Technology Challenges for Electric Aircraft

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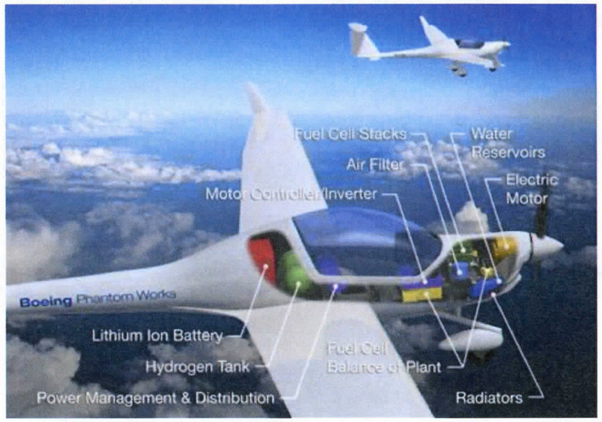
Current SOA for Electric Propulsion Limited to Small Recreational Aircraft



Boeing Dimona – 2008
PEM fuel cell
62 mph for 20 min

Antares DLR-H2 – 2008
PEM fuel cell + battery
170 km/hr, 10 min flight
750 km range

Siemens Hybrid Electric Aircraft
(IC engine + battery)

Yuneec E430 – 2009
Estimate – 1.5-2 hr with optimum cruise 60 mph
Li-ion battery powered

DigiSky SkySpark
155 mph, 8 minute flown

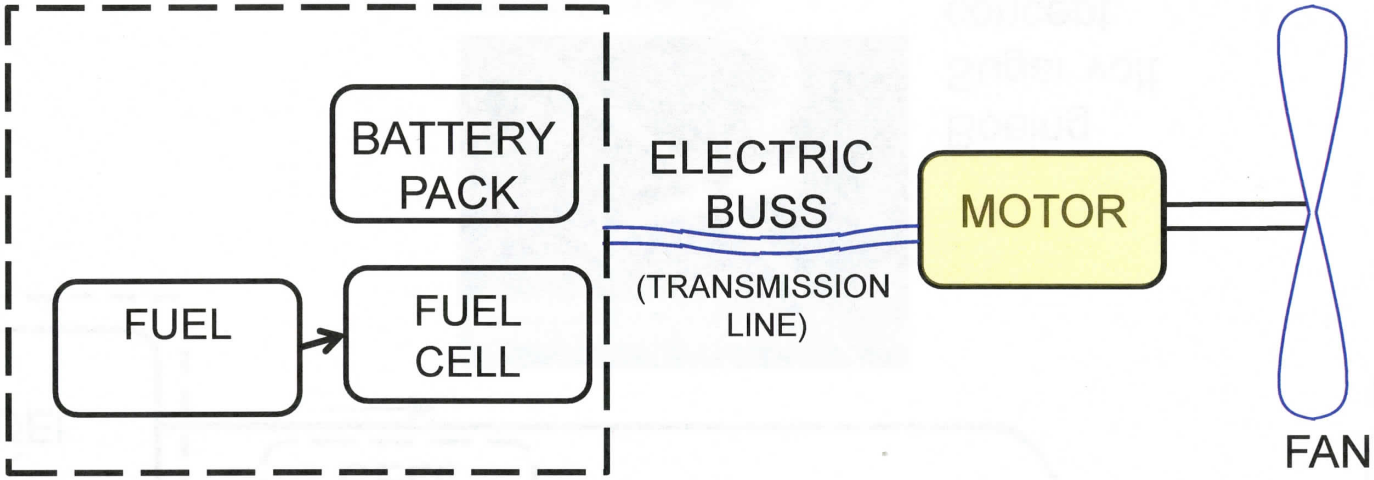
NASA/CAFÉ Green Flight Challenge Winner in 2011

- Roughly 2,350 pounds empty weight, nearly half of that is the battery
- 150 kilowatt (200 horsepower) electric motor

Benefits of Electric Propulsion

- Significantly reduced emission (near zero for certain concepts) – green system
- Significant reduction in fuel burn due to higher efficiency of electrical systems
- Reduction in noise
- Advanced concepts (such as distributed propulsion and boundary layer ingestion) might be enabled by certain electric propulsion concepts

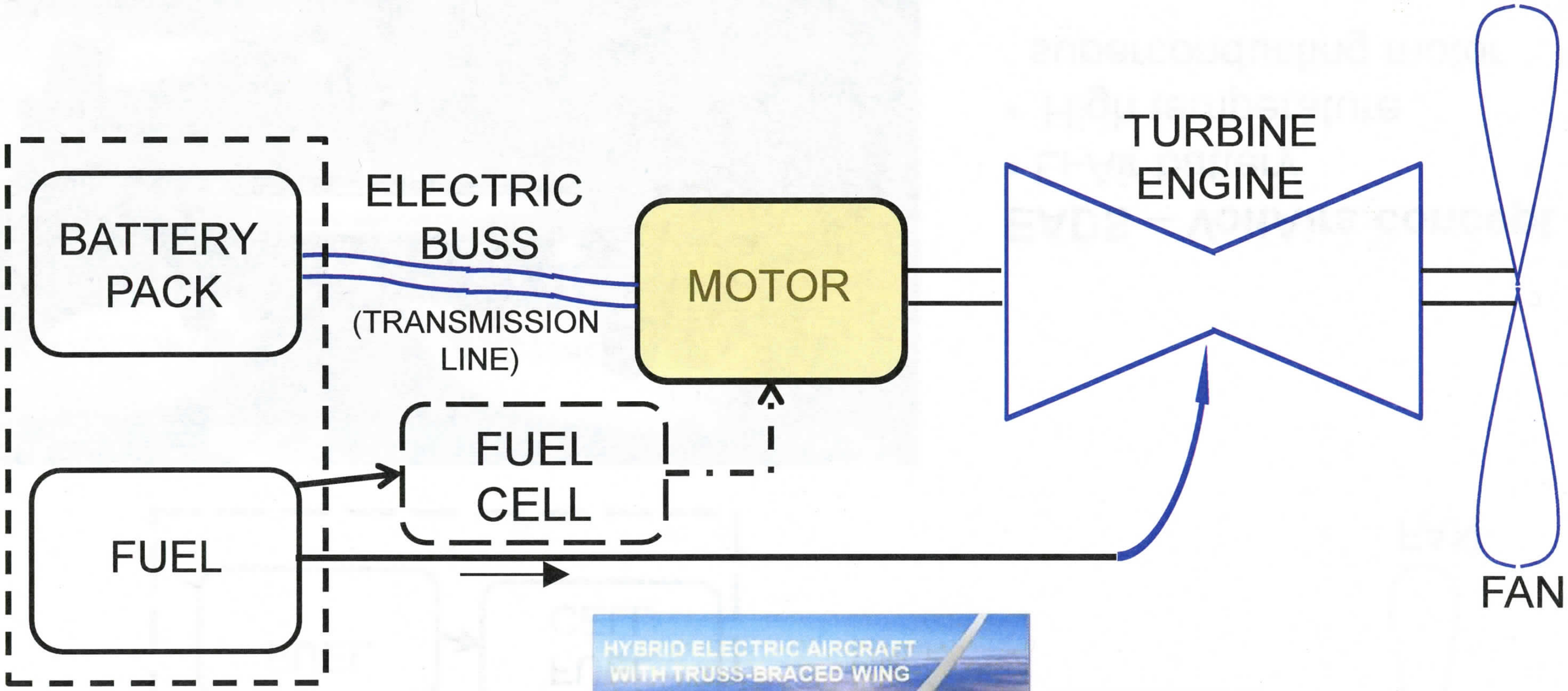
All Electric Propulsion



EADS – VoltAirs concept

- Li-Air battery
- High temperature superconducting motor

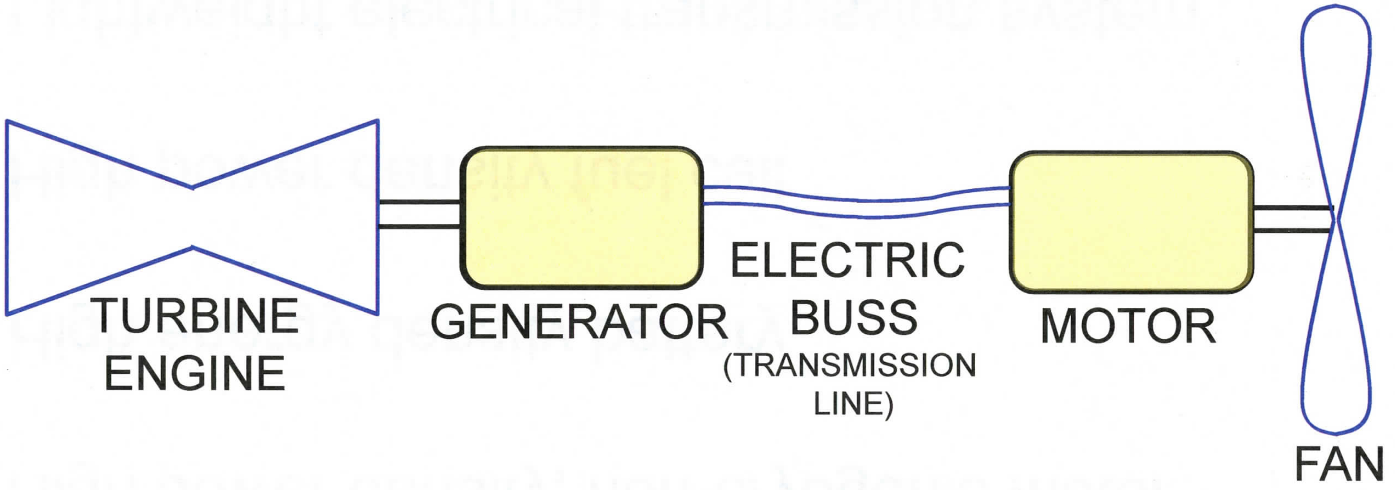
Hybrid Electric Propulsion



(PICTURE STOLEN FROM CHEVY VOLT)

Boeing
Sugar volt
concept

Turboelectric Propulsion

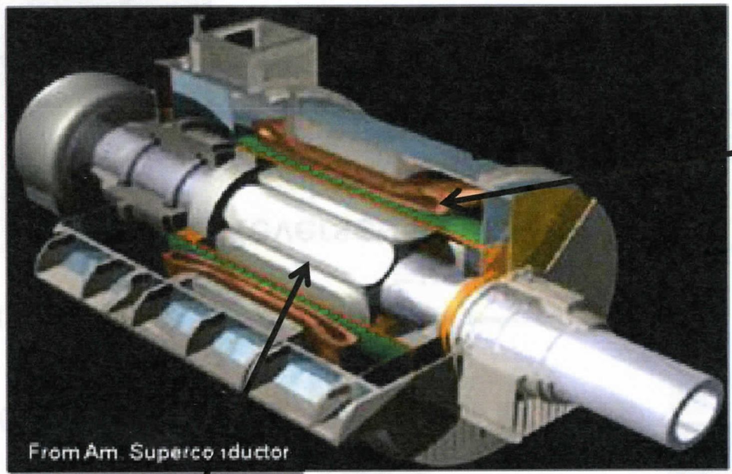


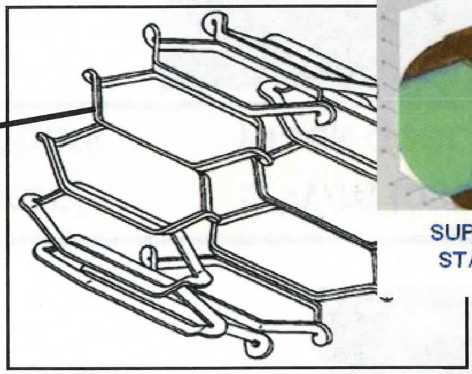
Turboelectric Distributed Propulsion Concept - GRC

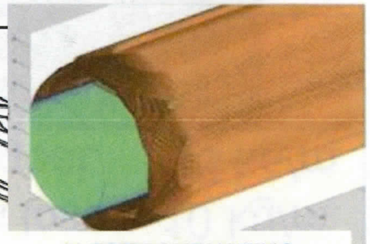
Technology Challenges for Large Commercial Aircraft with Electric Propulsion

- Superconducting motor and generator
- Lightweight cryogenic components for superconducting system
- High power density, non-cryogenic motor
- High energy density battery
- High power density fuel cell
- Lightweight electrical transmission system
- High voltage transmission system

Challenges for Superconducting Motor or Generator



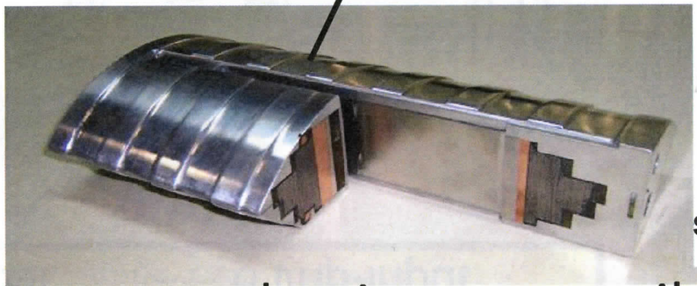


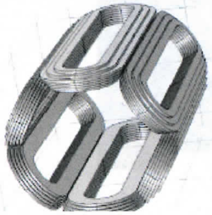


SUPERCONDUCTING STATOR WINDINGS

Superconducting AC stator coils

Intermediate-temp superconductor MgB_2





SUPERCONDUCTING ROTOR WINDINGS

Superconducting rotor coil packs

SOA: 6 hp/lb
Goal: >30 hp/lb

Technology Challenges:

- Composite formers and containment for rotor
- Composite torque tubes
- Low-loss super- or normal- conductors for stator windings

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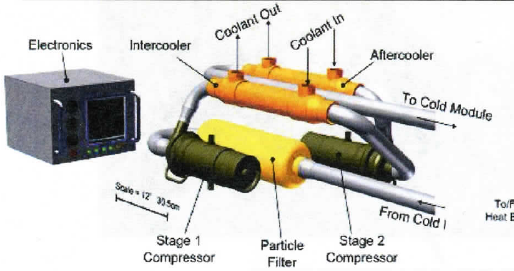
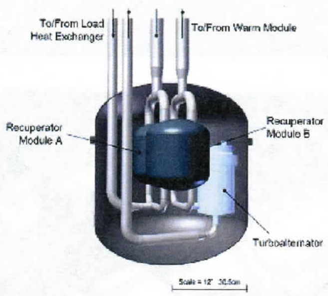
Superconducting System – Cryogenic Components

Cryocooler

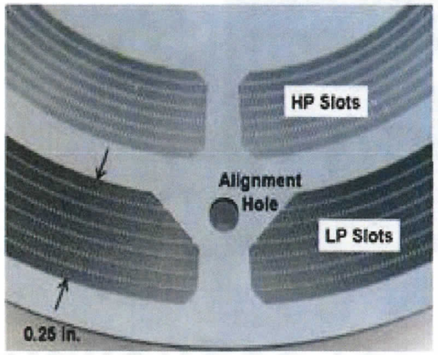
SOA:	30 lb/hp-input
Goal:	6 l/hp-input



Reverse-Brayton warm module (prelim. design)



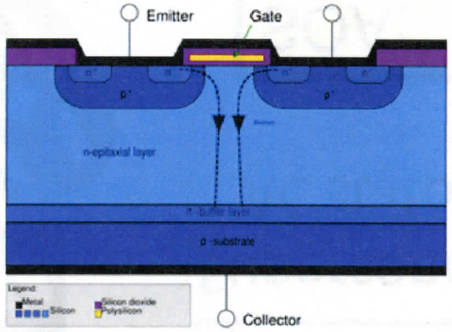
Reverse-Brayton cold module (prelim. design)

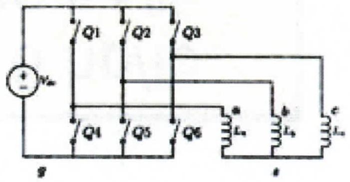


Recuperator plate

Cryogenic Inverter

Goal: ½ SOA weight and ~1/10th SOA loss



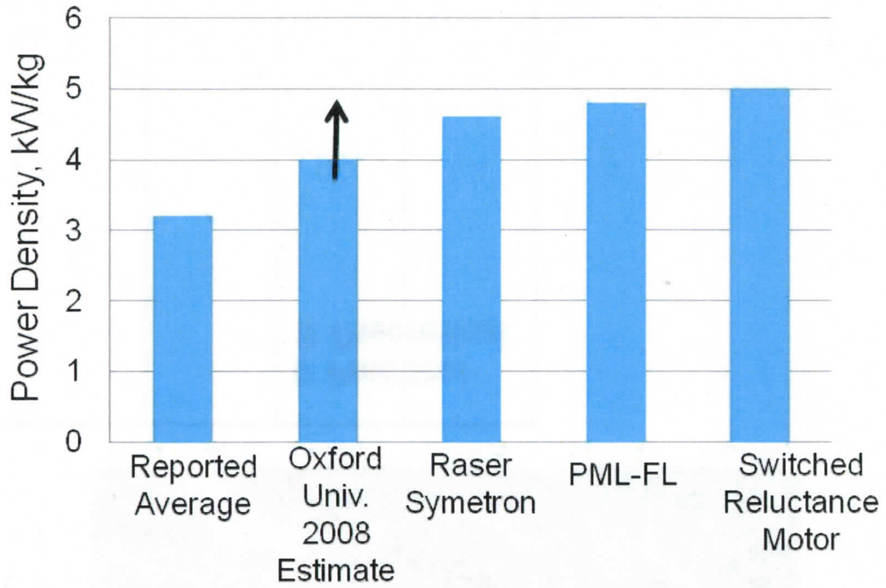


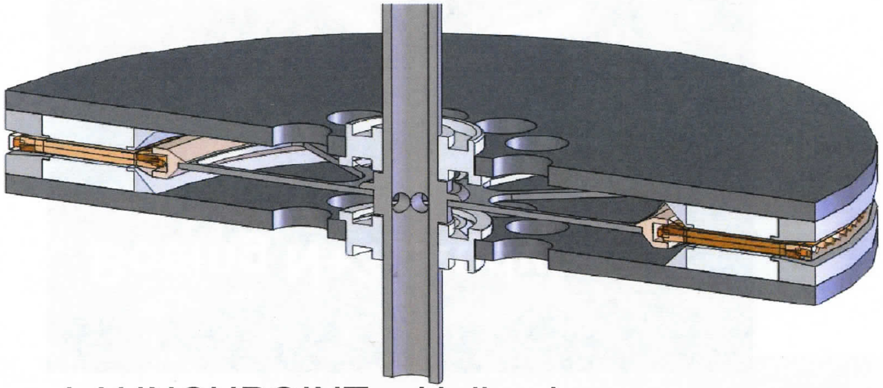
SOA numbers:	5 W/m loss,	10 kg/m
Target numbers:	Mass goal:	5 kg/m

Superconducting Transmission Line

Potential for Non-Cryogenic High Power Density Motor

- Multidisciplinary approach to increase power density of ambient temperature electric motors/genertaors (electrical engineering, materials, structures, thermal management, power electronics)
- High conductivity electrical coils (possibly CNT)
- Higher load bearing structure to increase rotational speed
- Lightweight structure (greater use of composite structures)
- Higher temperature insulation material
- Higher temperature magnets
- Improved motor design
- Improved cooling techniques and advanced thermal management
- Advanced power electronics for low switching loss



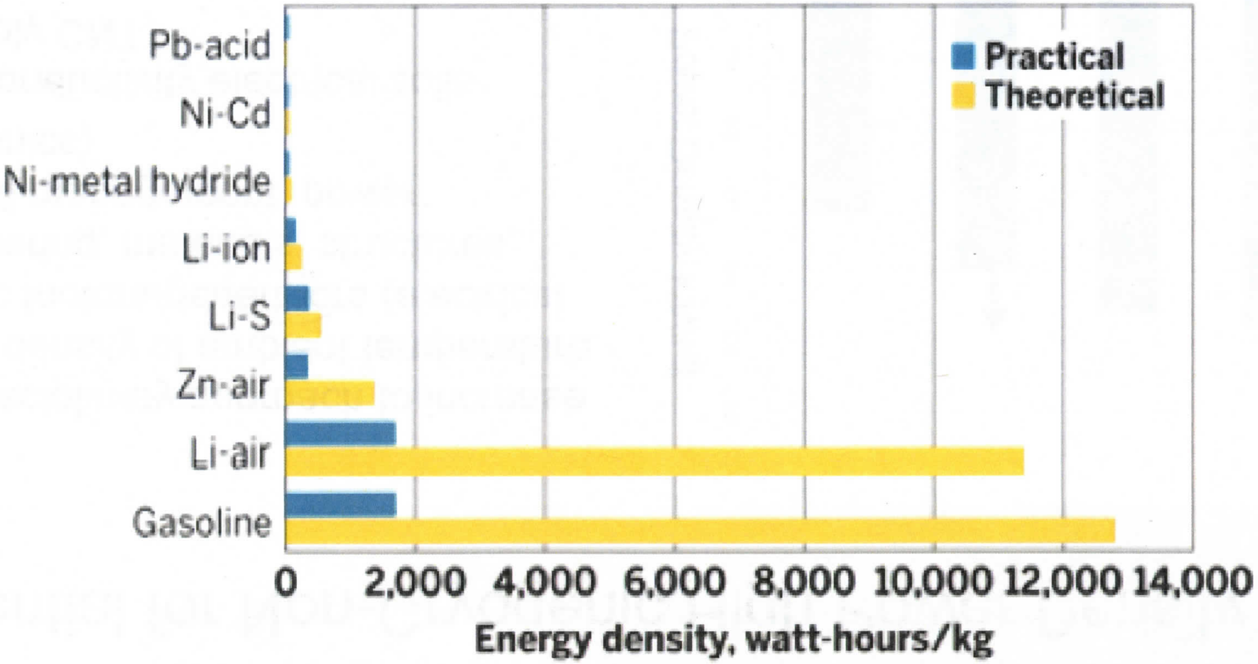


LAUNCHPOINT – Halbach arrays
(5 hp/lb – 8.2 kW/kg)

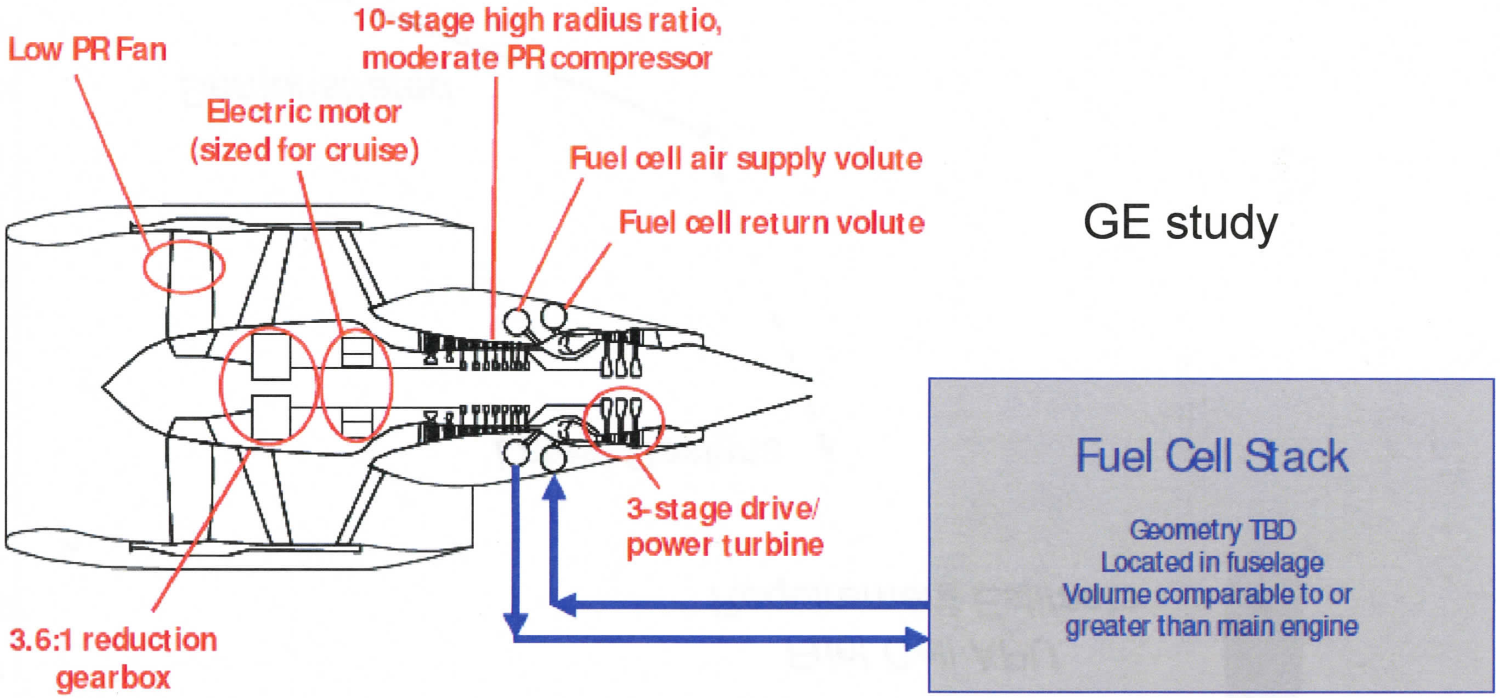
Hybrid Gas Turbine Battery Electric

Hybrid Gas Turbine Battery Electric

Rechargeable batteries with energy density on the order of 600 – 800 wh/kg required



Gas Turbine Solid Oxide Fuel Cell Hybrid System

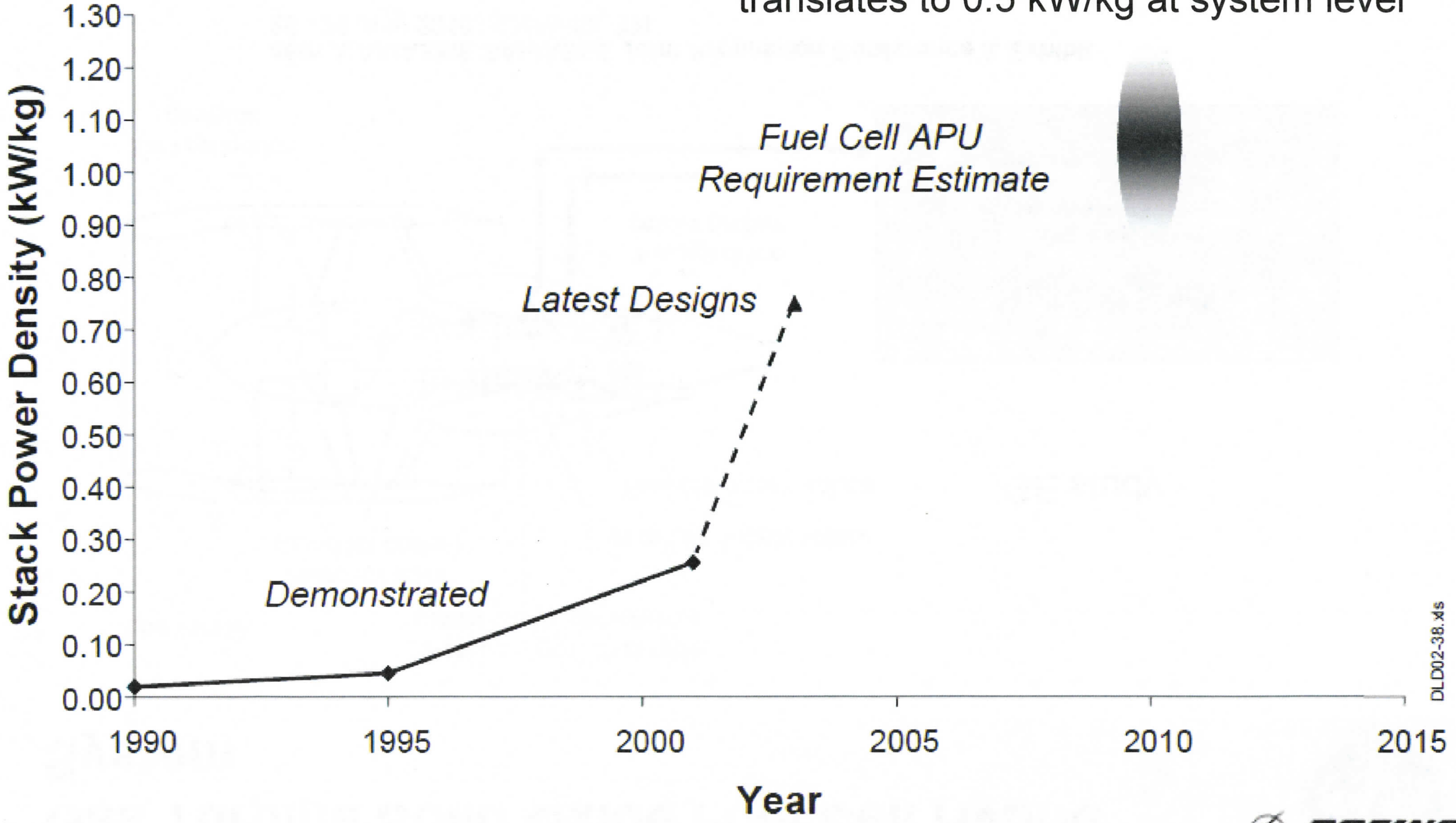


46th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit
25 - 28 July 2010, Nashville, TN

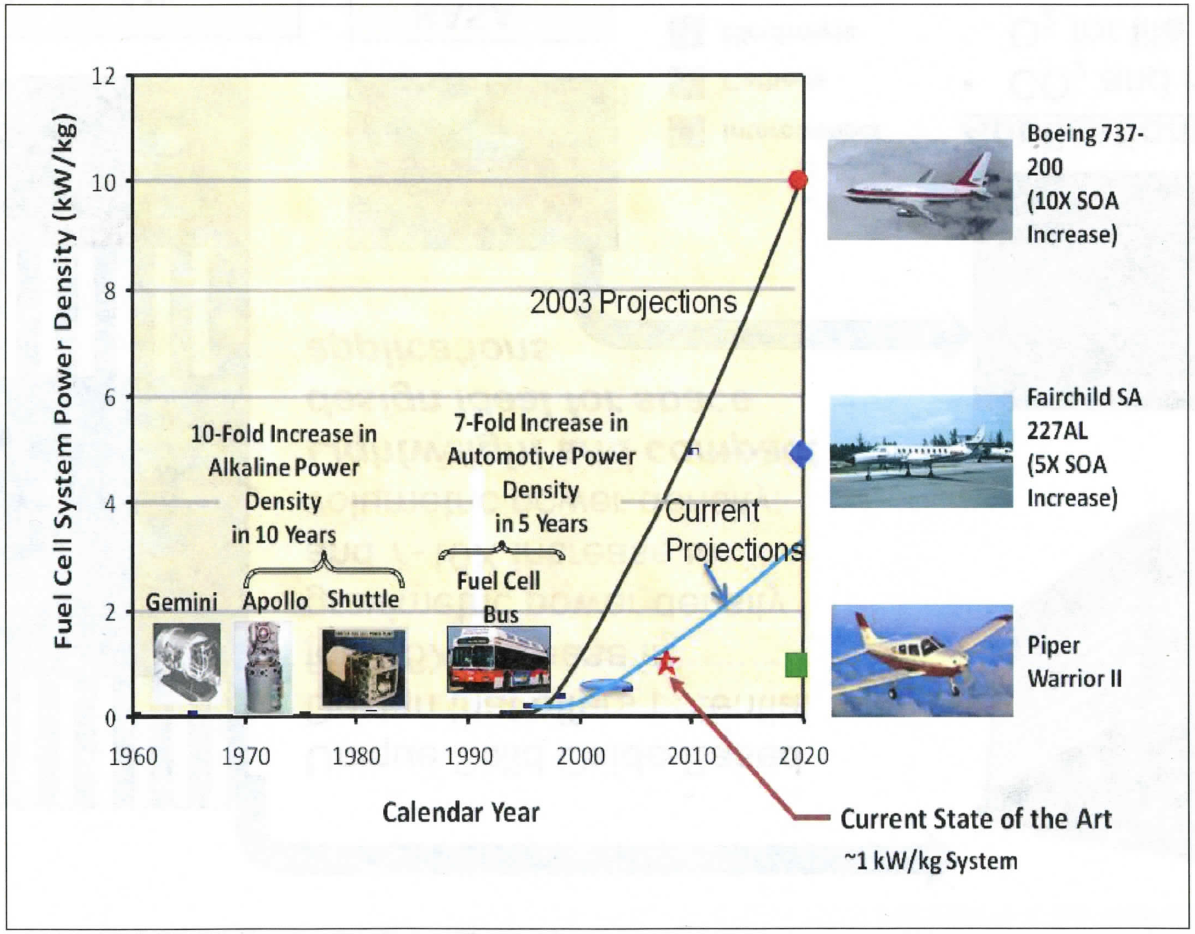
- Gas turbine – solid oxide fuel cell (SOFC) hybrid system offers significant improvements in efficiency
- Gravimetric (kW/kg) and volumetric (kW/l) power density too low for SOA SOFC system

Fuel cell stack power density needs to be at least 1kW/kg

Stack power density of 1 kW/kg
translates to 0.5 kW/kg at system level



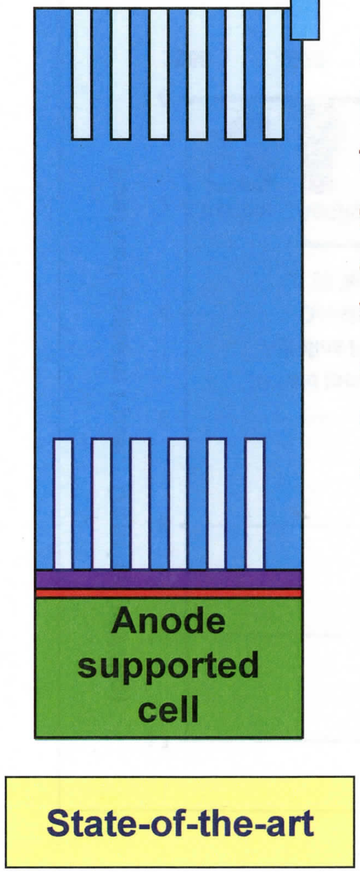
Required Powered Density For Fuel Cell Powered Airplane



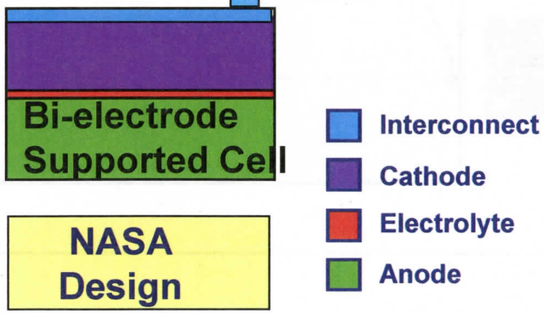
Fuel cell powered 10-20 passenger airplane can operate from smaller airports in a metroplex concept and provide point-point service. Besides low emission, a key benefit would be extremely low noise.

Power level would be in the range of 500 kW – 1 MW, system could also replace generators in more electric large airplane

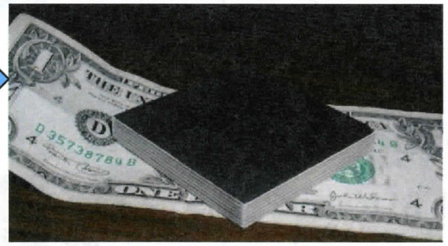
GRC-Developed High Power Density Solid Oxide Fuel Cell



Unique Solid Oxide-Based Design that offers potential for 3-5X increase in gravimetric power density and 7-10X increase in volumetric power density: ***Lightweight and compact design ideal for space applications***



- State-of-the-art SOFC stack from Delphi, 2.5 kW, 9 kg, 2.5 L
- Equivalent for 75 W – 270 g, 75 cm3



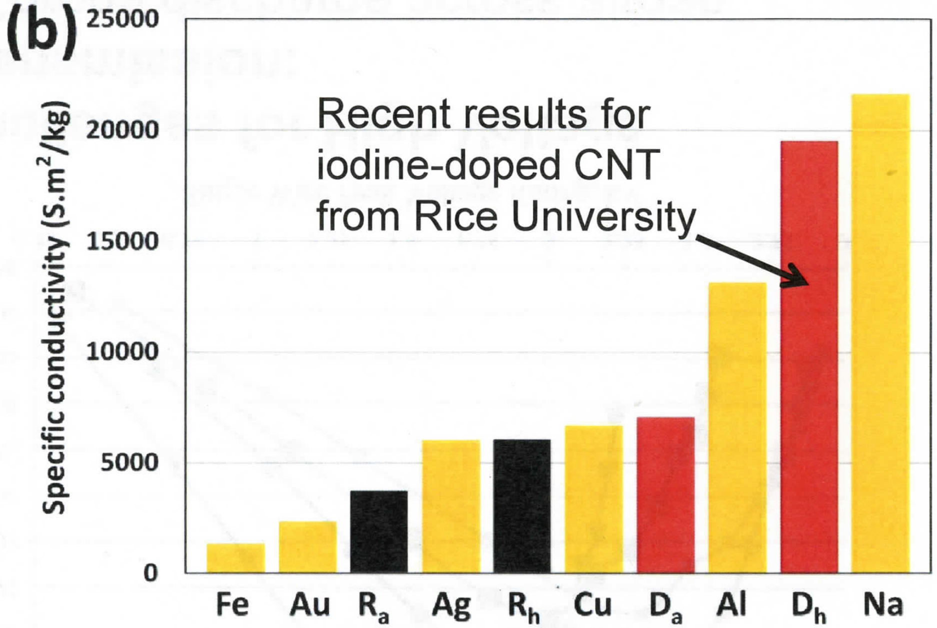
75 W, 7 cell stack, 71 g weight, 26 cm3 volume (First attempt – room for significant improvement)

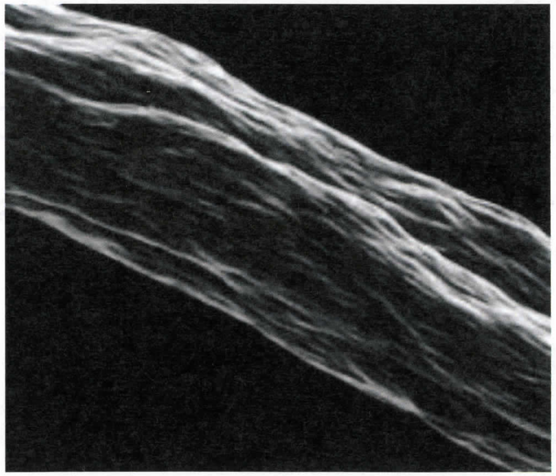
Applications:

- CO_2 and H_2O electrolysis to generate O_2 for life support
- CO_2 electrolysis for Mars ISRU
- Power generation from methane
- High pressure oxygen generation
- Power generation for aircraft and UAV and portable power

Carbon Nanotubes for Lightweight Electrical Transmission

- Materials with high absolute conductivity and high specific conductivity to reduce weight
- Carbon nanotube (CNT) offers potential for high specific conductivity
- Al-CNT composite might offer significant increase in specific conductivity
- CNT offers high current carrying capacity (A/m2); Cu and Al conductivity decreases with increasing temperature; CNT conductivity may not change with temperature
- Multifunctional structure with CNT





High Voltage Transmission

- Power supply voltage for today's aircraft
  - 27 v dc; 270 v dc; 115 V, ac
- Boeing 787: 230/400 V AC 360-800 Hz (variable frequency) and a 230/400 V which is further rectified to a +/-270 V DC (540 V DC) system
- Transmission of large amount of power (on the order of MW) will require even higher voltages to minimize loss and reduce weight of transmission system

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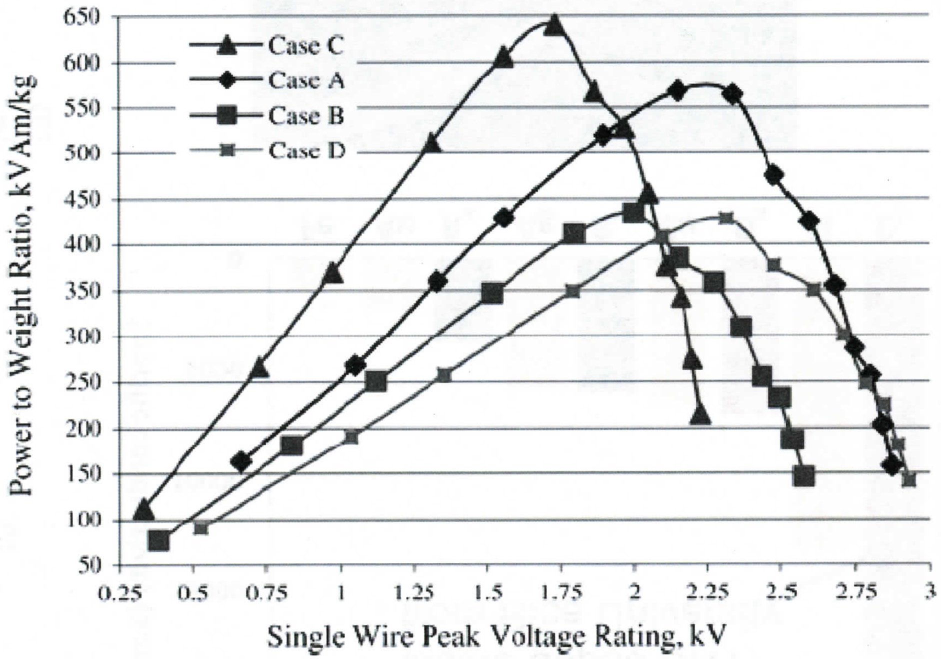

Challenges for High Voltage Transmission:

- Corona discharge across airgap
- Breakdown of insulation material
- Aircraft safety

Summary of Technology Challenges

- Low ac-loss superconducting system
- High power density, non-cryogenic motor
- High power density fuel cell
- High energy density batteries
- New energy storage concepts such as supercapacitors and flywheels
- High temperature power electronics
- Advanced thermal management techniques
- Advanced power system architecture for grid like system
- Analysis and modeling of power system architecture and power management, including large scale simulation
- High conductive electrical wiring and wire insulation with high temperature capability
- High voltage transmission system