Energy Conversion and Storage Requirements for Hybrid Electric Aircraft

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NASA Aeronautics Research Six Strategic Thrusts

Safe, Efficient Growth in Global Operations
- Enable full NextGen and develop technologies to substantially reduce aircraft safety risks

Innovation in Commercial Supersonic Aircraft
- Achieve a low-boom standard

Ultra-Efficient Commercial Vehicles
- Pioneer technologies for big leaps in efficiency and environmental performance

Transition to Low-Carbon Propulsion
- Characterize drop-in alternative fuels and pioneer low-carbon propulsion technology

Electric Propulsion

Real-Time System-Wide Safety Assurance
- Develop an integrated prototype of a real-time safety monitoring and assurance system

Assured Autonomy for Aviation Transformation
- Develop high impact aviation autonomy applications

Benefits of Electric Propulsion

Low Carbon Propulsion

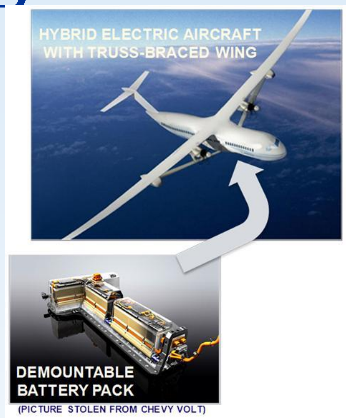
- NASA studies and industry roadmaps have identified hybrid electric propulsion systems as promising technologies that can help meet national environmental and energy efficiency goals for aviation

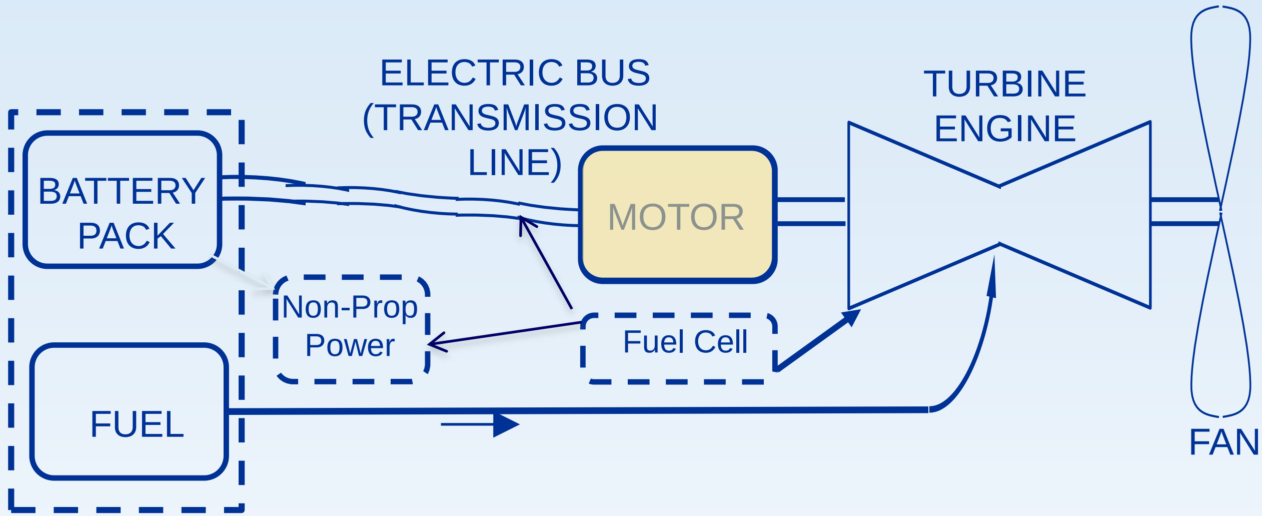
Potential Benefits

- Energy usage reduced by more than 60%
- Harmful emissions reduced by more than 90%
- Objectionable noise reduced by more than 65%

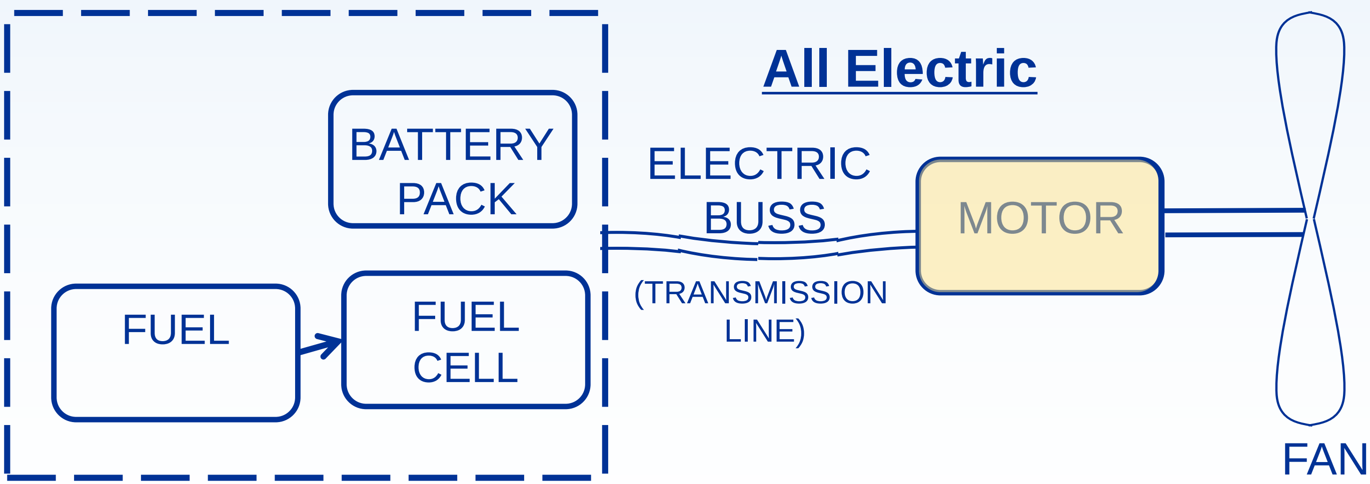
Types of Electric Propulsion

Hybrid Electric





All Electric



EADS – VoltAirs concept

Energy Conversion and Storage Systems

- Fuel Cell
- Batteries
- Supercapacitors
- Multifunctional structures with energy storage capability
- Other systems
  - Low energy nuclear reaction
  - Flywheel energy storage
  - Energy harvesting

Application of Proton Exchange Membrane (PEM) Fuel Cell

Boeing Flight Demonstration

Airbus Flight Demonstration – Emergency Power

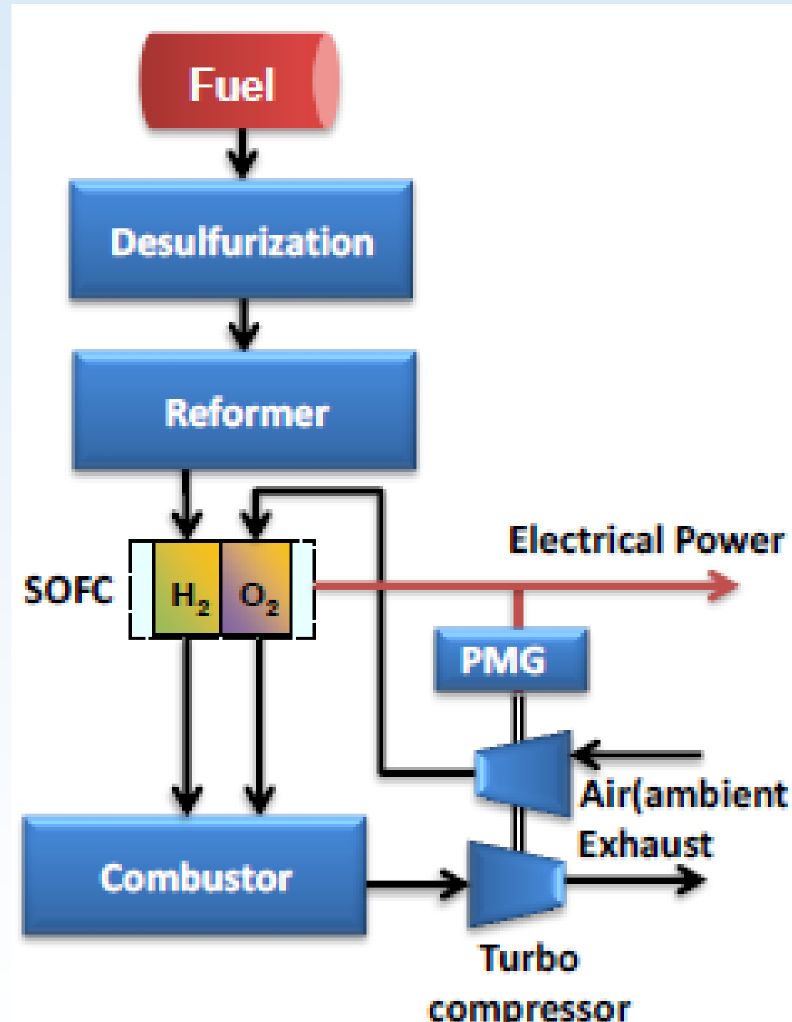
Solid Oxide Fuel Cell (SOFC)

Benefits:

- Can be used with both H_2 and CO
- Direct utilization of hydrocarbon fuel
- High temperature supports steam reforming, which boosts system efficiency
- Greater efficiency (> 60 %) with hybrid gas turbine + SPFC cycle
- High quality heat for thermal management

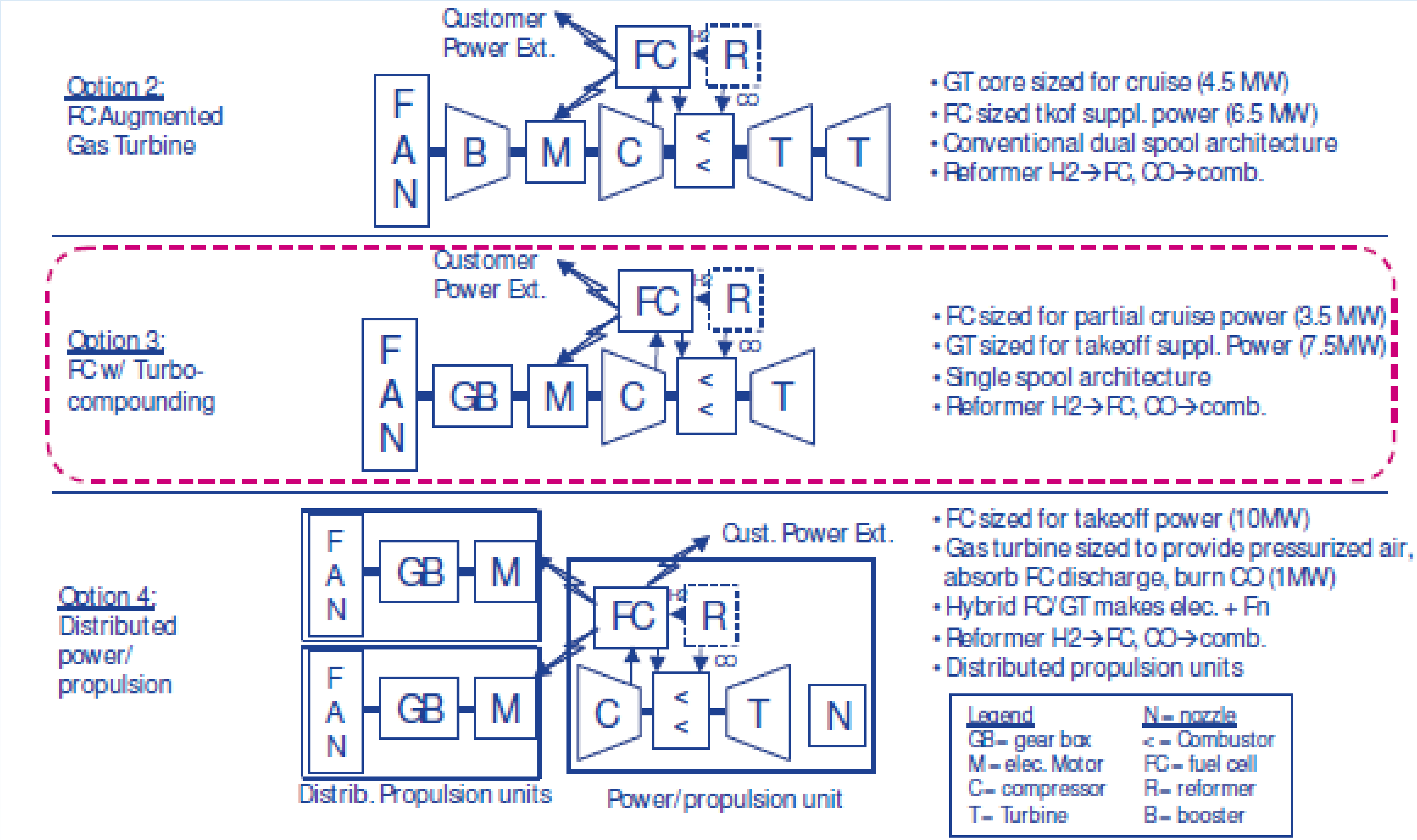
Early Demonstration of a Heavy Fuel Solid Oxide Fuel Cell – Enabled Power System for Electric Aircraft

- Integration of key technologies
- 160-190 knots cruise on 130-190 kW
- Hybrid solid oxide fuel cell with >60% fuel-to-electricity efficiency
- Designed for cruise power
- Applicable to APUs for large aircraft



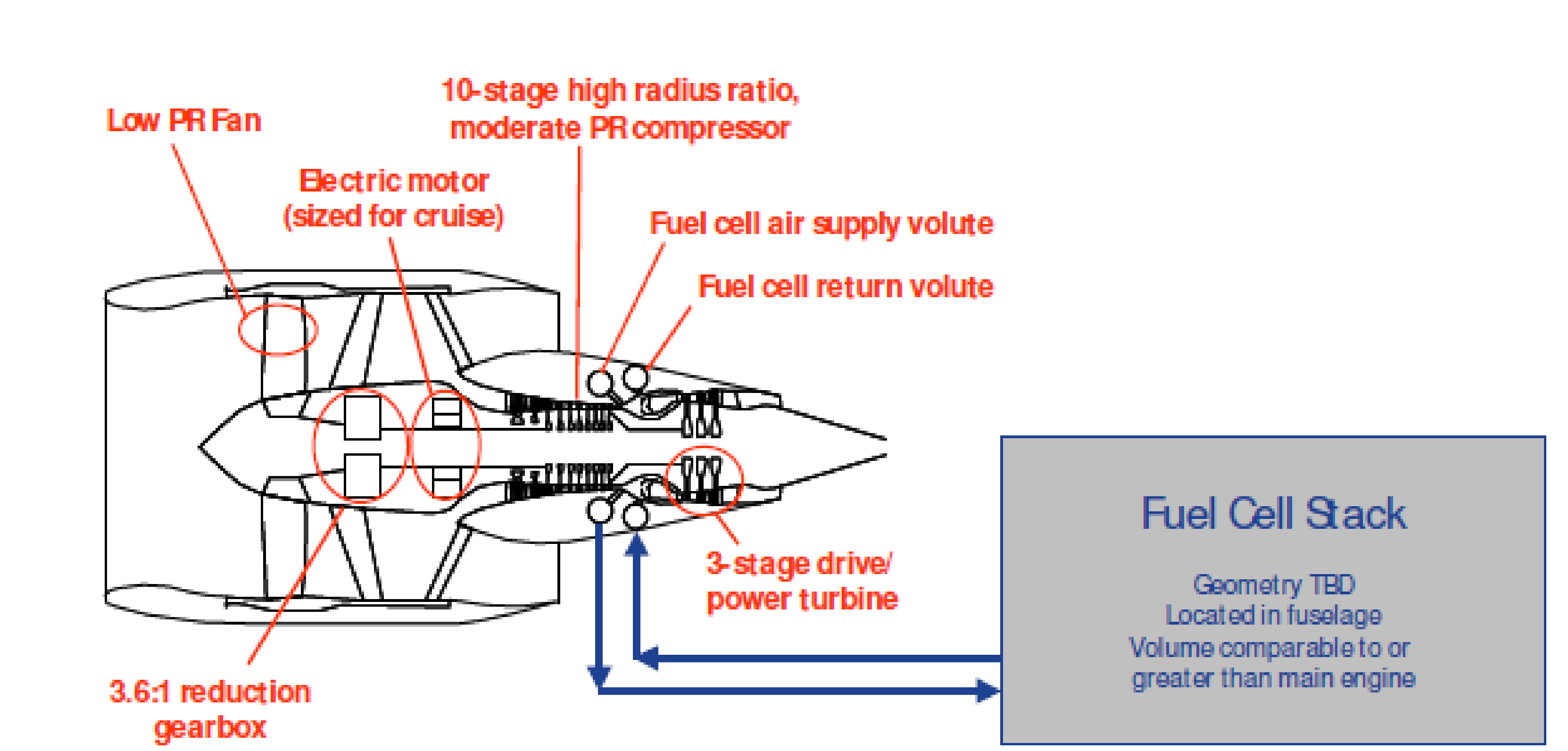
Nicholas Borer of NASA LaRC - Lead

Hybrid Gas Turbine – Solid Oxide Fuel Cell Concepts



GE Aviation work funded by NASA N+3 studies (AIAA 2010-6537)

Placement of Solid Oxide Fuel Cell in Gas Turbine Engine

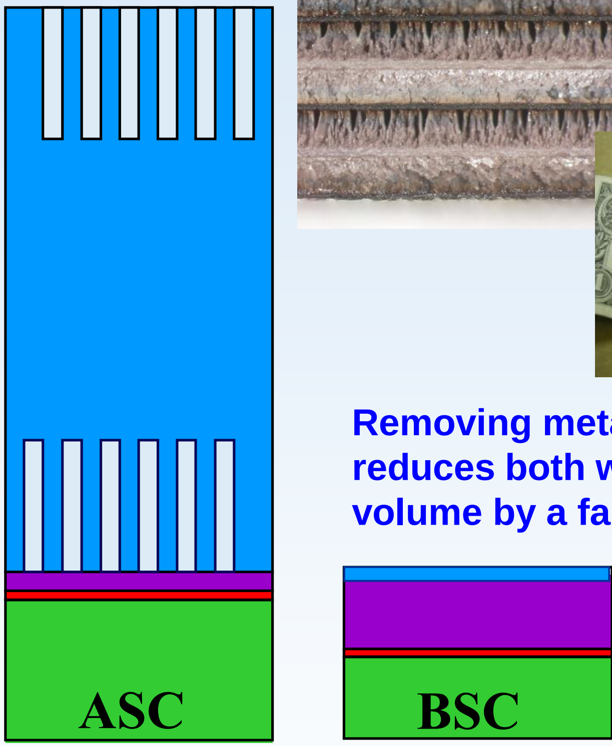


GE Aviation work funded by NASA N+3 studies (AIAA 2010-6537)

Solid Oxide Fuel Cell Requirements for Large Commercial Aircraft

- Need ~4X or higher increase in specific power (gravimetric and volumetric)
- Sulfur tolerant system
- Power output deterioration rate < 2% per 10,000 hours
- Idle-to-max power output rise compatible with flight safety requirements
- Heating in less than 30 min and durability under thermal cycling conditions
- Integration with aircraft without aerodynamic penalty

NASA High Power Density SOFC Design



Removing metal interconnect reduces both weight and volume by a factor of 5

Commercial Design

NASA Design

- Interconnect
- Cathode
- Electrolyte
- Anode

ASC = Anode Supported Cell
BSC = Bi-electrode Supported Cell

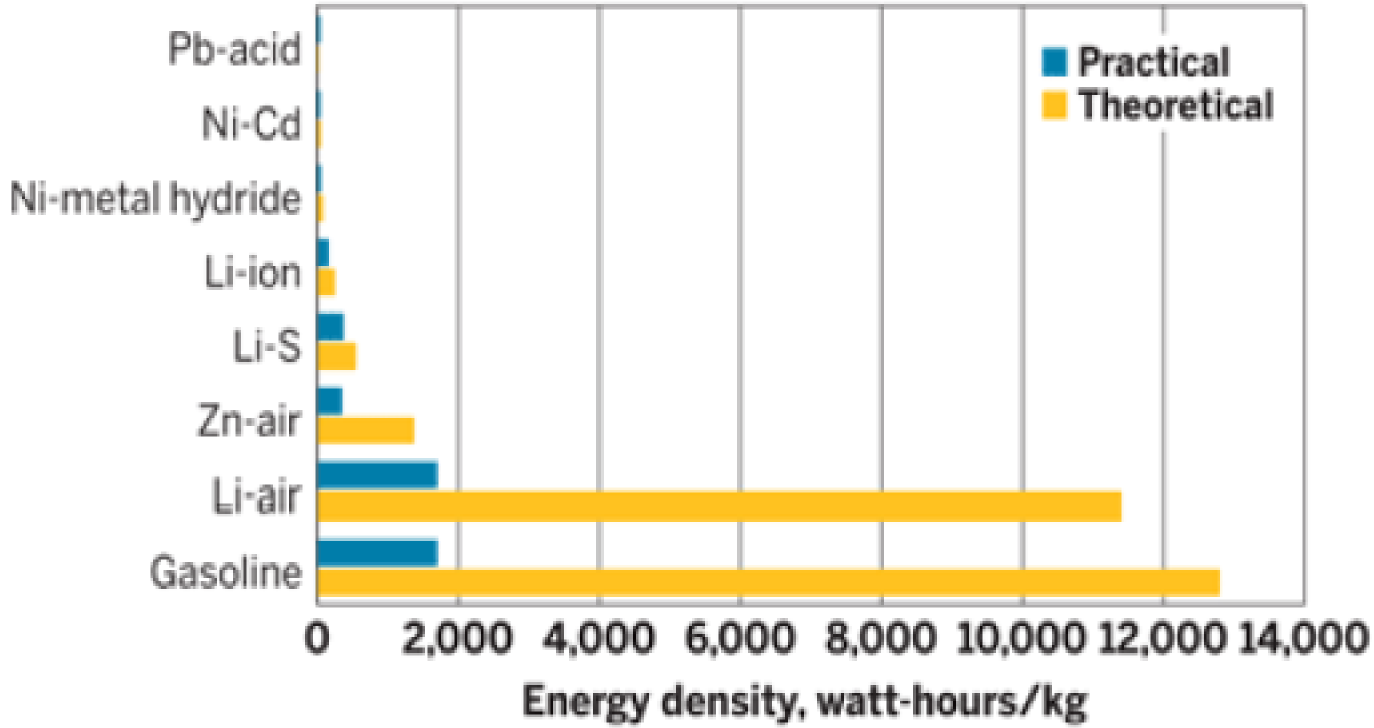
	W/kg	W/L
SOA ASC	200	470
NASA BSC	1100	4000

BSC Design Solution
Uniquely light weight and low volume

Fabrication method of co-firing all-ceramic stacks as a unitized block reduces internal resistance and increases manufacturing yields.

Low temperature electrode infiltration expands the range of catalysts for development of new electrodes for sulfur tolerance, direct hydrocarbon.

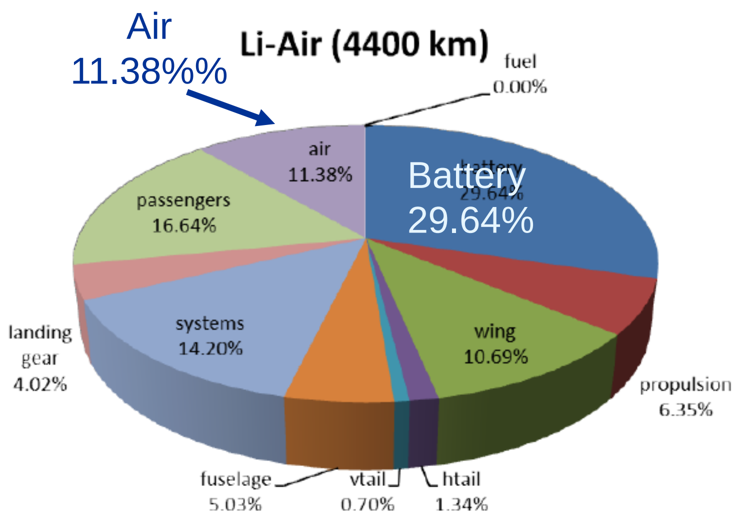
Energy Density of Batteries

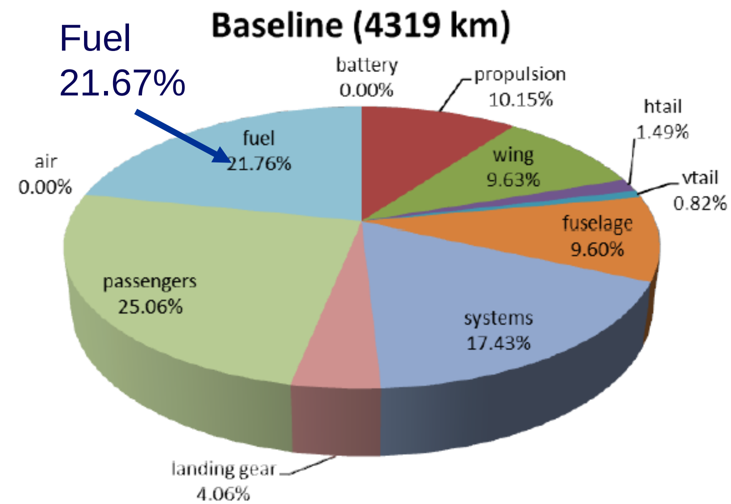


- Significant weight penalty from batteries
- Requirement for large commercial hybrid electric aircraft: 750 – 1000 w-h/kg

All Electric Aircraft Design with Li-Air Battery

114 passengers, all electric, design range of 2400 nautical miles, Li-Air battery energy density – 2000 watt-hour/kg



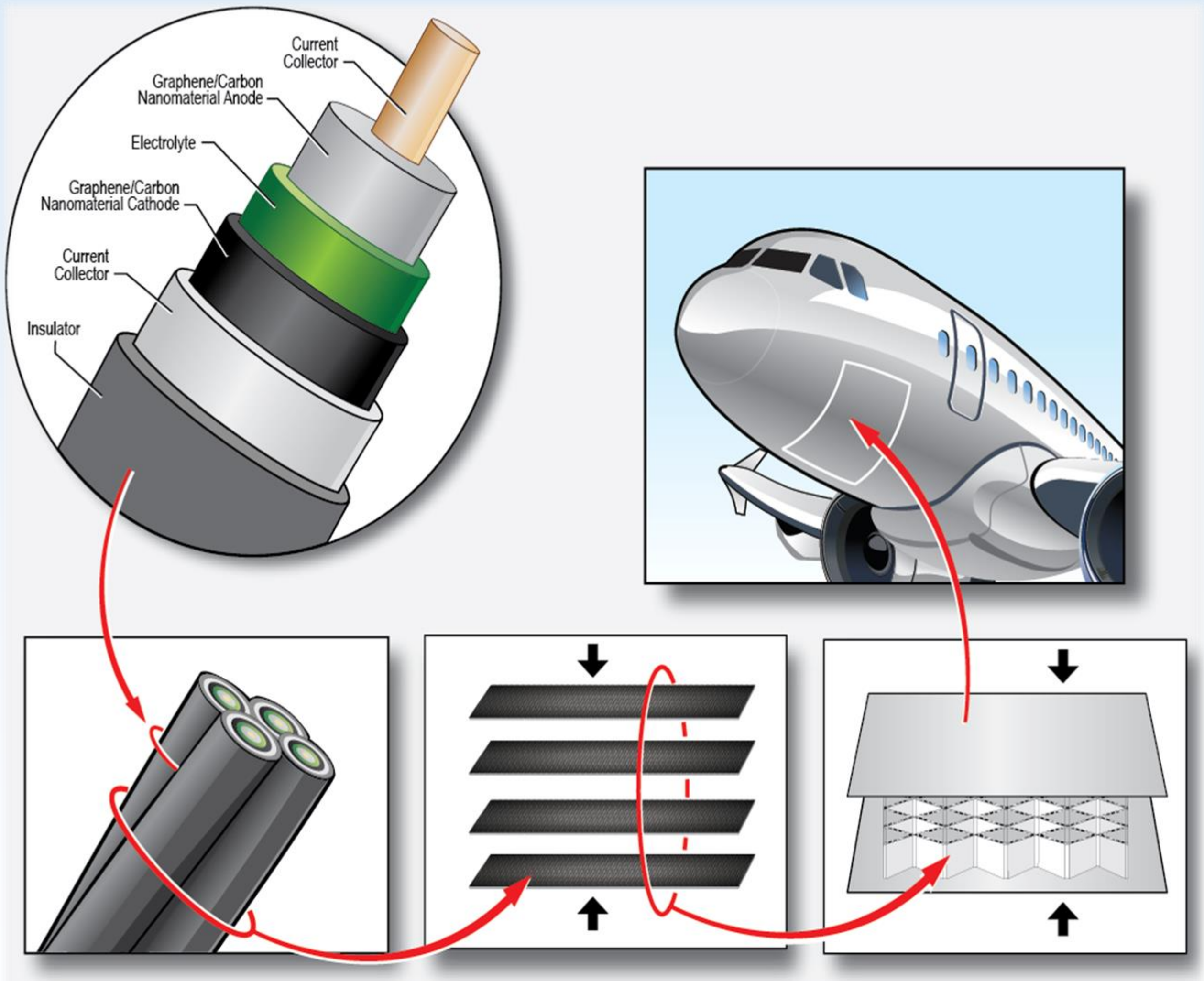


- Gross takeoff weight = 59786 kg
- Maximum landing weight = 67464 kg

- Gross takeoff weight = 52300 kg
- Maximum landing weight = 40400 kg

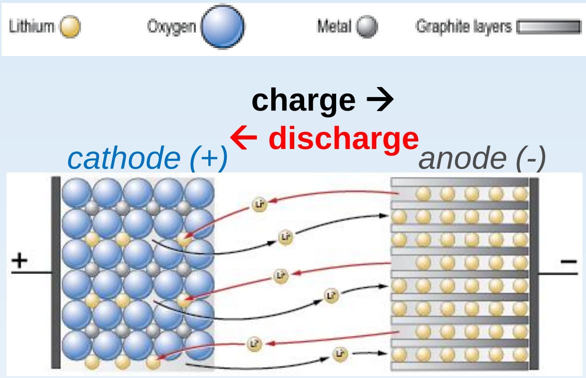
Work from Stanford University (Vegh and Alonso – AIAA Paper)

Multifunctional Structures with Energy Storage Capability

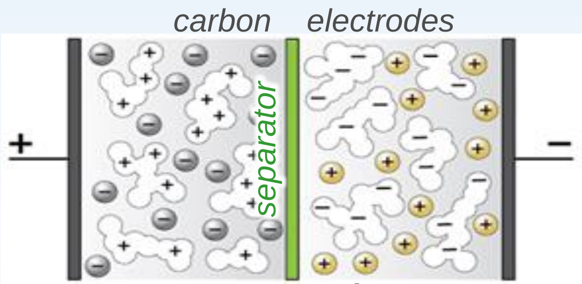


Current research at NASA

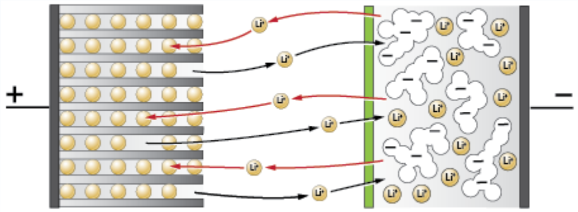
Hybrid Battery - Supercapacitors



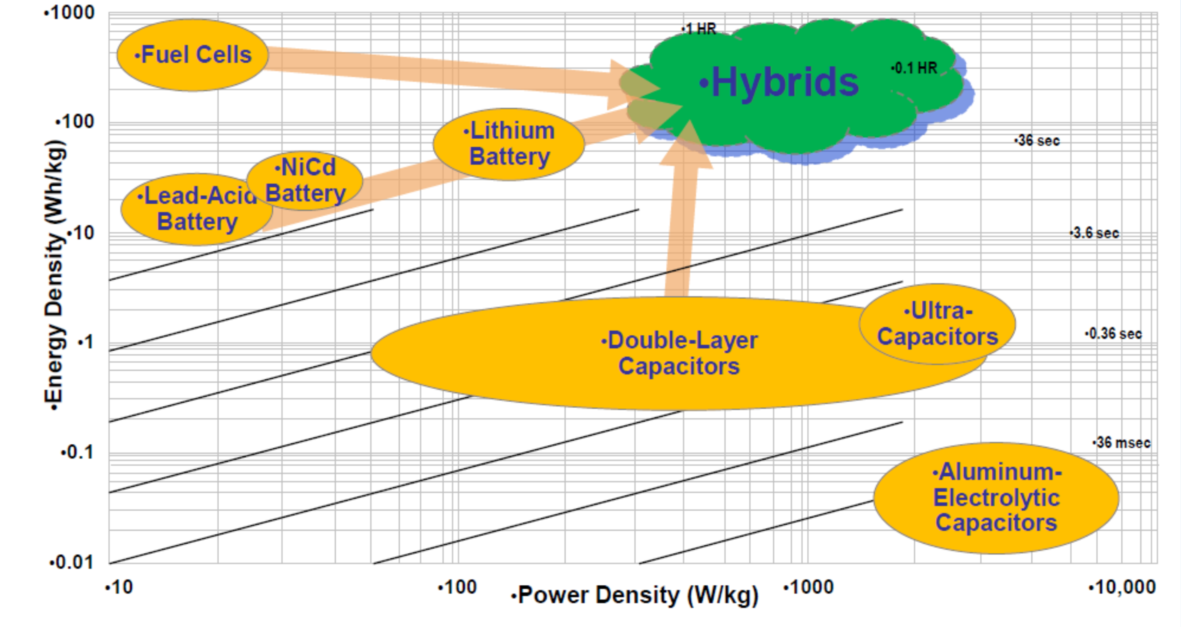
battery

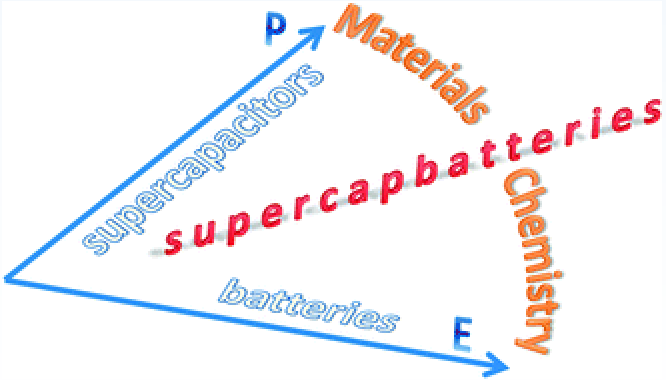


supercapacitor



hybrid supercapacitor

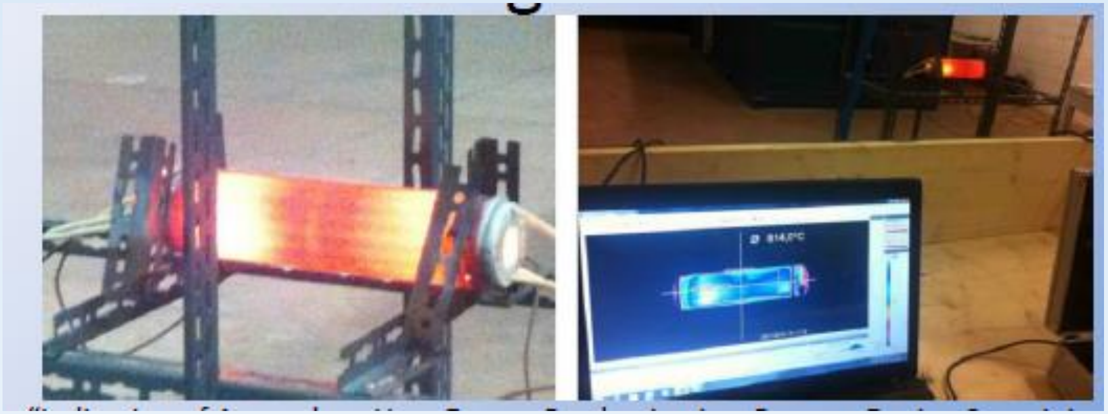




Energy Storage Requirements for Large Commercial Aircraft

- > 4X increase in specific energy compared to the state-of-the-art leading to weight reduction
- Long-term Durability with large number of charge-discharge cycles
- Faster charging time
- Integration with aircraft

Low Energy Nuclear Reaction for Aircraft Power



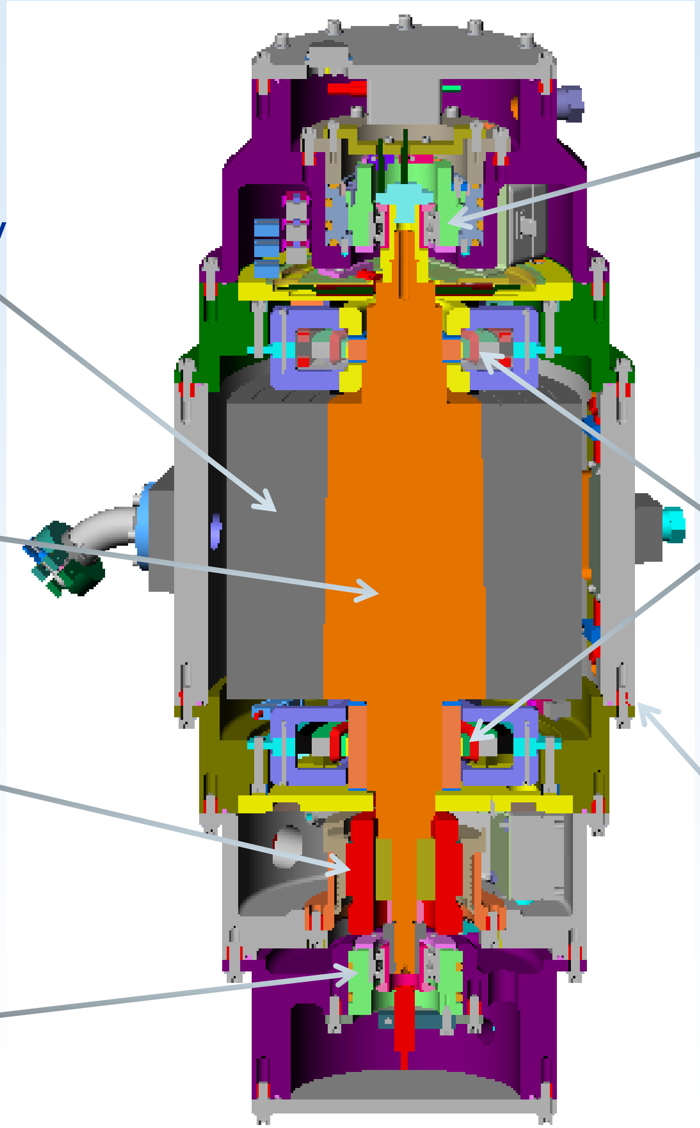
	Dec. 2012	Mar. 2013
Energy Produced (Wh)	62,000	160,000
Power Density (W/kg)	$5.3x10^5$	$7.0x10^3$
Thermal Energy Density (Wh/kg)	$6.1x10^7$	$6.8x10^5$
Initial Input Power (W)		120
Reaction Mass (g)	1	1
Start-up Time (h)		2
Total Test Duration (h)	96	116
Max. Temperature (deg. C)	496	308

NASA Aeronautics Seedling Studies – Wells – NASA TM-2014-218283

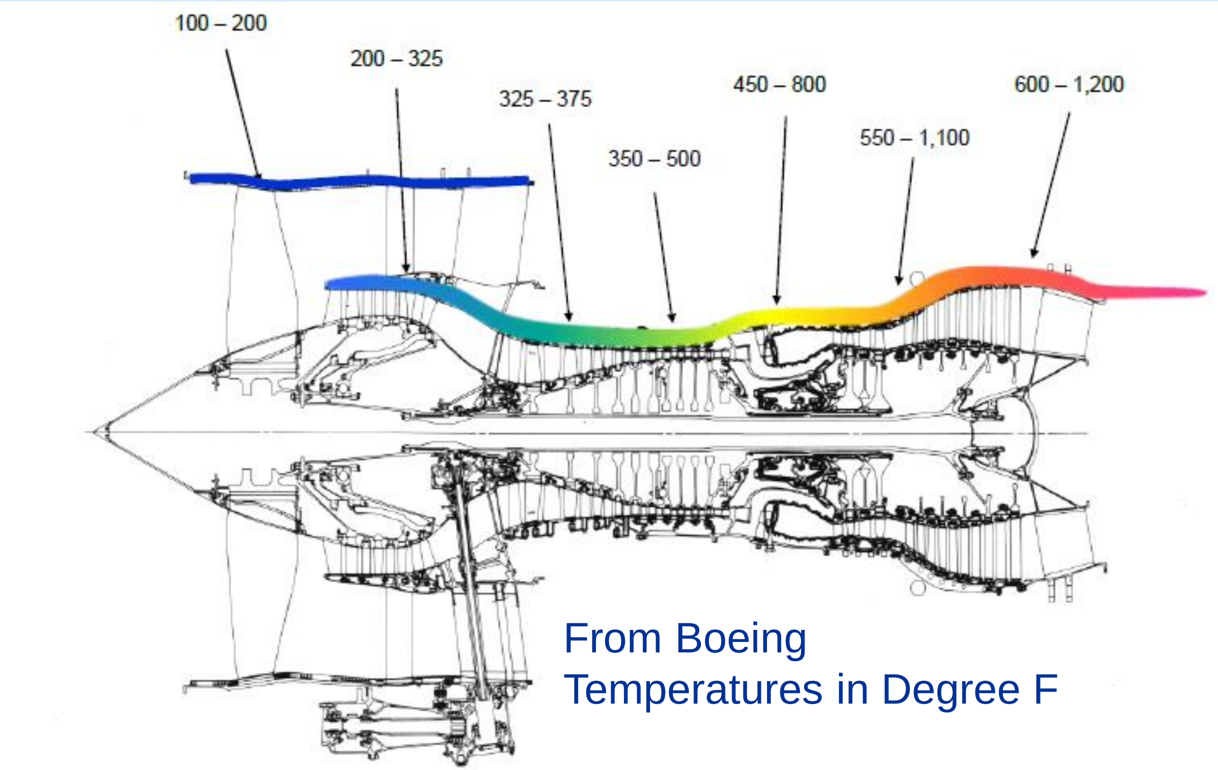
[1]Levi, G., Foshi, E., Hartman, T., Hoistad, B., Pettersson, R., Tegner, L., and Essen, H., “Indication of Anomalous Heat Energy Production in a Reactor Device Containing Hydrogen Loaded Nickel Powder”, May 2013.

Flywheel Energy Storage

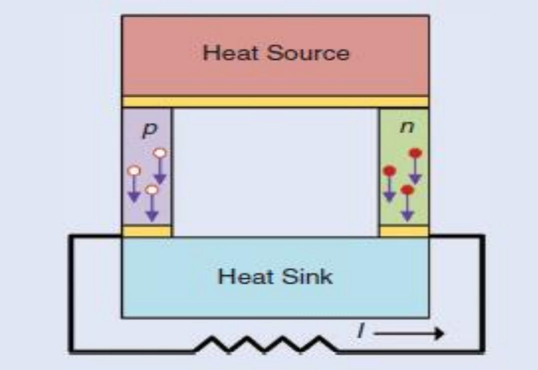
> 800 wh/kg specific energy density achievable with carbon nanotube-enabled fiber and high power density motor/generator



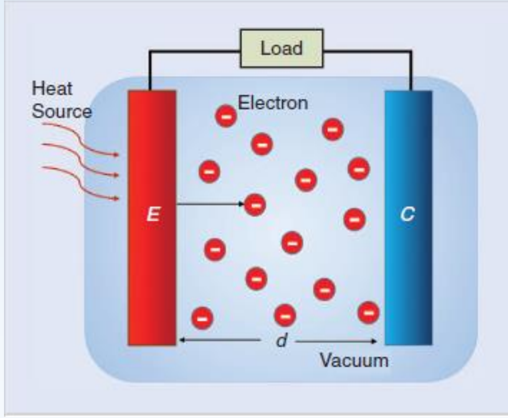
Energy Harvesting in Gas Turbine Engines



From Boeing
Temperatures in Degree F

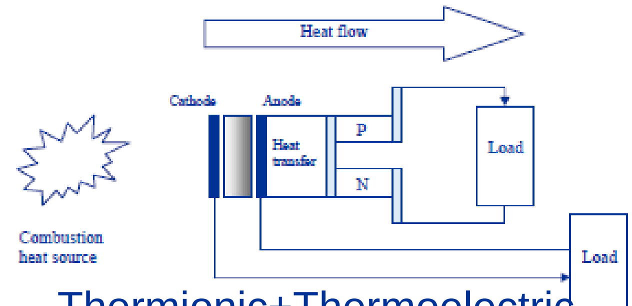


Thermoelectric



Thermionic

- Potential for kWs power generation
- Solid state energy harvesting
- Weight-optimized integrated turbine engine structure



Thermionic+Thermoelectric

NASA Aeronautics Team Seedling (NASA GRC, UTRC, Purdue, AFRL, CWRU)

Summary

- For large hybrid electric or all electric commercial airplane, 4-5X increase in power density of solid oxide fuel cell and specific energy or batteries required, along with long-term durability
- Faster charging time for batteries and heating time for solid oxide fuel cell required
- Multifunctionality can reduce weight of overall structural system containing power conversion and energy storage
- Integration with aircraft is a challenge and must be addressed early on with demonstration on smaller airplane