Hybrid Solid Oxide Fuel Cell Systems for Locomotives

2018 Annual Merit Review (AMR)
Washington DC

NATIONAL FUEL CELL RESEARCH CENTER
UNIVERSITY of CALIFORNIA · IRVINE

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Overview

Federal Railway Administration (FRA) funding: $500,000

Previous CARB & SCAQMD funding: $200,000

PHASE 1 (October 2015 – March 2016):

- Develop & apply model to evaluate hybrid SOFC systems
- Evaluate & engage potential technology development partners
- Apply model to a system design for a small prototype
- Identify the path and estimated costs to a line-haul product

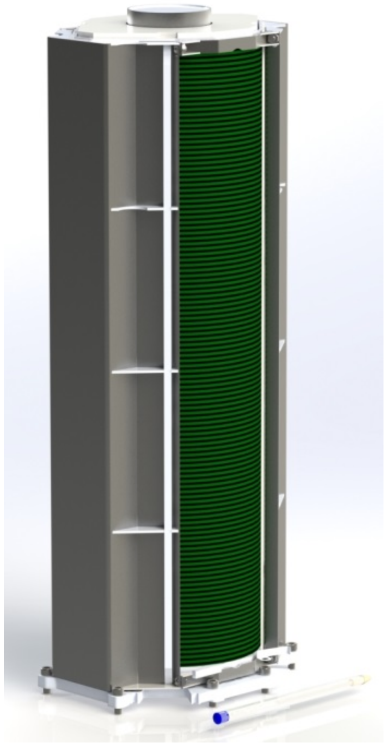
PHASE 2 (July 2016 – December 2017):

- Select partners for development & testing of hybrid prototype
- Design hybrid SOFC prototype
- Select an experimental test platform
- Design the hybrid SOFC prototype test protocol and test matrix
- Conduct economic analysis
- Establish prototype demonstration budget, approach, schedule

Task 6 – Design Prototype

- **SOFC System Selected – FuelCell Energy Compact Stack Architecture**
- ***Compact SOFC Architecture Stack***
- The CSA stack (shown in Figure 33) is a next generation SOFC stack which is suitable for various fuel cell (and electrolysis) applications.

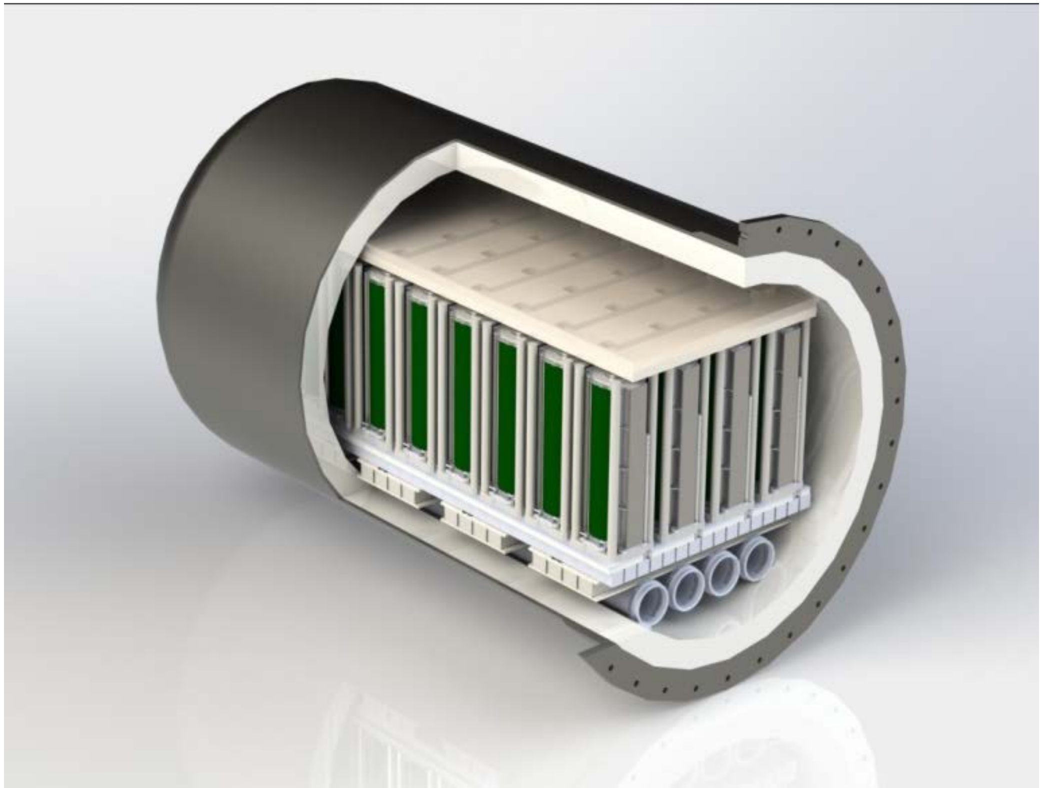
Selected Operating Parameters	Nominal	Units	Max	Min	Comment
Power Density	250	mW/cm^2	350		Atm. pressure operation
Current Density	290	mA/cm^2	440		Atm. pressure operation
Area Specific Resistance	~0.3	$\Omega - cm^2$			Function of T and P, see Eq. 3 below for P effect
Stack Fuel Utilization	65	%	80%	60%	Generally anode recycle desired for water independence and attainment of high system fuel utilization
Cell Operating Temperature	725	°C	650	800	



FuelCell Energy Compact SOFC Architecture (CSA) stack design

Task 6 – Design Prototype

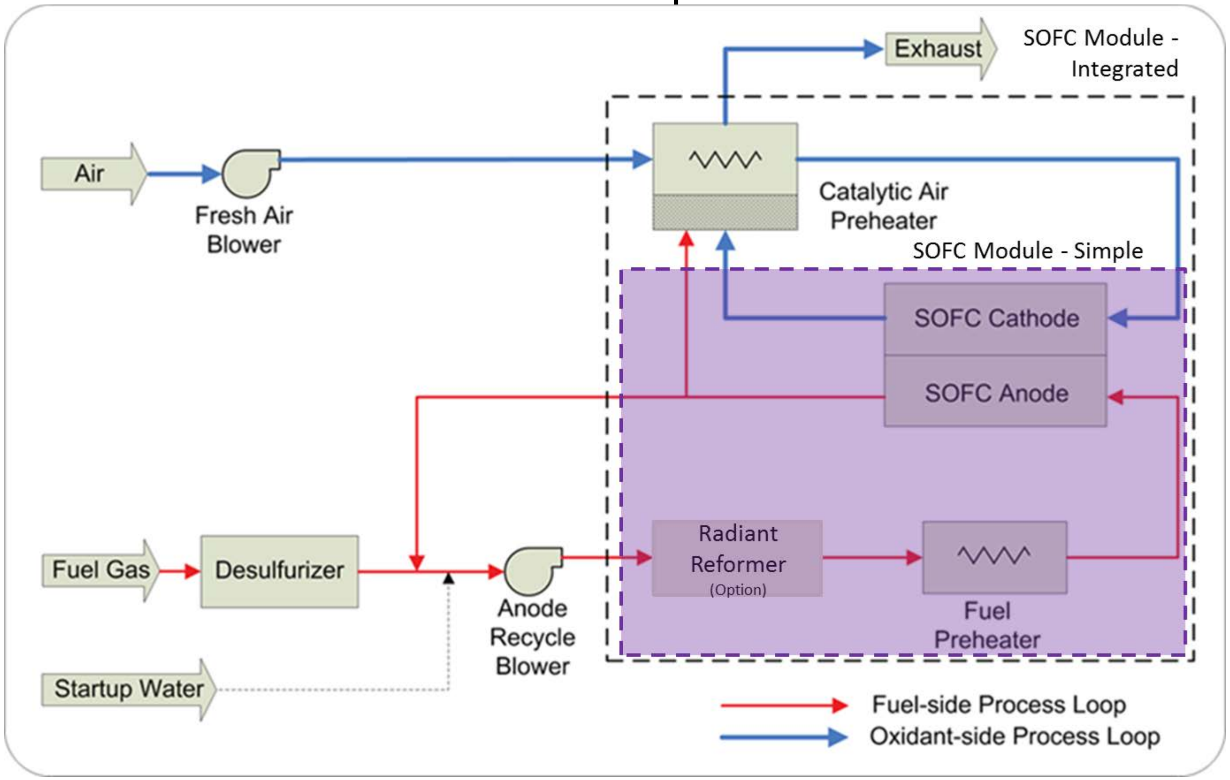
CSA Stack Module (simple) –Stacks, Manifolding and Thermal Insulation – Non-Pressure Rated



CSA Stack Module (simple) – Stacks, Pressure Vessel, Manifolding and Thermal Insulation – Pressure-Rated

Task 6 – Design Prototype

- A FuelCell Energy baseline SOFC system design
- As the turbine-hybrid process design will likely lead to a different and more integrated design, a more concise and simple stack module (shaded purple) has been selected for this document and the presented stack module requirements.



SOFC System Design – FCE Baseline

Task 6 – Design Prototype

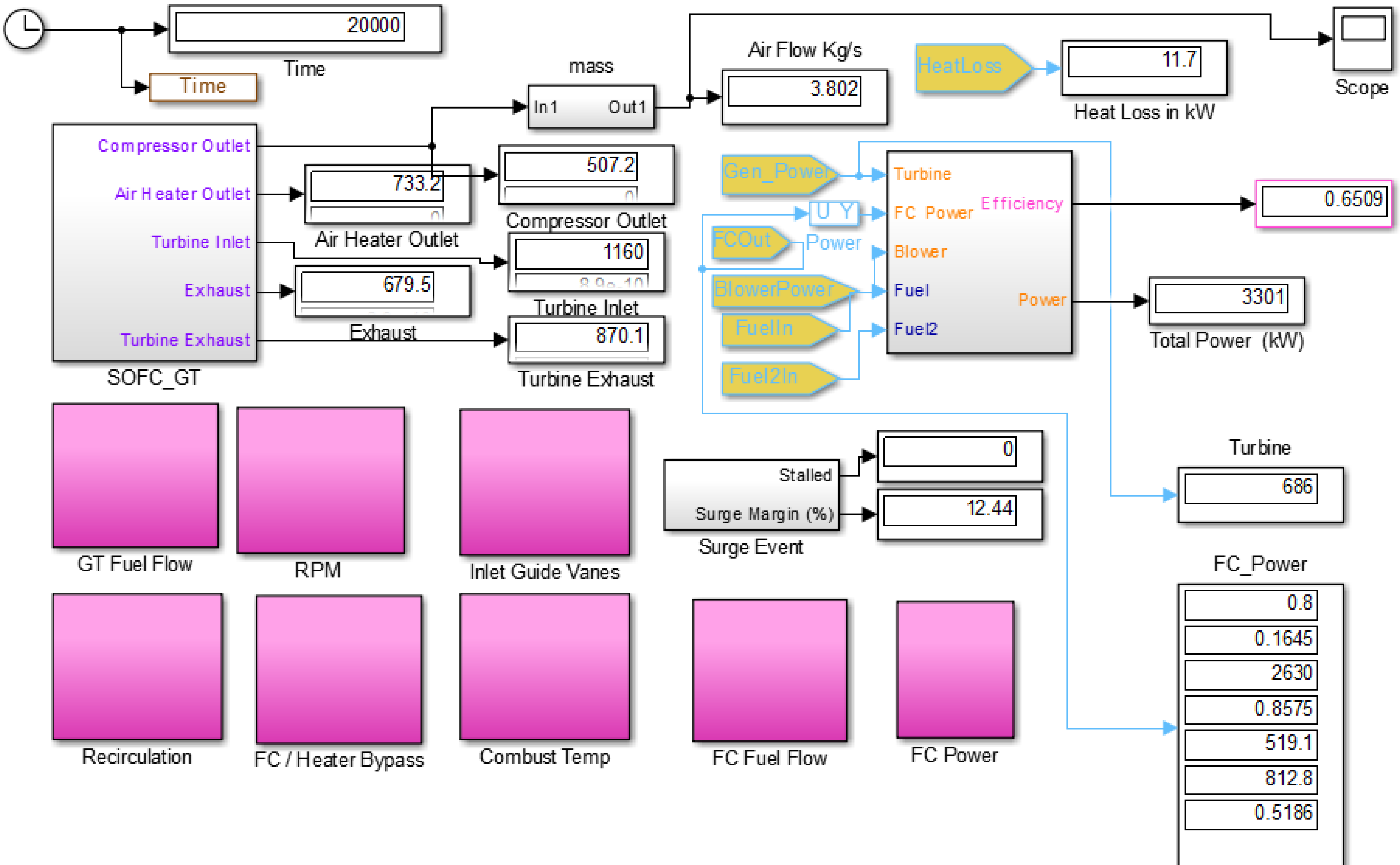
Gas Turbine System Selected – Capstone Turbines

- Capstone Turbines (Capstone), the world-leading manufacturer of micro-turbine generator (MTG) technology that is in the size class of the system requirements needed for the prototype system.
- The operating window of the C-250 turbine appears to be at heating rates between 250 and 800kW to produce between 50 and 250kW of electric power.

Specification	C-65	C-250	C-370 LP spool
Mass Flow (lb/s)	1.08	3.44	3.2
Compressor Outlet (°F)	424	469	397
Compressor Out (psig)	40	58.8	49
Recuperator Outlet(°F)	1050	1097	960
Turbine Inlet (°F)	1720	1788	1550
Efficiency (%)	31.2	33.25	34.5

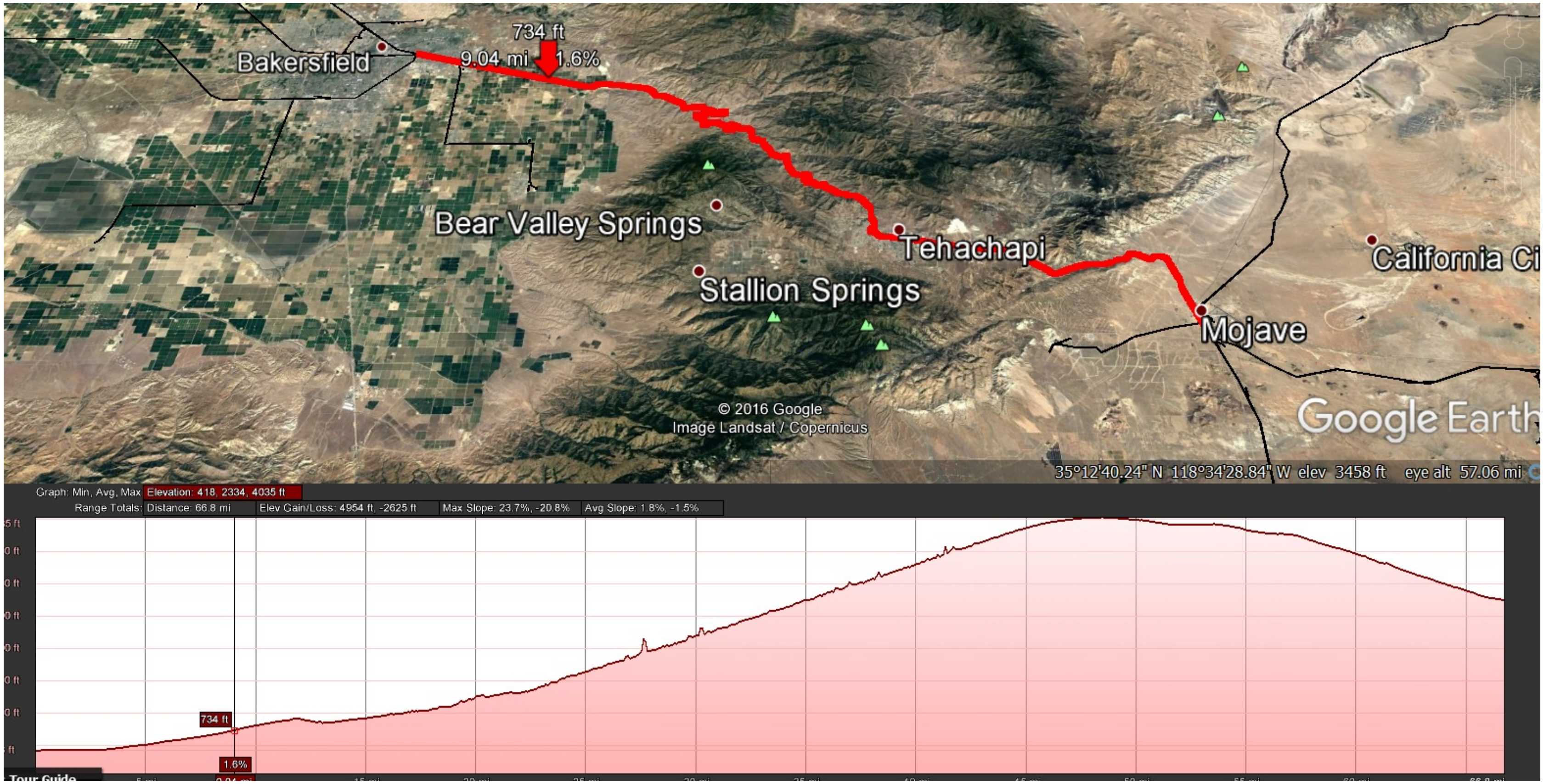
Capstone C65 Micro-turbine

Task 6: Prototype SOFC-GT Simulation

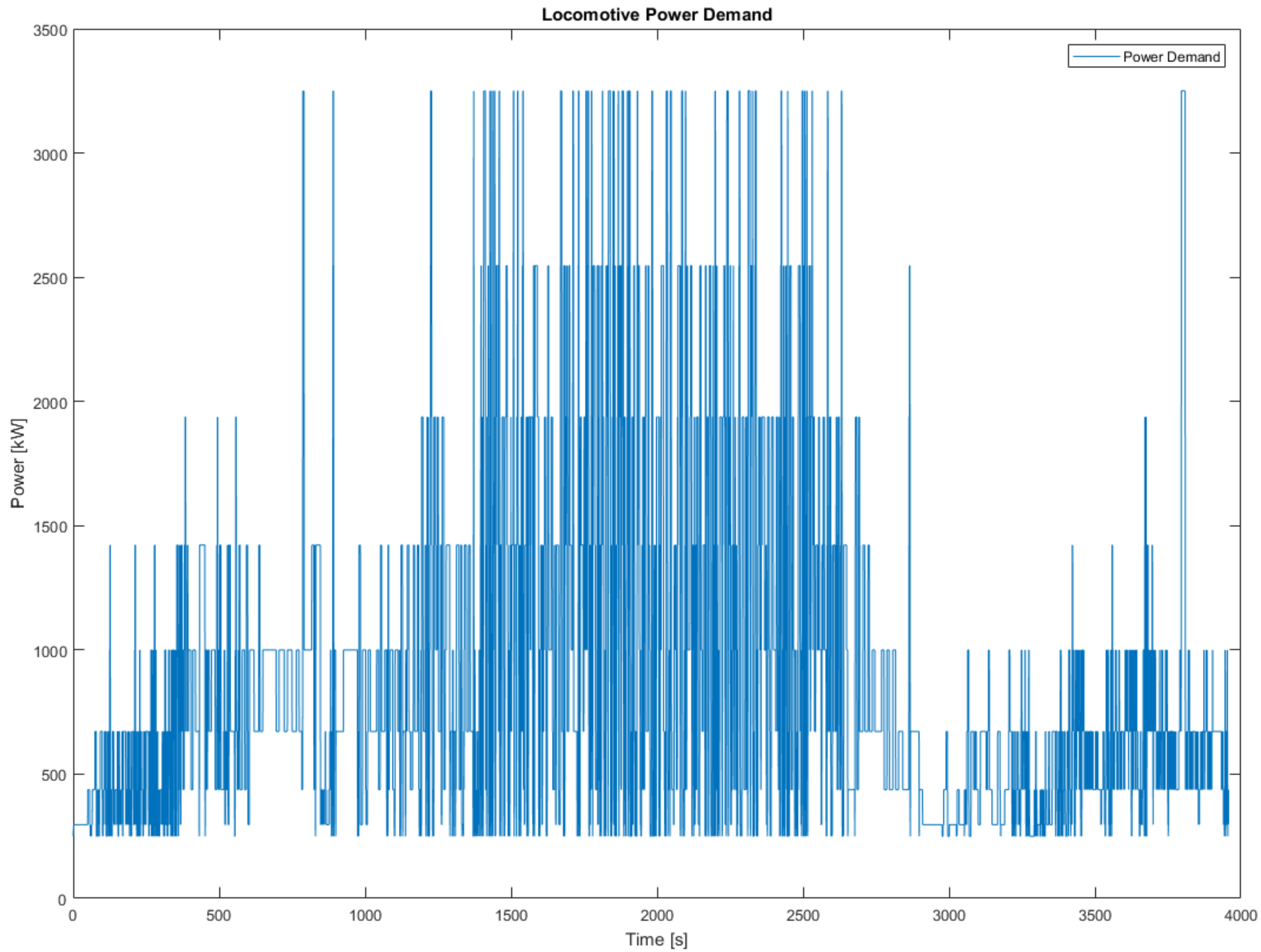


Tasks 7&8 – Experimental Platform & Test Plan

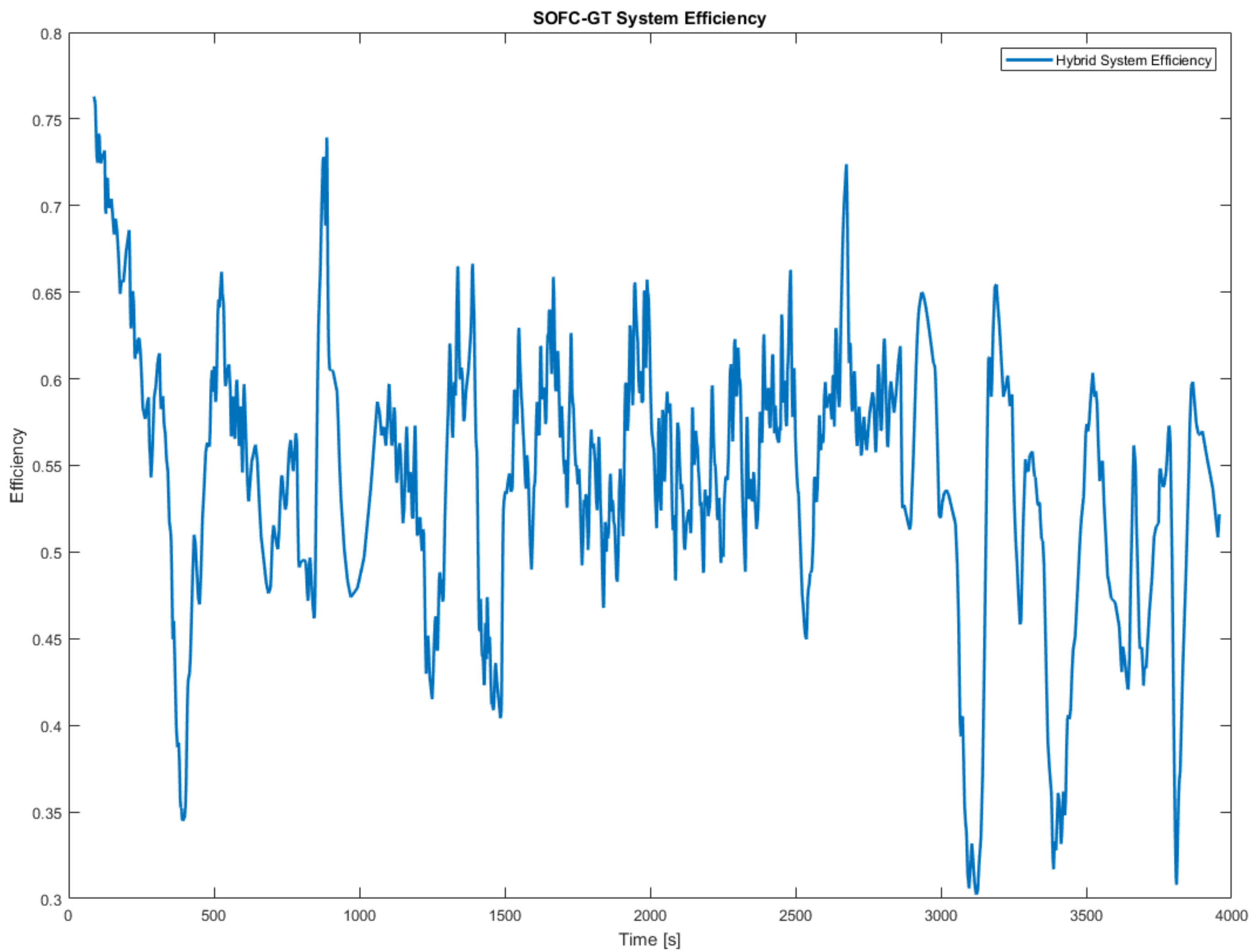
- New Route Simulation – Tehachapi loop



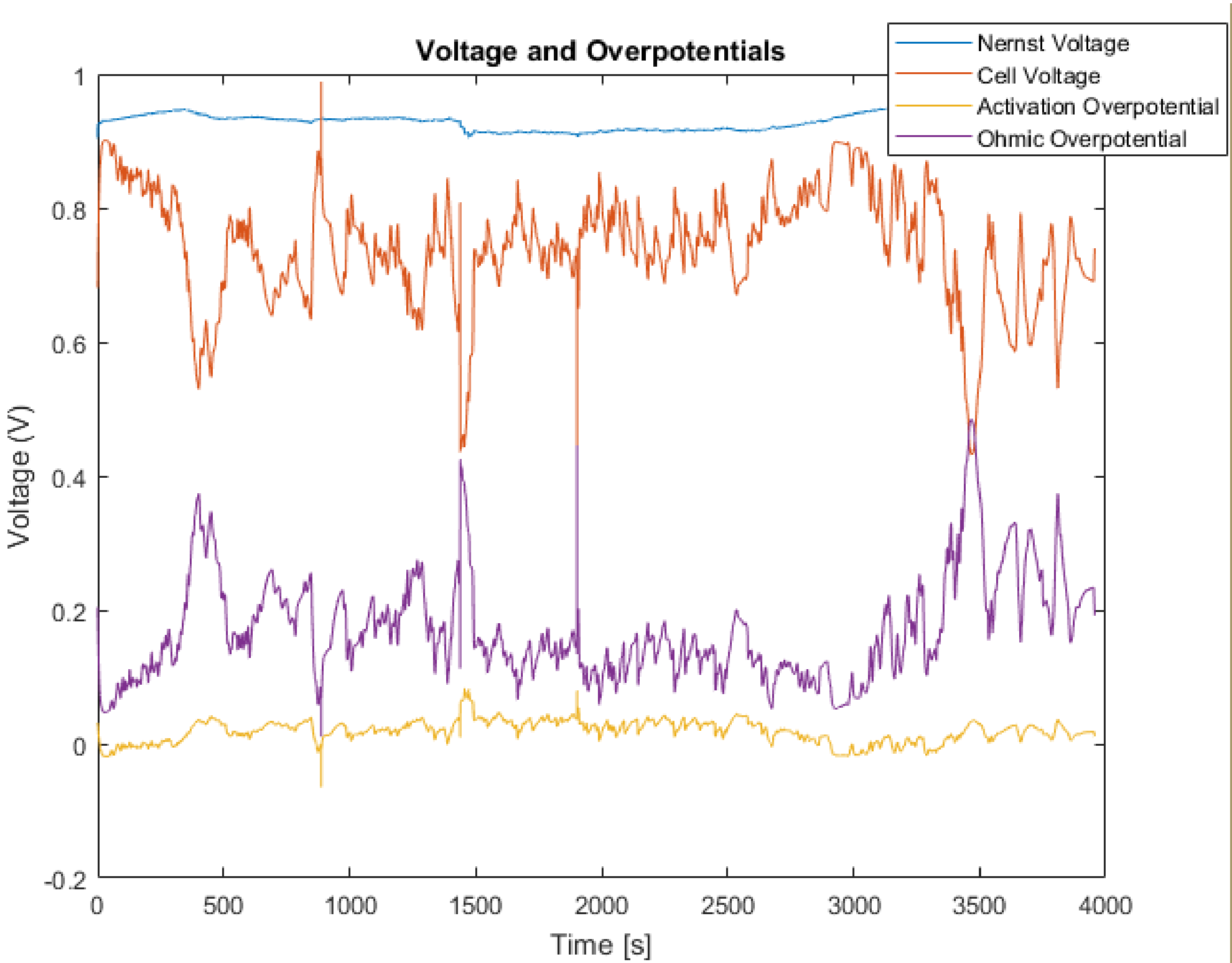
Raw Power Demand Curve Bakersfield-Mojave



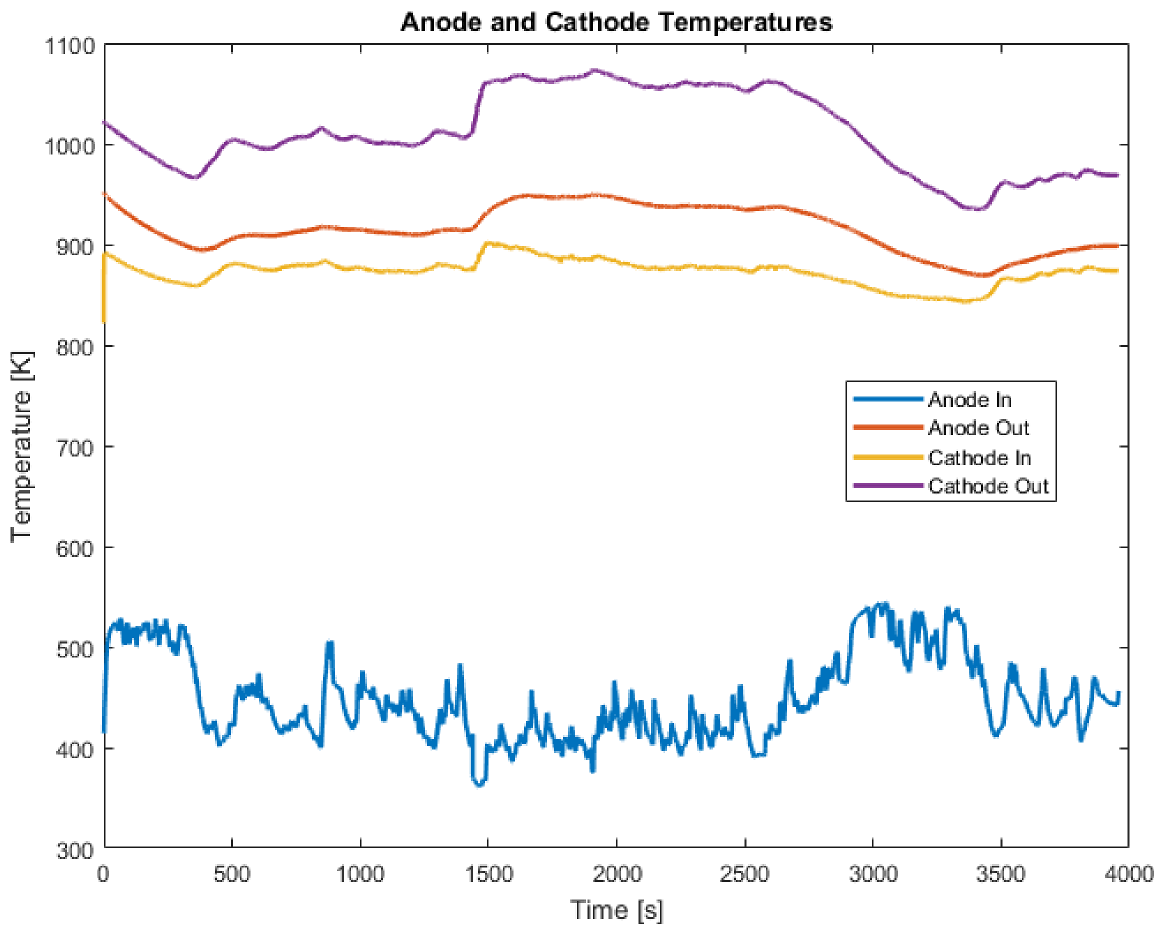
System Efficiency along the route



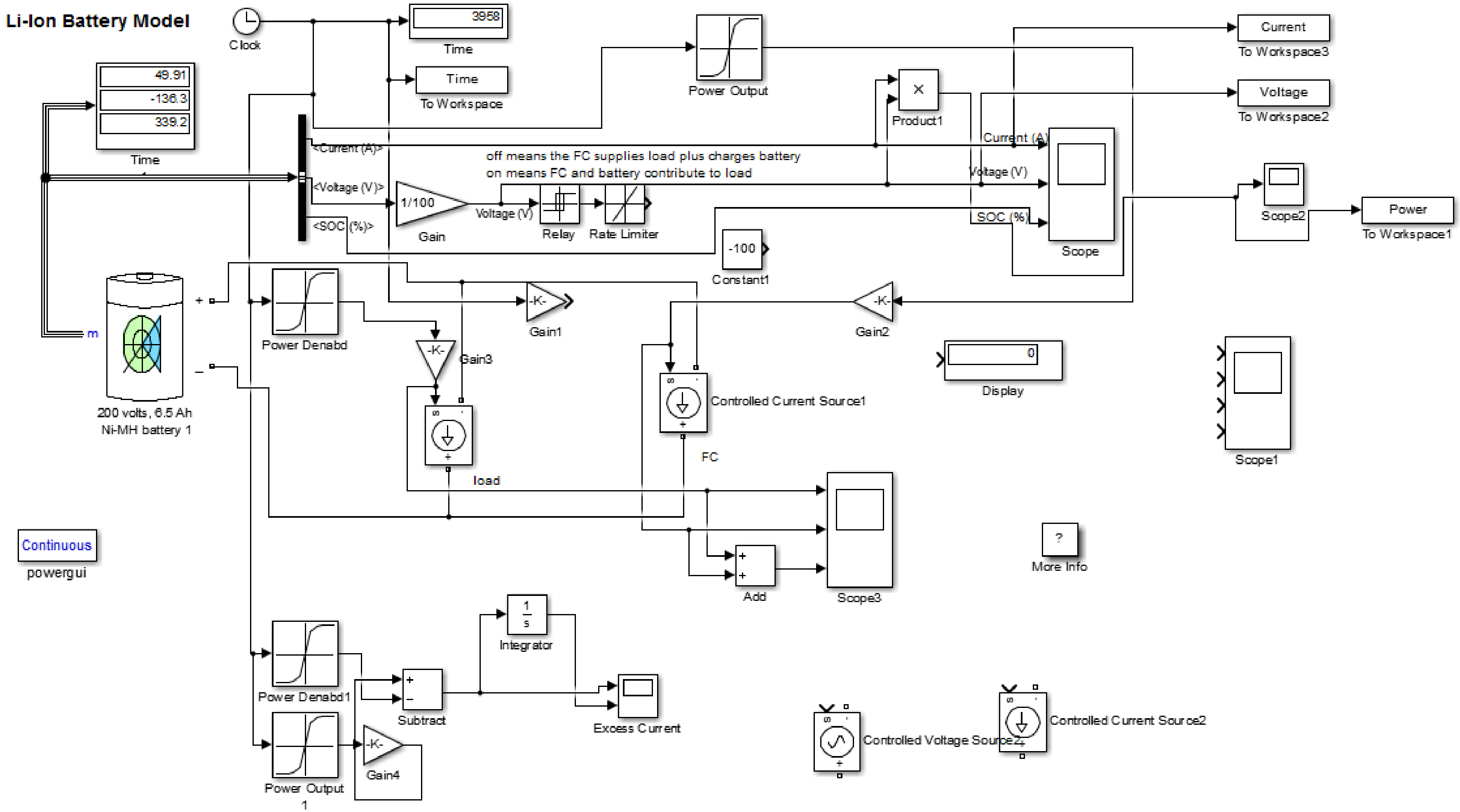
Voltage Losses



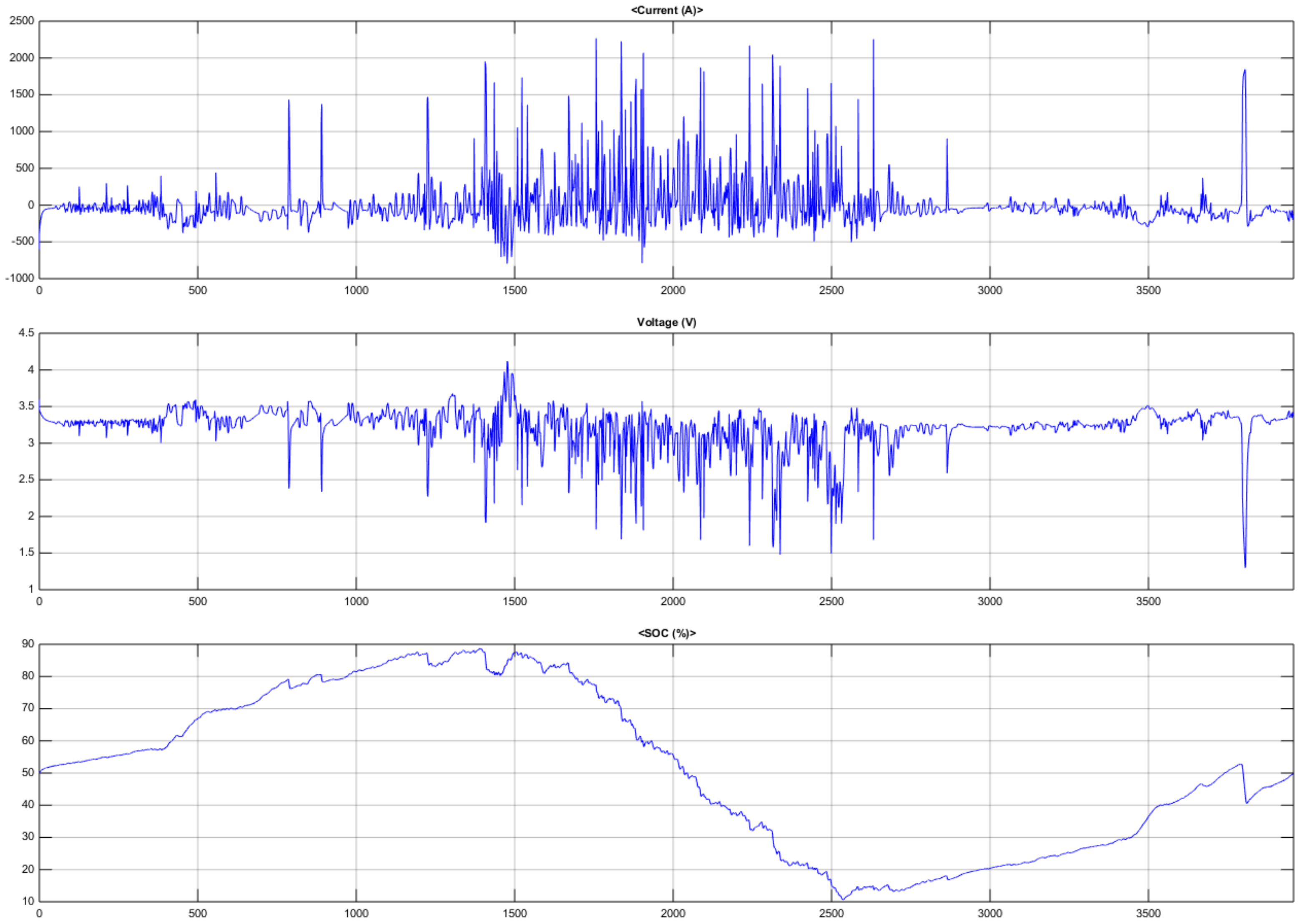
Anode & Cathode Inlet & Outlet Temperatures



Considering Small Battery for SOFC-GT Locomotive



Battery Cycle Data – Bakersfield to Mojave



Task 9 – Economic Analyses

- Base Case LCOE and Cents per Revenue Ton-Mile Results (No CO_2 Emissions Cost)

(No CO_2 Emissions Cost)	Tier 4 Diesel-Electric Locomotive	Diesel-Electric Locomotive + Battery Tender	Tier 4 Diesel-LNG Locomotive	SOFC-GT Locomotive (LNG Fuel)	SOFC-GT Locomotive (LH_2 Fuel)	Electric-Only Locomotive (Catenary)
LCOE ($/MWh)	$538.20	$1,740.21	$522.78	$535.22	$676.03	$582.38
Rank Order:	3	6	1	2	5	4
Year 1: ¢/Rev Ton-Mile	2.11¢	11.35¢	2.36¢	2.79¢	3.90¢	2.92¢
Rank Order:	1	6	2	3	5	4
Levelized (x 10^{-6}): ¢/Rev Ton-Mile	7.31¢	29.31¢	7.28¢	7.64¢	9.90¢	7.91¢
Rank Order:	2	6	1	3	5	4

Thank You!

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