



PROJECT FACTS

Fuel Cells

Testing and Evaluation of Solid Oxide Fuel Cells in Extreme Conditions— Naval Undersea Warfare Center

Background

The mission of the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) is to advance energy options to fuel our economy, strengthen our security, and improve our environment. With the Solid State Energy Conversion Alliance (SECA), NETL is leading the research, development, and demonstration of solid oxide fuel cells (SOFCs) for coal-fueled central generation power systems that enable low cost, high efficiency, near-zero emissions and water usage, and capture carbon dioxide (CO₂).

The Naval Undersea Warfare Center, (NUWC) is one of various SECA Core Technology Program participants working together to provide vital research and development and testing support that addresses applied technological issues common to multiple SECA Industry Teams developing SOFC technology for integrated gasification fuel cell (IGFC) systems.

SOFCs from Delphi Corporation (and previously SOFCs from Versa Power Systems) are being investigated by NUWC as power sources for unmanned undersea vehicles (UUVs). They offer rapid refueling capability, operation with readily available fuels, and high electric conversion efficiency of greater than 50 percent based on the lower heating value of the fuel. In this study, the performance of an integrated SOFC stack with fuel processor (steam reformer) was evaluated using liquid hydrocarbon fuel and pure oxygen.

Project Description

NUWC is conducting a refined analysis of fuel options, based upon prototyped hardware, for a SOFC-powered UUV. Sulfur-free fuels such as S-8 (synthetic diesel fuel from Syntroleum Corporation) and JP-10 jet fuel were compared to methane. With waste heat being at a premium in such a highly efficient system (more than 70 percent), it has been determined that steam reforming of liquid fuels will likely require an additional burner or a catalytic partial oxidizer (CPOX) reformer. This will decrease system efficiency and energy metrics. Methane is used in the form of liquefied natural gas as the fuel maximizes the hydrogen-to-carbon ratio and decreases the amount of oxygen storage and CO₂ sorbent to be stored on the vehicle. In addition to these energy gains, one of the advantages of using methane is that waste heat can be directly used for steam reforming both in the stack and throughout the CO₂ sorbent bed. Methane is also expected to be more resistant to carbon deposition, power transients, and flow disruptions. Natural gas or other light hydrocarbon fuels offer SOFC and other advanced energy solutions with higher efficiencies than standard diesel or gasoline generators. The National Aeronautics and Space Administration (NASA) is also interested in SOFC systems utilizing methane and pure oxygen for auxiliary power generation in next-generation space applications in which liquid methane and oxygen are being considered for main propulsion reactants.

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PARTNERS

Delphi Corporation
Versa Power Systems
NASA Johnson Space Center

PROJECT DURATION

Start Date	End Date
06/21/2007	12/31/2011

COST

Total Project Value
\$785,000

DOE/Non-DOE Share
\$785,000/\$0

AWARD NUMBER

NT43247

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For UUV-related tests, a Delphi Gen 3.2 SOFC stack was integrated with a Delphi Gen 8T fuel processor. The purpose was to utilize the latent heat in the anode exhaust to drive the steam reforming of S-8 and JP-10 liquid fuels as well as gaseous methane fuel. The steam reformer replenishes the anode reformat and results in an anode recycle loop that is continuous and highly efficient. In a fully operational system, reformat is directed back into the SOFC stack via a high temperature recycle blower.

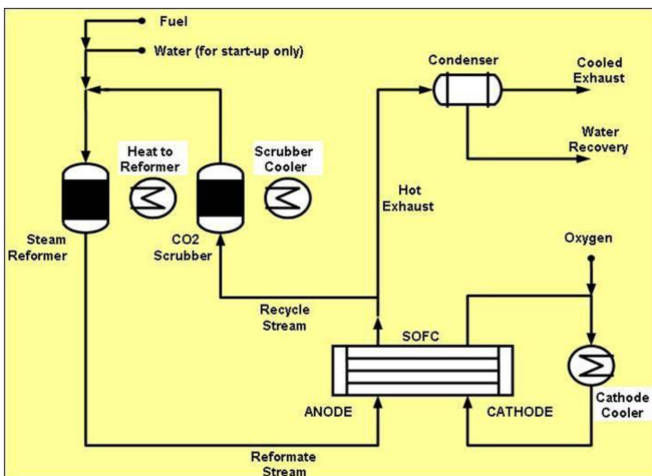
In NASA-related testing, a Delphi Gen 3.2 SOFC stack was integrated with a Delphi CPOX fuel processor. The goals were to demonstrate CPOX reformation of methane using pure oxygen instead of air, and to use the CPOX reformat in a SOFC stack to achieve high efficiency. This test was a baseline study for NASA.

Goals and Objectives

The overall goal of this project is to test and evaluate SOFCs in the extreme conditions demanded of power sources for the U.S. Navy's UUVs. Testing in 2011 focused on full system demonstrations using methane as the fuel.

Current project objectives are:

- Demonstrate successful cold start-up of Delphi fuel processor using air/methane burner.
- Utilize hot, steam-rich anode exhaust from a SOFC stack to drive steam reforming in Delphi's Gen 8T fuel processor.
- Demonstrate steady steam reforming of S-8, JP-10, and methane fuels to simulate half the proposed anode recycle loop for a UUV SOFC power system.
- Demonstrate a pure oxygen-blown CPOX reformer in conjunction with SOFC stack for NASA-specific missions.



Notional UUV SOFC energy system that uses steam reforming and carbon dioxide scrubbing in an anode recycle loop directed back into the SOFC stack.

Accomplishments

Accomplishments for fiscal year 2011:

- Established basis for proposing methane as a fuel for UUVs launched from surface ships. The use of methane as opposed to gasoline or diesel-type fuels could also be extended to other military platforms such as auxiliary power units and small vehicles. This could expedite usage of highly efficient SOFC-based platforms in advanced military settings as well as meet energy security and conservation goals mandated by U.S. Navy leadership.
- Demonstrated adequate steam reforming of JP-10, S-8, and methane fuel streams using a Delphi Gen 8T reformer. Concluded that methane-based systems offer the best prospect for successfully testing first-generation SOFC-powered UUVs.
- Demonstrated that a pure oxygen-blown CPOX reformer integrated with a 30-cell Delphi Gen 3.2 SOFC stack showed a reactant-based specific energy of 4,900 kilojoules per kilogram for use in a NASA-specific application. At 90 percent methane utilization, the system attained an efficiency of 45 percent, based on the lower heating value of methane fed into the CPOX reformer.

Benefits

Findings and inventions under the SECA Core Technology Program are made available to all SECA Industry Teams which serves to accelerate development. SECA will ultimately enable fuel cell-based near-zero emission coal plants with greatly reduced water requirements and the capability of capturing 99 percent of carbon at costs not exceeding the typical cost of electricity available today. Achieving this goal will significantly impact the nation given the size of the market, expected growth in energy demand, and the age of the existing power plant fleet. Federal funding support of this research is appropriate given the game changing nature of the technology, accompanied by risks higher than the private sector initially can accept. This project provides a high energy density system (including fuel) to enable longer mission durations.

Conceptual UUV (Unmanned Undersea Vehicle)

