High Power Density Carbon Neutral Electrical Power Generation for Air Vehicles

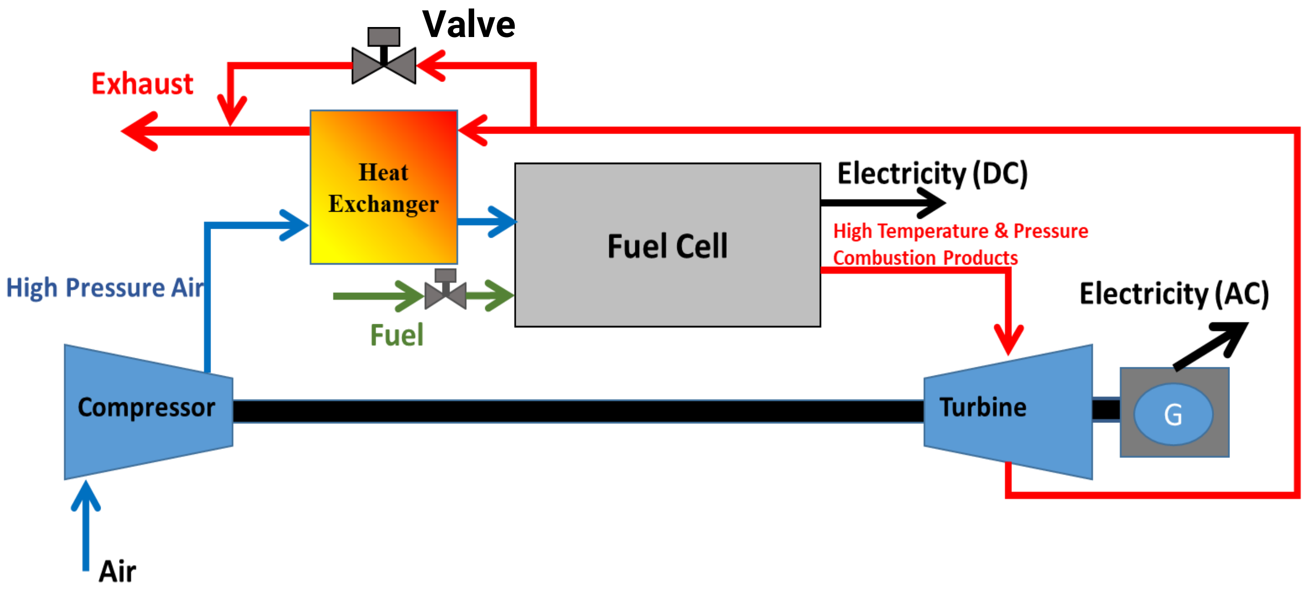
Rory Roberts, Tennessee Tech University

Project Vision

"We are solving the electrification of aviation by integrating the propulsion, power, and thermal systems for an energy optimized aircraft."

REEACH / ASCEND
Kickoff Meeting
January 26, 27, 28, 2021

Conventional Fuel Cell-Gas Turbine Hybrid (FC-GT)



<u>Pros</u>

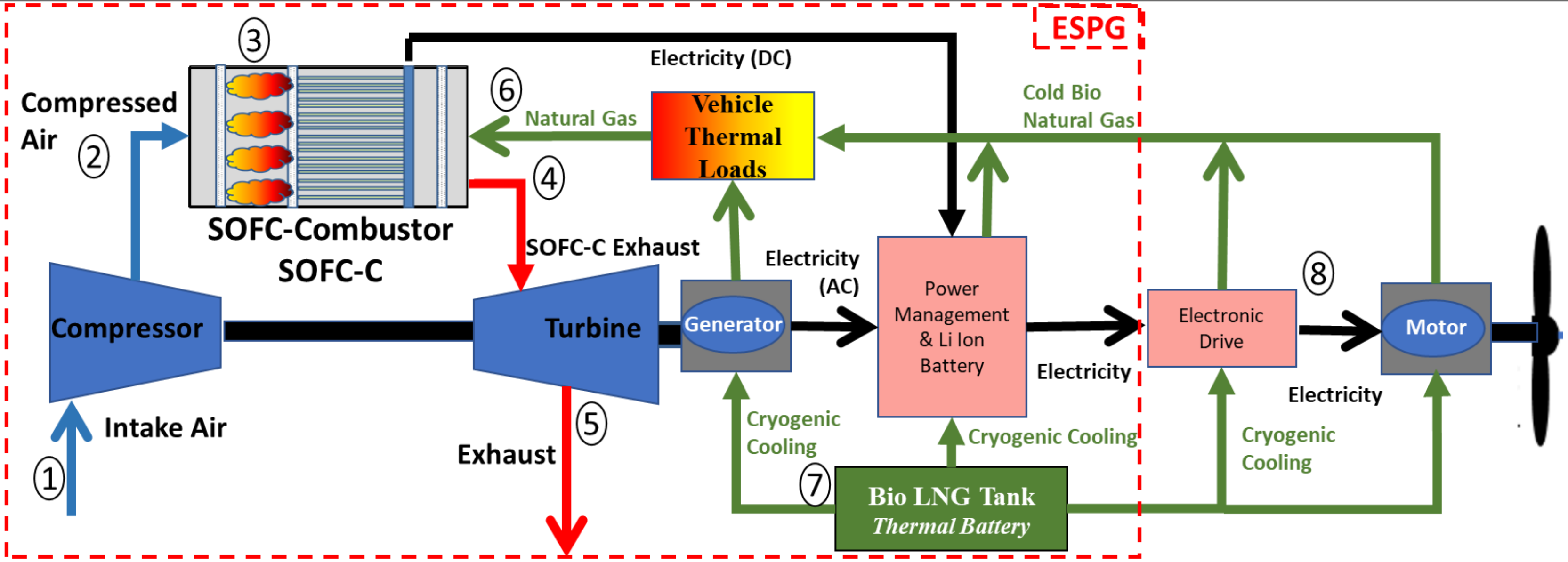
- **FC-GT provides ultra high chemical-to-electrical conversion efficiency**
- **Provides pressurized environment at high altitudes**

<u>Cons</u>

- **Large massive systems with low specific power**
- **Large thermal mass, sluggish response to perturbations**
- **Long cold startup times**
- **Complex thermal management of fuel cell typically with large valves**

Brief REEACH Phase 1 Project Overview

Fed. funding:	$1.44 M
Length	24 mo.



The Solid Oxide Fuel Cell–Combustor-Turbogenerator (SOFC-C-TG) concept:

- **Enabler of electrification for large aviation.**
- **Bio LNG was the natural choice for CNLF and addresses challenges in thermal management**
- **SOFC-Combustor:**
  - **No cathode heat exchangers required**
  - **No high temperature valves required**
  - **Rapid response to perturbations and startup**
- **Project objective:**
  - **Develop high power density SOFC –Combustor module**

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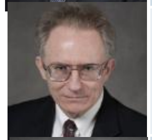
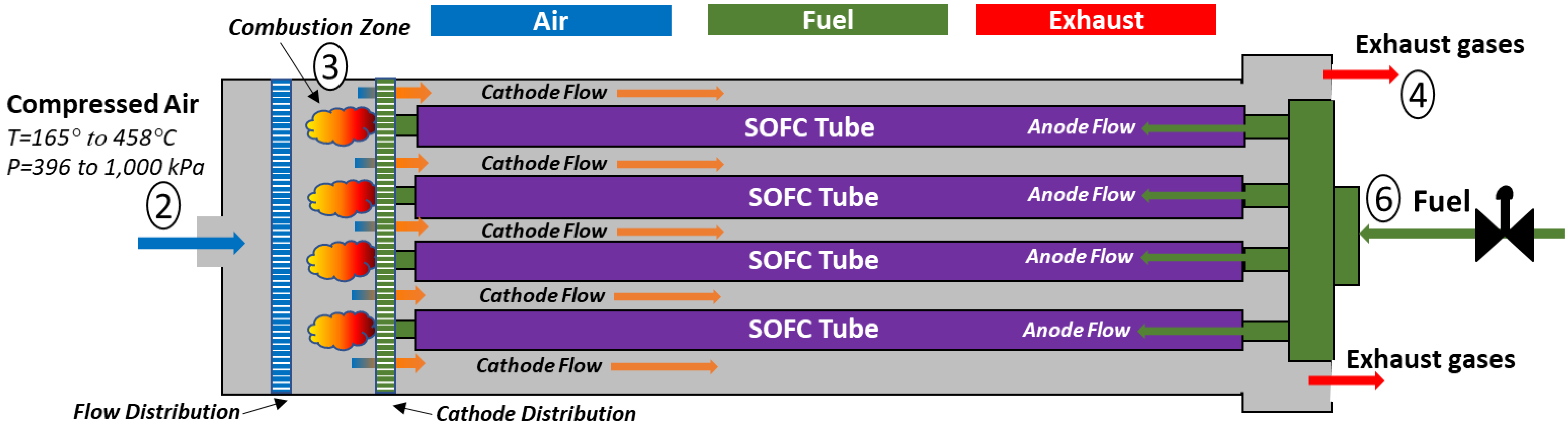
Team

	Team member	Location	Role in project
	Rory Roberts, *Tennessee Tech University*	Cookeville, TN	Project Lead, System design lead -18 years experience in SOFC technology - Integrated propulsion, power, thermal expert
	Ted Ohrn, *Special Power Sources*	Alliance, OH	SOFC tube and stack design-Lead -30 years experience in SOFC's
	Roland Dixon, *Special Power Sources*	Alliance, OH	Technology Transfer and Outreach-Lead -40 years government PM experience
	Chuck Lents, Raytheon Technologies	East Hartford, CT	Turbo-machinery & generator – Lead • 35 years in aircraft integrated system • RTRC electrified propulsion research
	Kashif Nawaz, *Oak Ridge National Lab*	Oak Ridge, TN	Fluid-thermal modeling and design -Expert in high temperature thermal mng.
	John Hull, *Boeing*	Seattle, WA	Integration with aircraft
	Mitch Wolff, *Wright State University*	Dayton, OH	Turbogenerator integration -Jet engine expert

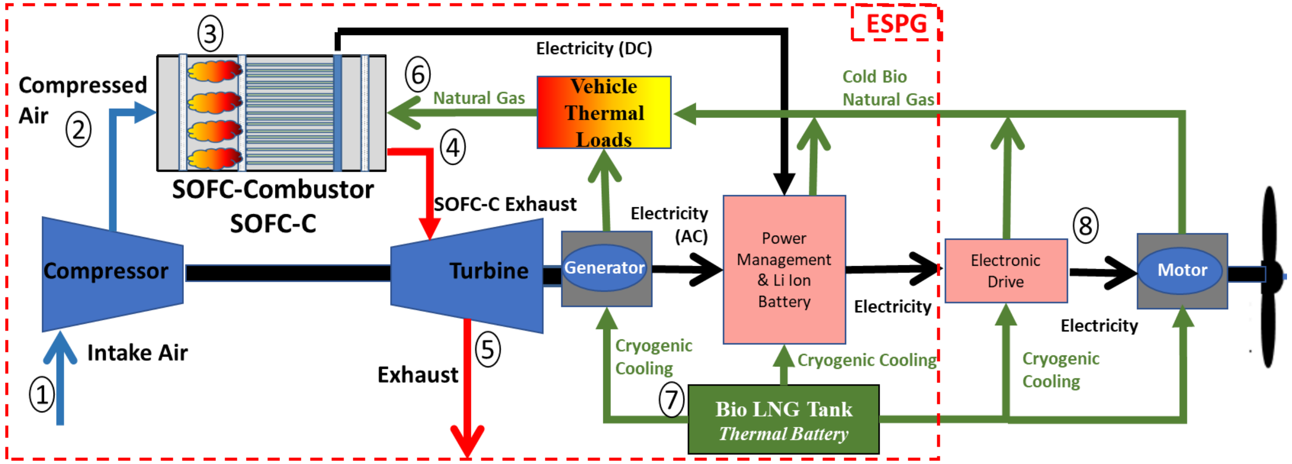
Innovation

- SOFC stack is integrated with a combustor <u>eliminating</u> the need for <u>cathode heat exchangers</u>
  - Provides precise control of cathode inlet temperature with minimum thermal mass upstream
  - Minimum valves and components
  - Built in redundancy in system



Innovation

- SOFC-Combustor is the key component being developed.
  - ESPG concept requires SOFC-Combustor, turbogenerator, and battery.
- The SOFC-Combustor concept eliminates massive and expensive components with elegantly simple system
  - No cathode heat exchangers
  - No valves for cathode flow
  - No external reformer
  - Minimum manifold and pipe network

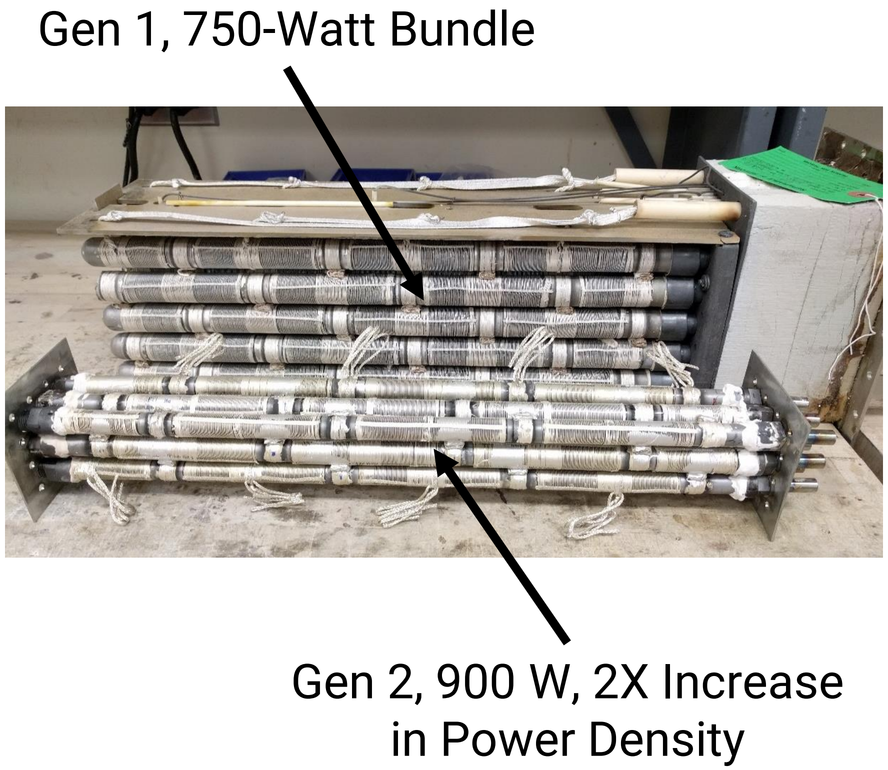


- The SOFC-C-TG ESPG will achieve \$0.143/kW-hr (\$0.15 TPT) with specific energy 3,809 Wh/kg (3,000 TPT)
- System design and optimization tools will be developed and utilized in the project.
  - Mission vehicle level modeling and simulation tool for ESPG optimization with controls

Technology Development Focus

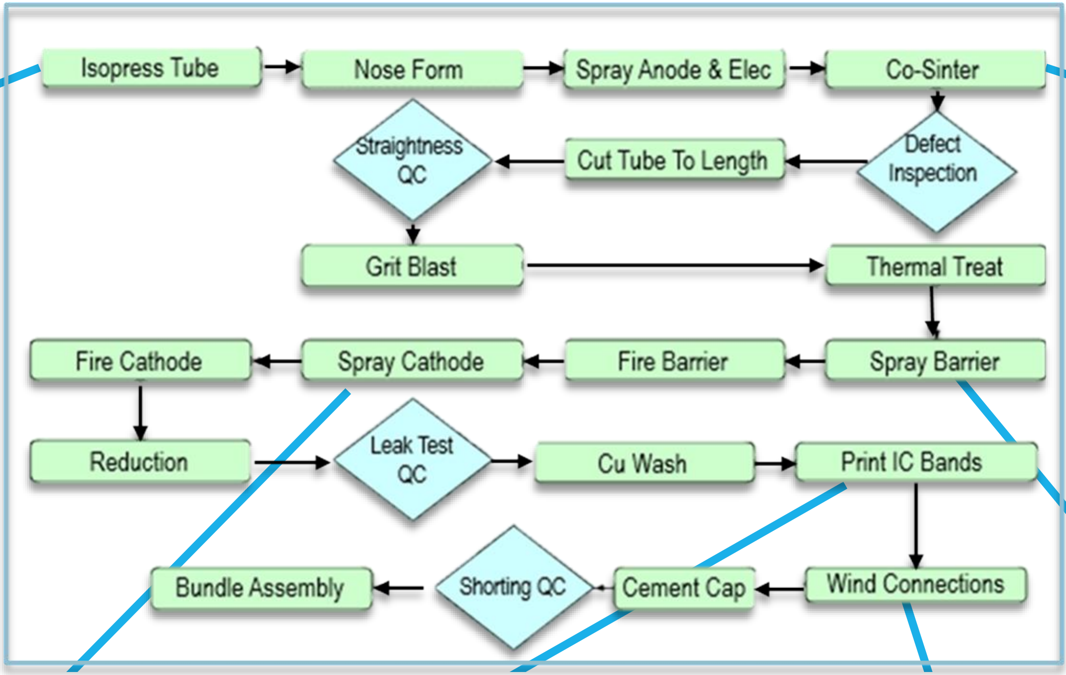
SOFC-Combustor

- Small SOFC Tube Development
  - High power density, light weight SOFC tubes
  - Pressurized testing and operation
- ESPG System Design
  - Optimize design for power density [kW/kg] while maintaining specific energy >3,000 W-hr/kg
  - Define turbogenerator design, and performance and development requirements
- SOFC Bundle Development
  - SOFC bundle development for take-off and cruise conditions



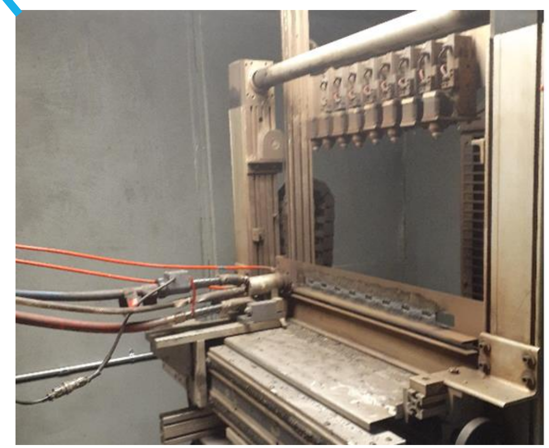
Fuel Cell Manufacturing Facilities, Special Power Sources

Static Iso-Press



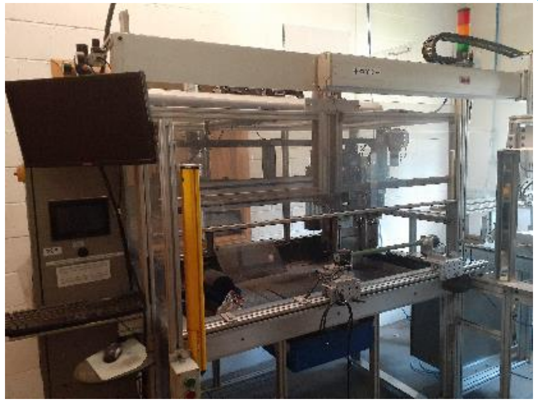
Sintering Furnace

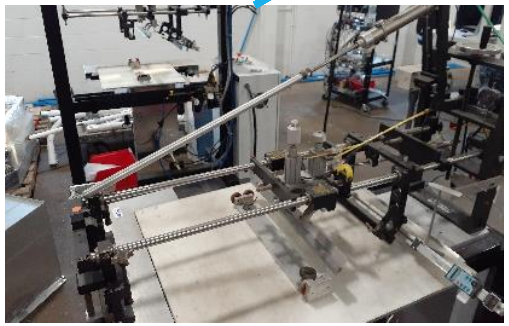
Plasma Spray



Fuel Cell Mfg. Process (Powder to Power)

Cathode Spray



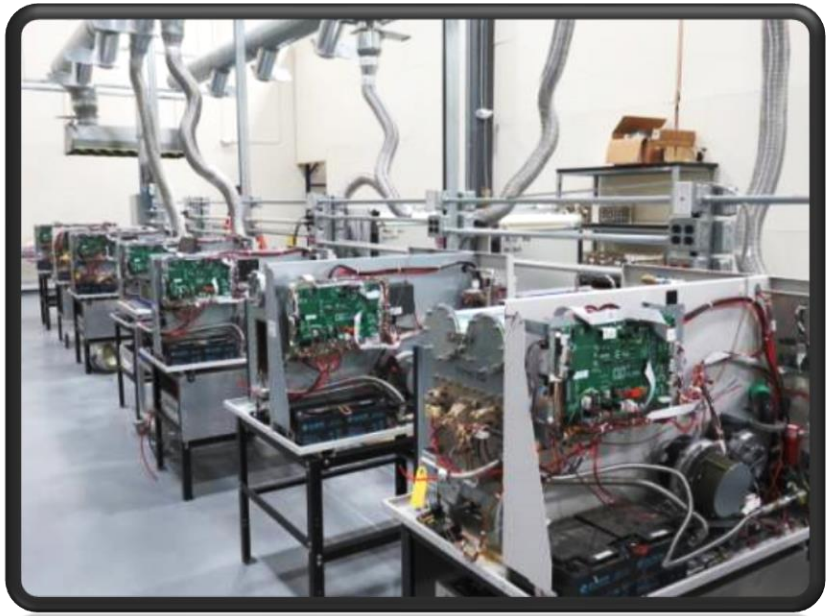


Screen Print

CC Winding

Testing Facilities

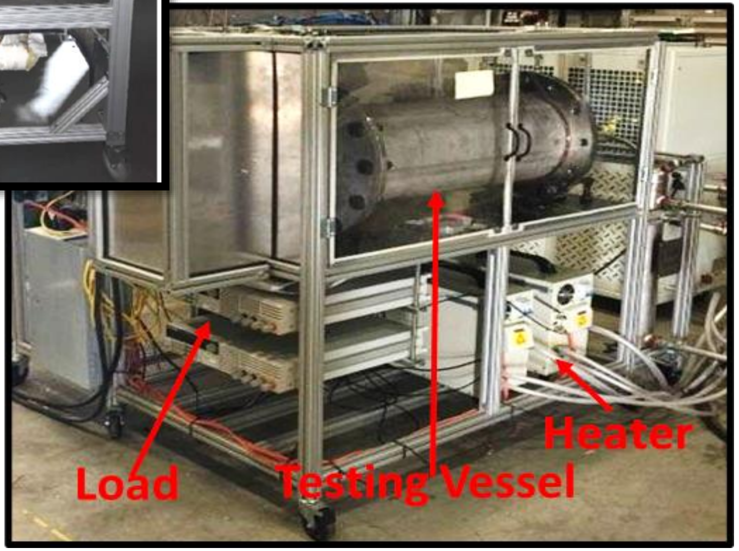
Special Power Sources
Atmospheric pressure test rigs ranging in size up to 5 kW



Tennessee Tech University
Pressurized test rigs ranging in capacity up to 7 Bar and 2 kW

Pressurized Test Rig
7 Bar, 1.8 kW

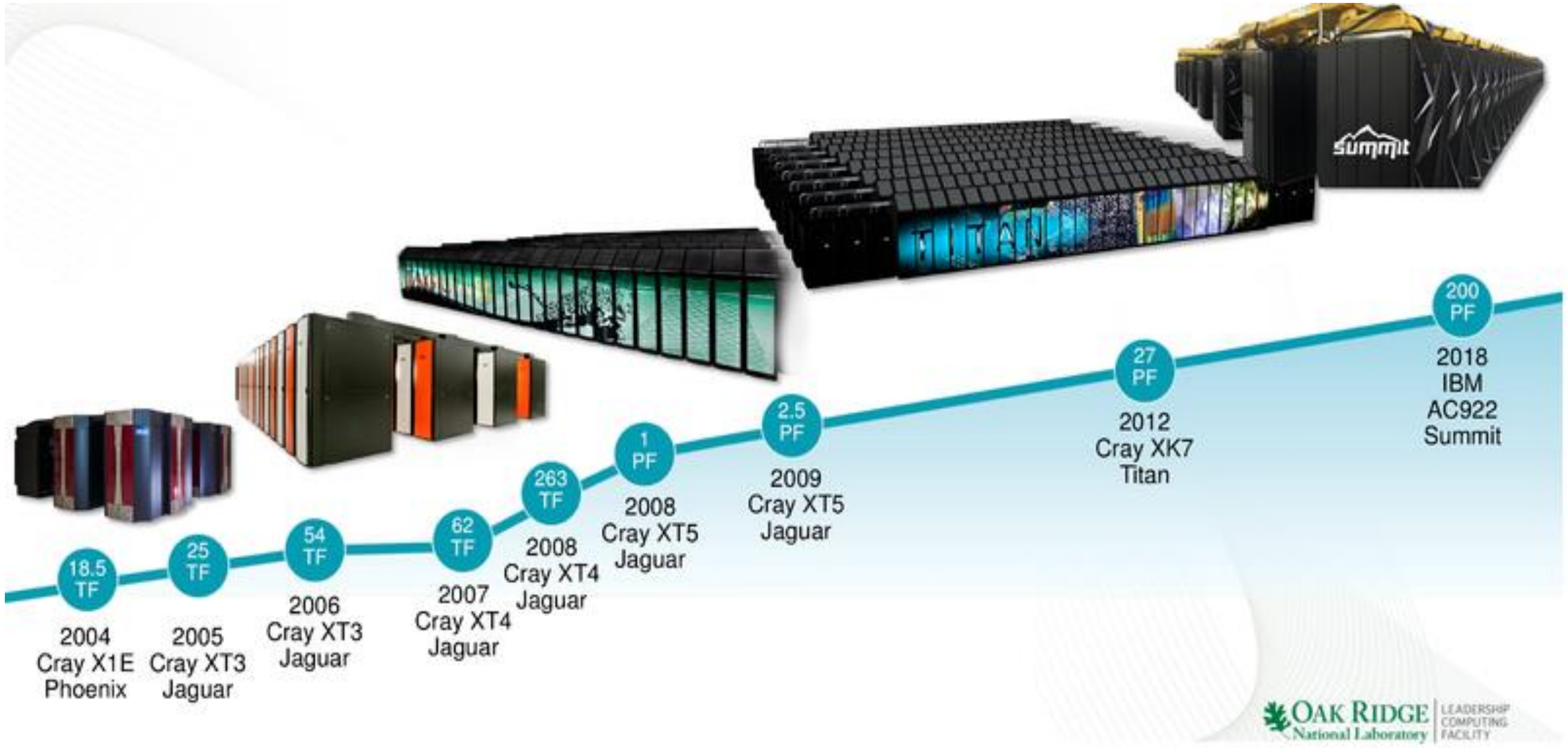
Pressurized Test Rig
4 Bar, 2 kW



Design Tools

Oak Ridge National Laboratory

- High Power Computing Cluster for thermal and structural analysis
- Analysis platforms ANSYS, Star CCM+, COMSOL
- Proprietary algorithms for structural analysis, durability assessment



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Risks and Challenges

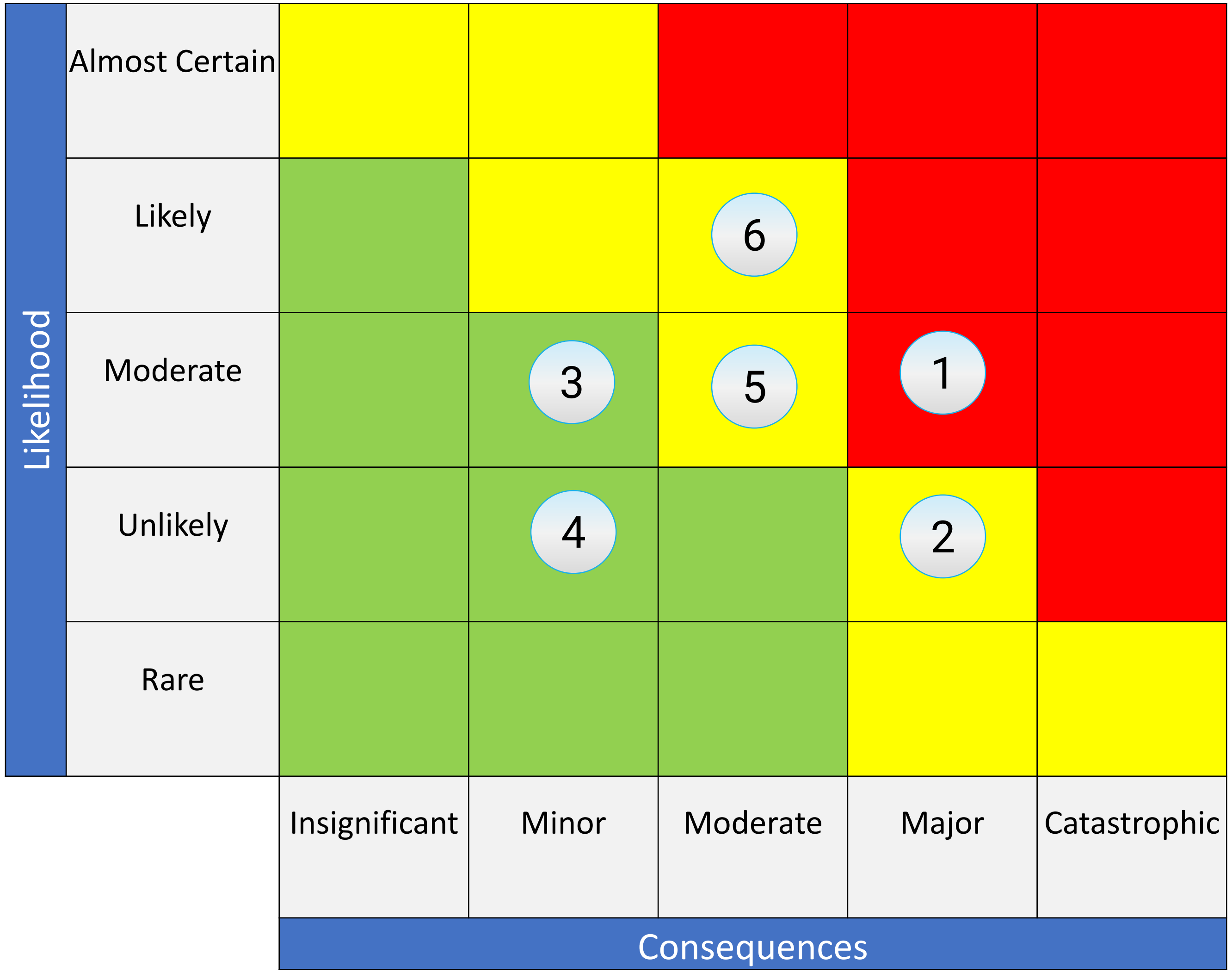
Primary Risks:

1. Development of high-power density low weight cells
2. Pressurized operation of the SOFC stack
3. On-anode reforming within SOFC tubes
4. Combustor instability for large range of equivalence ratios and residence times
5. SOFC-C integration with TG
6. SOFC-C is novel power technology and limited technical expertise exists to adopt for wide commercial use

Gen 1, 750-Watt Bundle

Gen 2, 900 W Bundle
2X Increase in Power Density

Initial Risk Assessment



Risk	#
Development of high-power density low weight cells	1
Pressurized operation of the SOFC stack	2
On-anode reforming within SOFC tubes	3
Combustor instability for large range of equivalence ratios and residence times	4
SOFC-C integration with TG	5
SOFC-C transformative power technology and limited technical expertise exists to adopt for wide commercial use	6

Task Outline & Technical Objectives

Phase 1 Objective: Develop high power density SOFC technology operating a high pressure and design ESPG

Phase 1 Tasks:

Task 1	Negotiation and program management
Task 2	Electrical Storage and Power Generation system design
Task 3	Single SOFC tube development
Task 4	SOFC bundle development
Task 5	Technology-to-Market

Deliverables:

Electrical Storage and Power Generation system design
High performance, high power density SOFC tube
1 kW SOFC bundle at a specific power density

Phase 2 Deliverable:

5 kW SOFC stack
– High efficiency – High specific power density

Needs and Potential Partnerships

- **Needs project has currently:**
  - Contact with airline customer for establishing customer needs
- **Anticipated needs following the completion of the award:**
  - Application of RTX generator capability to develop a multi-megawatt machine, not being addressed in this program
  - Power electronics to integrate and regulate voltage and current from SOFC and generator.
  - Infrastructure expertise related to aviation flight support
- **Capabilities that could be useful for other REEACH teams:**
  - Integrated propulsion, power, and thermal management expertise
  - Pressurized SOFC operation expertise
  - LNG for aviation fuel expertise

Questions?

SPS Special Power Sources
SUPPLYING YOUR REMOTE POWER NEEDS

Raytheon Technologies

Thank You

OAK RIDGE
National Laboratory

BOEING

WRIGHT STATE UNIVERSITY

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