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_2 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_2 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.**

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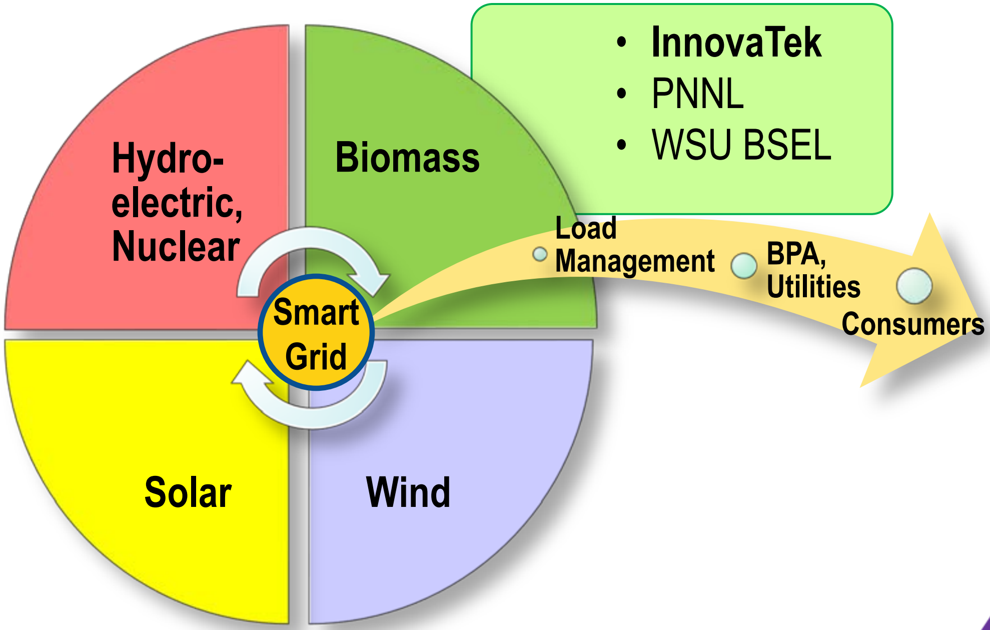
Relevance: Project Objectives

Year	Objective	DOE Barriers 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 Complete	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 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

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
- System to be demonstrated in Richland's renewable energy park and tied to grid



Mid-Columbia Energy Initiative:

Meets 2020 electrical load growth needs with renewables.

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

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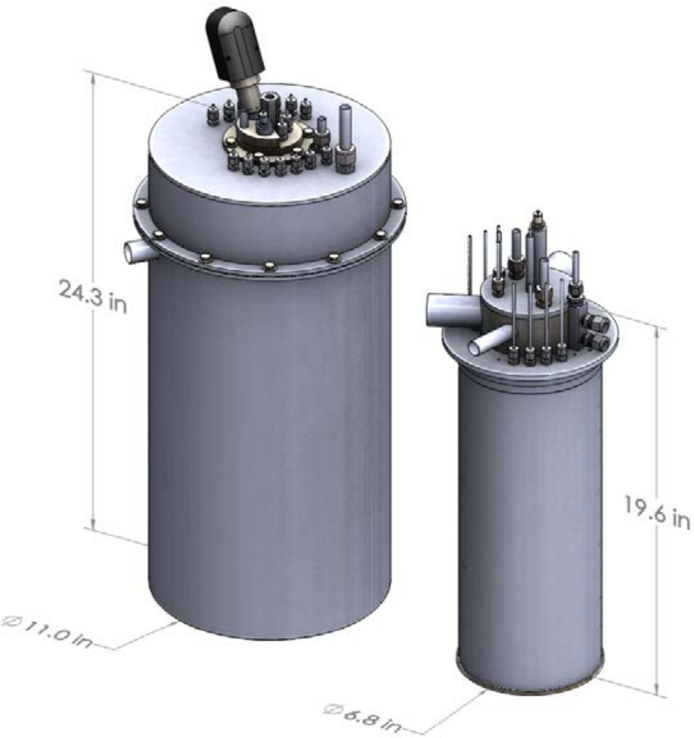
Approach: Optimization & Economic Analysis

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



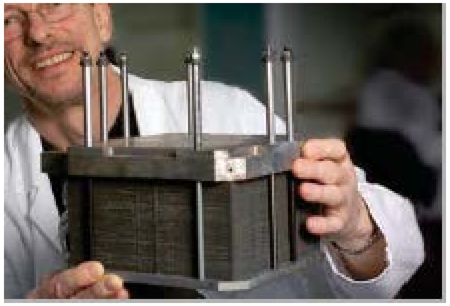
2012 2013

Size reduced, output increased

- 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

Transitioning to scaled-up SOFC



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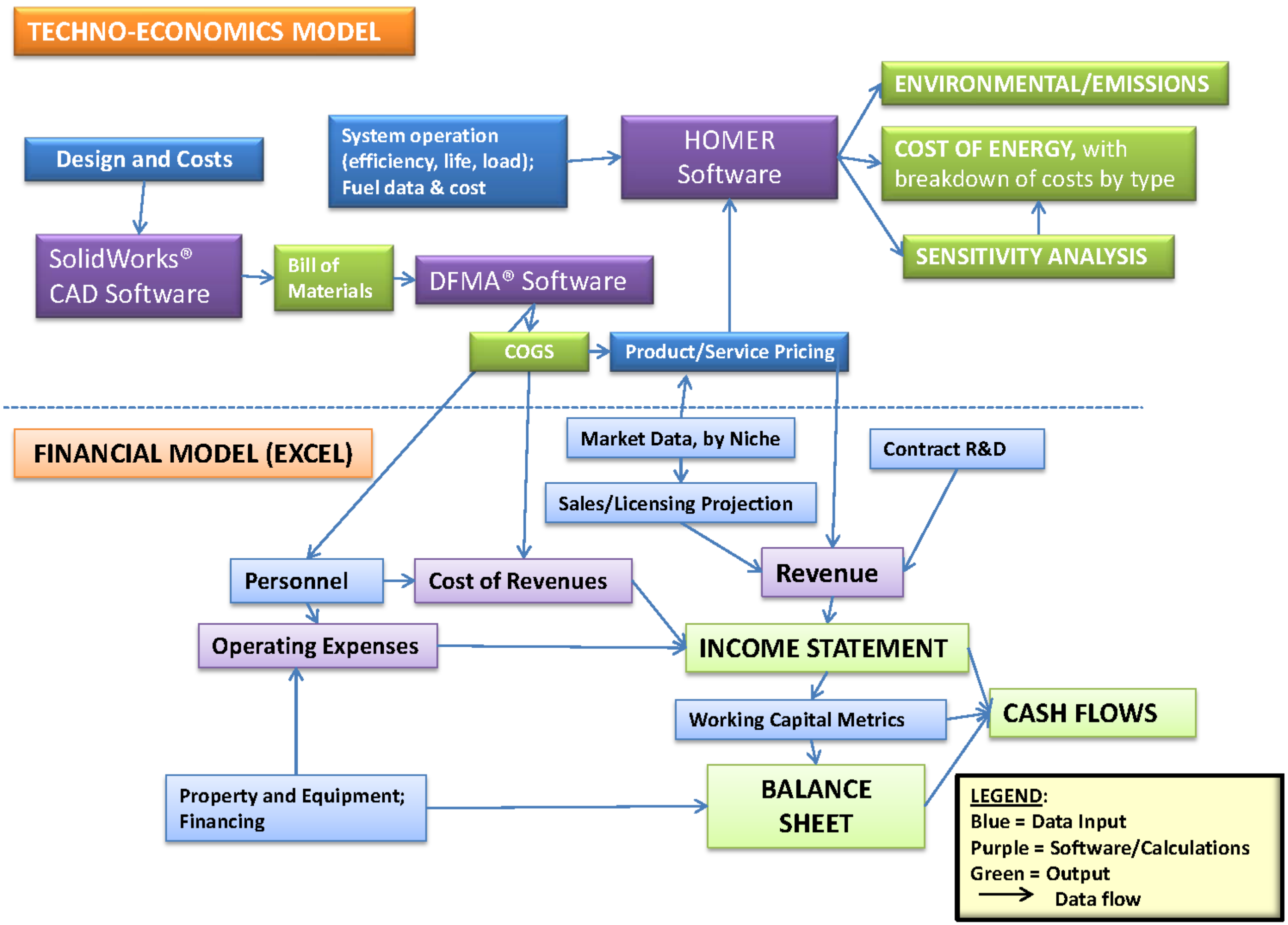
Approach: Economic Analysis Models



HOMER: analyzes cost of power

Financial: Determines business viability

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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 process stream
- Determines input, output, efficiency

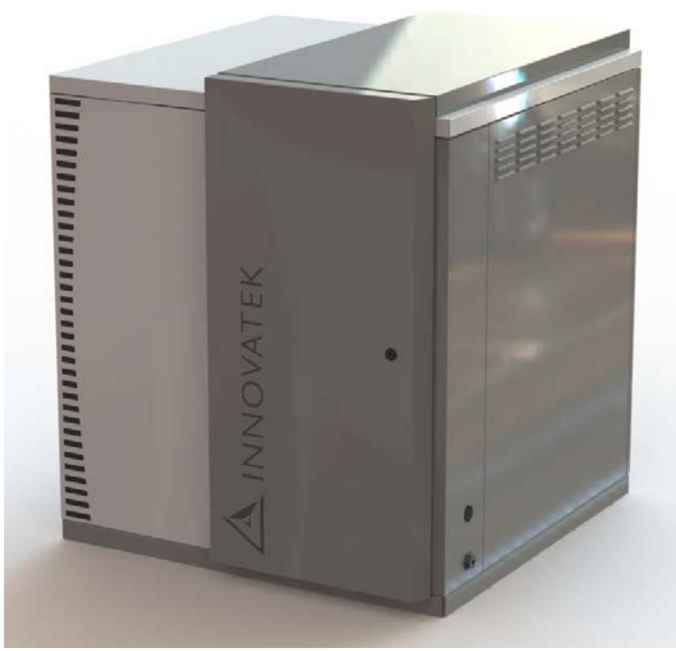
Optimized Layout, Piping & Instrumentation

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

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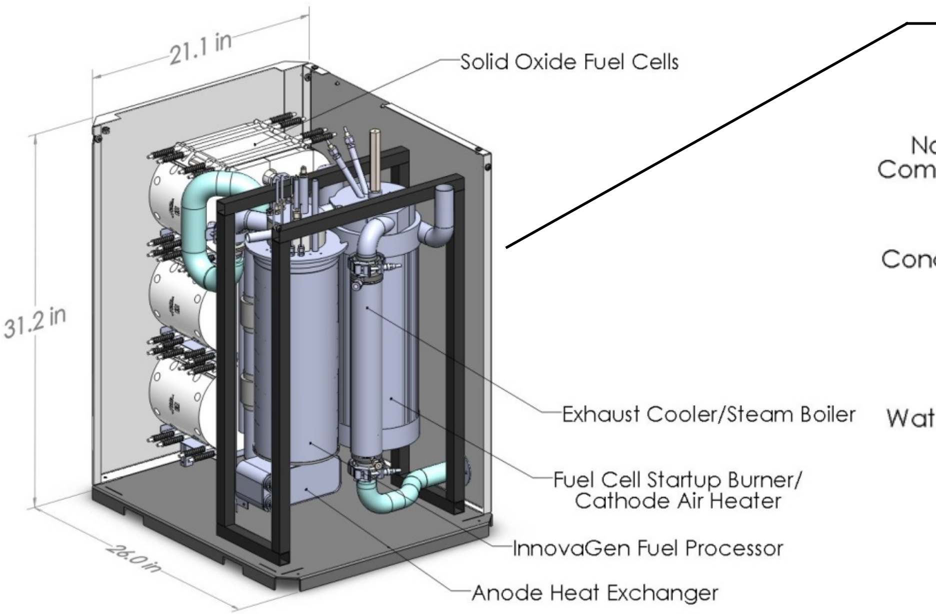
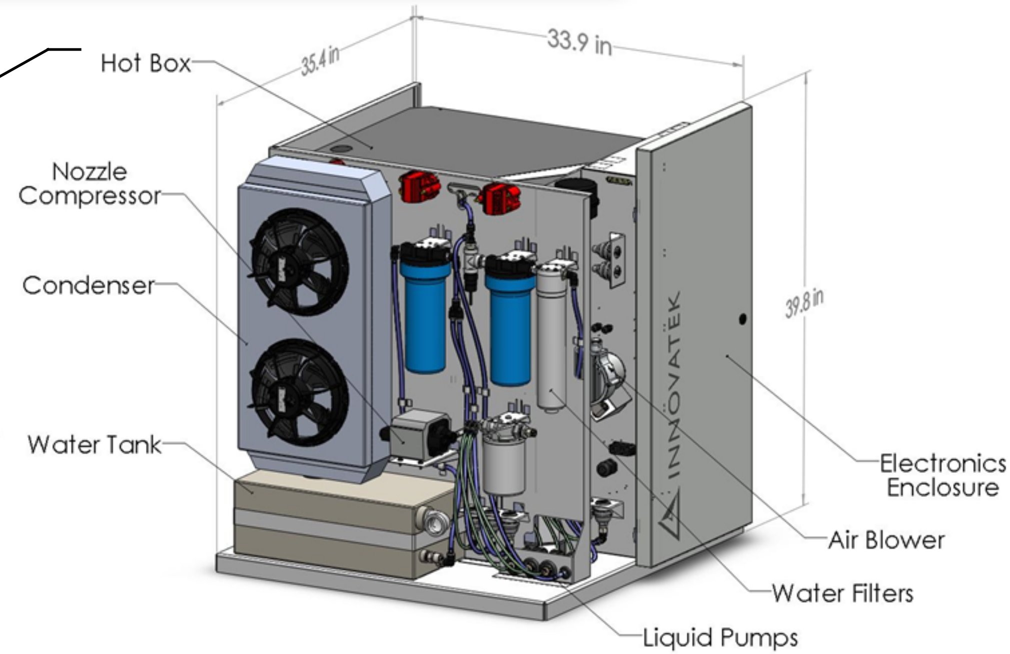
Accomplishments: Solid Model 4 kW

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



Hot Box Subassembly



Fully Integrated System

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Accomplishments: 41% System Efficiency

Gross DC Power, kW	4.2
Current density, mA/cm2	390
Cell active area, cm2	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 reformate

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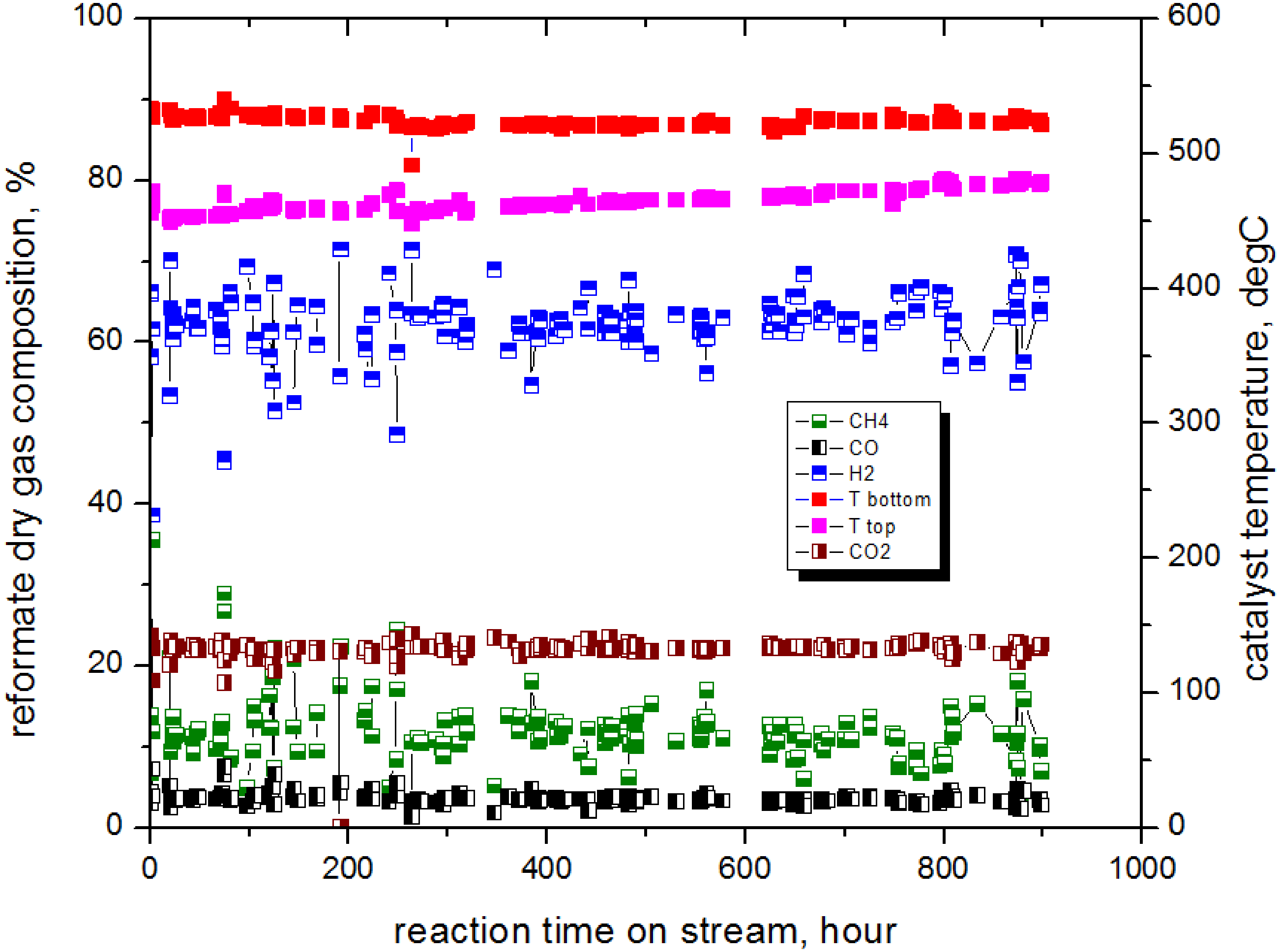
Accomplishments: Catalyst Durability



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
- Capitol 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.

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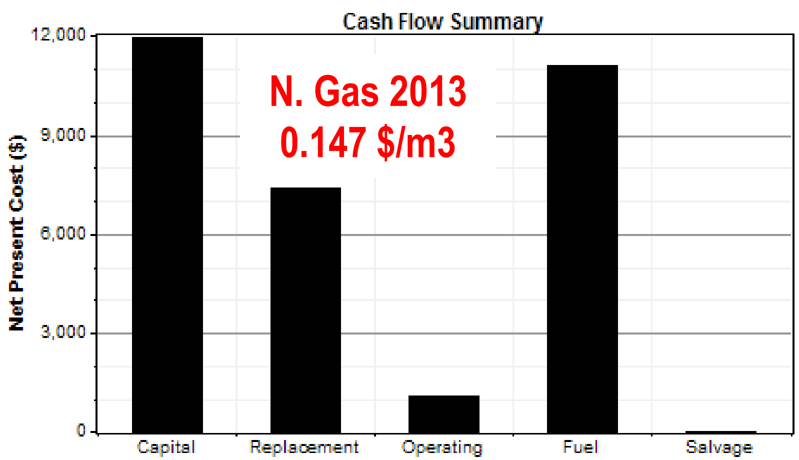
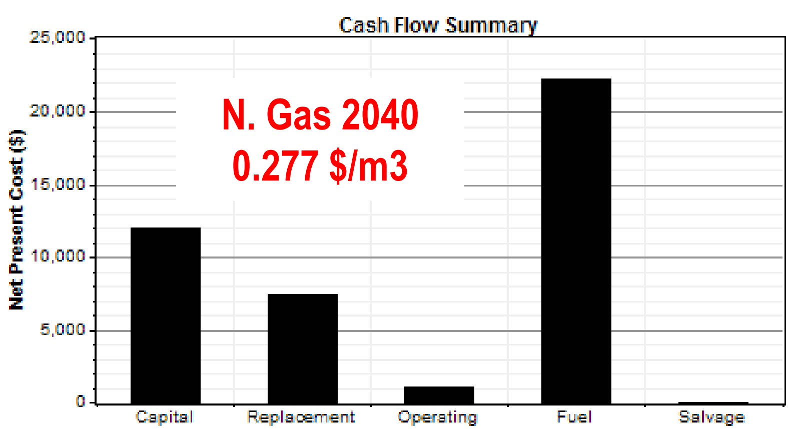
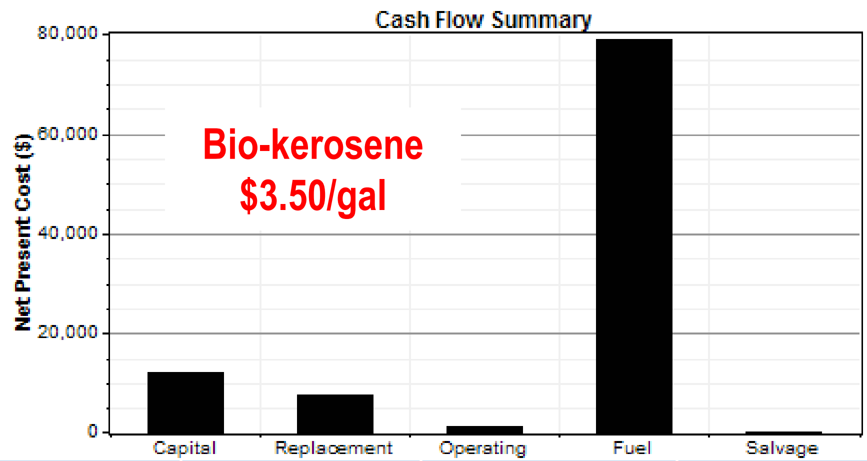
Progress: Economic Analysis for 5 kW FC

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	$0.107kWh	$0.136/kWh	$0.295/kWh
Operating cost	$3,222/yr	$4,503/yr	$11,485/yr

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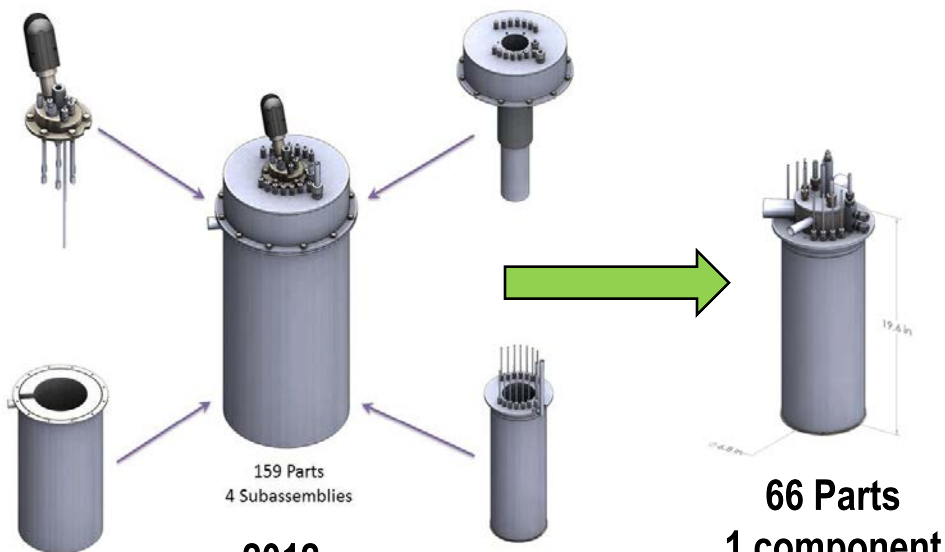
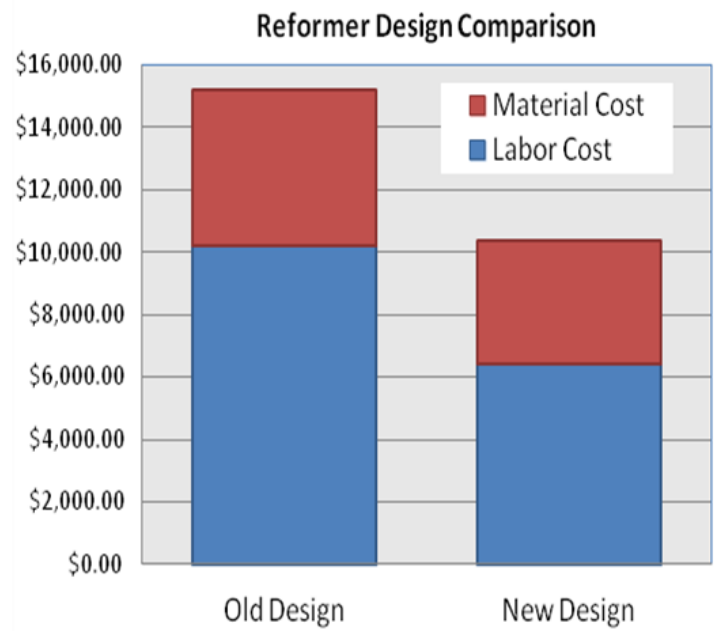
Progress: 32% Cost Reduction Fuel Processor



2012

66 Parts
1 component
2013



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

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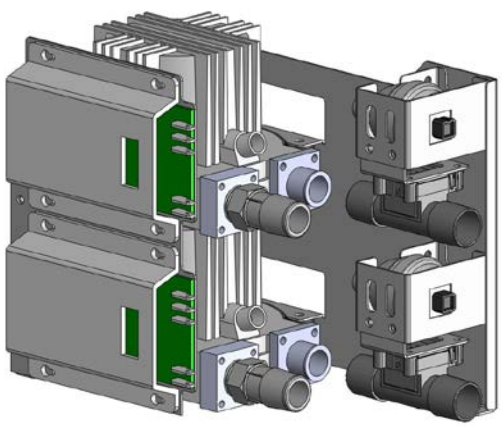
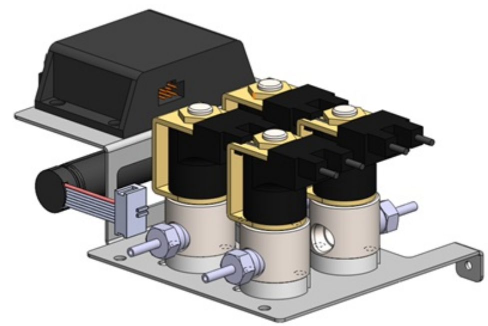
Progress: 79% Cost Reduction Fluid Handling

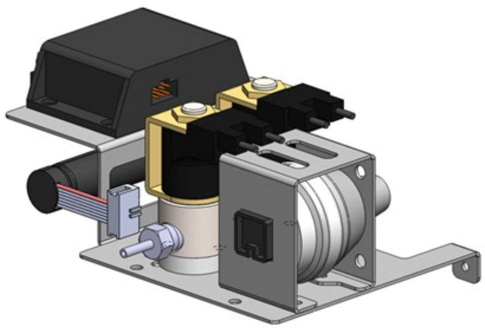
Air Handling Subassembly



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_2 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_2 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)

$P_{parasitic} := 300W$

regulated DC power

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

net DC power

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

net AC power

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

$$\eta_{ele} := \frac{AC_{net}(I_d)}{LHV_{spk} \cdot (n_{feed} + n2) \cdot MW_{spk}} = 40.793 \cdot \%$$

$\eta_{ele} = 0.408$

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

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

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

$OCV_{HHV} := 1.48volt$

$OCV_{LHV} := 1.25volt$

$$\eta_{volt} := \frac{Volt800_{cell}}{OCV_{LHV}} = 0.656$$

$$\eta_{fps} := \frac{LHV_{h2} \cdot N_{anode\_in_3} + LHV_{ch4} \cdot N_{anode\_in_0} + LHV_{co} \cdot N_{anode\_in_1}}{LHV_{spk} \cdot (n_{feed} + n2) \cdot MW_{spk}} = 112.977 \cdot \%$$

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