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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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

<table>
<thead>
<tr>
<th>Year</th>
<th>Cost/kW</th>
<th>Efficiency</th>
<th>Lifetime</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>$1700</td>
<td>42.5%</td>
<td>40,000h</td>
<td>5 kW Dist Gen Sys</td>
</tr>
<tr>
<td>2020</td>
<td>$1500</td>
<td>&gt;45%</td>
<td>60,000h</td>
<td>5 kW Dist Gen Sys</td>
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Budget
Total: $2.3M
Received FY11: $900K
Planned FY 12: $650K

Partners
Topsoe Fuel Cell
Washington State University & PNNL for BioFuel
Energy Technology Services
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.
## Relevance: Project Objectives

<table>
<thead>
<tr>
<th>Year</th>
<th>Objective</th>
<th>DOE Barrier Addressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>Establish design to meet technical and operational needs for distributed energy production from renewable fuels</td>
<td>SOFC power using renewable non-food biomass fuel; codes &amp; standards</td>
</tr>
<tr>
<td>Complete</td>
<td>Design, optimize, and integrate proprietary system components and balance-of-plant in a highly efficiency design.</td>
<td>Demonstration; system efficiency; design for low cost manufacturing</td>
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</table>
| 2012 | 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 2\textsuperscript{nd} 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
# Approach: Milestones & Go/No Go

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

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

Uses Bio-kerosene made from wood sawdust and non-food camelina
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
  - Developed System Requirements Document based on CSA-America FC1 – Stationary Fuel Cell Power Systems
    - Kelvin Hecht, Consultant
  - Developed Draft FMEA
Progress: Completed Process & Component Modeling and Simulation

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

![Chemical process diagram]

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
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

Temperature Comparison

Water Outlet Temp

Pressure Drop Comparison

Reformate Pressure Drop

Actual Simulated

Actual Simulated
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 $\text{H}_2$ essential for developing a desirable flame shape and optimizing heat transfer.
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
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
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
Progress: Proprietary Component Fabrication, Assembly and Integration

System is water neutral; no net consumption
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
Accomplishments: Integrated System
Produced Power from Bio-Fuel

Go Year 2

1.2 kW power sent to grid

Prototype InnovaGen FC power unit being tested

Fume hood with safety sensors

Control system monitors

AeroVironment power processing system
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
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: 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

Product Flow Rate & Composition vs Feed Rate

Bio-fuel feed rate, g/min

Product composition, %

H2 %
CH4 %
CO %
CO2 %
Product Flow rate

Linear (Product Flow rate)
Data Summary – Reformer Tests

Reformer Performance

Composition (per 1000) Temperature (°C) and Air Flow (sl/m)

Composition (per 1000) H2 Composition (per 1000)
CH4 Composition (per 1000) CO Composition (per 1000)
CO2 Composition (per 1000) Feed Rate (g/min)
Fuel Rate (g/min) Water Flow (ml/m)
Product Flow (sl/m)

Time Since Test Start (HH:MM:SS)

Water Flow (ml/m) Product Flow (sl/m) and Feed Flow (g/m)

Catalyst Bed TE-714 (C) Burner TE-913 (C)
Burner Air Flow (sl/m)
Accomplishment: Test of Integrated Reformer & 1 kW SOFC – Start-up
Accomplishment: Test of Integrated System – Steady state

Stable Operation at 1 kW