CHANGING WHAT'S POSSIBLE

Advanced SOFC Stack for Hybrid Power Systems

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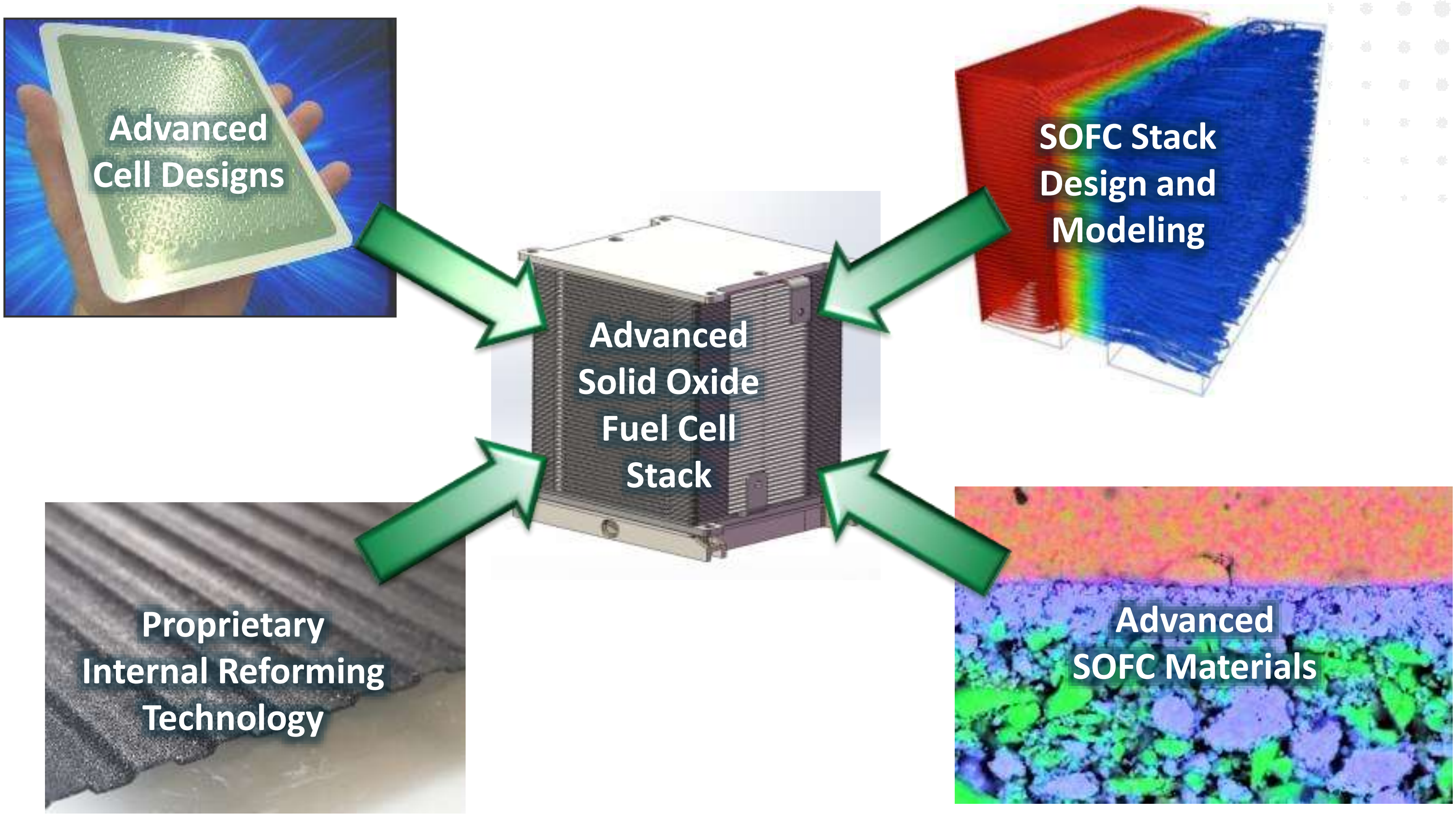
Project Vision

Nexceris will develop a pressure tolerant and ultra high efficiency solid oxide fuel cell stack (10-kW scale) that operates via internal reforming of methane and meets other requirements of hybrid power systems.

Project Overview

Federal Funding:	$2.15M
Project Duration:	24 months



Innovation and Objectives

SOFC Stack Innovations

- Novel planar cell designs and high performance SOFC materials
- Improved stack sealing to enable stack to withstand pressure spikes
- Internal reforming technology to minimize thermal gradients

Task Outline

- Cell Development and Validation
- Internal Reforming Technology
- Stack Design
- Stack Fabrication and Testing
- T2M

Tech-to-Market

- Nexceris aims to be an SOFC stack manufacturer
- Focusing on military markets as bridge to commercial markets
- Collaboration with system integrator partners as commercial path

About Nexceris

Nexceris, LLC

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

Our Brands

Nexceris' SOFC History

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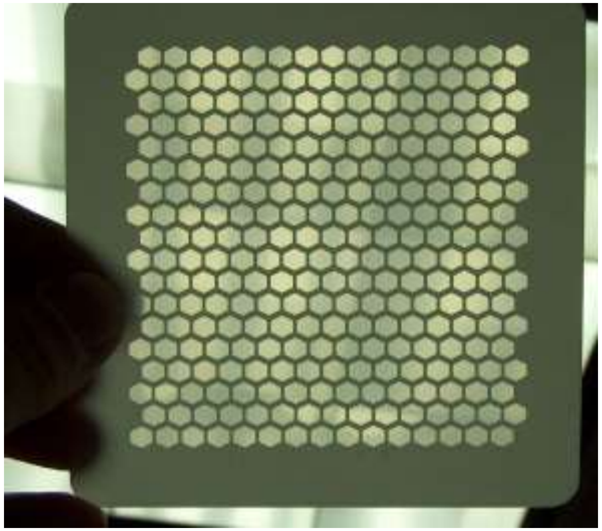
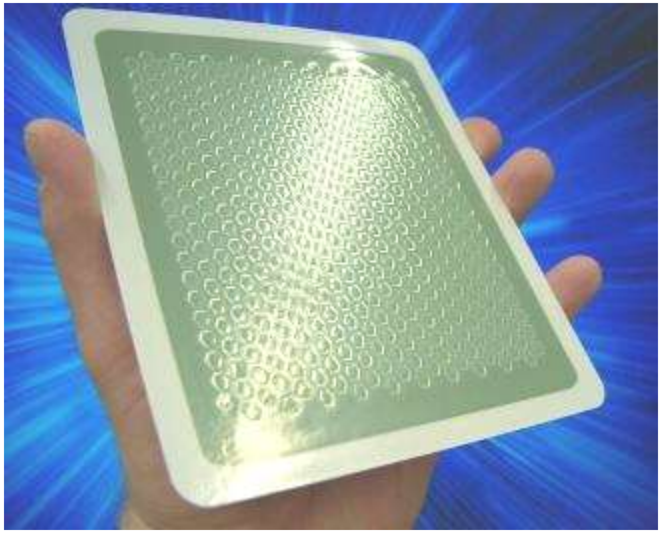
- Nexceris Founded ···· 1994
- 1995 ···· Initiated work on SOFC materials development
- Established *fuelcellmaterials* division, began selling products ···· 2000
- 2004 ···· Initiated development of planar cell designs (three patents)
- Initiated SOFC stack development, focusing on military applications ···· 2007
- 2011 ···· Focused efforts on SOFC materials for high performance & durability
- Established military purpose (high power density) stack design ···· 2015
- 2019 ···· Breadboard system testing

Planar SOFC Cell Designs





FlexCell

- ❑ U.S. Patent No. 8,192,888
- ❑ Two-layer structure with a perforated mesh layer mechanically supporting a thin electrolyte membrane

Hybrid Cell

- ❑ U.S. Patent No. 7,736,787
- ❑ Identical to FlexCell, except that an anode layer is located between the support and membrane layers

Internal Reforming Model

Modeling Approach

- Created a multi-physics (COMSOL) model of internal reforming
- Modeling approach based on literature model of anode supported cells. Replicated literature results to validate model.
- Assumptions and variables for internal reforming model:
  - Internal reforming of methane (not pre-formed natural gas)
  - Fuel composition: 50% anode exhaust recycling and 72% fuel utilization
  - Variables included anode inlet temperature and pressure
- Assessed impacts of grading catalytic activity of current collectors within anode channels

Model Results

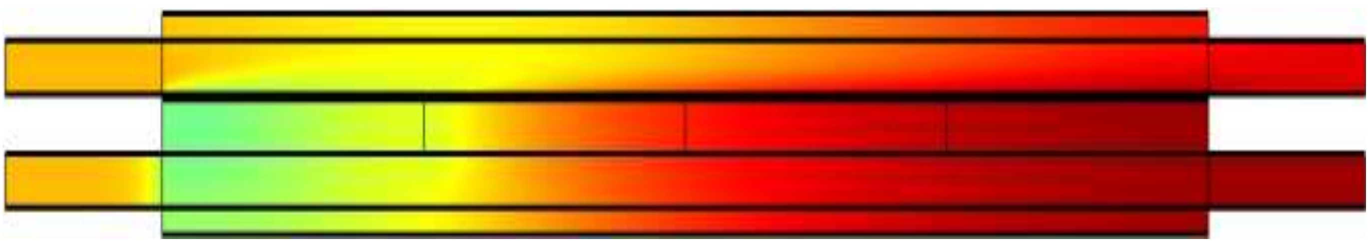
High SMR catalyst activity throughout stack (P = 1 bar, T_{AI} = 800 °C)

T_{MAX} = 818 °C

T_{MIN} = 757 °C

ΔT = 61 °C

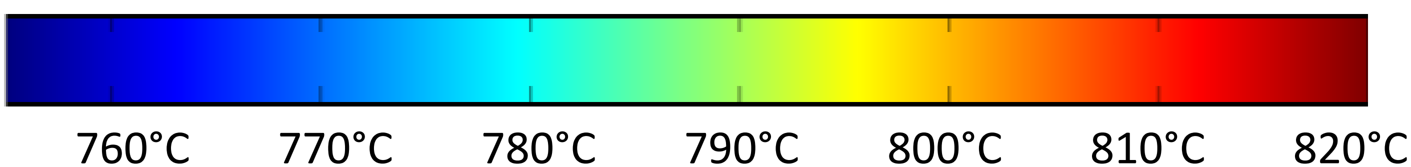
Reduced SMR activity at front of stack (P = 1 bar, T_{AI} = 800 °C)



T_{MAX} = 818 °C

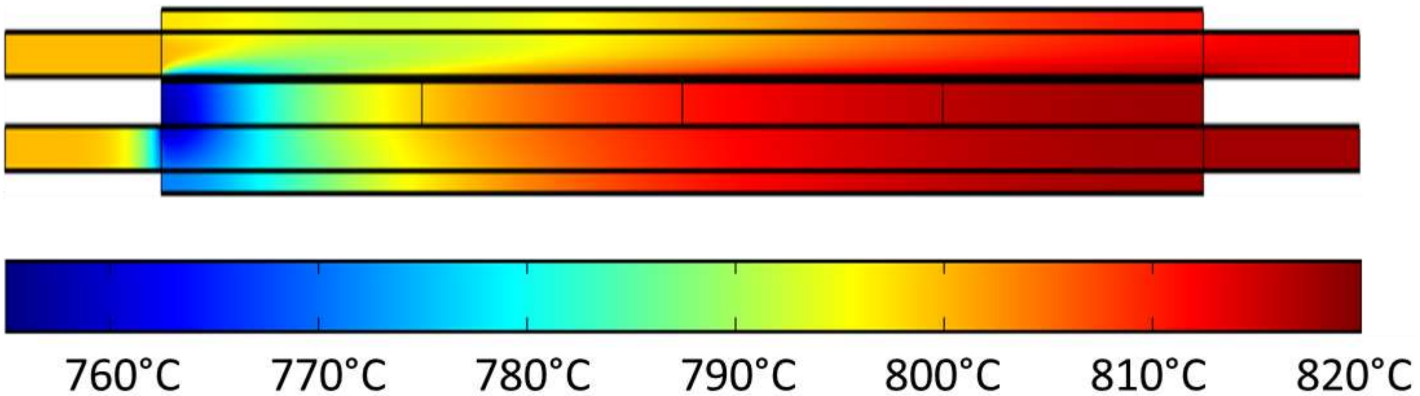
T_{MIN} = 786 °C

ΔT = 32 °C



Model Validation

Model Conditions: T_{AI} = 800 °C, U_F = 72%



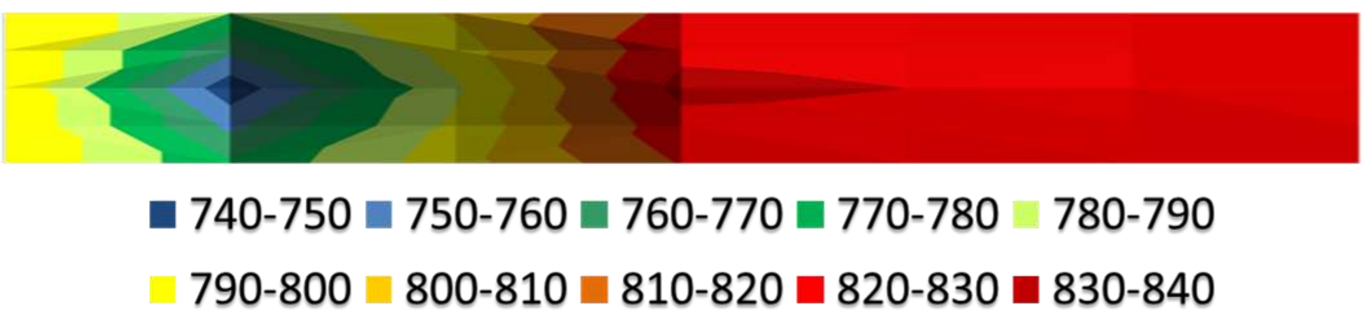
T_{IN} = 757 °C

T_{MID} = 810 °C

T_{OUT} = 818 °C

ΔT = 61 °C

Stack Data: T_{AI} = 800 °C, U_F = 65%



T_{IN} = 763 °C

T_{MID} = 826 °C

T_{OUT} = 823 °C

ΔT = 63 °C

SOFC Stack Development

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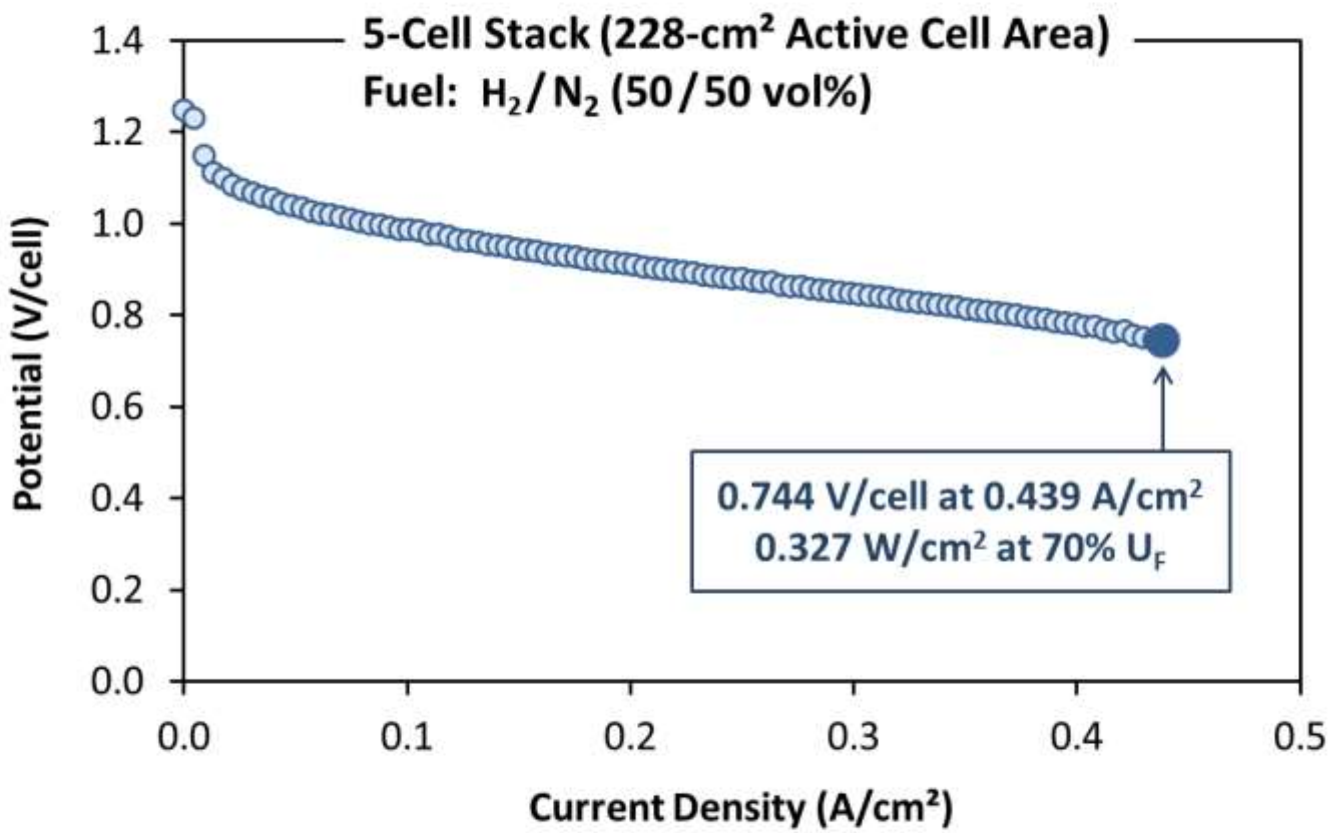
Current Status

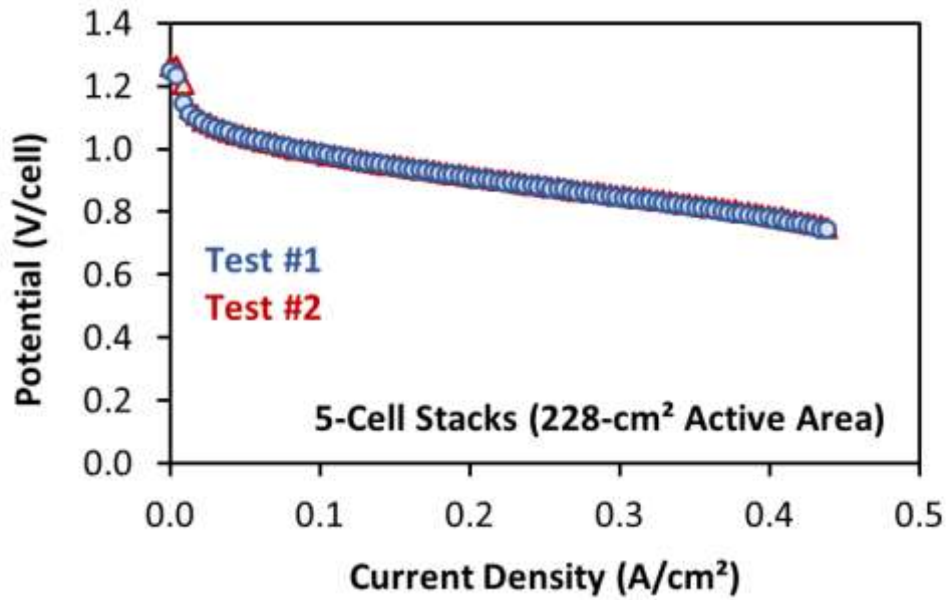
- Stack process modeling to determine operating conditions and stack sizing for a 10-kW scale stack at 65% efficiency
- Stack design established with following goals:
  - Open (flow-through) cathode
  - Hot box design with integrated insulation and compression
  - Cell-in-frame approach to get cells out of the stack periphery
  - Improved seals to enable near-hermetic anode cavities
- Established sub-scale (228-cm^2 active cell area) design to enable testing to prove viability of repeat unit design approach
- Stack design validation testing completed, scale-up to larger stack size is ongoing.

SOFC Stack Development

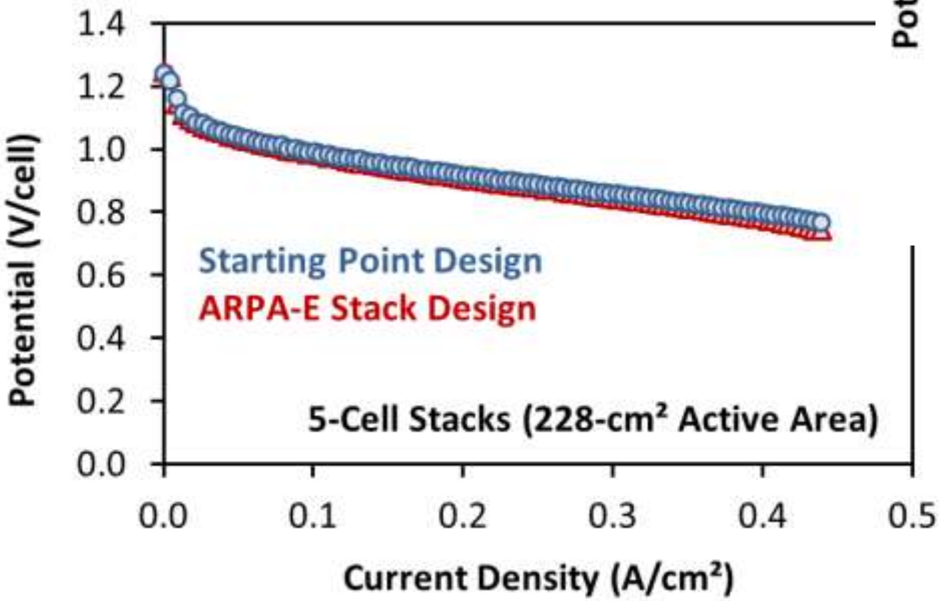


Stack meets expectations for performance and fuel utilization.

SOFC Stack Development



Performance of the ARPA-E stack design replicates that of starting point design.



Two tests of the ARPA-E stack design provided perfect repeatability.

Risks

Technical Challenges and Current Status

- Achieving target stack performance with a new stack design platform. ***So far so good!***
- Achieving sufficient stack sealing to facilitate pressurized operation. ***So far so good!***
- Reducing thermal gradients via precise control of the internal methane reforming reaction. ***Needs to be demonstrated in full-scale stacks.***
- Achieving long-term stack durability at high operating temperature and high current density. ***Testing required to see where we are.***
- Achieving sufficient stack mechanical robustness for integrated systems. ***Needs to be proven.***

Tech-to-Market

Nexceris aims to be a SOFC stack supplier, initially in military markets, eventually in commercial markets:

- Aligned with Nexceris core competencies
- Smaller financial barrier to market entry
- Strong value proposition for military power systems
- Leverages current customer base

Nexceris Transition Approach

- Continue to advance stack technology with DOE and DoD sponsored projects
- Collaborate with system integrators on system-level demonstrations
  - Define a detailed set of requirements
  - Customize the stack design to those requirements
  - Deliver stacks for customer testing and prototype system builds
- Identify the best approaches for scale-up as stack production volumes increase

Tech-to-Market

Markets Served by the ARPA-E Stack Technology

- Military power (e.g., unmanned ground and aerial vehicles)
- Range extenders for electric vehicles (military and commercial)
- Industrial scale (100+ kW) combined heat and power
- Grid-scale power (100+ MW)
- Large-scale hydrogen production (via electrolysis)
- Reversible fuel cells for grid-level energy storage

Current Status of Product Development

- Military purpose stack being developed with DoD funding
- SOFC systems being designed for military power applications
- Breadboard system testing ongoing to increase stack TRL
- SOFC stacks being supplied to development partners
- Commercial stack platform being developed on this project
- Exploring other solid oxide applications (SOEC and RSOFC)

Tech-to-Market

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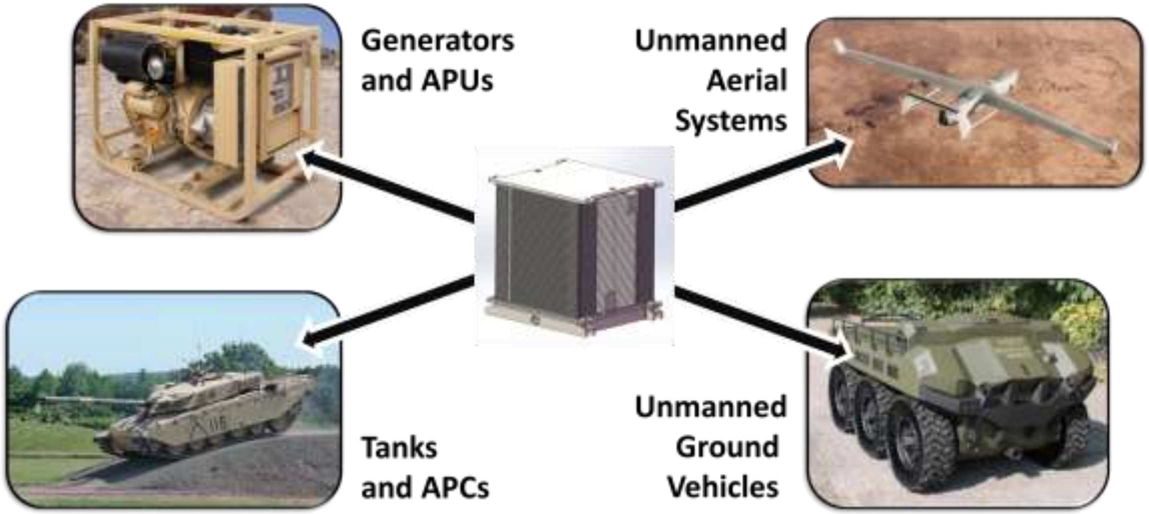
Value Proposition for Military Applications

- **Higher Efficiency:** Longer mission durations
- **Better Reliability:** Compared to currently used generators
- **Quiet Operation:** Enables silent watch missions
- **Sulfur Tolerance**: Facilitates use of military logistic fuels
- **High Power Density:** Essential for military applications



Stack Manufacturing Cost Analysis (500 MW/Year)

Cost Category	Yearly Cost	Cost Per Stack	Cost Per kW
Raw Materials	$141,415,006	$2,828.30	$282.83
Depreciation	$572,060	$11.44	$1.14
Labor	$2,162,160	$43.24	$4.32
Utilities	$15,420,845	$308.42	$30.84
Operating Supplies	$7,070,750	$141.42	$14.14
Local Taxes	$114,412	$2.29	$0.23
Maintenance & Repairs	$2,828,300	$56.57	$5.66
Insurance	$45,765	$0.92	$0.09
Totals	**$169,629,297**	**$3,392.59**	**$339.26**

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Questions?

Nexceris is grateful for the opportunity being provided by ARPA-E, and we look forward to working with all INTEGRATE program participants and stakeholders!