

# 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: 03-31-2014

66% Complete

## DOE Barriers: Cost, Durability & Performance

**DOE 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 FY12: \$650K

Expected FY 13: \$748K

## Partners

Topsoe Fuel Cell

Fuel Cell Energy/Versa Power

Impact Washington

# Relevance: Public Benefits; H<sub>2</sub> from Diverse Sources

## Addressing DOE Barriers and Targets: 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, and does not increase the price of energy

Our technology will address these issues by:

- Helping shift the primary energy source for H<sub>2</sub> from fossil fuels to renewable non-food biomass, using natural gas as the bridge.
- 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 at competitive cost.



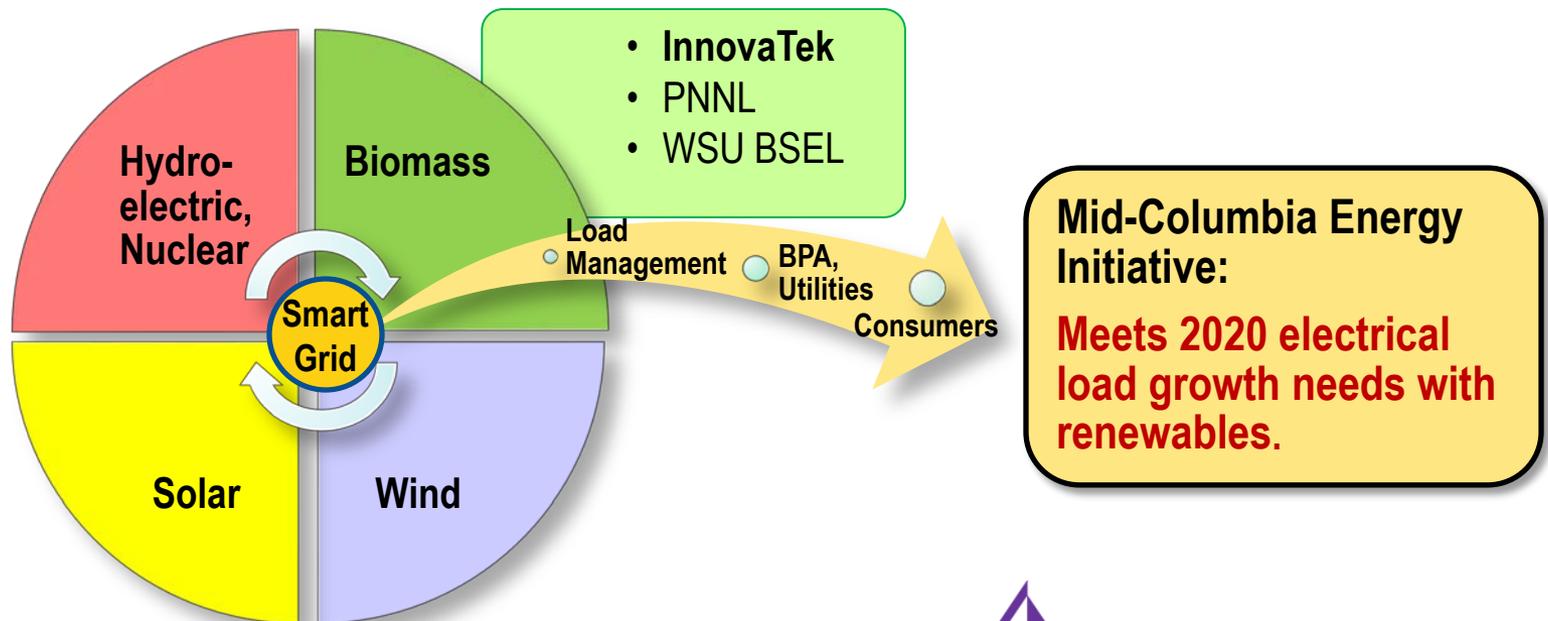
# Relevance: Project Objectives

Year	Objective	DOE Barriers Addressed
2011 <b>Complete</b>	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 <b>Complete</b>	Design, optimize, and integrate proprietary system components and balance-of-plant in a highly efficient design.	Demonstration; system efficiency; design for low cost manufacturing
2013/ 2014 <b>Not started</b>	Demonstrate the technical and commercial potential of the technology for energy production, emissions reduction, and process economics	<ul style="list-style-type: none"> <li>• 40,000 h lifetime</li> <li>• 99% availability</li> <li>• &gt;40% efficiency</li> <li>• \$1700/kW equipment cost</li> </ul>

# Approach: Project Goal

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

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



# Approach: Milestones & Go/No Go

Date	Milestone or Go/No Go	Status
Jan 2013	M4: Achieve 40% system operating efficiency with revised/optimized system design	41%
Feb 2013	M5: System performance proves superior energy efficiency & emissions reductions compared to conventional technology	Complete
March 2013	Go/No Go: Analysis of process economics supports commercial feasibility (Cost of power is competitive)	Complete
Oct 2013	Complete fabrication of Gen3 prototype for field demonstration	Not started
March 2014	Complete 6 months of field demonstration	Not started

# Approach: Optimization & Economic Analysis

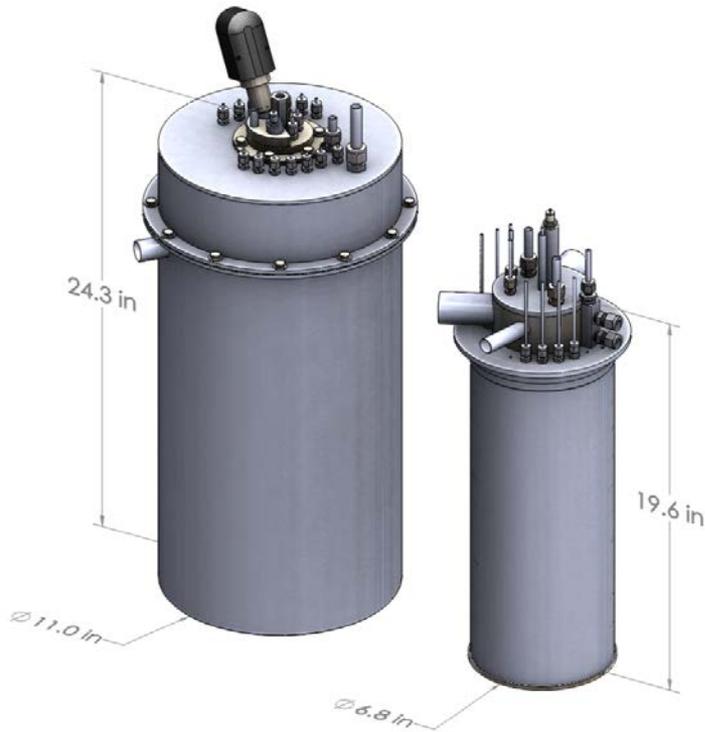
1. **Use simulation and modeling studies to optimize system design for performance and cost reduction.**
  - **Optimize process configuration using MathCAD and FEMLAB**
  - **Conduct FMEA to assess necessary redesign, determine maintenance requirements and costs, lifetime**
  - **Conduct DFMA analyses to identify design changes to improve manufacturability and reduce production & operation costs**
  - **Use HOMER model to assess cost of power**
2. **Translate dimensions, geometries, and flow patterns defined from optimization modeling to 3-D CAD images**
3. **Complete Bill of Materials & SolidWorks drawing libraries for all original hardware designs and BOP**
  - **Use this information to model capital equipment costs and parasitic power requirements**

# Approach: Scale-up & Optimize Core Technology

## InnovaGen® Fuel Processor for 4 kW power

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

## Solid Oxide Fuel Cell



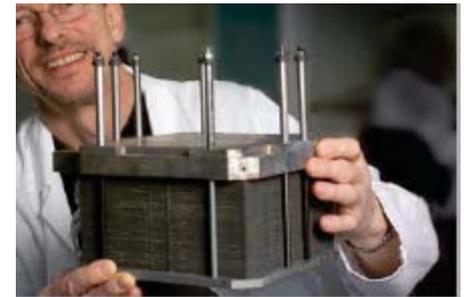
2012

2013

Size reduced, output increased

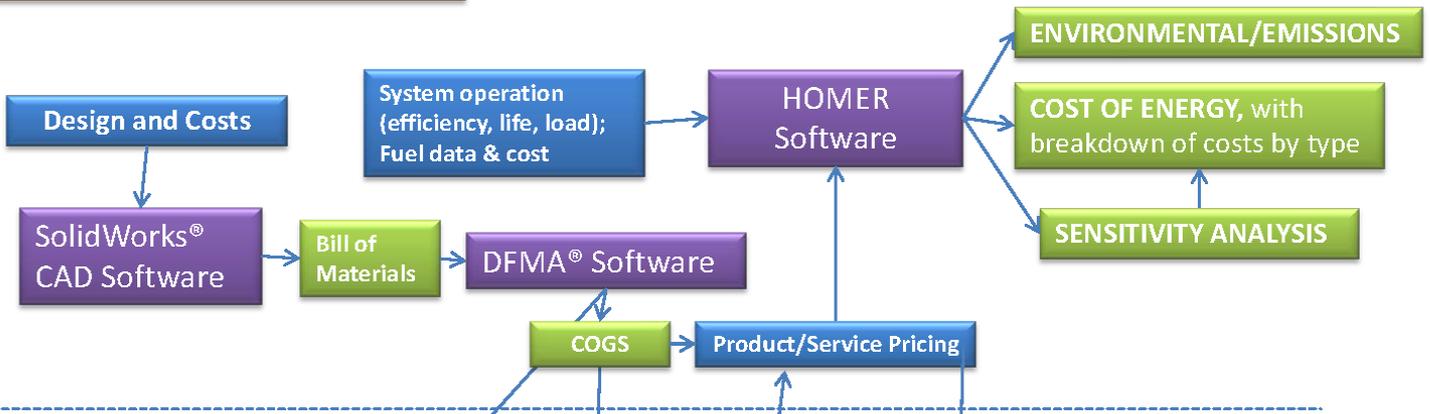


Transitioning to scaled-up SOFC



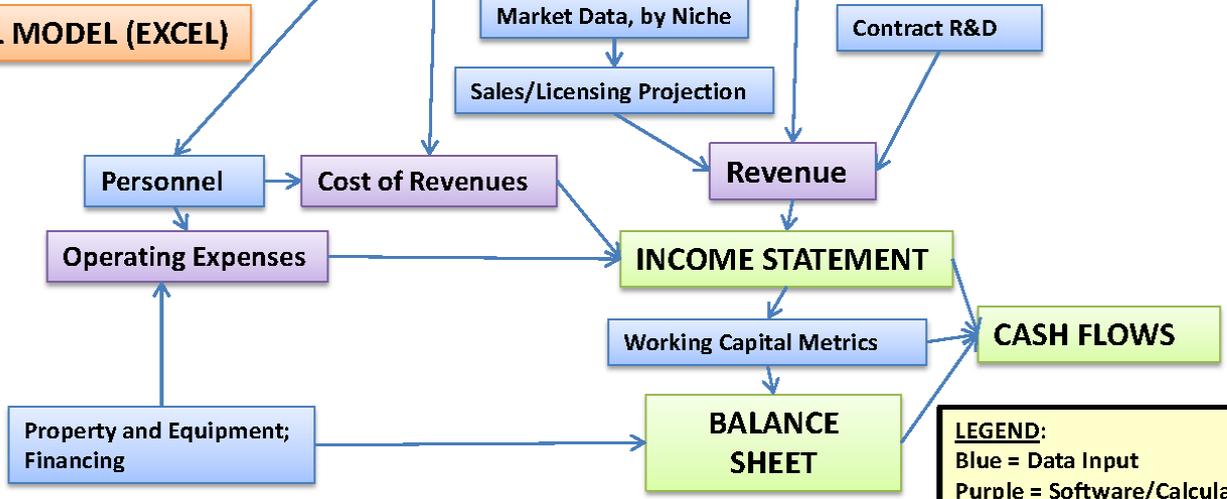
# Approach: Economic Analysis Models

## TECHNO-ECONOMICS MODEL



**HOMER:**  
analyzes  
cost of  
power

## FINANCIAL MODEL (EXCEL)



**Financial:**  
Determines  
business  
viability

**LEGEND:**  
Blue = Data Input  
Purple = Software/Calculations  
Green = Output  
→ Data flow

# Accomplishments: Developed Highly Efficient Thermally Integrated System Design

## Process Flow Diagram

- Subdivided into 21 process streams

## Mass and Energy Balance

- Completed for each process stream
- Determines input, output, efficiency

## Optimized Layout, Piping & Instrumentation

## Solid Model of Integrated System

Milestone 3

## Component Design and Analysis

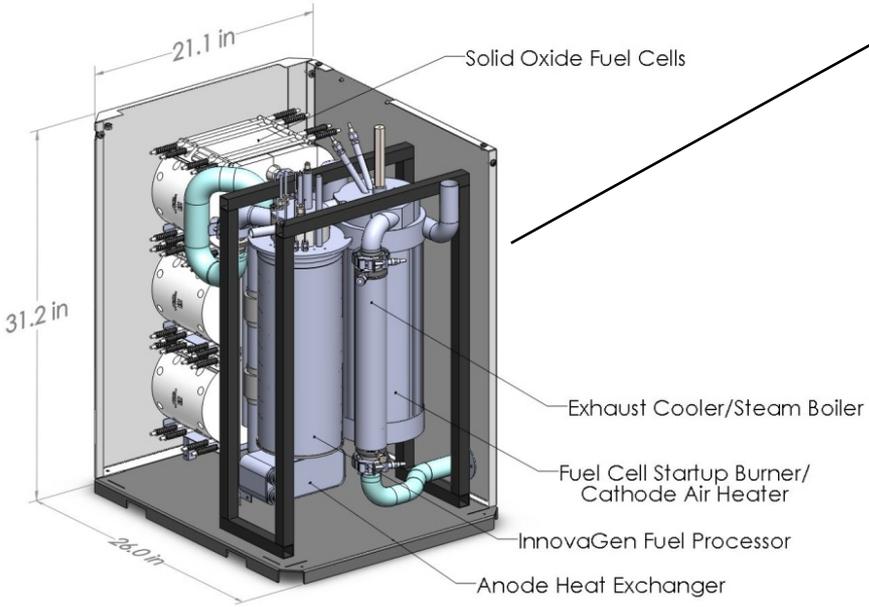
- Process simulations
- Design trade-off analyses



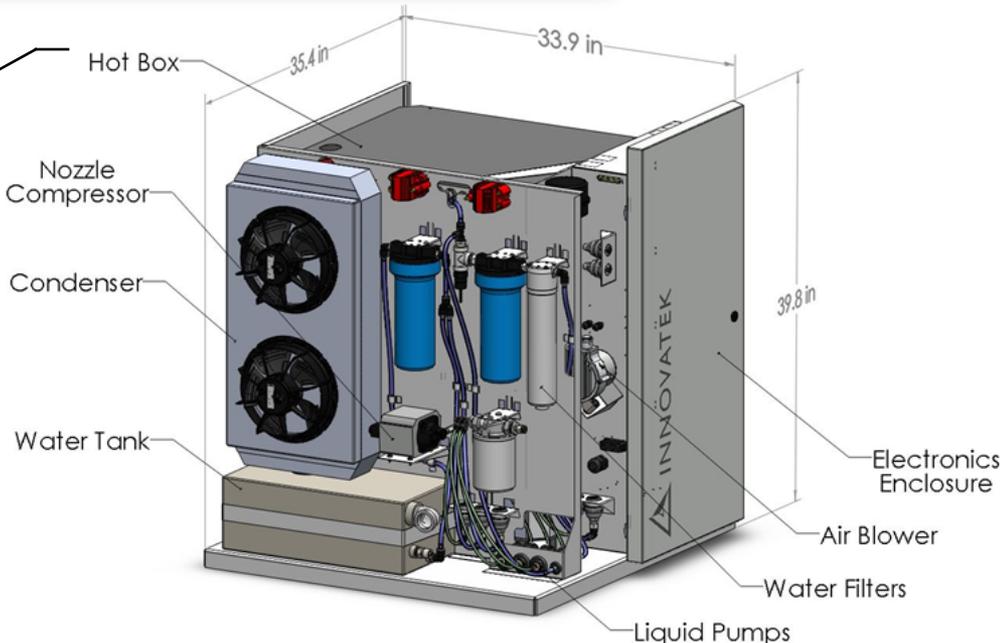
5kW fuel cell system that operates on liquid bio-fuel

# Accomplishments: Solid Model 4 kW

Design includes complete Bill of Materials and P&ID  
Part count reduced by ~74%  
Cost reduced by ~40%



Hot Box Subassembly



Fully Integrated System



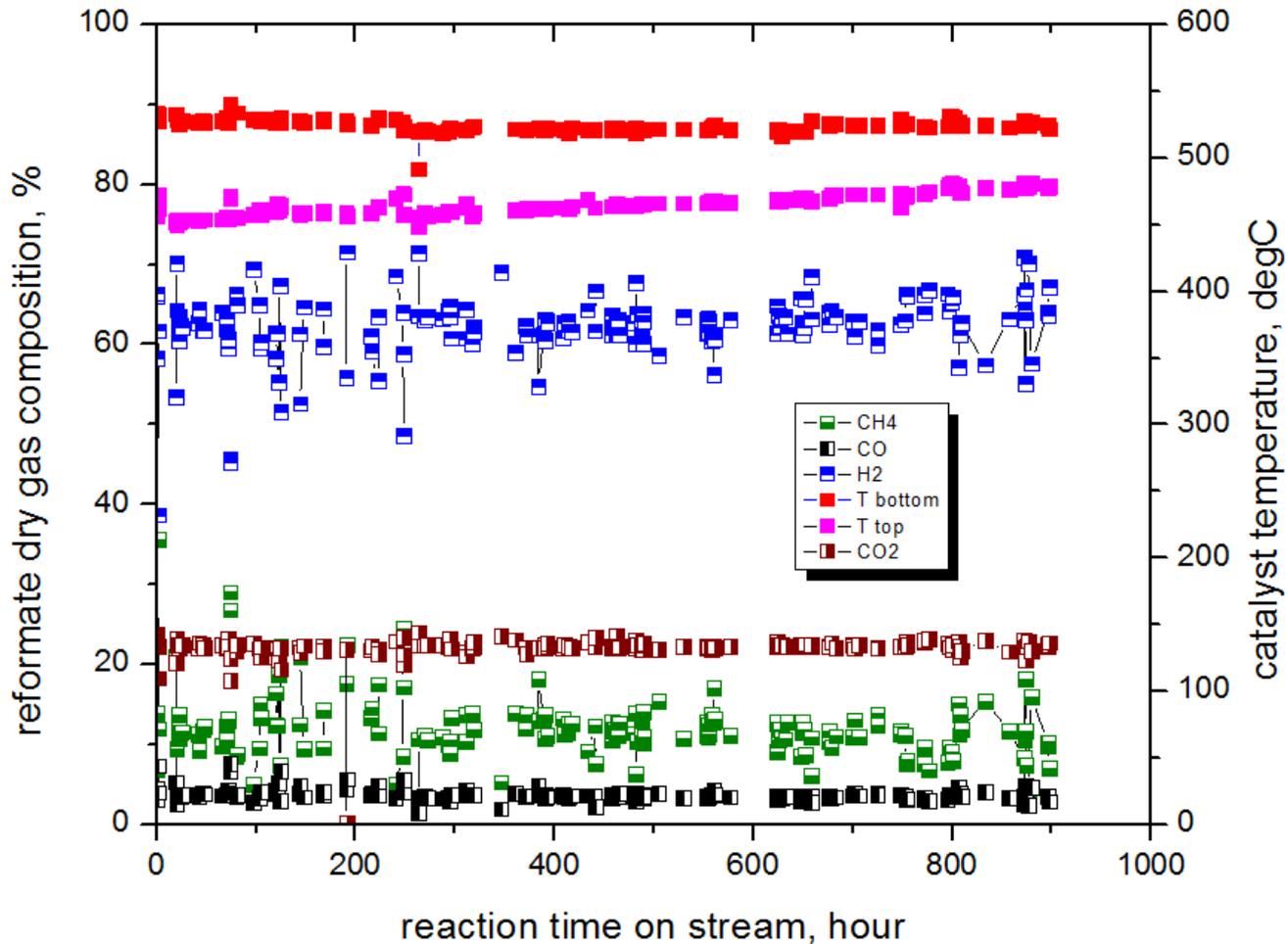
# Accomplishments: 41% System Efficiency

Gross DC Power, kW	4.2
Current density, mA/cm <sup>2</sup>	390
Cell active area, cm <sup>2</sup>	550
Stack current, A	214.5
Cell voltage, volt	0.82
Number of cells	24
gross DC power, watt	4221
stack electrical efficiency	65.60%
parasitic power, watts	300
Net AC electrical efficiency	40.8%

Improved from last year  
(37.5%) due to:

- Better stack efficiency
- Lower parasitic power due to lower stack pressure drop
- Less waste heat loss through improved thermal integration and heat transfer
- Higher methane content in reformat

# Accomplishments: Catalyst Durability



100%  
conversion of  
bio-kerosene  
for >900 hrs

# Accomplishments: Analysis of Energy Cost

## Adapted EERE's HOMER Model for fuel cell system

- ❖ Examined several scenarios for delivering 5 kW electrical AC power for 10 years using InnovaGen FC power unit
- ❖ Compared bio-kerosene & natural gas
- ❖ Capital and operating costs based on Bill of Materials and Testing
- ❖ Used projected production and fuel pricing data from DOE sources

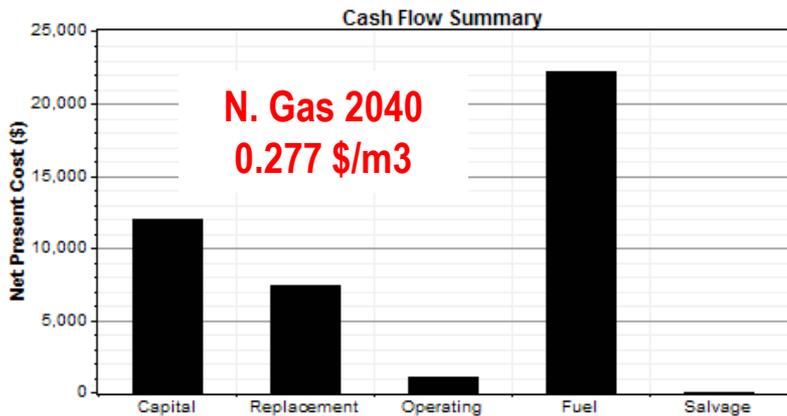
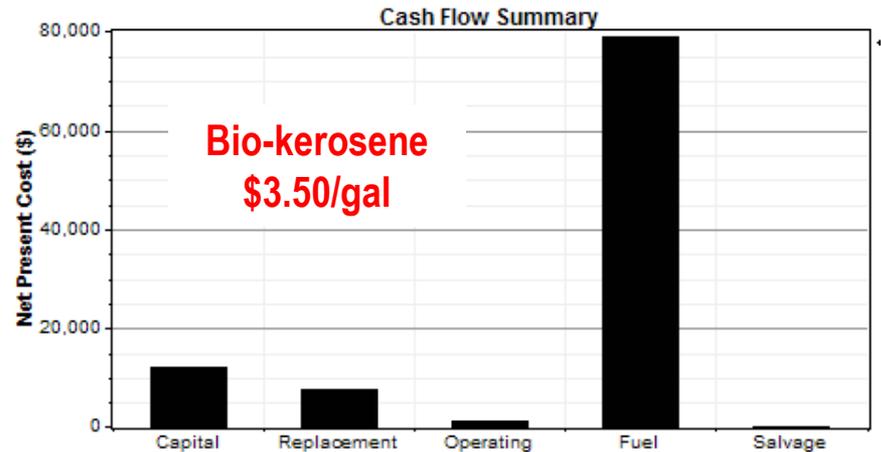
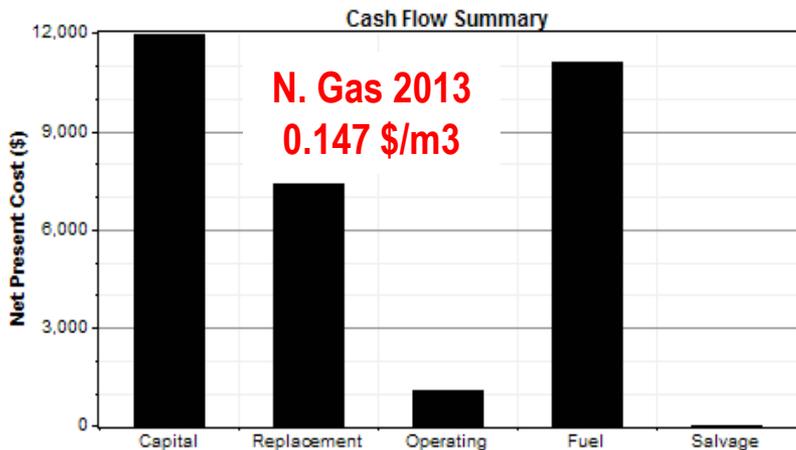
### Significant Findings:

1. Our fuel cell generator operating on natural gas could produce electricity at prices at or below current grid prices (<\$0.09/kWh) when volume production brings capital costs down.
2. The price for liquid bio-fuel, estimated at \$3.50 per gallon, is the dominant factor affecting cost of electricity when operating on bio-fuel.

# Progress: Economic Analysis for 5 kW FC

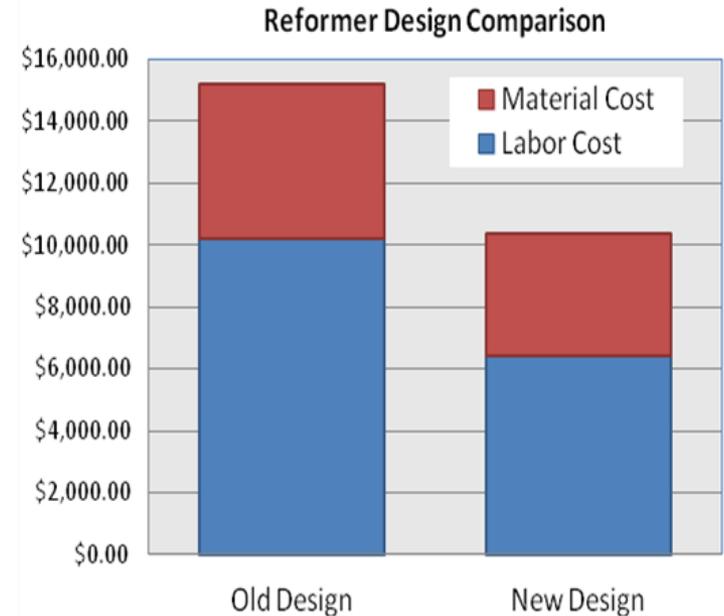
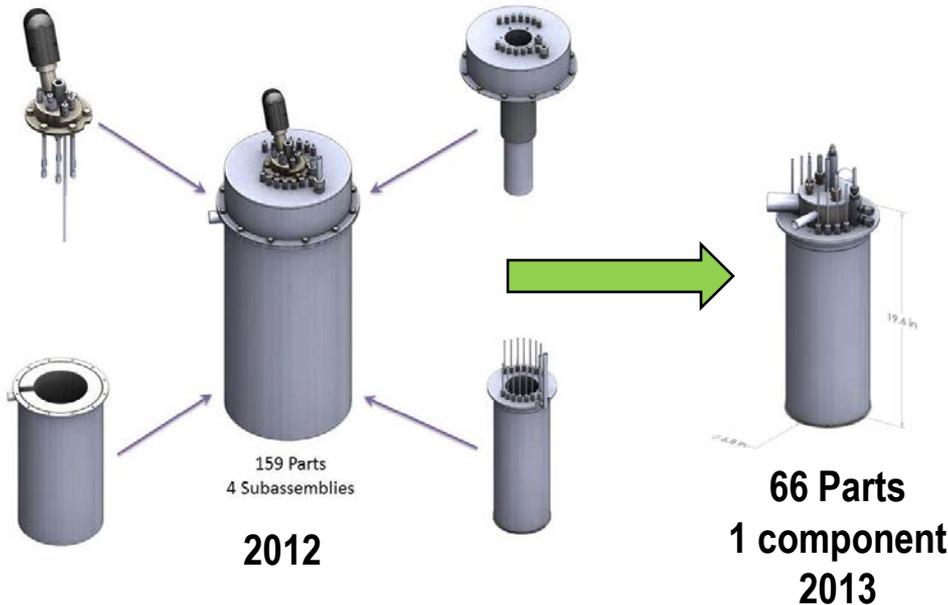
Cost of energy using InnovaTek's 5 kW fuel cell system with n.gas at current & forecasted spot price

Cost of energy using InnovaTek's 5 kW fuel cell system using bio-kerosene with Honeywell's projected price



	Natural Gas 2013	Natural Gas 2040	Bio-fuel
Total net present cost	\$37,938	\$48,329	\$104,959
Levelized cost of energy	\$0.107/kWh	\$0.136/kWh	\$0.295/kWh
Operating cost	\$3,222/yr	\$4,503/yr	\$11,485/yr

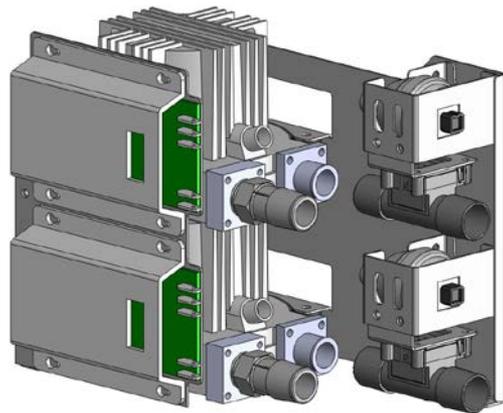
# Progress: 32% Cost Reduction Fuel Processor



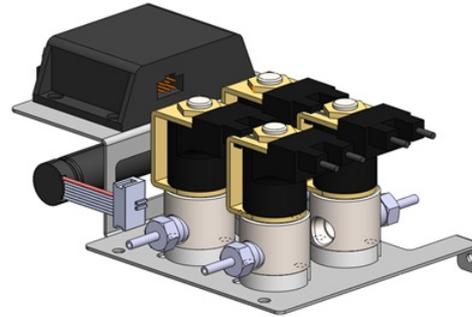
Reformer System	Labor Cost	Material Cost	Total Cost	Parts	Approx Volume (L)
Original Design	\$10,201	\$4951	\$15,152	159	13.87
Revised Design	\$6,374	\$3997	\$10,371	66	6.88

# Progress: 79% Cost Reduction Fluid Handling

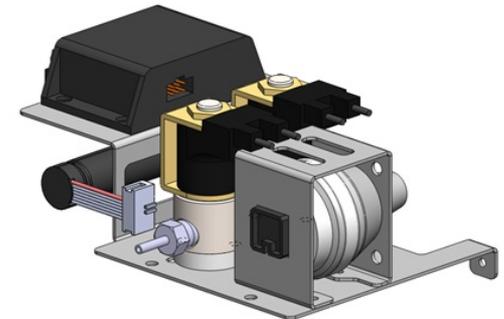
Air Handling Subassembly



Feed Handling Subassembly



Fuel Handling Subassembly



	Design	Labor Cost	Material Cost	Total Cost	Parts
Air Delivery	Original	\$210	\$2,630	\$2,840	136
	Revised	\$22.50	\$762	\$785	16
Fuel & Fuel Delivery	Original	\$390	\$11,573	\$11,963	118
	Revised	\$60	\$2,230	\$2,290	25

# Collaborations

## Subcontractors

- ❖ Fuel Cell Energy – Versa Power SOFC (within DOE H<sub>2</sub> Program)
- ❖ Boothroyd Dewhurst – Design for Manufacturing & Assembly training
- ❖ Manufacturing partners – shift from welding to brazing

## Strategic Partners

- ❖ Impact Washington – manufacturing design support
- ❖ PNNL – provided upgraded bio-oil made from non-food biomass (within DOE H<sub>2</sub> Program)
- ❖ Honeywell UOP – provides bio-kerosene
- ❖ City of Richland Electric Utility – providing site for field demo
- ❖ Mid-Columbia Energy Initiative

## Education

- ❖ Supported 3 student interns from WSU, U of WA, Delta HS in mechanical engineering and chemistry

# Proposed Future Work

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

## FY13

- Optimize performance by testing & adjusting operating parameters
- Further improve system efficiency & durability; reduce cost
  - Enhance FC-FP integration; evaluate BOP alternatives

## ■ FY14

- Fabricate and assemble fully integrated grid-ready 5 kW system
- Verify performance and durability with 6 month field demo at City Utility
- Analyze process economics

# 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:** Achieved 41% system efficiency

- Used simulation and modeling to optimize component & system designs
- Prepared solid model of system & complete Bill of Materials with P&ID
- Developed optimized catalyst for biofuel reforming; demonstrated >900hrs durability
- Determined capital and operating expenses; modeled process economics

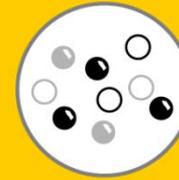
**Collaborations:** Supported 3 students; Subcontractors for fuel cell & manufacturers;

- Partnerships with PNNL, WSU, Boeing , City of Richland, Regional Energy Initiative

**Future:** Complete laboratory tests with 4 kW prototype

- Fabricate prototypes for grid interconnect
- Conduct field demonstration and long term operation
- Complete further analysis of process economics

# Technical Back-up



# Technical: System Efficiency Algorithms

system efficiency (electrical efficiency)

$$P_{\text{parasitic}} := 300W$$

regulated DC power

$$DC_{\text{reg}}(I_d) := DC_{\text{gross}}(I_d) \cdot \eta_{\text{dc\_dc}}$$

net DC power

$$DC_{\text{net}}(I_d) := DC_{\text{reg}}(I_d) - P_{\text{parasitic}}$$

net AC power

$$AC_{\text{net}}(I_d) := DC_{\text{net}}(I_d) \cdot \eta_{\text{dc\_ac}}$$

$$\eta_{\text{ele}} := \frac{AC_{\text{net}}(I_d)}{LHV_{\text{spk}} \cdot (n_{\text{feed}} + n_2) \cdot MW_{\text{spk}}} = 40.793\%$$

$$\eta_{\text{ele}} = 0.408$$

$$\eta_{\text{fps}} := \frac{LHV_{\text{h2}} \cdot N_{\text{anode\_in}_3} + LHV_{\text{ch4}} \cdot N_{\text{anode\_in}_0} + LHV_{\text{co}} \cdot N_{\text{anode\_in}_1}}{LHV_{\text{spk}} \cdot (n_{\text{feed}} + n_2) \cdot MW_{\text{spk}}} = 112.977\%$$

$$DC_{\text{gross}}(I_d) = 4.221 \times 10^3 W$$

$$\eta_{\text{dc\_dc}} := 95\%$$

$$\eta_{\text{dc\_ac}} := 92\%$$

$$OCV_{\text{HHV}} := 1.48\text{volt}$$

$$OCV_{\text{LHV}} := 1.25\text{volt}$$

$$\eta_{\text{volt}} := \frac{\text{Volt}_{800_{\text{cell}}}}{OCV_{\text{LHV}}} = 0.656$$