FuelCell Energy

Project Kickoff Meeting
SOFC Prototype System Test (DE-FE0026199)

Presented To:
National Energy Technology Laboratory (NETL)

December 14, 2015
Webconference

Ultra-Clean, Efficient, Reliable Power

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Meeting Agenda

Attending Organizations: National Energy Technology Laboratory (NETL/DOE), Fuel Cell Energy (FCE), Versa Power Systems (VPS)

14:00 - 14:15	Introductions and brief procurement discussions	All
14:15 – 14:35	Project Overview	H. Ghezel-Ayagh
14:35 – 15:10	Work-Scope: Cell/Stack Fabrication	Eric Tang / Michael Pastula
15:10 - 15:30	Work Scope: Module/System Fabrication	Steve Jolly / Keith Davis
15:35 - 15:45	Q&A and Follow up Discussion	All

* Times are in EDT (Eastern Daylight Saving Time)

Project Overview

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Project Objectives

The overarching goal is to advance Solid Oxide Fuel Cell(SOFC) technology that will ultimately be deployed in coal power systems with:

- **greater than 60% percent efficiency based on Higher Heating Value (HHV) of fuel**
- **capability for ≥97% CO_2 capture**
- **near term (by 2020) deployment targeting a ≥20% reduction in cost of electricity compared to current state-of-the-art technologies, and long-term (by 2030) widespread deployment reflecting further performance improvements and cost reduction**

The main objective of the project is to test a 400 kWe thermally self-sustaining atmospheric-pressure SOFC prototype system at a prominent site for ≥ 5000 hours and to verify the feasibility of SOFC stack power degradation rate of ≤1.5% per 1000 hours at thermally self-sustained normal operating conditions (NOC) with an average stack operating temperature greater than 700°C.

Project Approach

- Design and fabricate a 400 kWe SOFC prototype system comprised of 2 x 200 kW self-sustained power plants.
- Install the 400 kWe SOFC prototype system at a prominent host site.
- Commission and operate the 400 kWe SOFC prototype system for at least 5,000 hours at normal operating conditions using natural gas fuel and with stack operating temperature greater than 700 ° C, to verify stack degradation of ≤1.5% per 1000 hours.
- Estimate SOFC stack cost, based on high-volume manufacturing levels and the experimentally-observed stack performance at normal operating conditions, towards the goal of $225/kW (based on system net AC power in year 2011 dollars).
- Estimate the Power Block cost (exclusive of fuel supply, contaminant removal, and CO2 capture subsystems) of an advanced Integrated Gasification Fuel Cell system, towards the goal of $900/kW (based on system net AC power, in year 2011 dollars).

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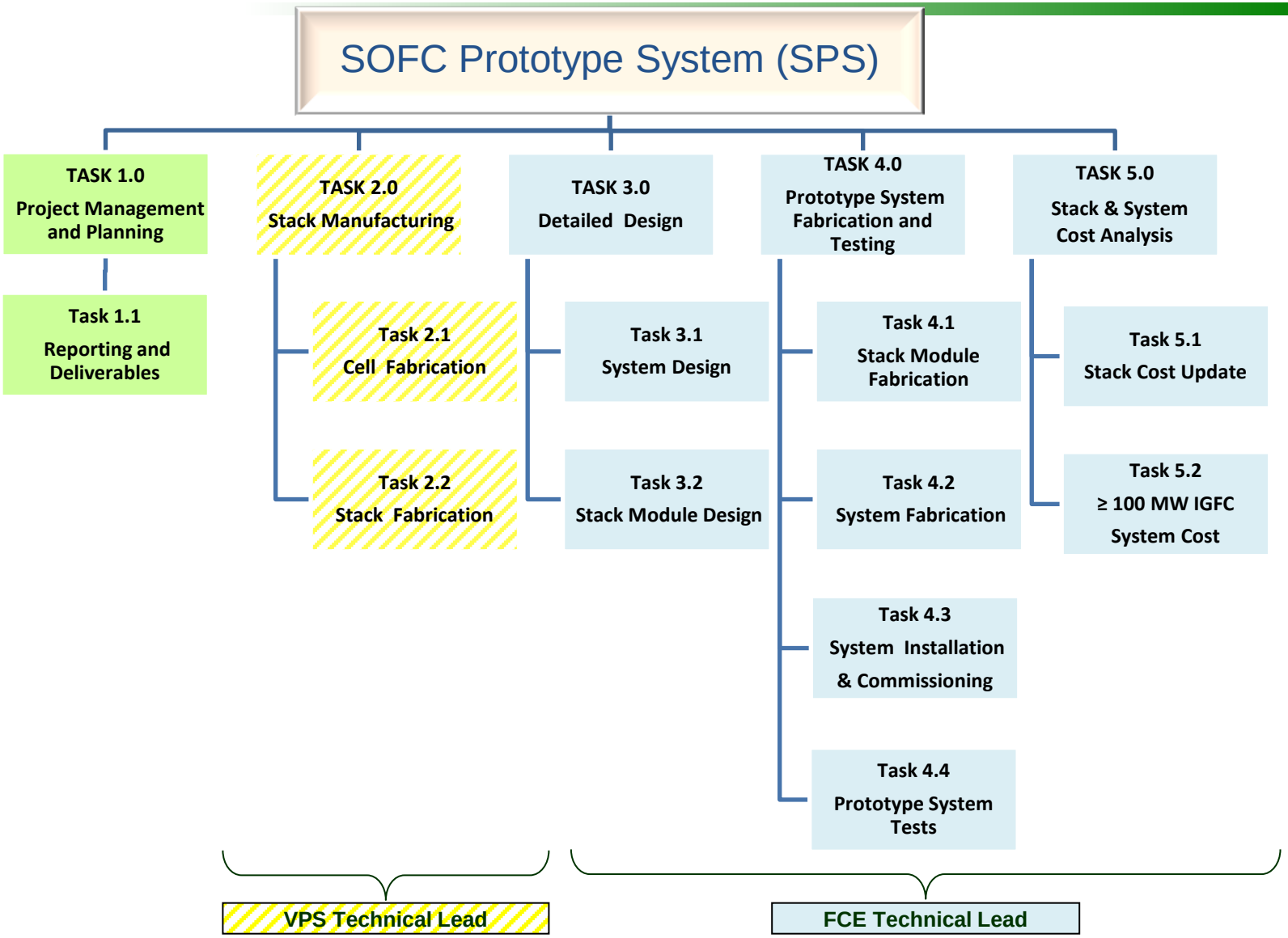
Project Structure



The work breakdown structure is designed to ensure success in achieving the program objectives with minimal risk.

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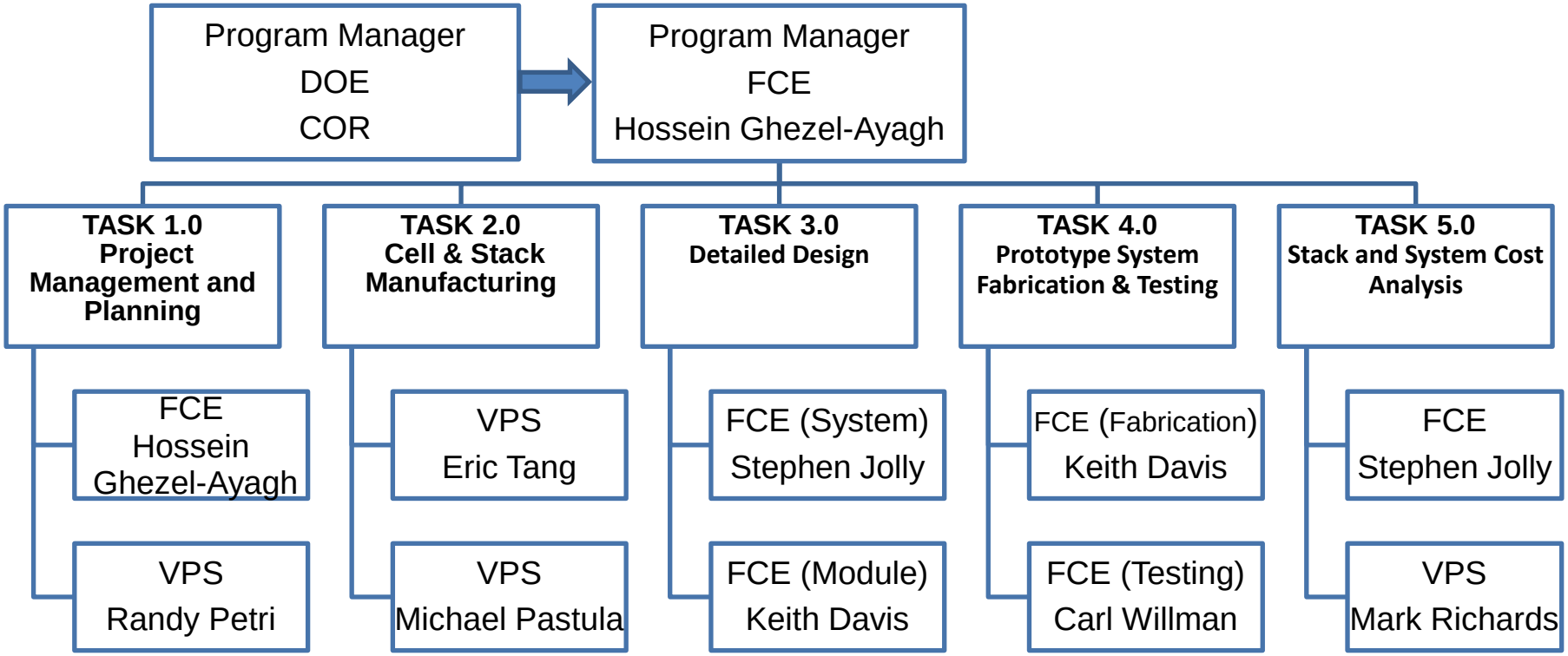
Project Team Task Leaders(TTL)



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Project Budget

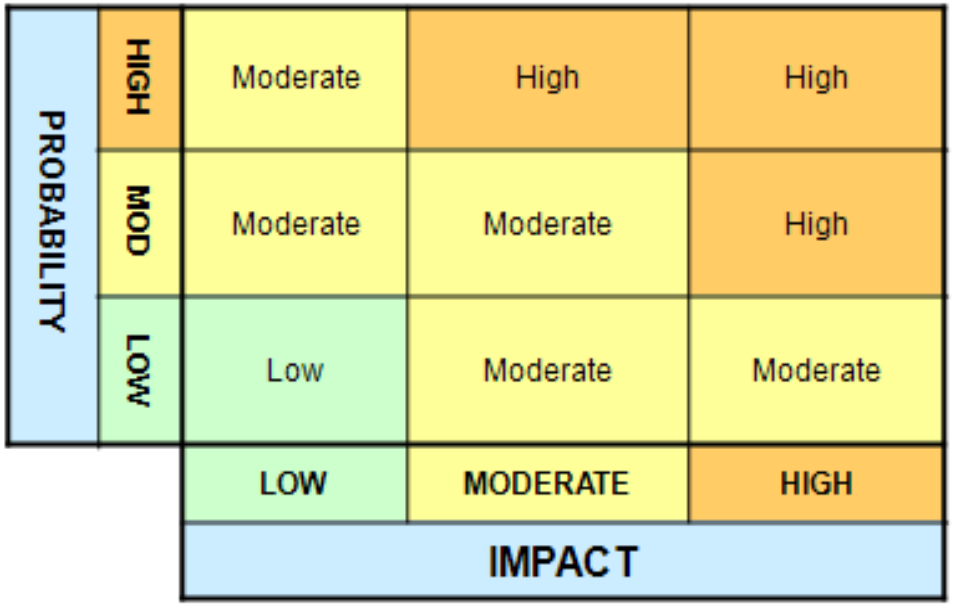
Team Member	Project Period 10/01/15-09/30/17		Total
	Government Share	Cost Share	
Total	$6,000,000	$4,917,887	$10,917,887
Percentage	55.0%	45.0%	

Project Risks

Risk Categories:

- Technology
- Resources
- Management

Degree of Risk Calculation Chart



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Milestone Log

Id.	Task /Subtask No.	Milestone Description	Planned Completion	Actual Completion	Verification Method
1	3.2	Complete Stack Module Final Design and Fabrication Plan	5/31/16		Letter to DOE PM
2	3.1	Complete Detailed Prototype System Electrical Design	8/24/16		Report
3	3.1	Complete Detailed Prototype System Mechanical Design	10/17/16		Report
4	3.1	Complete Detailed Prototype System Process Design	11/3/16		Report
5	2.2	Complete Stack Block Fabrication for Prototype System	12/8/16		Letter to DOE PM
6	4.2	Complete 400 kW SOFC Prototype System Fabrication and Assembly	1/6/17		Letter to DOE PM
7	5	Complete Validation of Stack & IGFC System Costs to Meet DOE's Goals	9/5/17		Topical Report
8	4.4	Complete Tests of 400 kW SOFC Prototype System for > 5,000 hours of Operation	9/23/17		Report

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Decision Points

Go/No-Go Point	Date	Success Criteria
Proceed with system design and fabrication for installation at identified demonstration site, OR identify alternative site	12/31/15	1) Commitment has been received from a prominent demonstration site that maximizes visibility of the project. 2) Site meets prototype system location requirements for installation and interconnection (electrical/ gas)

Work Scope
Task 2

Task 2: Cell and Stack Manufacturing

- **Objective**

Fabricate and deliver SOFC stacks for the 400 kW SOFC Prototype system with emphasis placed on quality, yield, repeatability, and reliability in order to meet the project goals of less than 1.5% per 1000 hours power degradation over 5000 hours of system operation.

- **Work Plan**
  - **Task 2.1 Cell Manufacturing:** A total of about 4000 cells, each sized 254 mm by 254 mm with thickness of ~0.6 mm, will be manufactured based on the baseline TSC3 design, fabrication technologies and specifications.
  - **Task 2.2 Stack Manufacturing:** Thirty two (32) SOFC stack blocks, each using 120-cells, will be fabricated for the 400 kW SOFC Prototype system. The stacks will be based on VPS's large area stack (LAS) block design and specifications. Rigorous quality control will be applied during the manufacturing process. All stacks will be conditioned and performance-tested at VPS prior to installation in the power plant.

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Task 2 Activities and Schedule

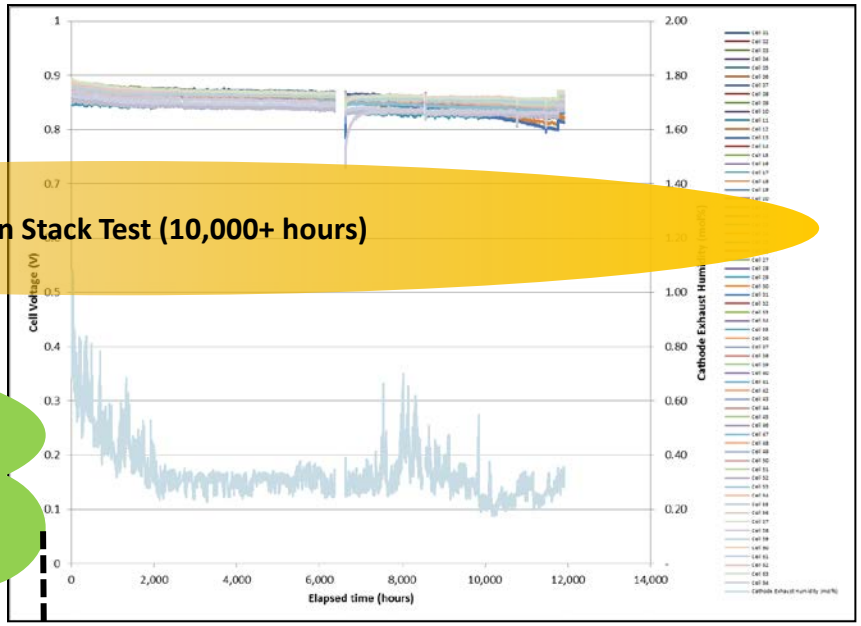
Q4, 2015 | Q1, 2016 | Q2, 2016 | Q3, 2016 | Q4, 2016 | Q1,2017 | Q2,2017 | Q3,2017

Technology & Manufacturing Readiness Assessment

1 **Stack Design Freeze**
Mar 1, 2016

80-cell Build

Validation Stack Test (10,000+ hours)



2.1 Cell Fabrication

Batch 1 | Batch 2 | Batch 3 | Batch 4

Batch 1 | Batch 2 | Batch 3 | Batch 4

2.2 Stack Fabrication

2 **Stack Deliverables**
Dec 8, 2016

400 kW SOFC System

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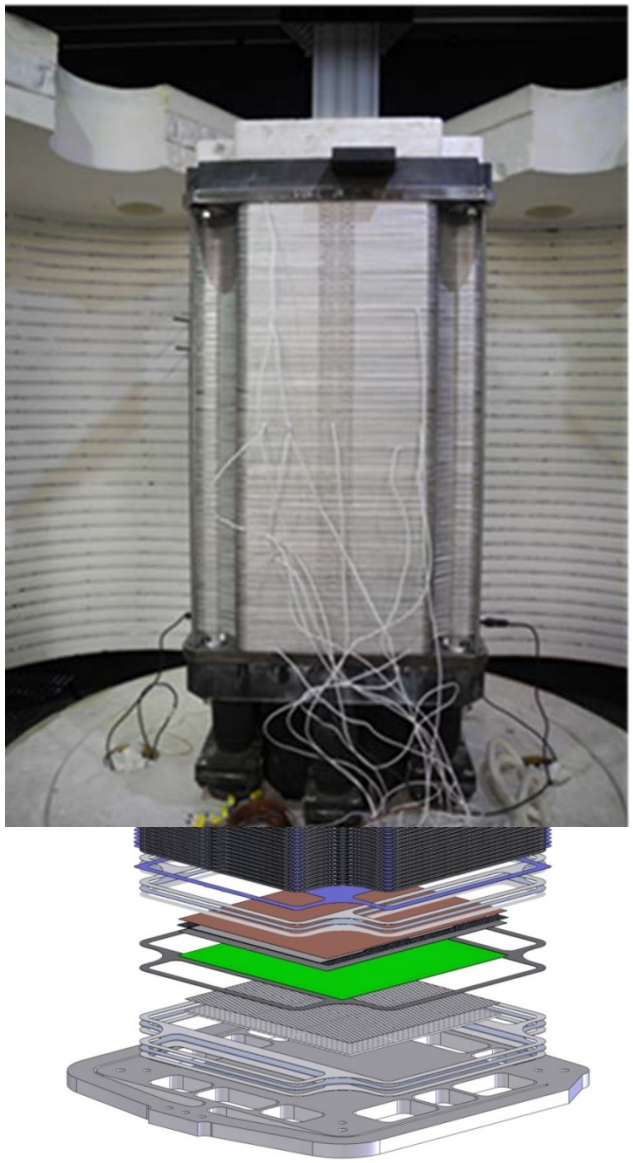
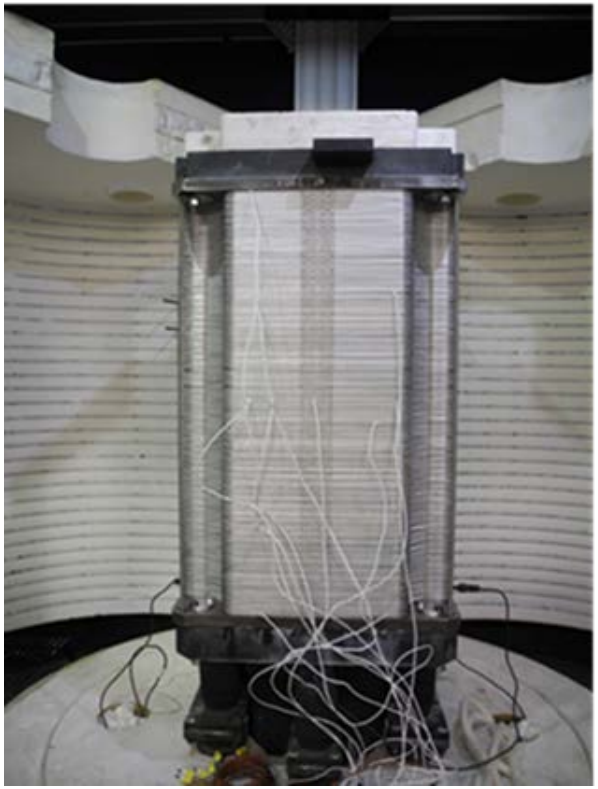
Anticipated Stack Design Freeze

- Stack Design: PCI 3 GT059881
- Cell: 120 Cells
  - TSC3, 0.6 mm thickness
  - 235 x 235 mm^2 (550 cm^2) active area
- Cr mitigation technology Gen2.0
- Standard compressive ceramic seal
- Sheet ferritic stainless steels for metallics
- Formed flow field materials for cell to interconnect contact on both anode and cathode sides
- 11 on-cell thermocouples (9 active + 2 spare)
- Electrically-live small footprint stack end plates
- ~16 kW output @ 160 A



Stack Factory Acceptance Testing (FAT)

- **Step 1: Initial Stack Conditioning and Anode Reduction**
  - Step-wise increase stack mechanical compression and heat-up stack to operating temperature
  - Introduce hydrogen and carry out anode reduction
- **Step 2: Fuel Utilization Curve**
  - Load stack to 160 A (291 mA/cm^2) at 25% in-stack reforming (DIR)
  - Test at 50% to 75% U_f in 5% increments
  - All cells greater than 0.8 V at 75% U_f
- **Step 3: Steady State Hold**
  - Stack is held at constant conditions representative of the 400 kW system testing for more than 24 hours to demonstrate stable performance of all cells
- **Step 4: Cooldown**
  - Cool to room temperature



All stacks will be fully Factory Acceptance Tested prior to delivery

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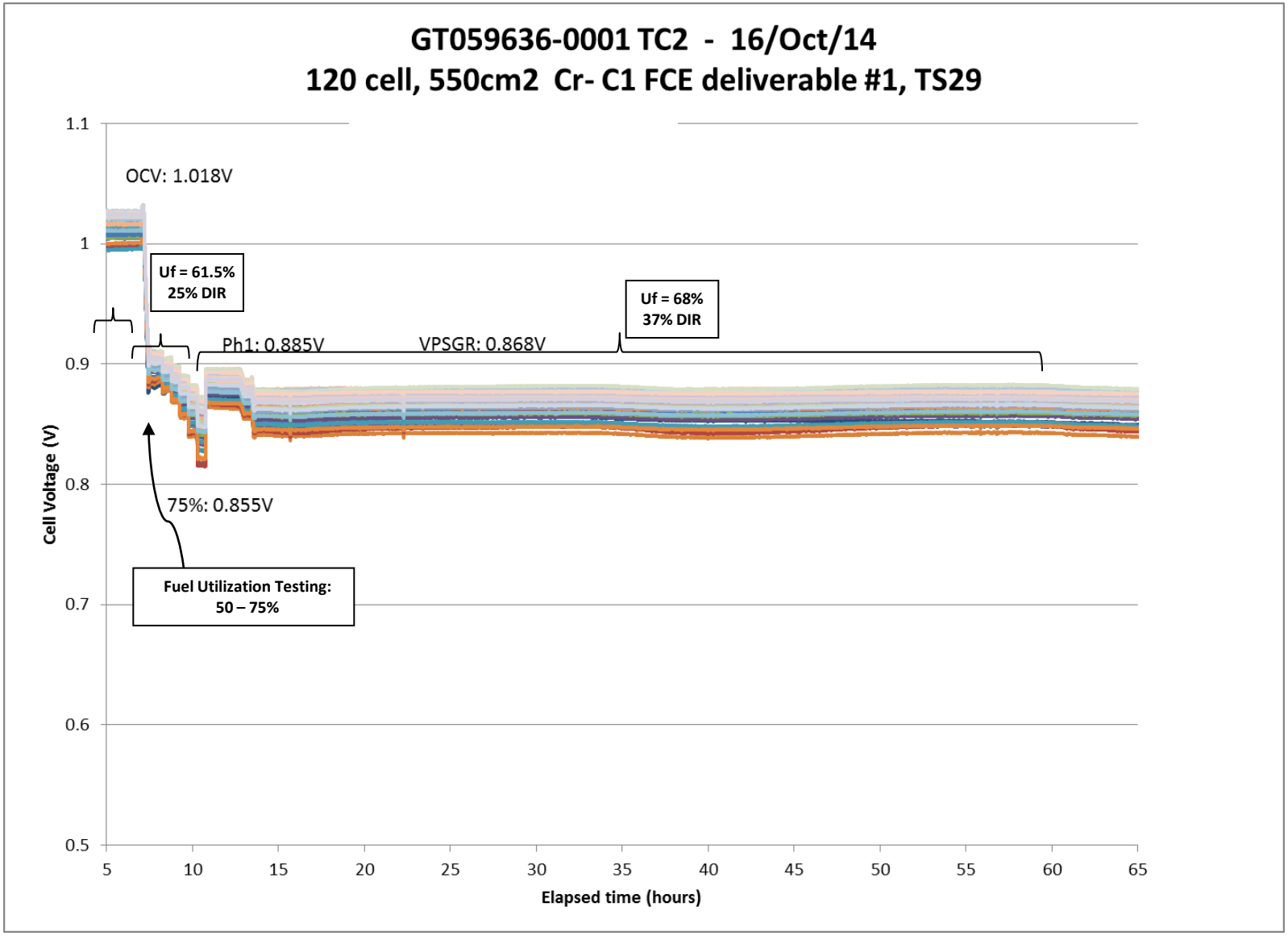
Sample FAT Test



Work Scope
Tasks 3

Task 3: Detailed Design

- **Objective**

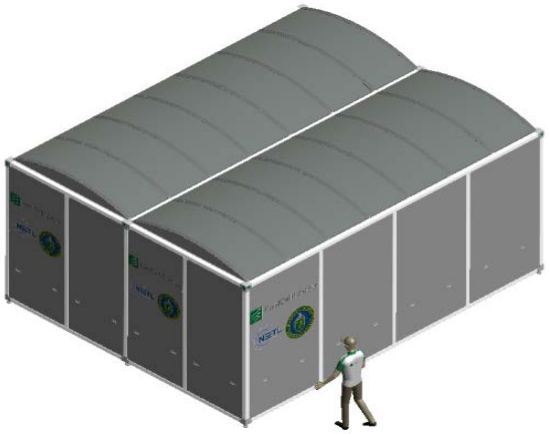
Complete the detailed design for the 400 kW SOFC Prototype system including Balance of Plant (BOP) and 100 kW "Modular Power Block" (MPB) stack module.

- **Work Plan**
  - **Task 3.1 System Design:** Develop the detailed, approved-for-construction, engineering and design package for the 400 kW SOFC prototype system. The results of the detailed engineering design activities shall include a complete set of documents encompassing analyses, fabrication drawings, specifications, vendor data, and instructions required to construct the power plant.
  - **Task 3.2 Stack Module Design:** The existing 100 kW MPB stack module design will be reviewed for improvements. Refinements will be incorporated based on the lessons learned from the tests performed in the previous DOE Co-operative Agreements. Computational fluid dynamics (CFD) and finite element analysis (FEA) models will be updated to ensure uniform flow and thermal distribution among the stacks, and acceptable mechanical stresses within the MPB components.

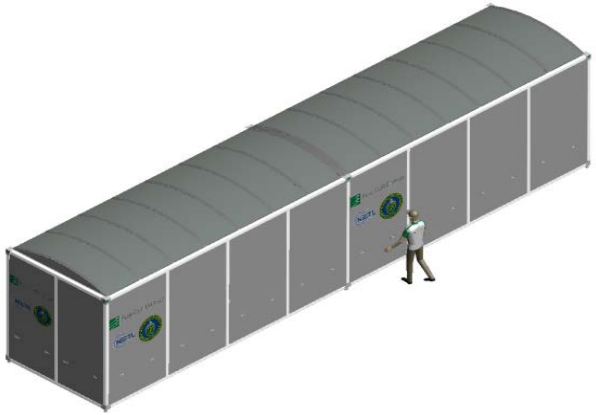
400 kW SOFC System Demonstration

- 400 kW Prototype SOFC System is comprised of 2 x 200 kW SOFC sub-systems

Two Installation Options for 400 kW System:



10’ H x 15’ W x 19.25’ L
(B)



10’ H x 7.5’ W x 38.5’ L
(A)

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200 kW SOFC System Performance

200 kW SOFC System Performance Summary

SOFC Gross Power	Normal Operating Conditions		Rated Power	
DC Power	**225.0**	**kW**	**246.4**	**kW**
Energy & Water Input				
Natural Gas Fuel Flow	19.7	scfm	21.6	scfm
Fuel Energy (LHV)	323.2	kW	355.5	kW
Water Consumption @ Full Power	0	gpm	0	gpm
Consumed Power				
AC Power Consumption	10.8	kW	12.5	kW
Inverter Loss	11.3	kW	12.3	kW
Total Parasitic Power Consumption	**22.0**	**kW**	**24.8**	**kW**
Net Generation				
SOFC Plant Net AC Output	**203.0**	**kW**	**221.6**	**kW**
Available Heat for CHP (to 120°F)	**84.7**	**kW**	**95.3**	**kW**
Efficiency				
Electrical Efficiency (LHV)	**62.8**	**%**	**62.3**	**%**
Total CHP Efficiency (LHV) to 120°F	**89.0**	**%**	**89.1**	**%**

➡ **200 kW SOFC system is designed for incremental improvements over the 50 kW PCM system in terms of electrical efficiency and CHP capabilities, while minimizing BoP risk**

Work Scope
Tasks 4

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Task 4: Prototype System Fabrication and Testing

- **Objective**

Fabricate, install, and test the 400 kWe SOFC Prototype system.

- **Work Plan**
  - **Task 4.1 Stack Module Fabrication**: Preform procurement and fabrication of components and assembly of stacks to construct 4x100 kW MPB stack modules. MPBs will include integrated hot BOP equipment (catalytic air preheater, radiative fuel reformer, anode recycle blower) and stack assembly components in addition to the SOFC stacks.
  - **Task 4.2 System Fabrication:** The system will be fabricated as 2 x 200 kW skids each utilizing two MPB modules. The two 200 kW skids will undergo factory acceptance tests (FAT) to ensure a functional system before shipment to the test site.
  - **Task 4.3 System Installation & Commissioning**: Test site location will be identified. The installation and commissioning of the 400 kW SOFC prototype system at the host site will be completed.
  - **Task 4.4 Prototype System Tests**: 400 kW Prototype system testing will include ≥5000 hours of operation at normal operating conditions.. Tests will be performed in accordance with the “Stack Metric Test and Cost Estimation Guidance”, included in DE-FOA-0001244 Section I-C. A test plan will be developed and submitted for DOE approval prior to the test start.

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200kW SOFC Plant System

Work Scope
Tasks 5

Task 5: Stack & System Cost Analysis

- **Objective**

SOFC power block and stack capital costs (de-escalated to 2011 US dollars) will be estimated for mature market production of ≥100 MWe Integrated Gasification Fuel Cell System with CCS (excluding coal gasification, syngas clean-up and CO2 separation subsystems).

- **Work Plan**
  - **Task 5.1 Stack Cost Update:** Factory Cost estimation of the stack will be completed.. The cost estimate shall be performed in accordance with the “Stack Metric Test and Cost Estimation Guidance”, included in DE-FOA-0001244 Section I-C.
  - **Task 5.2 ≥ 100 MW IGFC System Cost:** Cost estimation of the IGFC system Power Block will be completed. The cost estimate will be based on the updates of FCE’s IGFC design. The updates will include the systems performance parameters resulted from the SOFC stack performance at NOC realized in the 400 kW prototype system tests.

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Stack Factory Cost Model

- The cost model includes:
  - Fabrication labor
  - Assembly labor
  - Purchased materials
  - Manufactured materials
  - Equipment and plant depreciation,
  - Tooling amortization
  - Equipment maintenance
  - Utilities
  - Indirect labor & materials
- Costs for raw materials and purchased components include:
  - A combination of current and past vendor quotes and invoices or catalog prices, sometimes scaled for order quantity and adjusted for the time of the quote or invoice
  - DOE provided data regarding a number of raw material inputs
- Indirect costs include:
  - cell fabrication maintenance
  - cell fabrication consumables
  - cell fabrication QA/QC
  - stack assembly consumables
  - indirect labor
  - overhead