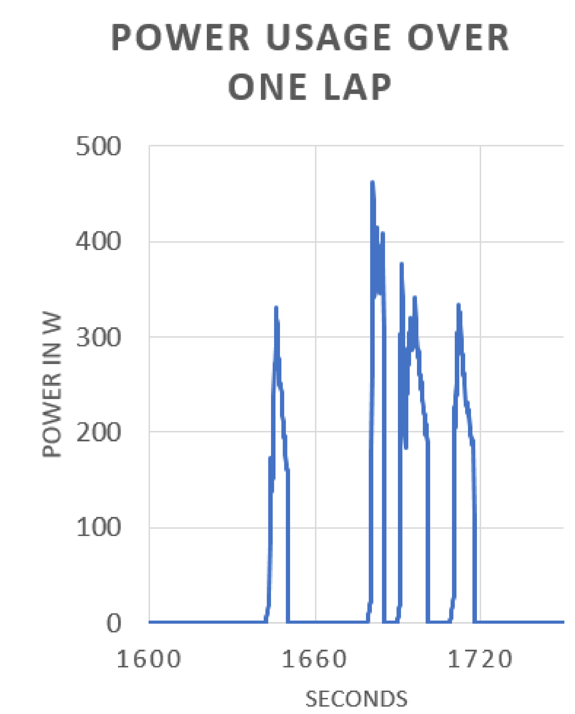
Determine best way to vary controllable variables:
- Humidity, temperature, pressure, purging frequency, fan speed, short circuit
- Focused on pressure, purging frequency, fan speed: have biggest impact on efficiency
- Pressure: inlet pressure of hydrogen
- Purging: commercial fuel cell purges excess hydrogen + humidity every 10 s.
- Fan speed: cools fuel cell and provides air

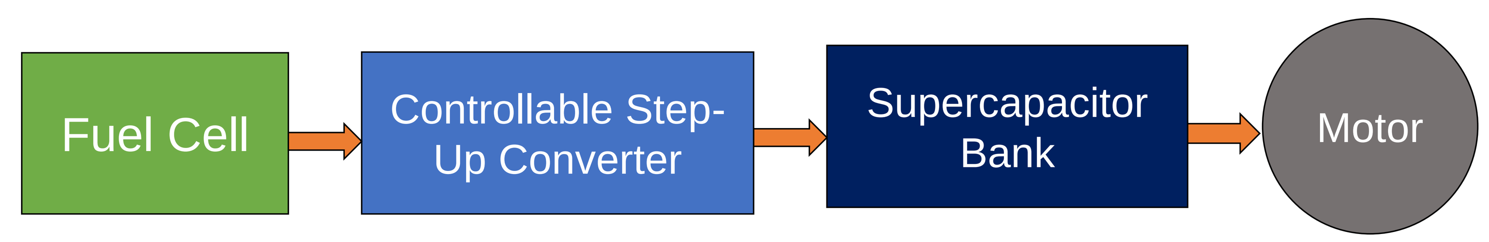
Energy Storage

- Car speed kept constant to minimize aerodynamic losses
- Motor is off for majority of lap due to track elevation profile
- Power demanded in short, powerful bursts

- Energy storage system developed to allow FC to store energy in supercapacitor bank
- Motor draws directly from this bank in bursts.

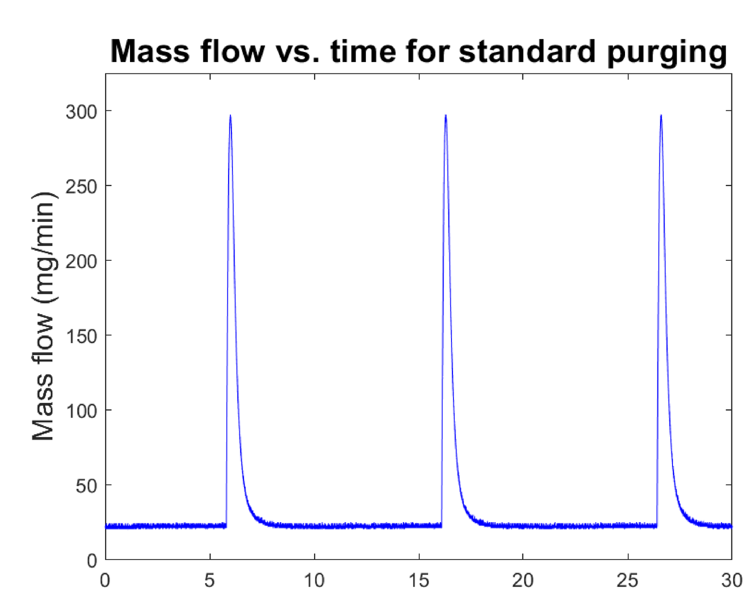
- Power converter is fully controllable
- Operates at 96% efficiency
- Allows fuel cell to be run at its optimal point.

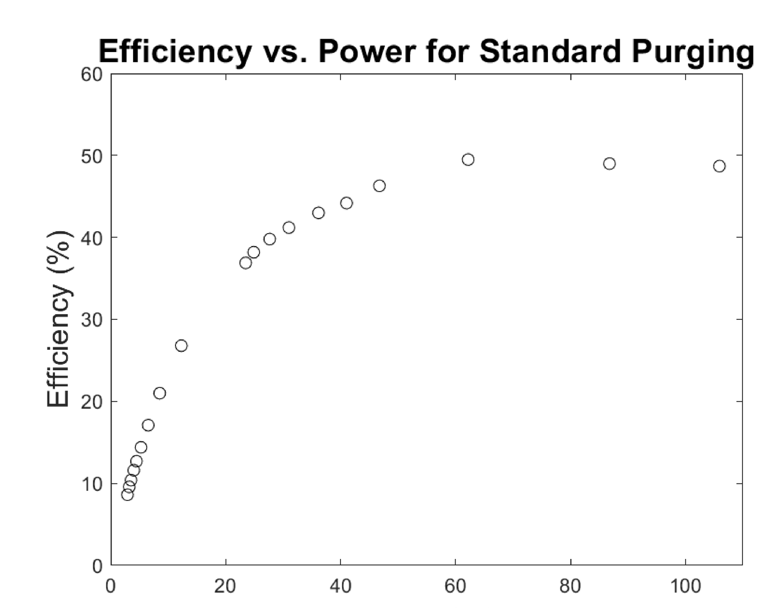


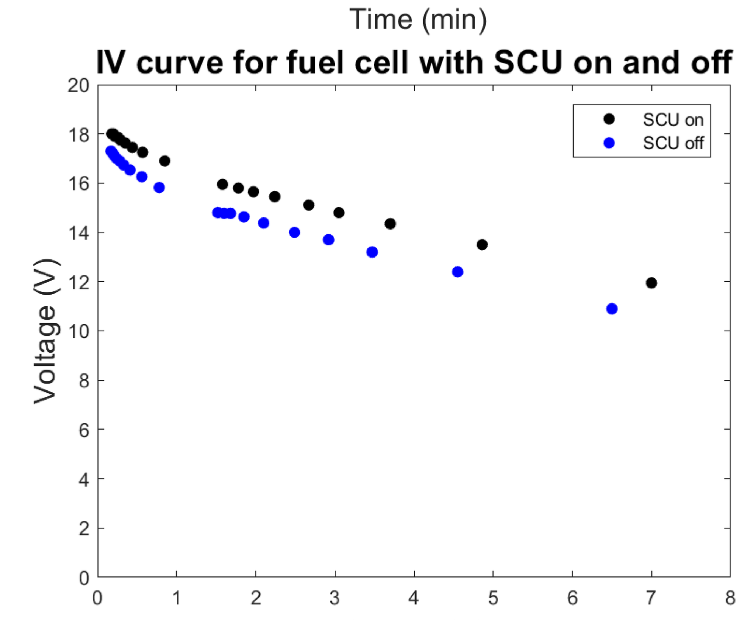


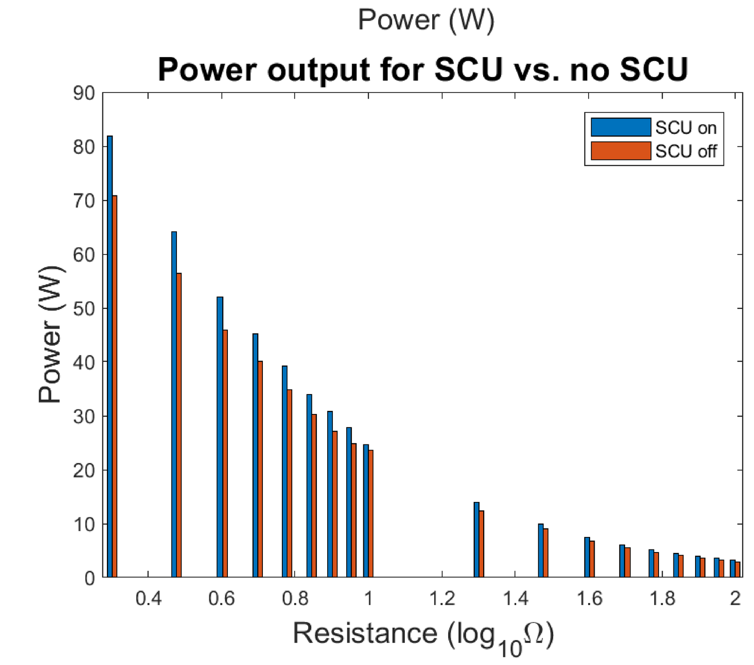
Fuel Cell Characterization

- Commercial Horizon 100W PEM fuel cell
- Rated for 40% at 100W
- Standard operating points:
  - 7.5 psig inlet hydrogen pressure
  - 10s purging frequency for 100ms
  - 10s SCU frequency for 100ms
  - Fan speed PWM 12% on at 12 V



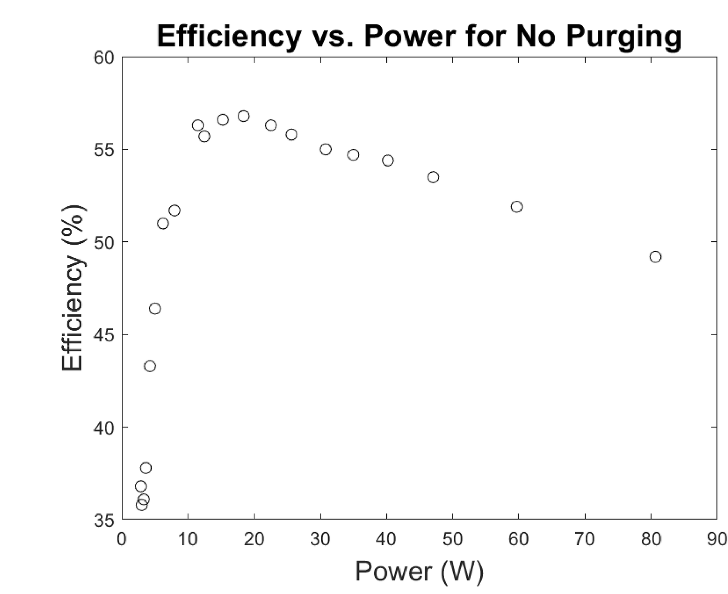


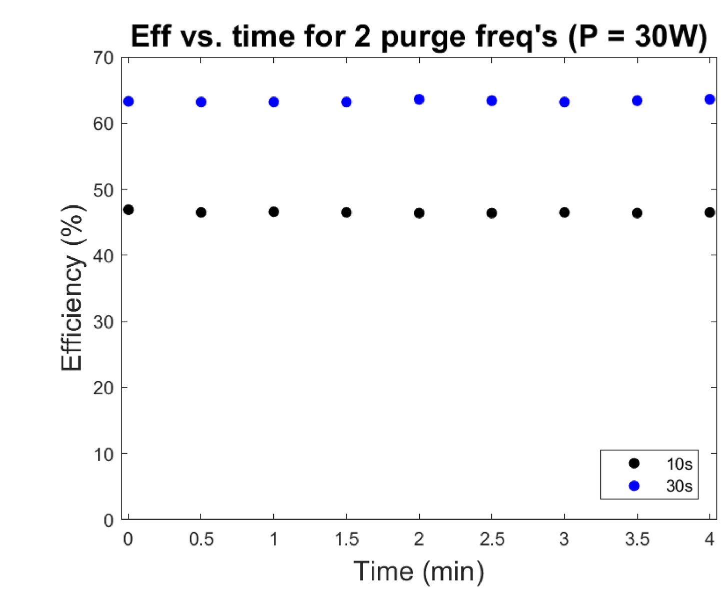


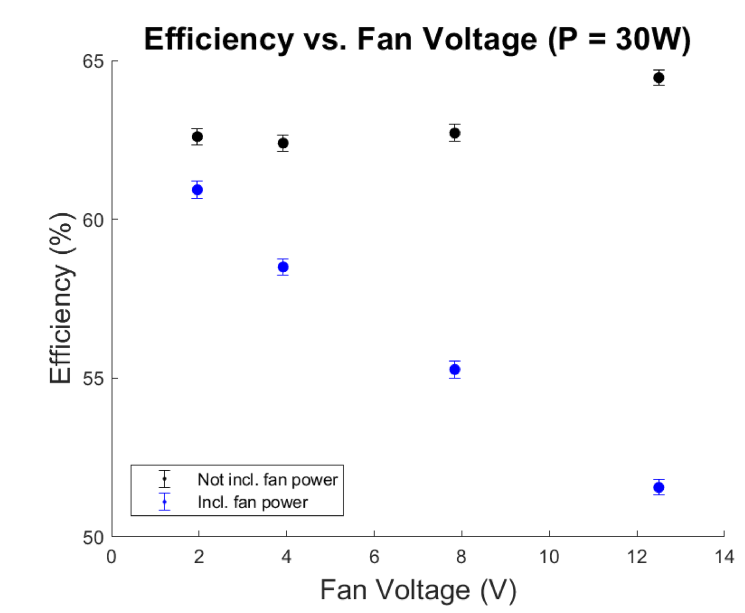


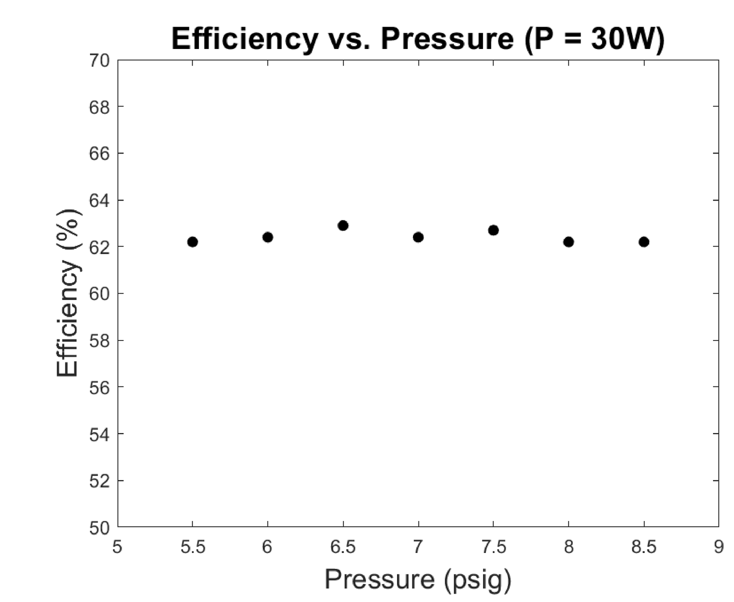
Fuel Cell Optimization

- Decreasing purge frequency improved efficiency
  - No significant decrease in efficiency over time
- Reducing fan speed rapidly dropped power
  - Change in temperature over time?
- Increasing pressure improved(?) efficiency





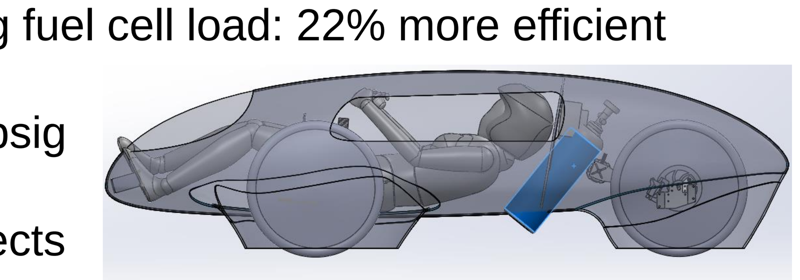




Conclusions and Next Steps

- Planning to run fuel cell at constant 50W
- Predicted efficiency is 53.5%
- Significant improvement over varying fuel cell load: 22% more efficient
- Optimal running parameters:
  - No purging, fan on, pressure 7.5 psig

Next steps:
- Experiment with inlet humidity effects
- Isolate air flow from temperature
- Implementation of H2FC in vehicle (redesign)



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