Advanced SOFC Stack for Hybrid Power Systems

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Nexceris (Lewis Center, Ohio)

Project Vision

Nexceris and its team will design, build and demonstrate an ultra-high efficiency hybrid power system based on Nexceris’ pressure tolerant and high efficiency solid oxide fuel cell stack and a gas turbine.
Phase II Project Overview

Transition to Phase II:

- Technical focus shifts from stack to hybrid (SOFC/turbine) system
- Need to define market application(s) to drive T2M activities
- Integration of new partners to the team
- Pressurized stack testing at NETL (extension of Phase I project)
- System integration strategy and design (initial Phase II work)

<table>
<thead>
<tr>
<th>Team Member</th>
<th>Location</th>
<th>Project Role(s)</th>
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<tbody>
<tr>
<td>Nexceris</td>
<td>Lewis Center, OH</td>
<td>Project Management, SOFC Stack Technology</td>
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<tr>
<td>Czero</td>
<td>Fort Collins, CO</td>
<td>System Integration and Demonstration</td>
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<tr>
<td>Brayton Energy</td>
<td>Hampton, NH</td>
<td>Gas Turbine and Heat Exchanger Hardware</td>
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Nexceris, LLC

- Founded in 1994 as NexTech Materials, privately held
- Technology Developer – advanced ceramics, electrochemical devices
- Product Developer – sensors, fuel cells, batteries, and catalysts
- Manufacturer/Distributor – sensors, materials, solid oxide fuel cells, and related products
- ISO 9001:2015 Certified – covers all products and services

Our Brands

[Logo of Nexceris]
Czero, Inc.

- Founded in 2007, privately held.
- Engineering Firm – specialized in early-stage, concept-to-prototype R&D for advanced technologies.
- Czero partners with companies of all sizes: startups, multinational OEMs and Tier 1 suppliers, government agencies including U.S. Departments of Defense and Energy, and research institutions (including Colorado State University, Oregon State University and Brown University).
- Czero works in industrial machinery, automotive, oil and gas, and clean tech industries.
- Core competencies include R&D, mechanical design, modeling and simulation, control systems, build and test.
Brayton Energy, LLC

- Core experience: Gas turbines, microturbines, turbomachinery, combustion, compact high-temp heat exchangers.

- Applications: Advanced gas turbine cycles, distributed generation, hybrid vehicle propulsion, UAV propulsion, energy storage, concentrated solar power, modular gas cooled reactors, alternative fuels

- Design, prototype manufacturing and testing.

- Specialized turbomachinery CNC manufacturing, heat exchanger manufacturing center.

- Turbomachinery and combustion test cells

- Founded in 2004, roughly 50-person technical staff. Roughly 30,000 SF in three building/4-acre campus
The Phase I project focused on design and development of an SOFC stack tailored to the demanding requirements of hybrid power systems.
Phase I Retrospective

Project Accomplishments

- Developed and validated model for controlling thermal gradients during internal reforming by spatially distributing reforming reaction.
- Established two pressure tolerant stack design platforms (half-scale design for validation testing and full-scale design for scale-up).
- Implemented improved sealing approaches into the stack designs.
- Validated stack designs by replicating targeted performance in stacks with 228 and 456 cm² active area.
SOFC Stack Performance

10-Cell Stack (228 cm$^2$ Active Area)
Fuel: H$_2$/N$_2$ (50/50 vol%)

Targeted performance achieved and replicated in new stack designs.

0.766 V/cell at 0.439 A/cm$^2$
0.336 W/cm$^2$ at 70% $U_F$
SOFC Stack Performance

Stack performance was maintained throughout re-design and scale up.
Manufacturing Cost Analysis

Approach and Results

- Estimated manufacturing cost of planar cells and SOFC stacks at volume of 500 MW per year
  - Electrolyte Supported Cells: $77 per kW
  - 10-kW Scale SOFC Stacks: $361 per kW

- Performed sensitivity analysis on assumptions used in the analysis. Key sensitivities include:
  - Area-specific power density
  - Cost of ferritic steel interconnect material
  - Seals and interconnect coatings
  - Stack conditioning
Phase II Plans

Task 7 (Nexceris)  Presurized Stack Testing (Phase I)
Testing of 2.5-kW and 10-kW stacks at 3-4 atm in NETL’s Hyper Facility.

Task 8. SOFC Technology Development (Nexceris)
Scale-up of cell and stack manufacturing. Stack performance validation. Production and delivery of SOFC stacks for integration into prototype system.

Task 9. Micro-Turbine Development (Brayton)
Design and modification of commercial micro-turbine. Design and construction of recuperators and combustor.

Task 10. System Design, Integration and Testing (Czero)
Hybrid system design and modeling. Controls development. Pressure vessel design. System integration, construction and testing.
Hybrid System Design

System Design Targets

- SOFC/Turbine Hybridization
- Stack operation at 3-4 atm
- Natural gas fuel
- 100 kW (net) power
- 70 percent LHV efficiency
- Installed Cost: $1800 per kW
Hybrid System Design

System Design Considerations

- Power split between SOFC and turbine
- Stack thermal management
- Internal versus external reforming
- Recycling strategies (anode exhaust back to stack or to reformer)
- Integration of multiple stacks into system (e.g., one large pressure vessel or multiple smaller ones)
- Start-up requirements
- Controls strategy
Phase I T2M work focused on stack-only markets.

Our team’s first T2M task in Phase II will be to identify and down-select a target market. Candidates include:

- Ships and port installations
- Rail (locomotives)
- Grid-edge and grid-independent distributed generation
- Micro-grids

It is important that we select our target market early in Phase II so that application-specific requirements are considered during system design.
## Risks

<table>
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<tr>
<th>Risk</th>
<th>No.</th>
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<tbody>
<tr>
<td>Dynamic Operation</td>
<td>1</td>
</tr>
<tr>
<td>Pressurized Stack Operation</td>
<td>2</td>
</tr>
<tr>
<td>System Thermal Management</td>
<td>3</td>
</tr>
<tr>
<td>Start-Up and Shut-Down</td>
<td>4</td>
</tr>
<tr>
<td>System Cost</td>
<td>5</td>
</tr>
<tr>
<td>Achieving Target Efficiency</td>
<td>6</td>
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<tr>
<th>Likelihood</th>
<th>Almost Certain</th>
<th>Likely</th>
<th>Moderate</th>
<th>Unlikely</th>
<th>Rare</th>
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<tbody>
<tr>
<td>Consequences</td>
<td>Insignificant</td>
<td>Minor</td>
<td>Moderate</td>
<td>Major</td>
<td>Catastrophic</td>
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- **5**: Achieving Target Efficiency
- **6**: Dynamic Operation
- **1**: Pressurized Stack Operation
- **2**: System Thermal Management
- **3**: Start-Up and Shut-Down
- **4**: System Cost
De-Risking: SIL Control Validation

- Control of the SOFC/GT system, though complex, will be significantly de-risked through full Software-in-the-Loop validation before implementation.

- A detailed Simulink based dynamic model of the integrated system is nearing completion.

- The same controls code used during SIL validation will be deployed on the Simulink based control system and used to control the prototype system.
Needs

Our team currently has the following needs:

- Direction from commercial stakeholders in potential markets
- Inexpensive balance-of-plant components
Questions?

Nexceris and its team are grateful for the opportunity provided by ARPA-E, and we look forward to working with all INTEGRATE program stakeholders!