POWER GENERATION FROM AN INTEGRATED BIOMASS REFORMER AND SOLID OXIDE FUEL CELL

SBIR Phase III Xlerator Program

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INNOVATEK

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Project ID: FC096

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Overview

Timeline

Start: 10-01-2010

Finish: 09-30-2013

2nd Period funding delay until 4-1-2012

33% Complete

Barriers

Cost, Durability & Performance

Targets: H2 production from diverse domestic sources; distributed power demo 2Q 2018

Year	Cost/kW	Efficiency	Lifetime	Technology
2015	$1700	42.5%	40,000h	5 kW Dist Gen Sys
2020	$1500	>45%	60,000h	5 kW Dist Gen Sys

Budget

Total: $2.3M

Received FY11: $900K

Planned FY 12: $650K

Partners

Topsoe Fuel Cell

Washington State University & PNNL for BioFuel

Energy Technology Services

Relevance: Public Benefits

Environmental Quality & Energy Security

The full benefits from fuel cells are possible only if the feedstock for hydrogen production is a renewable, domestically produced commodity that does not compete in the food chain.

Our technology will address these issues by:

- Helping shift the primary energy source for H_2 from fossil fuels to renewable non-food biomass.
- Using less fuel through high system efficiency by effective thermal integration and off-gas recycling.
- Providing an alternative method for distributed power generation near the source of the feedstock, enhancing grid stability.

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Relevance: Project Objectives

Year	Objective	DOE Barrier Addressed
2011 Complete	**Establish design to meet technical and operational needs for distributed energy production from renewable fuels**	SOFC power using renewable non-food biomass fuel; codes & standards
2011/2012 **50% complete**	**Design, optimize, and integrate proprietary system components and balance-of-plant in a highly efficiency design.**	Demonstration; system efficiency; design for low cost manufacturing
2012 2013 Not started	**Demonstrate the technical and commercial potential of the technology for energy production, emissions reduction, and process economics**	• 40,000 h lifetime • 99% availability • >40% efficiency • $1700/kW equipment cost

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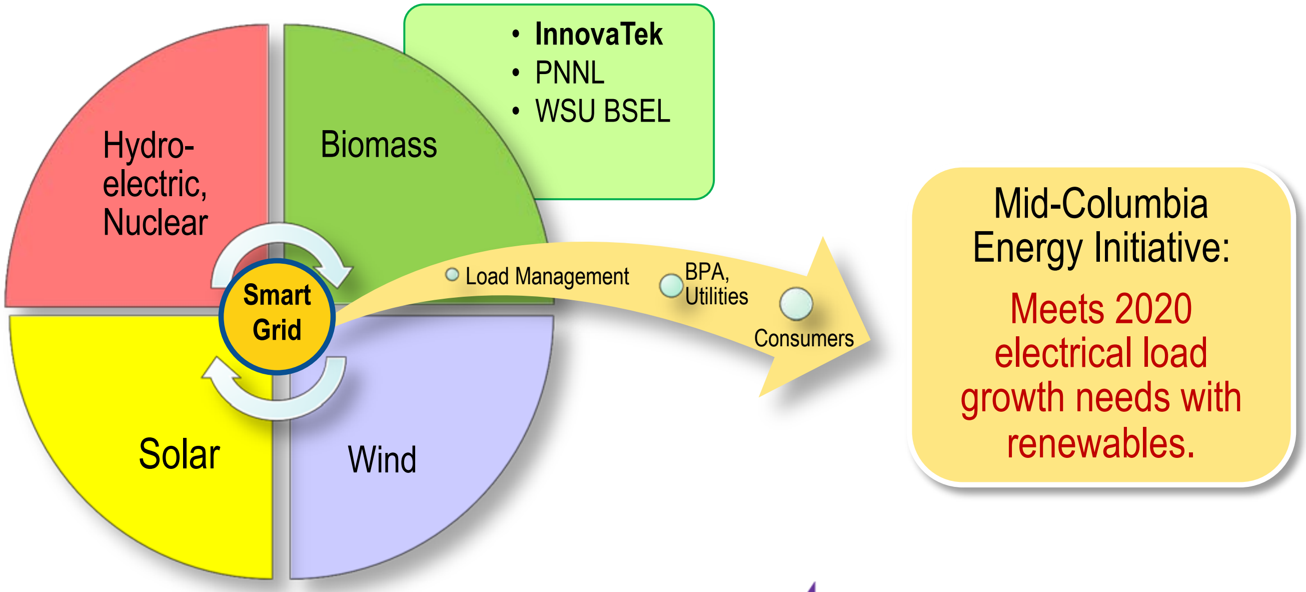
Approach: Project Goal

Develop and demonstrate a fuel cell distributed energy system that operates with 2nd generation biofuel.

- **System based on InnovaTek's steam reforming process and SOFC**
- **Non-food biofuels include pyrolysis oil and bio-kerosene processed locally**
- **To be demonstrated in Richland's renewable energy park and tied to grid**



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Approach: Milestones & Go/No Go

Date	Milestone or Go/No Go	Status
Dec 2010	M1: Criteria for design review to confirm compliance with user requirements/ codes & standards	Completed
Mar 2011	M2: 3rd Party Review completed for System Design and Layout that meets Criteria	Complete for Gen1 continuing for Gen2
Sept 2011	M3: Solid model & CAD drawings complete; OEM components specified & acquired	Complete for Gen1 continuing for Gen2
Dec 2011	Go/No Go: Laboratory prototype system produces power from biofuel	Achieved for Gen1
July 2012	M4: Achieve 40% system operating efficiency	In progress
Aug 2012	M5: System performance proves superior energy efficiency & emissions reductions compared to conventional technology	In progress
Sept 2012	Go/No Go: Analysis of process economics supports commercial feasibility	Not started

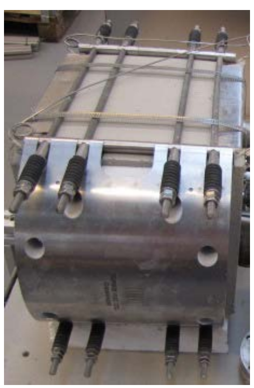
Approach: Core Technology

InnovaGen® Fuel Processor

- Creates hydrogen from a range of liquid and gaseous fuels with high energy density
- Proprietary catalyst & hardware
- Water neutral steam reformer
- Compact and efficient

Uses Bio-kerosene made from wood sawdust and non-food camelina

Topsoe Solid Oxide Fuel Cell



- 1.5 kW, 80V DC, 0-25 A
- 340mm x 200mm x 200mm
- 67% fuel utilization
- 750°C
- 20 kg

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Accomplishments: Established System Requirements & Specifications

Address DOE Barriers for Codes & Standards, Field Demonstration

- **Technical, operational, & safety requirements defined**
  - Energy Technology Services provided advice and 3rd Party Oversight, including regulatory codes & standards
    - NFPA 30 - CSA FC1 - CFR 47 FCC
    - NFPA 853 - ASME PTC 50 - IEEE 1547
    - NFPA 70 NEC - UL 1741
  - City of Richland Utilities established demo requirements
  - Milestone 1 ➔ Developed System Requirements Document based on CSA-America FC1 – *Stationary Fuel Cell Power Systems*
    - *Kelvin Hecht, Consultant*
  - Developed Draft FMEA

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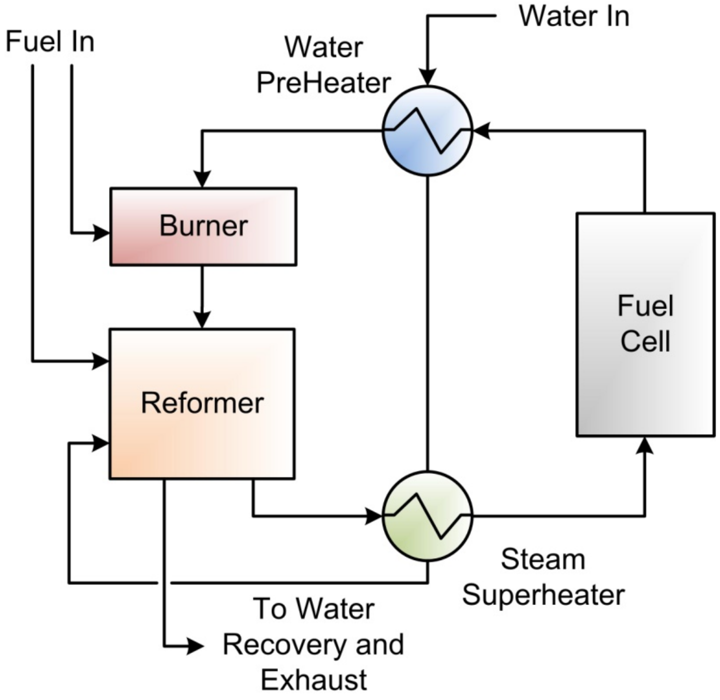
Progress: Completed Process & Component Modeling and Simulation

Use process simulation tools, CFD & FEA to develop optimal designs for chemical conversion and heat transfer.



CFD simulations used to design core fuel processor components and identify critical design features to help balance:

- Heat Transfer
- Thermal Stresses
- Pressure Drop
- Desired flow patterns

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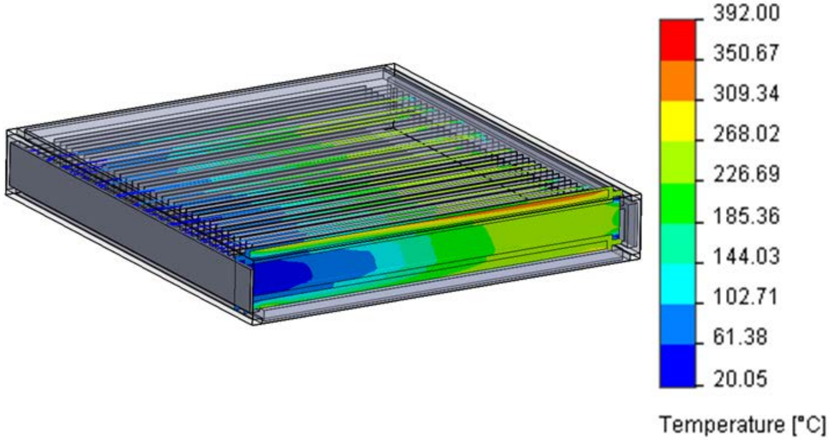
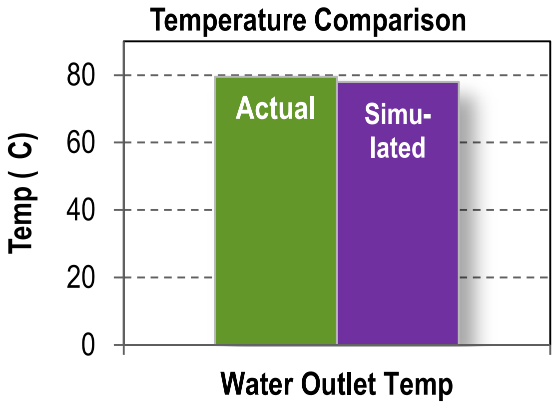
Progress: Component Modeling & Simulation used for design optimization

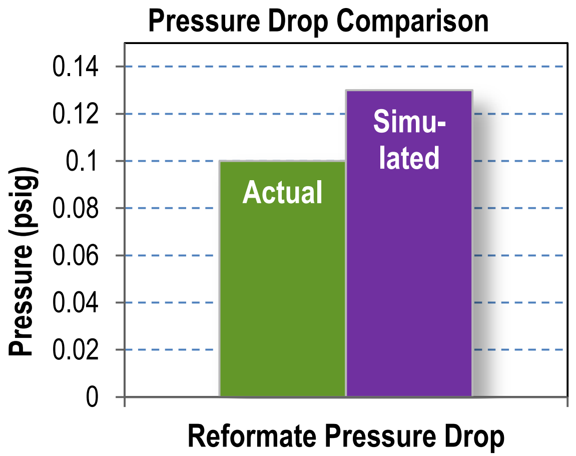
Microchannel Heat Exchanger: Pre-heats process water and cools anode off-gas in cross flow design



- Simulation verified that pressure drop across channels meets design criteria;
- Design results in high heat transfer density, meeting performance criteria.

Component test results verified simulation





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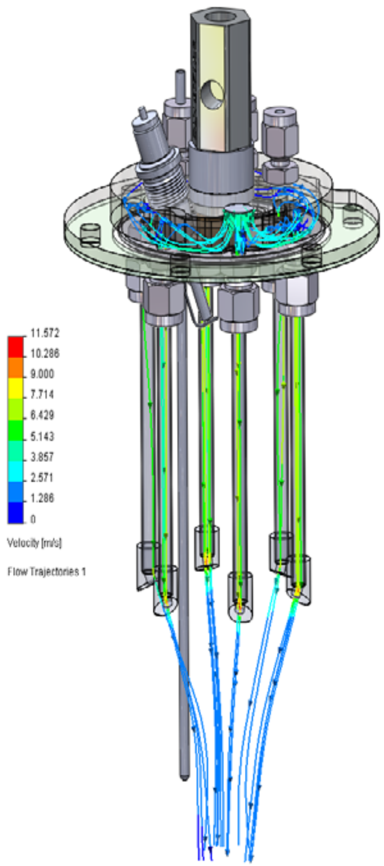
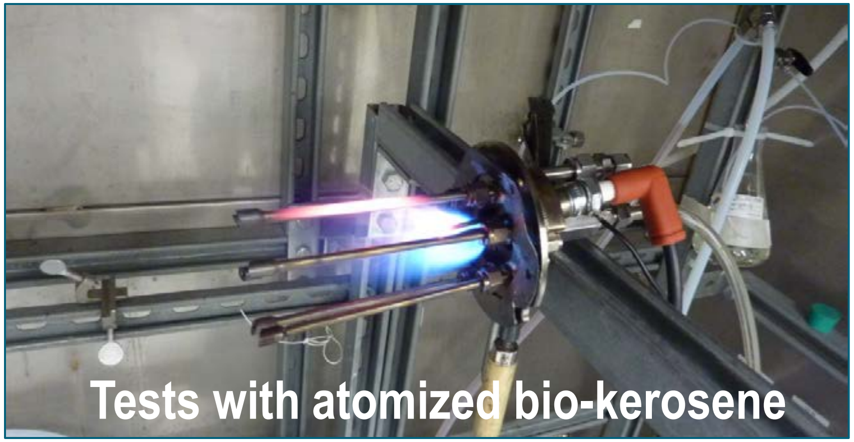
Progress: Used simulation to design multi-fuel burner; Confirmed during test

The fuel/off-gas burner is the primary source of thermal energy for the reforming reaction.

Correct distribution of H_2 essential for developing a desirable flame shape and optimizing heat transfer.





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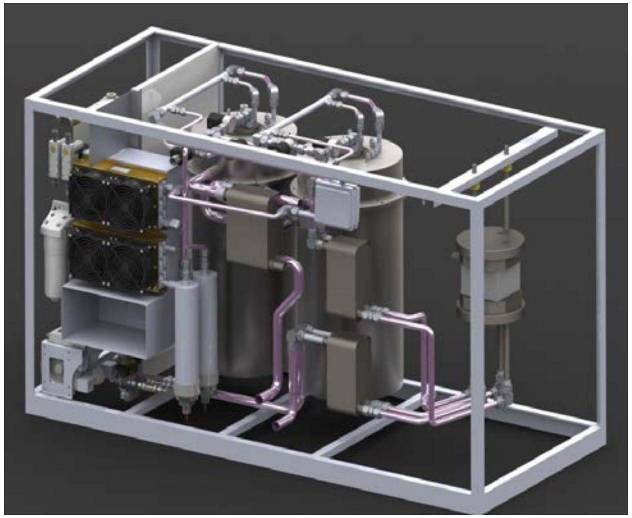
Accomplishments: Developed Highly Efficient Thermally Integrated System Design



Process Flow Diagram

- Subdivided into 21 process streams

Mass and Energy Balance

- Completed for each of 21 process streams
- Determines input, output, efficiency

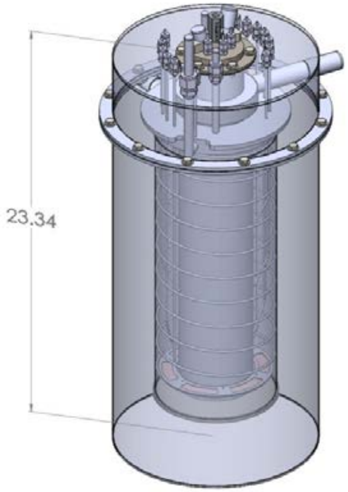
Optimized Layout, Piping & Instrumentation

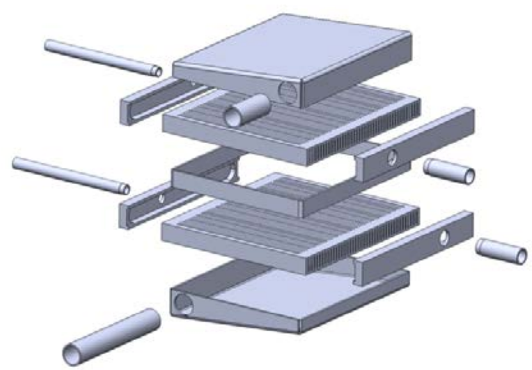
Solid Model of Integrated System

Milestone 3

Component Design and Analysis

- Process simulations
- Design trade-off analyses





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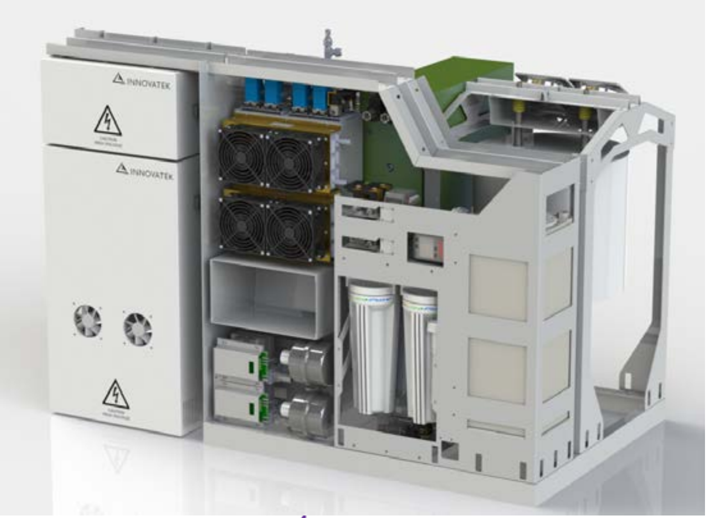
Progress: Design Review & Materials Analysis

Design for manufacturing and assembly review

- **Conducted by expert consultant** ⇐ **Milestone 2**
- **Focus on materials and joining technology**
- **Assessed appropriateness for manufacturability**
- **Provided advice on reducing cost & increasing durability**
  - Materials selection
  - Forming selection
  - Standardization
  - Consolidation of parts
  - Optimization of tolerances
  - Design for assembly
  - Vendor selection



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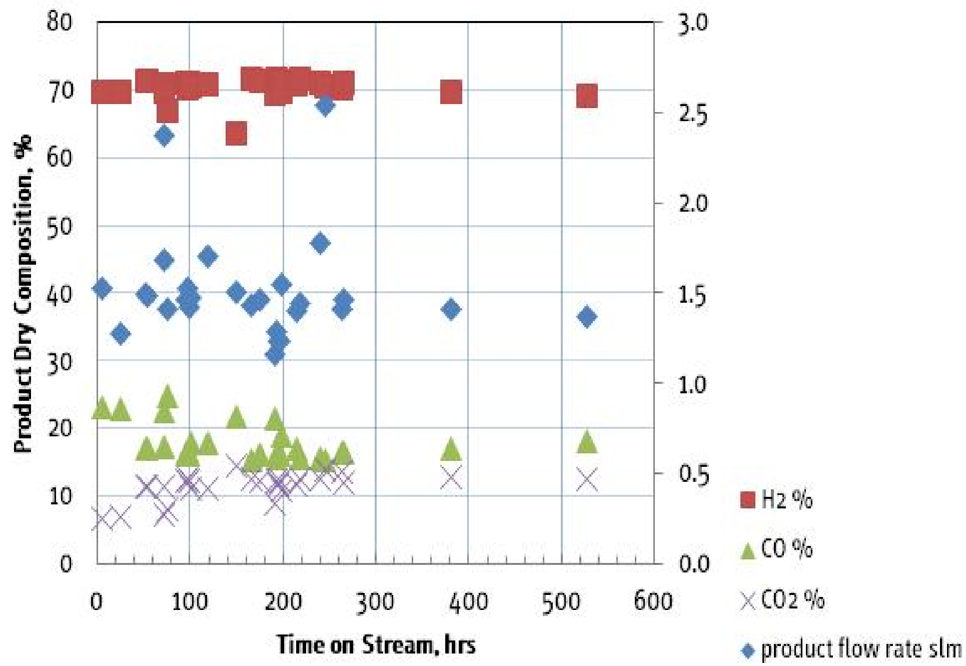
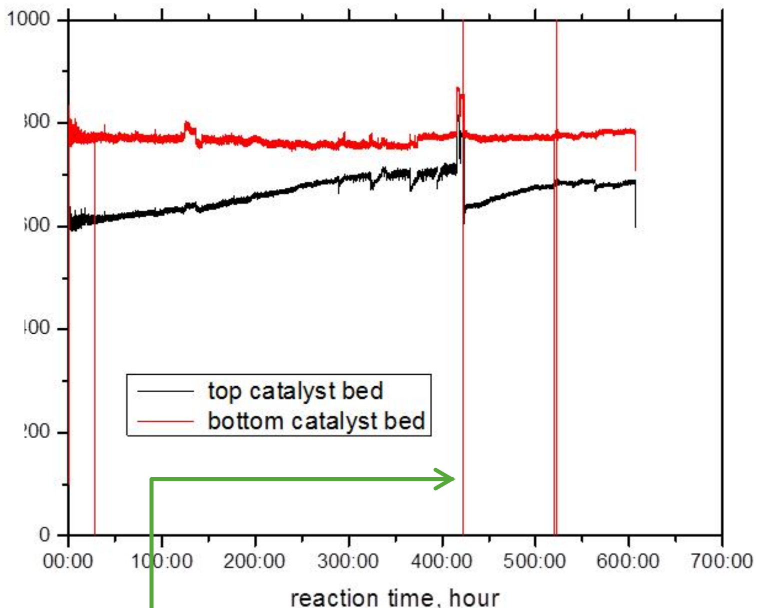
Accomplishments: InnovaTek Proprietary Catalyst Reforms Bio-Kerosene during long-term test

Stable over 600 hours with successful regeneration

Product flow rate and composition





Regeneration cycle at 420 hr after inadvertently running for several hrs without water

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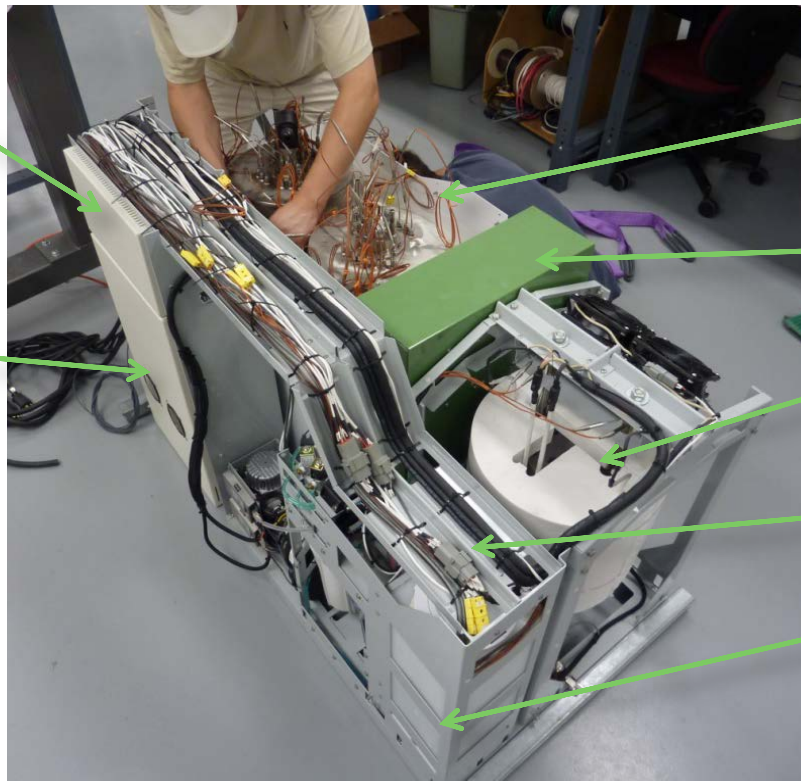
Progress: Proprietary Component Fabrication, Assembly and Integration

Control system

Air handling



Fuel processor

Thermal management

Insulated fuel cell

Pumps

Water treatment

System is water neutral; no net consumption

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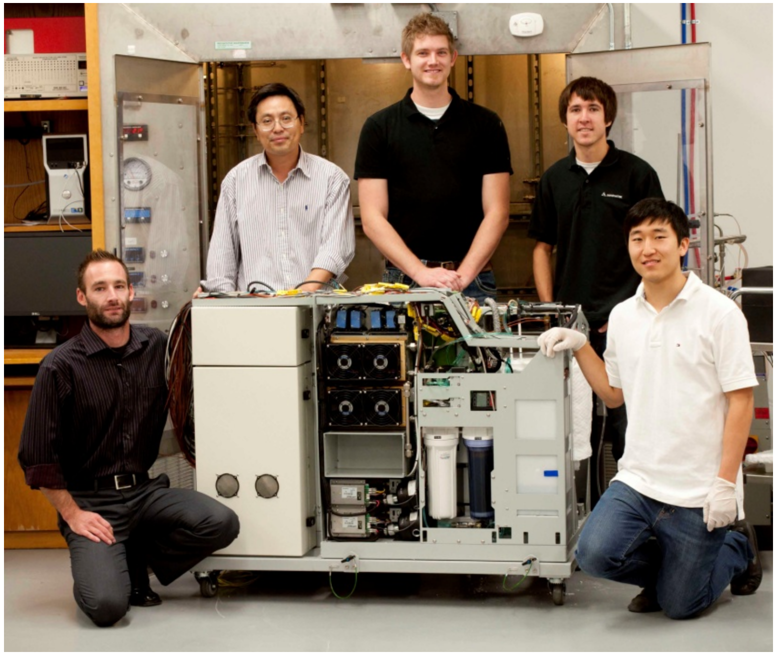
Accomplishments: Fully Integrated InnovaGen® Power Unit Built & Tested

Proprietary Components

- Hardware
  - Chemical processing
  - Thermal management
  - Water management
  - Electrochemical
- Software
  - Control systems
  - Safety features
- Catalysts
  - Convert multiple fuels including biofuel



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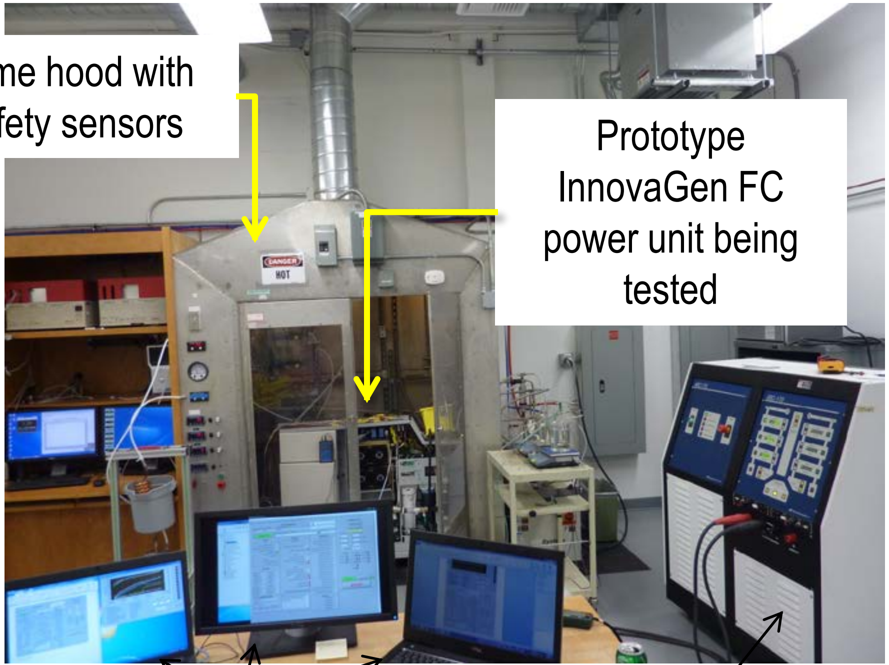
Accomplishments: Integrated System Produced Power from Bio-Fuel

Go Year 2

1.2 kW power sent to grid

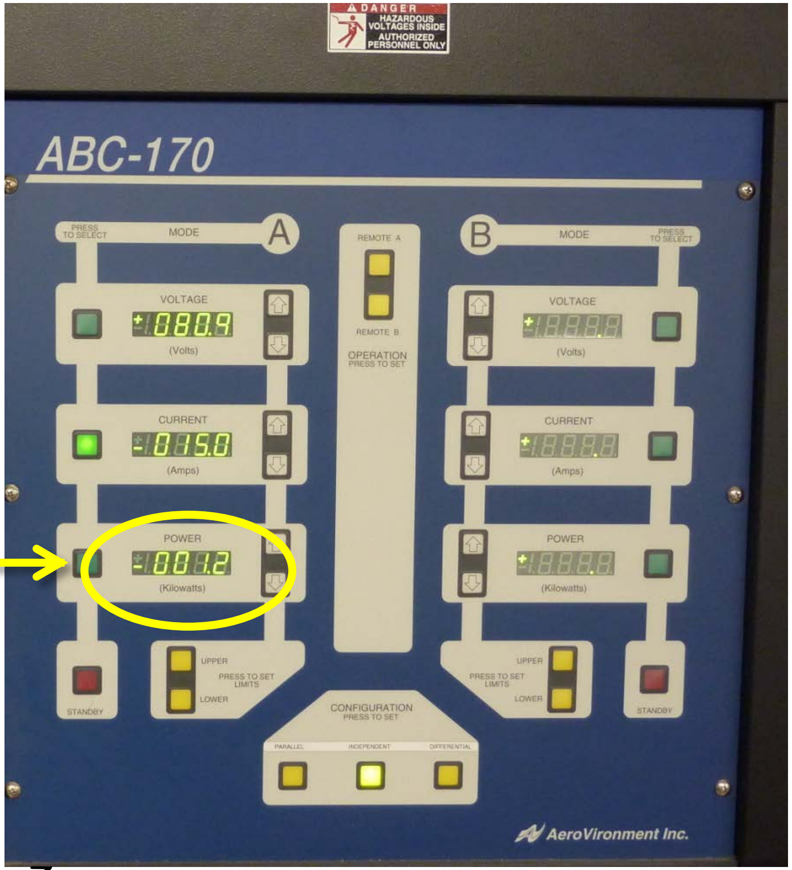


Fume hood with safety sensors

Prototype InnovaGen FC power unit being tested

Control system monitors

AeroVironment power processing system



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Accomplishments: Analysis of Process Economics

Used EERE's HOMER Model in Phase II

- Examined several scenarios for delivering 5 kW electrical AC power for 20 years using InnovaGen FC power unit
- Compared bio-kerosene, upgraded bio-oil, non-upgraded pyrolysis oil, natural gas
- Used projected production and fuel pricing data from DOE sources

Significant Findings:

1. A fuel cell generator that operates on natural gas could produce electricity at prices at or below current grid prices when volume production brings capital costs down.
2. Up-graded bio-fuel is less costly to create electricity than raw pyrolysis oil because of its much higher heating value

Collaborations

Subcontractors

- Energy Technology Services – former senior staff of UTC; developed first fuel cell system for NASA; acted as 3rd party design reviewers & advisors for codes & standards
- Topsoe Fuel Cell – provided SOFC stack

Strategic Partners

- PNNL & WSU-BSEL – provided bio-oil made from wood sawdust
- Boeing – provided bio-kerosene made from camelina
- City of Richland Electric Utility – providing site for field demo
- Mid-Columbia Energy Initiative

Education

- Supported 5 student interns from Kettering, WSU, U of WA in mechanical engineering, chemistry, electrical engineering, & business

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Proposed Future Work

Objective 3. Prove the technical and commercial potential of the technology

- **Increase system efficiency & durability; reduce cost**
  - Reduce FC parasitic power; improve FP thermal management
  - Enhance FC-FP integration; evaluate BOP alternatives
- **Assess Versa Power SOFC – Collaborator**
- **Optimize performance by testing & adjusting operating parameters**
- **Analyze process economics**

Go/No Go decision to proceed to Year 3

- **Design for manufacturing to reduce costs**
- **Build demo systems**
- **Verify durability with field demo at City Utility**

Summary

Relevance: Shift primary energy from fossil to renewable fuels
- Address codes & standards for fuel cells
- Increase system efficiency, lifetime and durability; decrease cost
- Distributed power production near source of feedstock to enhance grid stability

Approach: Develop reformer that generates hydrogen from non-food biofuels
- Develop highly efficient processing design of integrated SOFC and fuel processor
- Prove technology in long-term field demonstration with utility partner

Accomplishments: Developed system design criteria for codes and standards
- Used simulation and modeling to develop superior component /system designs
- Developed optimized catalyst for biofuel reforming
- Fabricated and integrated proprietary system hardware, software, and catalysts
- Demonstrated 1.2 kW power from bio-kerosene and sent to grid

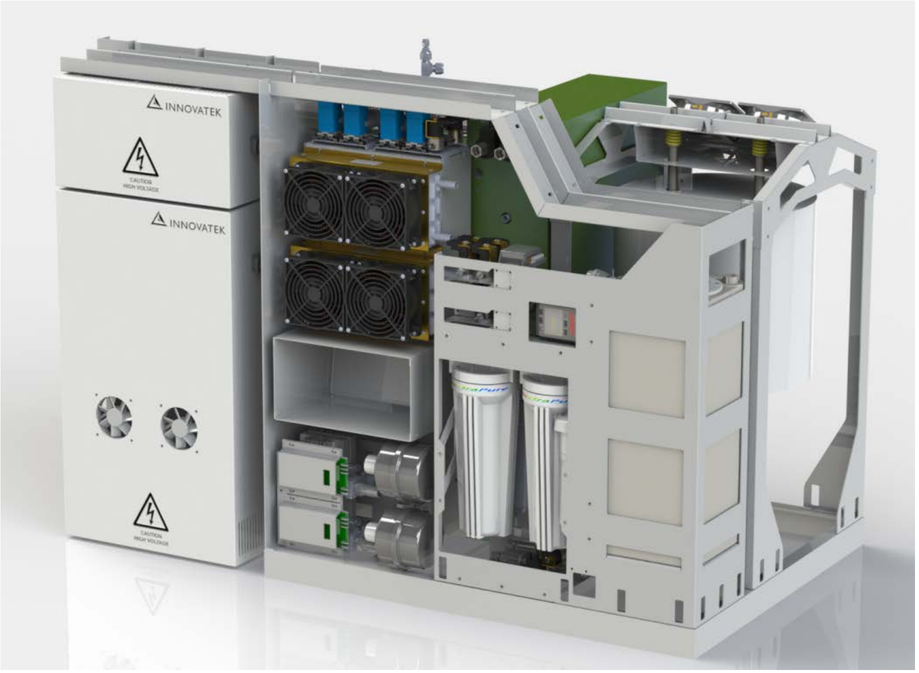
Collaborations: Supported 5 students; Subcontractors for fuel cell & 3rd party oversight;
- Partnerships with PNNL, WSU, Boeing , City of Richland, Regional Energy Initiative

Future: Further technology improvements and system optimization
- Additional fuel cell collaborators; Analysis of process economics
- Field demonstration and long term operation

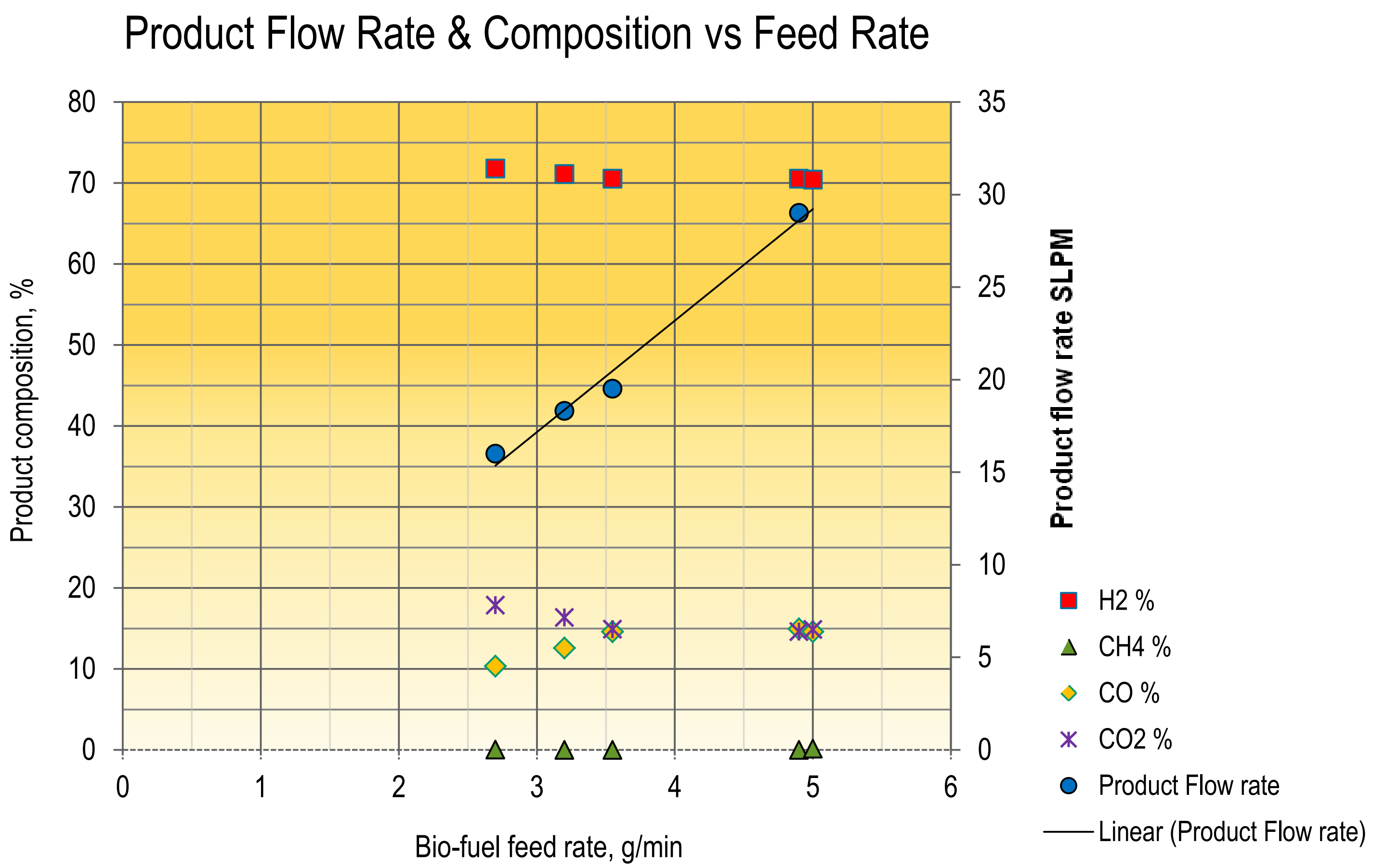
Technical Back-up

Technical: Developed & Integrated All Subsystems of Complete Power Unit

- Fuel processing
- Oxidant processing
- Thermal management
- Water treatment
- Power conditioning
- Automatic controls
- Ventilation
- Topsoe SOFC
- Onboard energy storage



Reformer Test Results with Bio-Kerosene



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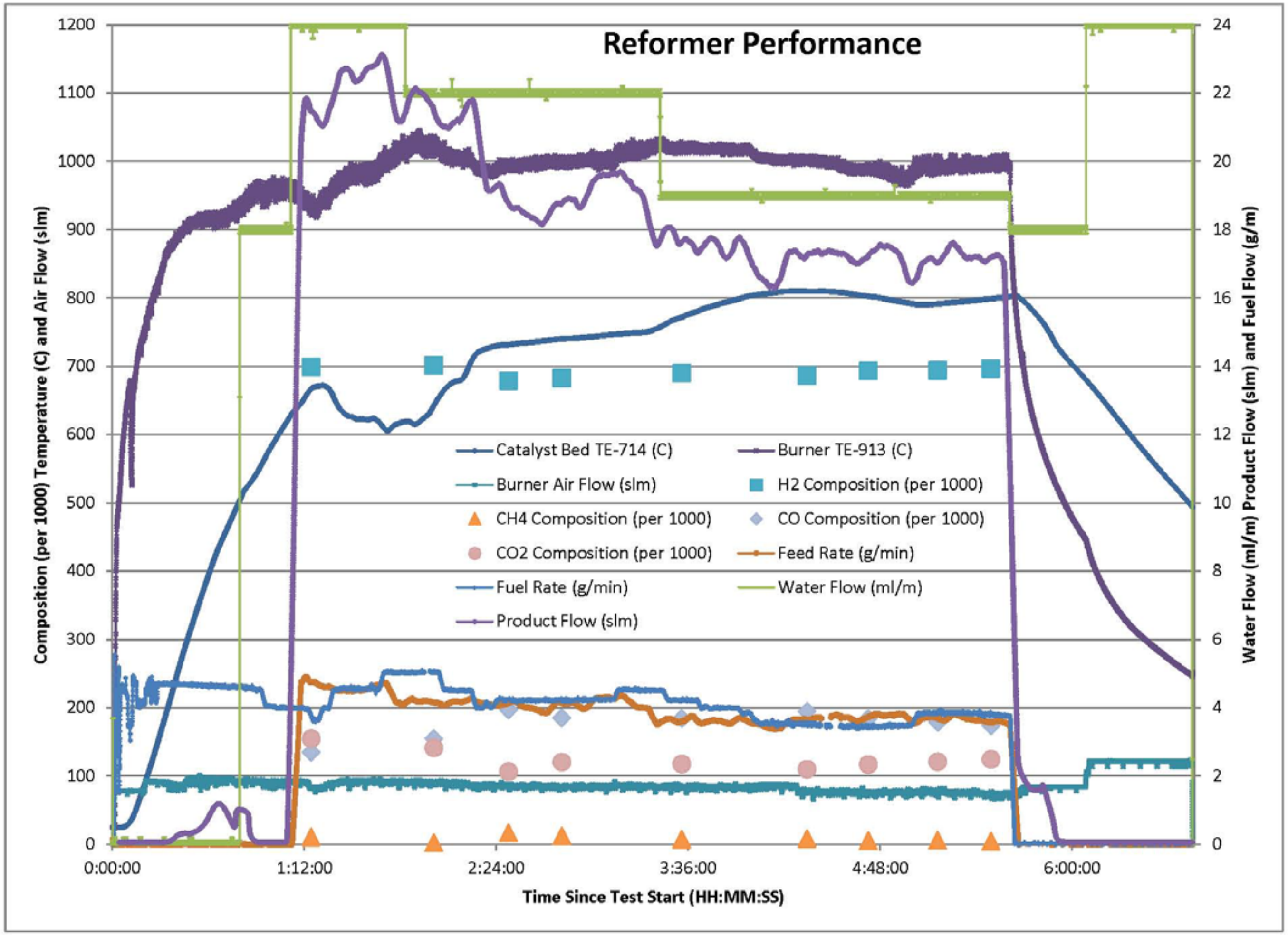
Data Summary – Reformer Tests



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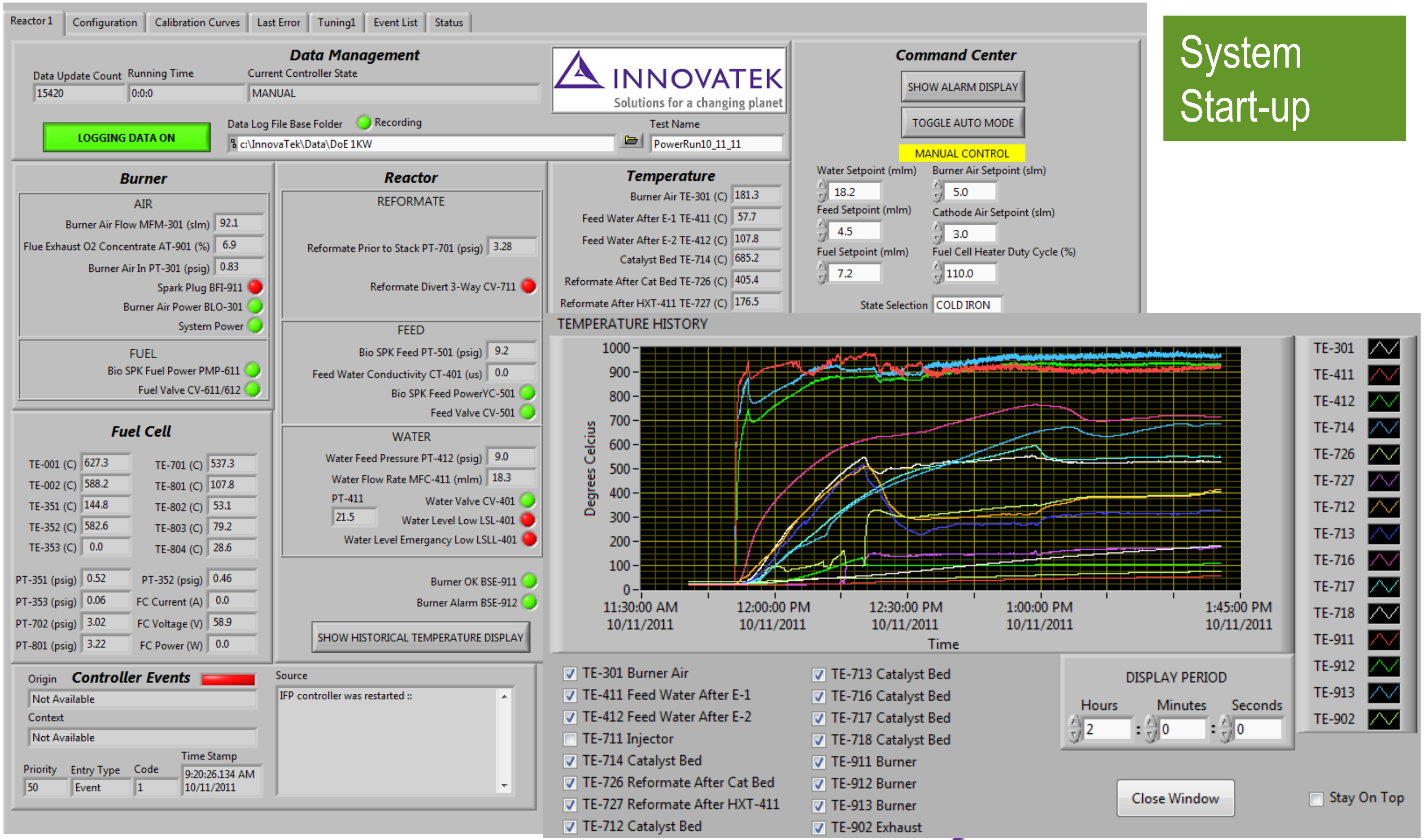
Accomplishment: Test of Integrated Reformer & 1 kW SOFC – Start-up



System Start-up

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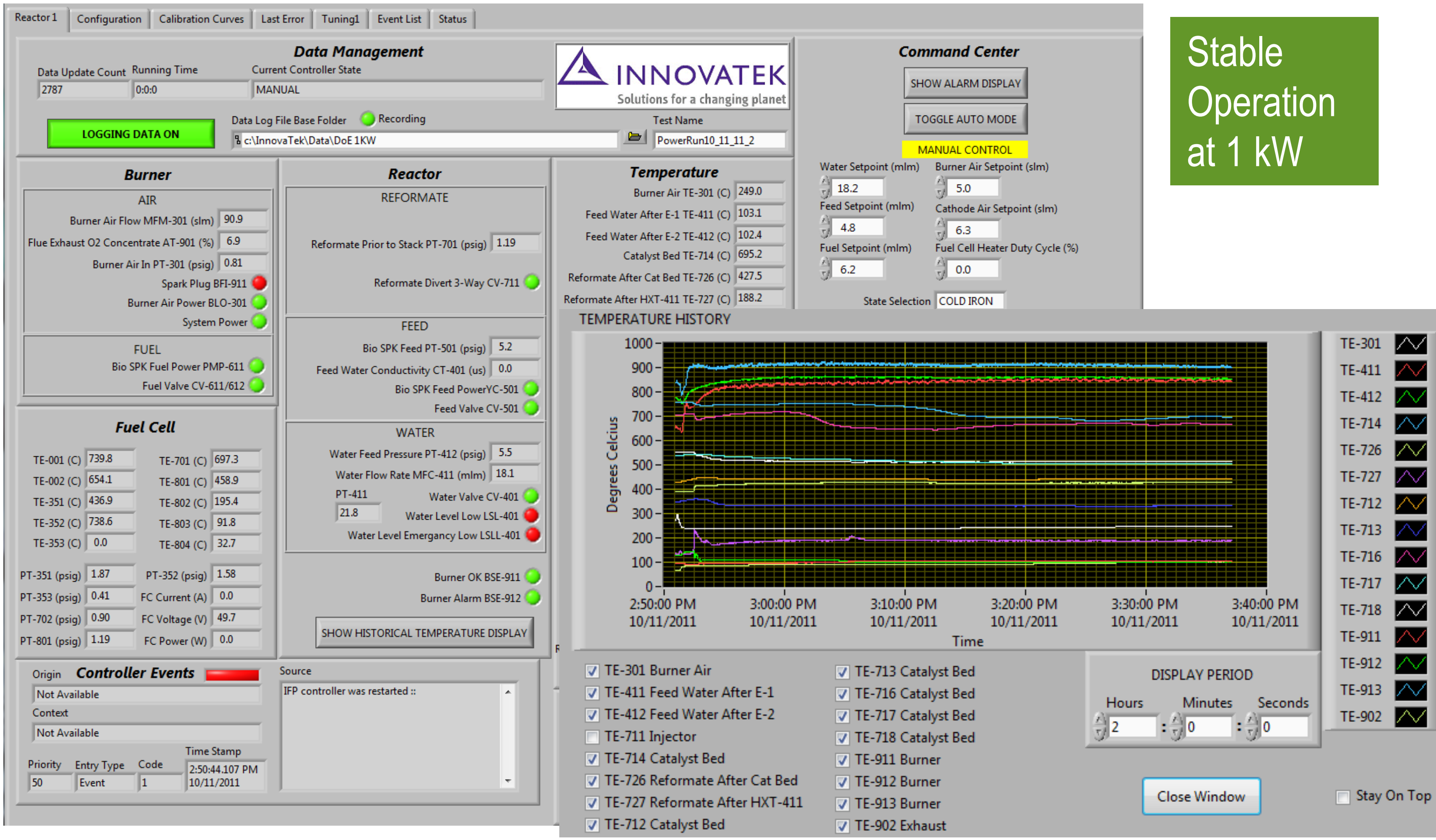
Accomplishment: Test of Integrated System – Steady state



Stable Operation at 1 kW