Emerging Fuel Cell Developments at NASA for Aircraft Applications

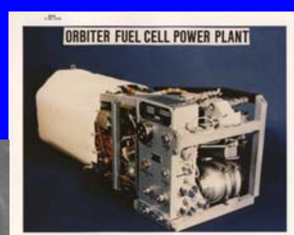
By

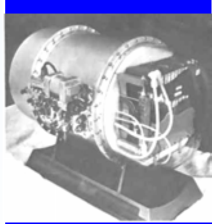
Anita Liang
Chief, Aeropropulsion Projects Office
NASA Glenn Research Center

EVOLUTION OF FUEL CELL AEROSPACE APPLICATIONS

Multi kW

Power Levels





00-10's Aerospace Applications

90's- Lunar/Mars Base, High Altitude Balloon

80's- Shuttle Orbiter Fuel Cell

50-70's- Gemini, Apollo Missions

PAST

PRESENT

FUTURE

Fuel Cells for Aerospace Missions

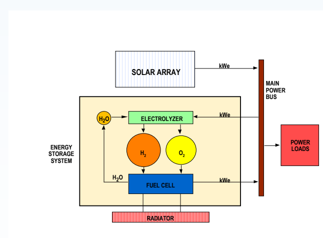
Major Challenges

- Ultra High Energy Density Power Source
- Fuel Cell Stack Configuration
- Fuel Processing & Reforming
- Thermal management
- Nano, Light Material Systems
- High Voltage Power & Control
- Multidisciplinary CFD

Fuel Cell Type

PEM

SOFC

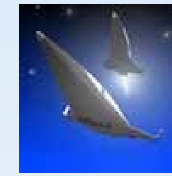


Regenerative Fuel Cell

Aerospace Applications

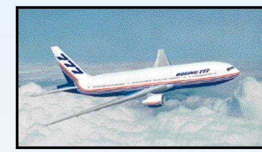
Space Transportation

Shuttle



RLV

More Electric Aircraft/UAV



MEA

UAV

Homeland Defense & Earth Observatory Systems

High Altitude Aircraft/ Airship

Planetary Exploration

Flyer

Surface Power

Early Demonstration Opportunities For Electric Propulsion & Power

All Electric Fuel Cell Powered Light Aircraft

Fuel Cell Based APU Demonstration

All Electric High Altitude Airship

Mars Airplane

Solid Oxide Fuel Cell Technology for

Next Generation Clean Aircraft Power

- NEXCAP Project –

Formulation Objectives

- Build on Department of Energy's Successes with the Solid-State Energy Conversion Alliance (SECA) Program by Developing a Long Term Technology Plan to Advance Solid Oxide Fuel Cell Capabilities for a wide range of aircraft power and propulsion applications.

- Complement SECA's program objectives on cost reduction to address power density (kW/L) and specific power (kW/kg) challenges critical for aircraft applications.

- Establish NASA leadership and Build National Support for Aircraft Fuel Cell Powered Technology Plan.

SOFC for Commercial Aircraft APU

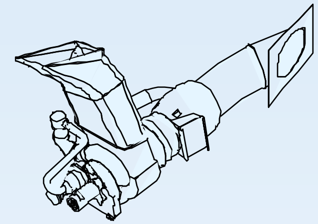
Current Gas-Turbine APUs operate at ~15% load cycle efficiency, contribute up to 20% of the aircraft ground based emissions, and APU/secondary power systems account for 50% of the maintenance delays which presents 12% of the maintenance cost.

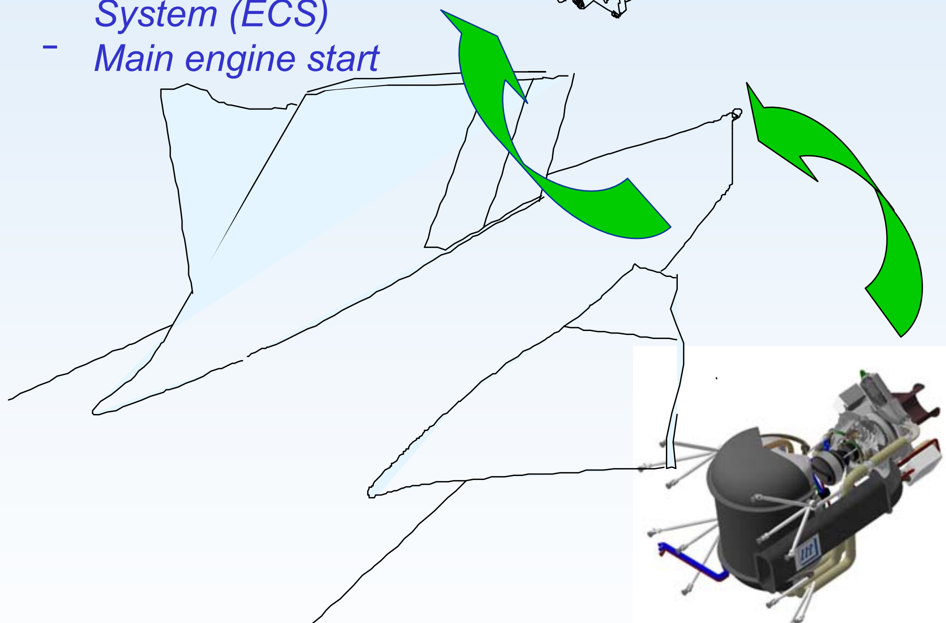
SOFC Offers:

- **Solid state characteristics, making them simpler in concept and design.**
- **Greater fuel flexibility and simpler fuel reforming enabling the transition from petroleum to hydrogen economy.**
- **Higher quality heat effluent making them particularly suitable for hybrid gas turbine systems with the highest potential system efficiencies.**
- **Inherently environmentally friendly, producing no/negligible NOx and significantly reduced CO_2 with hydrocarbon fuels.**
- **Suitability to multiple markets spanning stationary, transportation, aerospace, and military applications, facilitating DOE, DOD, and NASA Collaboration.**

Present GT-APU:

- *On-ground and emergency In-flight electrical power*
- *On-ground Environmental Control System (ECS)*
- *Main engine start*





Full time, Fuel Cell Power Unit (FCPU) Concept *:*

- *Environmental Control System (ECS)*
- *Electric main engine start*
- *De-icing*
- *Onboard water generation*
- *electric actuated control surfaces*

Aircraft Challenges

Airline Industry requires a single fuel, jet fuel, on the aircraft for operations for the foreseeable future.

- Require compact, light weight, and efficient fuel reformer and desulfurization systems
- Determine and develop most effective fuel reformer (Steam, CPOX, autothermal) from an integrated system perspective
- Determine and develop most practical method to address fuel sulfur challenge (remove at refinery, liquid or gas phase removal in ground based or flight based system, sulfur tolerant anode and catalysts, etc.)

Fuel Cell Stack/System power to weight and volume requirements for flight applications are at least an order of magnitude greater than current SOA and several times greater than SECA's 2010 goal.

- New anode/electrolyte/cathode material systems to reduce electrochemical losses
- Durable, light weight fuel cell interconnects and improved gas seals
- Advanced stack cooling concepts to enable higher power density operation
- Optimize designs for gas flow, current and temperature distribution
- Fabrication process development for large stacks without performance degradation
- Durability of stack under aircraft operating conditions (vibration, acoustics --)

Aircraft Challenges, Con’t

“Balance of Plant” represents 2/3 of the total system and it is complicated by high temperature operations.

- Highly integrated components to achieve weight and volume goals
- Effective thermal management for stack heat dissipation and system thermal balance
- Advanced controls and diagnostic systems for autonomous/long life operations
- High temperature heat exchangers
- Improved insulation materials
- Light weight electrical power management and distribution systems
- Lightweight materials and structures to reduce weight

Aircraft applications require operating life 2 to 4 times greater than DOE transportation based systems.

- Planar SOFCs still at TRL ≤ 3 for ground based applications!

Current Capability Vs. Goal

Attributes	Current Capability	Goal
Total Power	2-5 kW (Planar) –dev > 100 kW +(tubular) > 1 MW (planned)	5 kW for early aviation demo 145 kW for 100 passenger 450 kW for 305 passenger 3 – 10 kW (SECA transportation)
Specific Power for entire SOFC system incl. BOP	0.02-0.04 kW/kg – developmental	0.5 kW/kg (NASA/DOD) 0.1 kW/kg (DOE - SECA)
Specific Power for stack	< 0.2 kW/kg for stacks and 1-5 kW total power	1 kW/kg with TBD stack kW total power requirements
Area Specific Power density for cell/stack (W/cm^2)	0.5-1 W/cm^2 cell ~.4 W/cm^2 stack	2 W/cm^2 cell >1 W/cm^2 stack
Fuel Reformation	Mature at the industrial scale	Compact, lightweight system with high conversion efficiency
Sulfur Tolerance	Limited exp. with logistic fuels, 100's of hrs	300 – 700 ppm current jet fuel sulfur level Aircraft life 40,000 hrs

Current NASA Activities – System Study

Evaluate system-level benefits of a full-time, fuel cell based aircraft APU to determine concept feasibility.

- Contracted effort with Boeing targeting a jet fuel based fuel cell with a 2015 Entry-Into-Service (EIS) application.
  - The Boeing 777-200ER aircraft selected for the study
  - A More Electric Aircraft (MEA) architecture chosen.
  - Subcontracts with Fuel Cell Companies to provide fuel cell information
- In-house effort with a broader scope to address alternative fuels and advanced concepts for both near and far term EIS.
  - Top level assessment of fuel cell technologies to identify promising concepts for aircraft applications.
  - Establish system level and higher-fidelity modeling capability to evaluate candidate SOFC cycle concepts (models being shared with Boeing).
  - Identify critical technology areas and define a technology maturation plan.

Augmentation - Conceptual Design Studies

- Initiate contracted conceptual design studies (6 – 9 month efforts) with competing fuel cell and aerospace companies to
  - Identify the most promising concepts for 2015 EIS applications based on aircraft power system requirements developed under Boeing Study.
  - Develop a Technology Maturation Plan

Current NASA Activities
Critical Technology Development

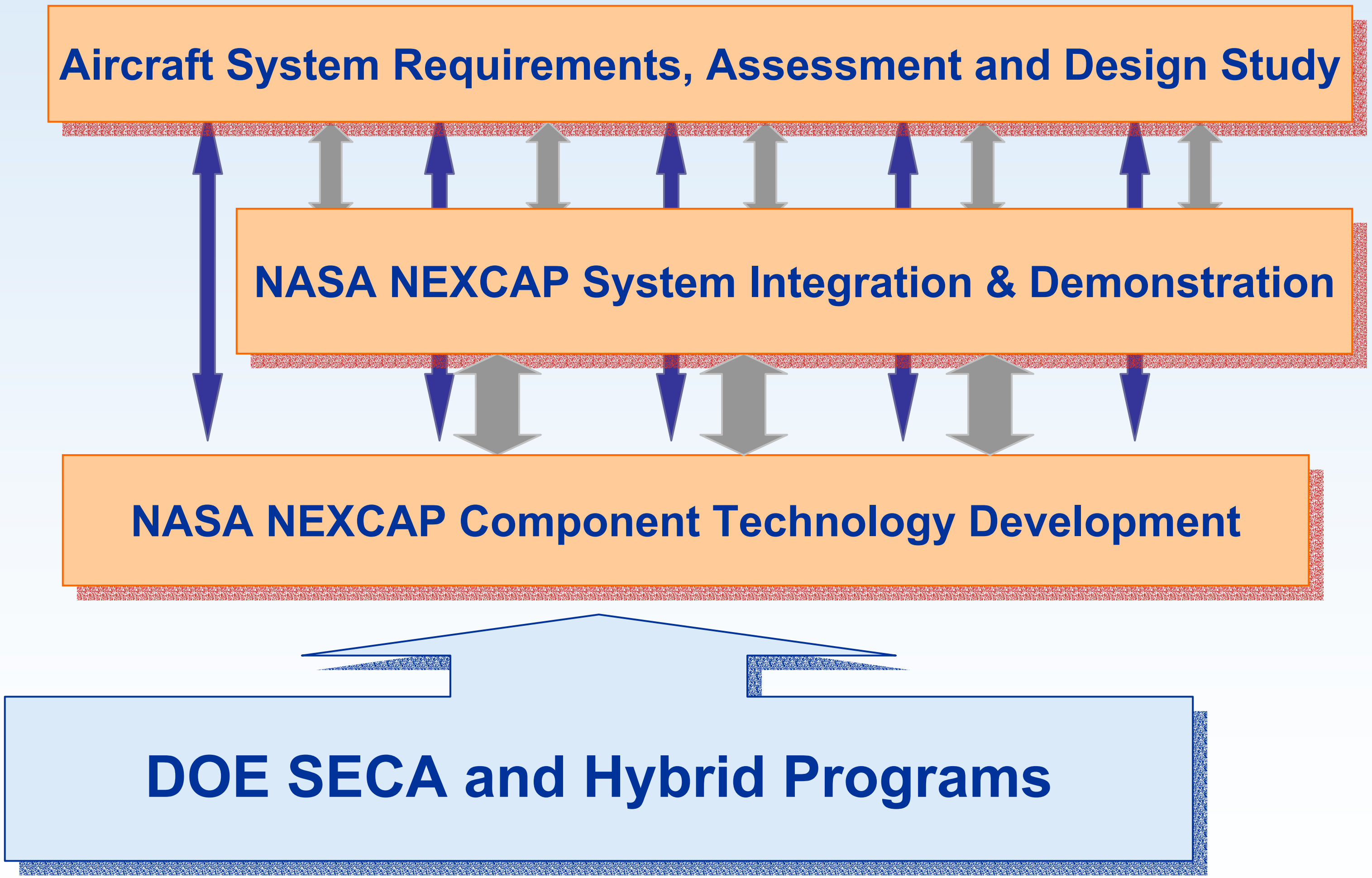
Develop compact, lightweight, and efficient jet-fuel processing technology to enable near term application of SOFCs to aircraft power systems with collaboration from DOE.

- Obtain a fundamental understanding of SOFC reforming process and to access SOFC and system integrators for technology advancement, performance improvement, and system optimization.
- Identify and characterize promising candidate hydrocarbon fuels by developing a fundamental database of chemical kinetic reaction rates and high temperature characteristics.

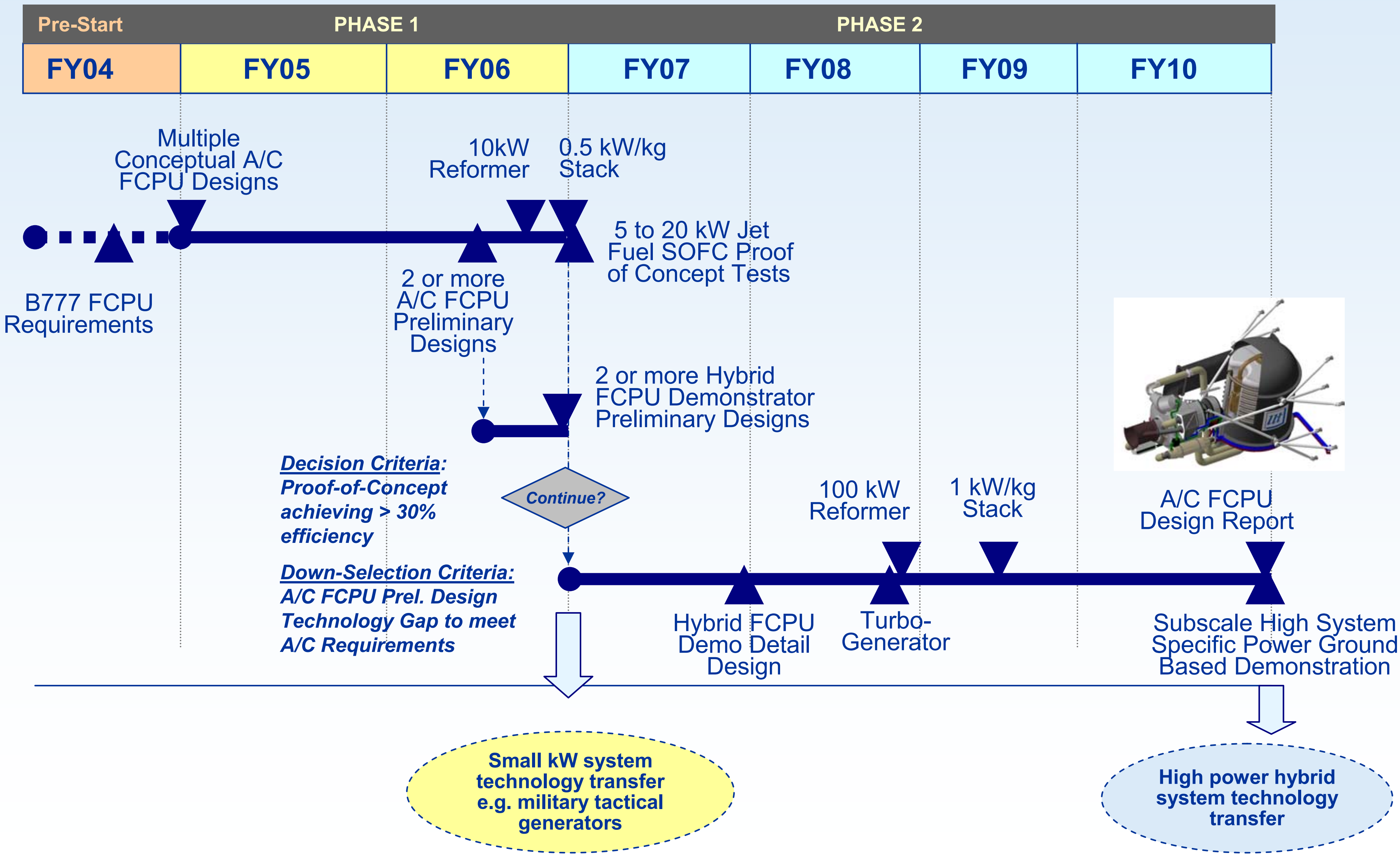
Improve SOFC material capabilities to meet aircraft performance, size, weight and life requirements.

- Improve power density through a combination of reducing anode thickness by a factor of 10-15 and reducing electrochemical losses by developing new and improved cathode material.
- Improved, durable high temperature seal.

NEXCAP Strawman - *A Technology Maturation Project*



NEXCAP Milestones and Deliverables



NEXCAP Participants

	NASA	DOE & National Labs	DOD	Industry	Academia
Follow on Flight Demo	x		x	X	
Aircraft System Definition	X	x	X	X	
SOFC System Integration	X	x	x	X	
Core Technology	X	X		X	X

NASA's Vision for Fuel Cell Powered Aircraft