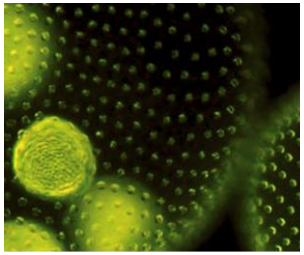
Consideration of Fuel Cells for Future Airplanes

Al Carlo
Pressurized Compartment Fire Marshal
Payloads Engineering
October 29, 2014

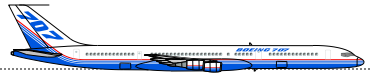
Addressing CO_2 as a Priority



- Renewable fuel and energy solutions
- Operational efficiency
- Environmentally progressive products and services

Through innovative research and development

Building on a Strong Track Record



Early Jet Airplanes

MORE FUEL

Relative fuel use

LESS FUEL

EVEN LESS

HIGHER DECIBELS

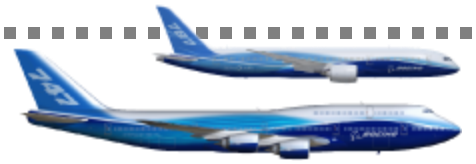
Noise dB

LOWER DECIBELS

EVEN LOWER

90% Reduction in Noise Footprint

70% Fuel Improvement and Reduced CO_2



New Generation Jet Airplanes

1950s → 1990s

Noise footprint based on 85 dBa.

More Electric Airplane (MEA) Background

- **Efficiency changes in 787 due to:**
  - **Composite airframe**
  - **Efficient no-bleed engines**
- **Transition in power sources in the MEA**
  - **Increase in electric power to ~1.5 MW**

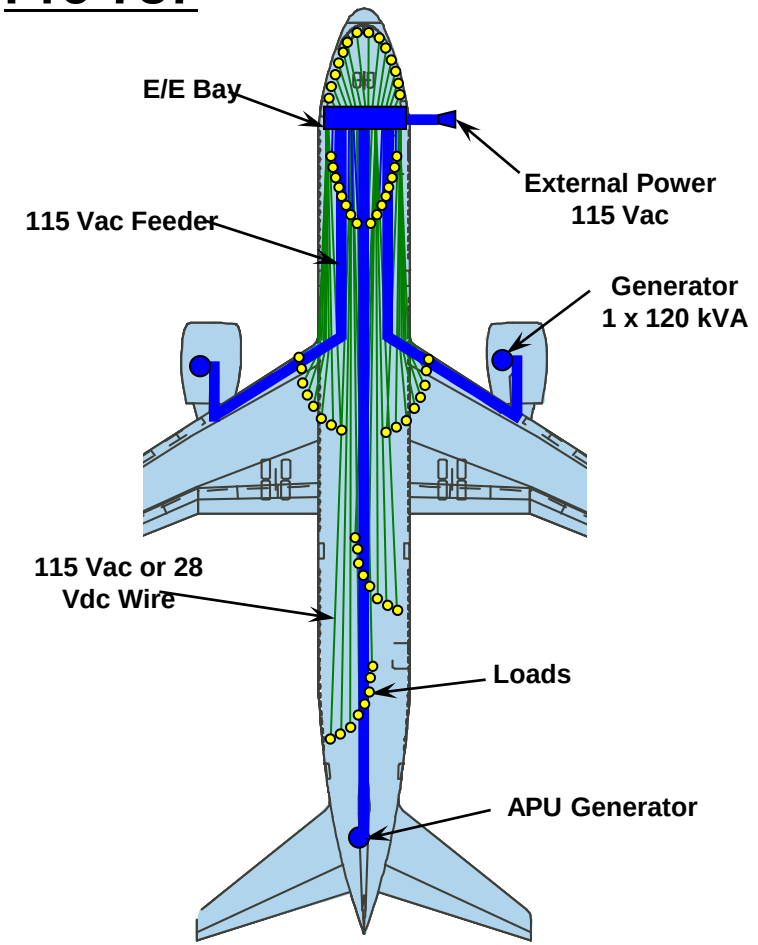
Efficient No-Bleed Engines

Power Source	Bleed	No Bleed + MEA
Electrical	Cabin Lighting Avionics, Fuel Pumps, etc.	Engine start, De-Ice ECS & Pressurization, Cabin Lighting, Avionics, Fuel Pumps, Brakes, Flight Controls, etc.
Hydraulic	Brakes, Flight Controls, Landing Gear, etc.	Flight Controls, Landing Gear
Pneumatic	Engine start, De-Ice ECS & Pressurization	Cowl De-Ice

The More Electric Airplane Is Moving Toward A More Distributed System

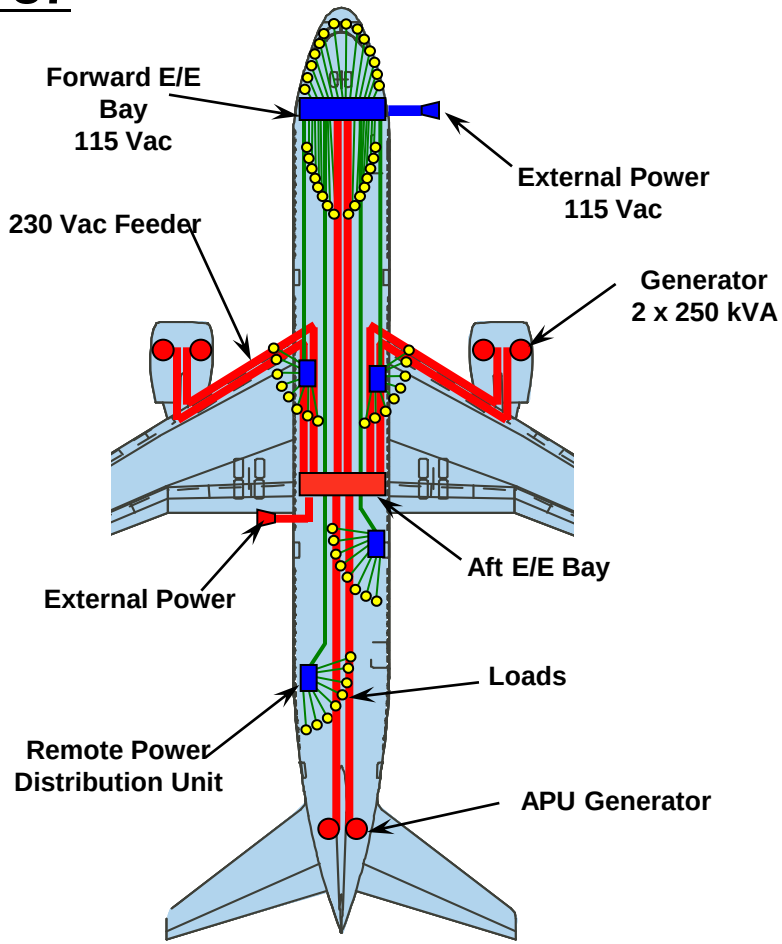
Centralized Distribution (Traditional)
Circuit Breakers, Relays and Contactors

Pre-787

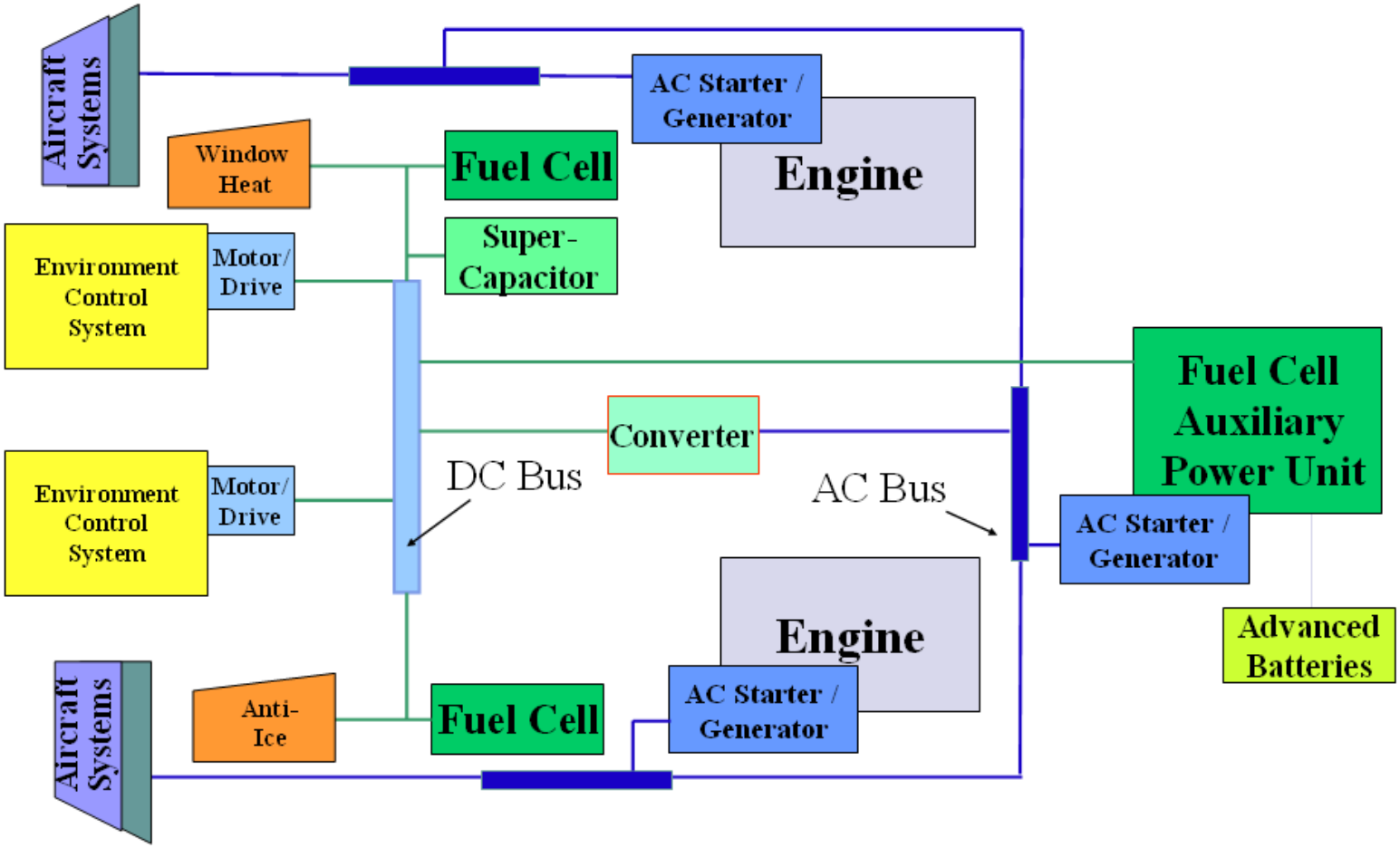


Distributed - More Electric Architecture
Solid State Power Controllers and Contactors

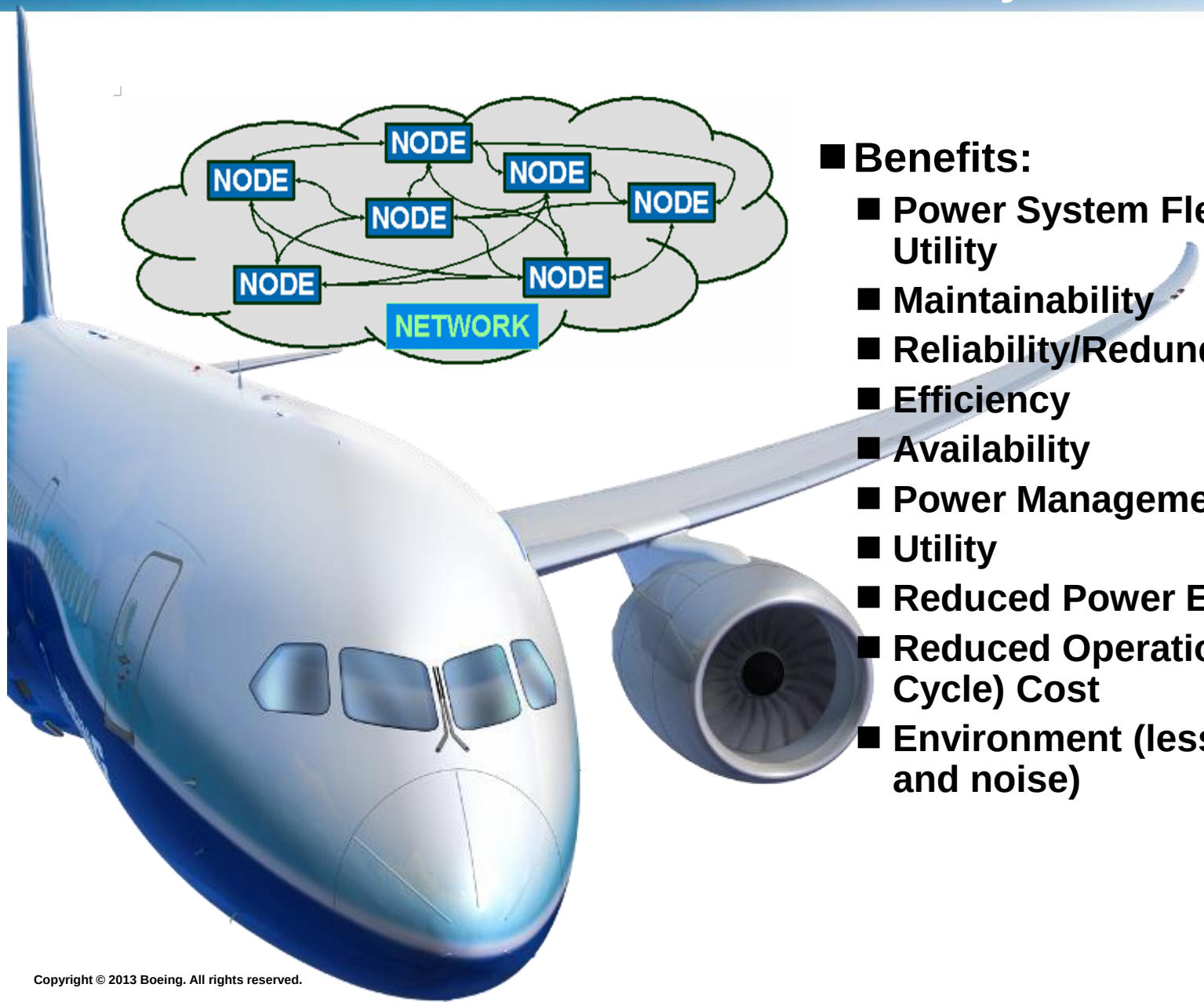
787



Electrical Power Technologies Integration



Potential Future Grid-Like Power Systems



- **Benefits:**
  - **Power System Flexibility and Utility**
  - **Maintainability**
  - **Reliability/Redundancy**
  - **Efficiency**
  - **Availability**
  - **Power Management**
  - **Utility**
  - **Reduced Power Extraction**
  - **Reduced Operational (Life Cycle) Cost**
  - **Environment (less emissions and noise)**

“More Electric” Is Industry Trend

POWER ELECTRONICS (Si, SiC, FUTURE)

- SEMICONDUCTOR SWITCHES
- CAPACITORS
- CIRCUITRY
- OTHER COMPONENTS

ENERGY STORAGE

- BATTERIES
  - MAINTENANCE FREE
  - LITHIUM RECHARGEABLE
- SUPERCAPACITORS

THERMAL MANAGEMENT

- ACTIVE VS. PASSIVE
- SPRAY COOLING
- “ELECTRIC” AIR CONDITIONING
- Solid State Thermal Engine

POWER GENERATION / UTILIZATION

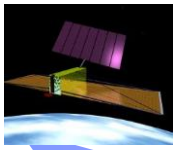
- MOTOR TYPES
  - SWITCHED RELUCTANCE
  - INDUCTION
- STARTER / GENERATORS
- COOLING
- MAG BEARINGS
- CONTROLLERS
- ELECTRIC ACTUATION

POWER DISTRIBUTION / SYSTEM INTEGRATION

- VOLTAGE TYPE
- HIGH VOLTAGES, FREQUENCY
- QUALITY / STABILITY
- EMI
- MODELING
- DEMONSTRATIONS
- SIGNAL CONTROLS
  - ELECTRIC
  - PHOTONIC

More Electric Platforms



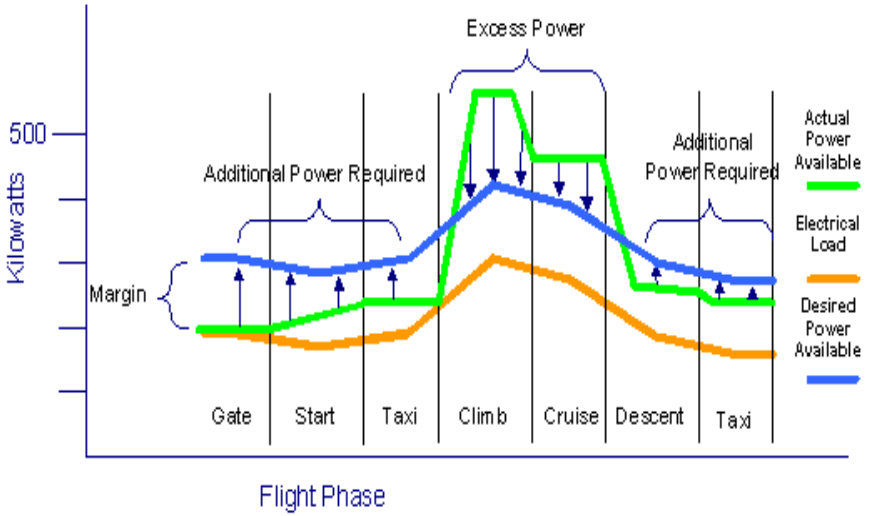


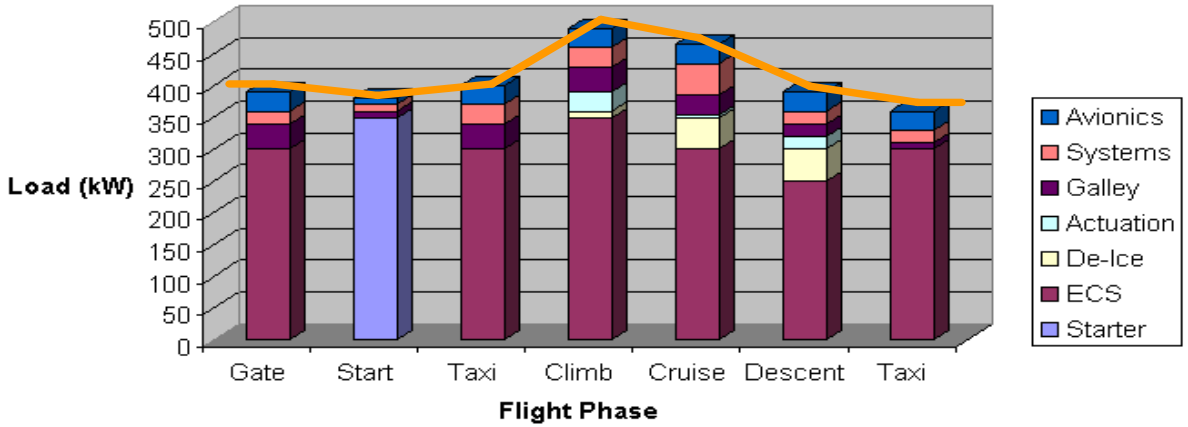
COMMERCIAL AIRCRAFT




Fuel Cells Can Support Optimized Power Management

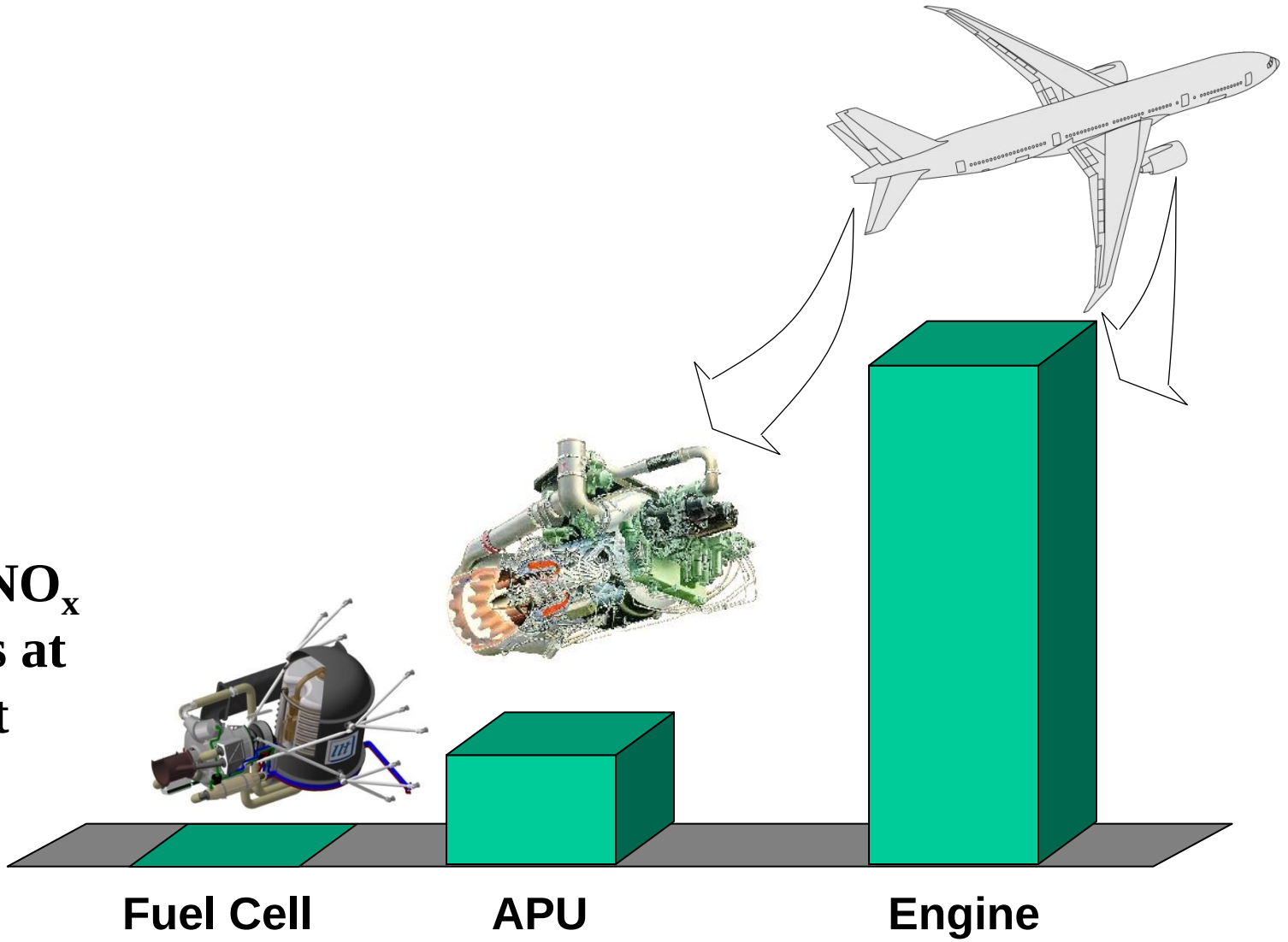
- **Lower power margin during idle descent**
- **Energy storage & load management opportunities**
- **Potential to improve airplane efficiency & reduce power system rating**





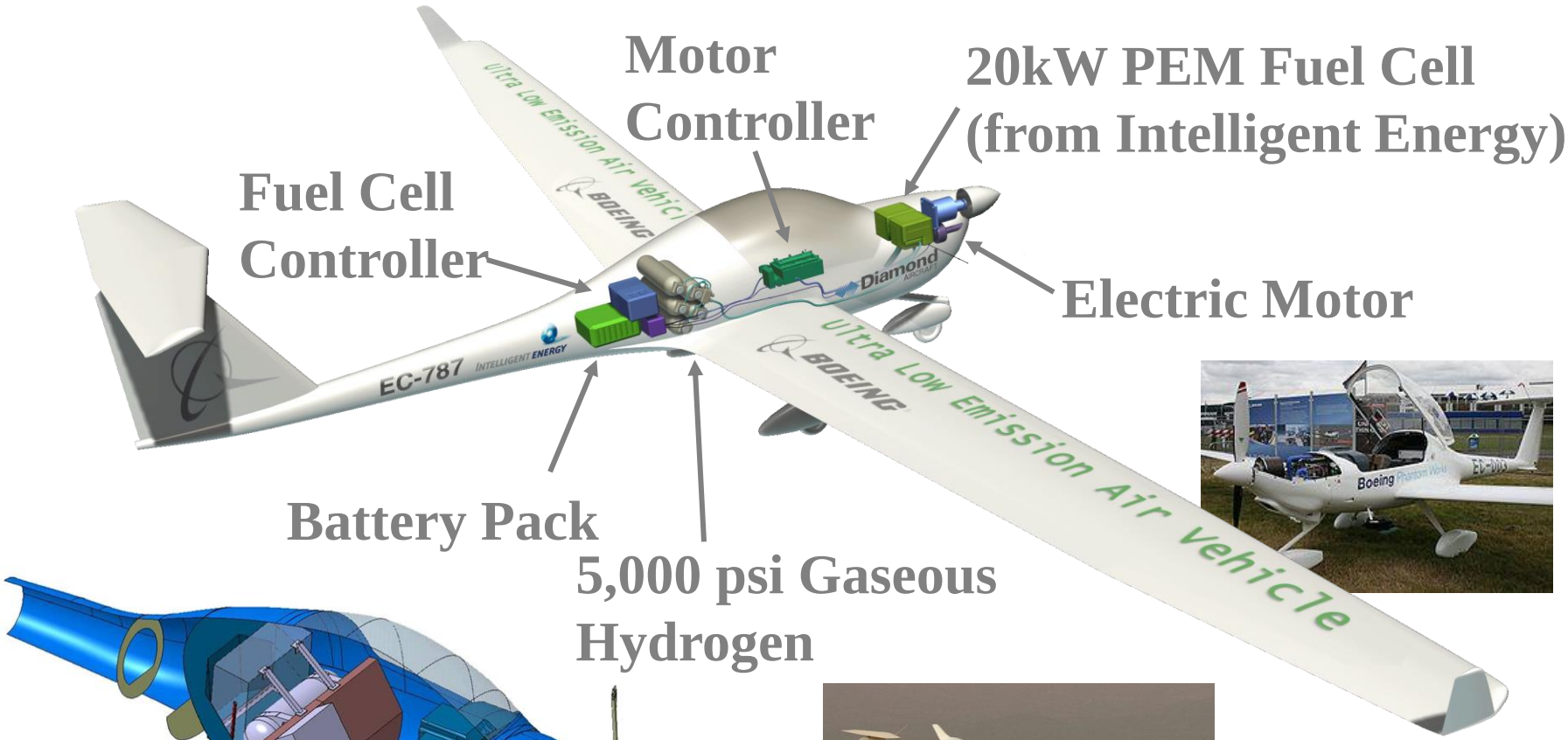
Fuel Cell APU Can Cut Airplane NO_x Emissions At The Airport

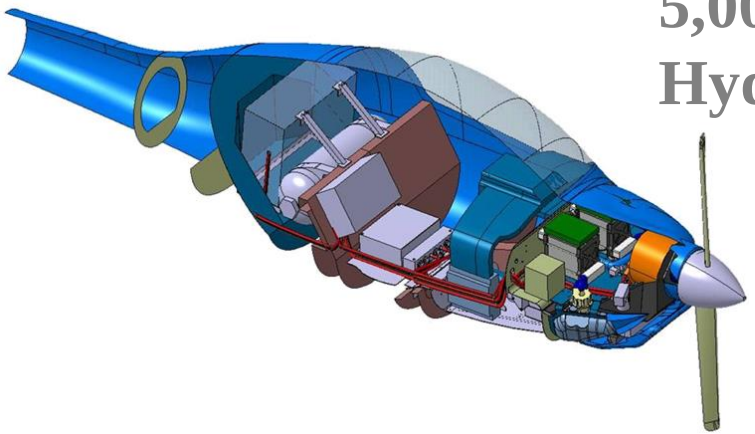
Large Airplane NO_x Emissions at Airport



Demonstrators Are A Means To Get Familiar With Integration And Operational Issues

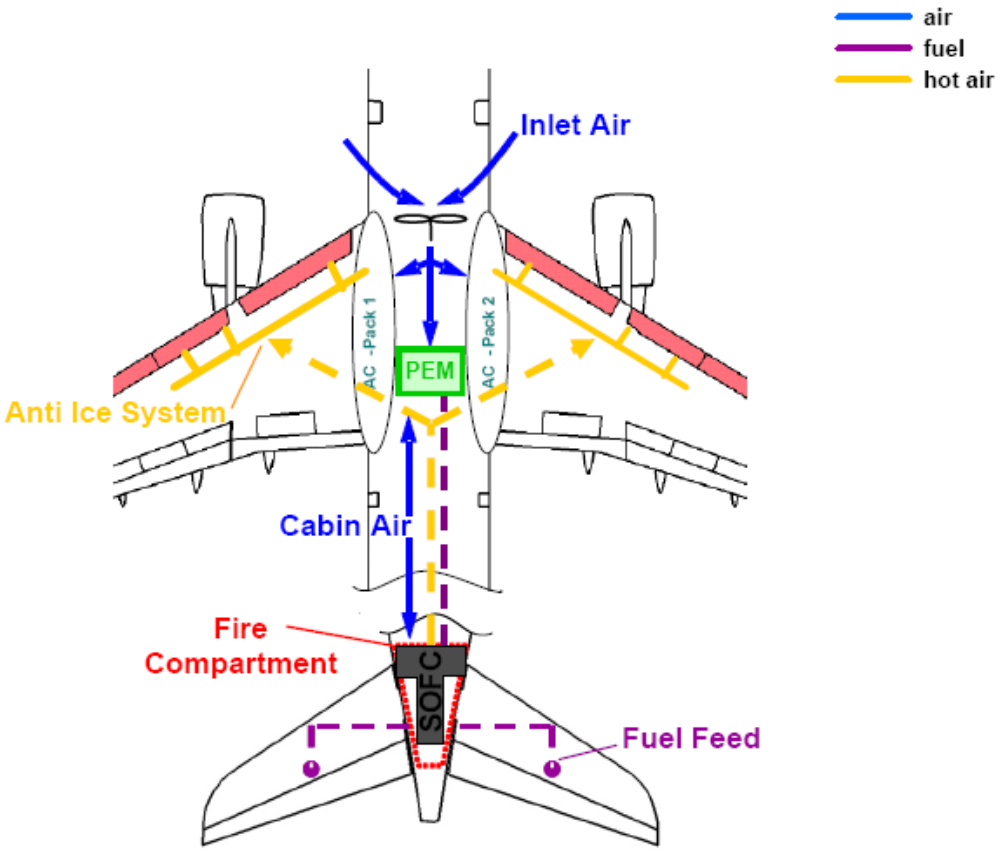
Boeing Fuel Cell Airplane Demonstrator





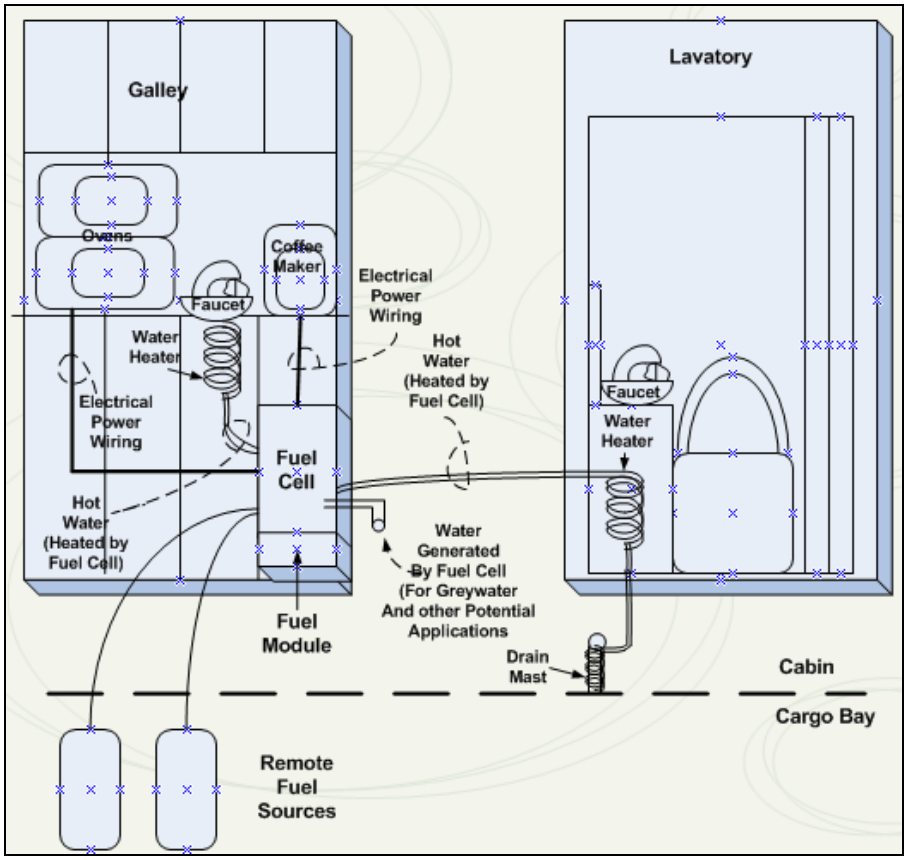
The Architecture Is Key To Understanding Fuel Cell Application In Airplanes

- **Need to develop and evaluate optimum fuel cell architectures including type and size of fuel cells, operation, infrastructure, fuels, etc.**
- **Some of these architectures can begin to be evaluated on the ground**
- **Supporting infrastructure and airplane interface can also be addressed with ground networks**



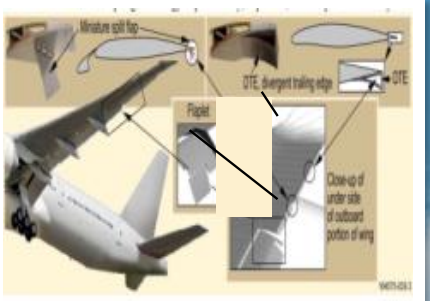
FUEL CELL APU'S IN COMMERCIAL AIRCRAFT – AN ASSESSMENT OF SOFC AND PEMFC CONCEPTS, ICAS 2004, 24TH INTERNATIONAL CONGRESS OF T HE AERONAUTICAL SCIENCES

Fuel Cells For Non-Essential Loads



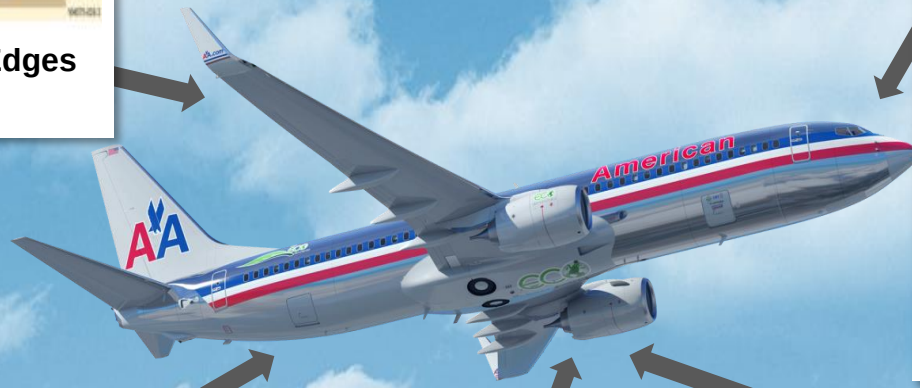
- Fuel cells can be used to power non-critical loads like galleys and In-Flight Entertainment systems
- Potential to remove these loads from the power system
  - Decreases the size of the generating system
  - Decreases the engine power extraction
- Provides improved operational efficiency for airlines
- Micro-grid approach provides increased configuration flexibility

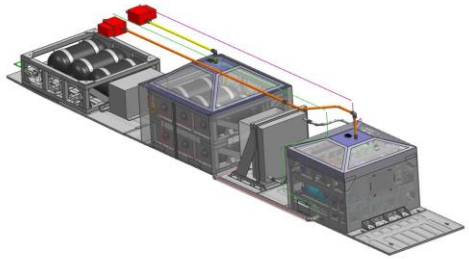
2012 ecoDemonstrator Program



Adaptive Trailing Edges (FAA CLEEN)

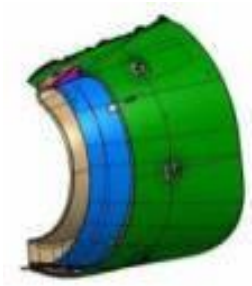
Advanced Air Traffic Management Flight Trajectory Optimization And Information Management





Regenerative Fuel Cell with IHI and IHI Aerospace

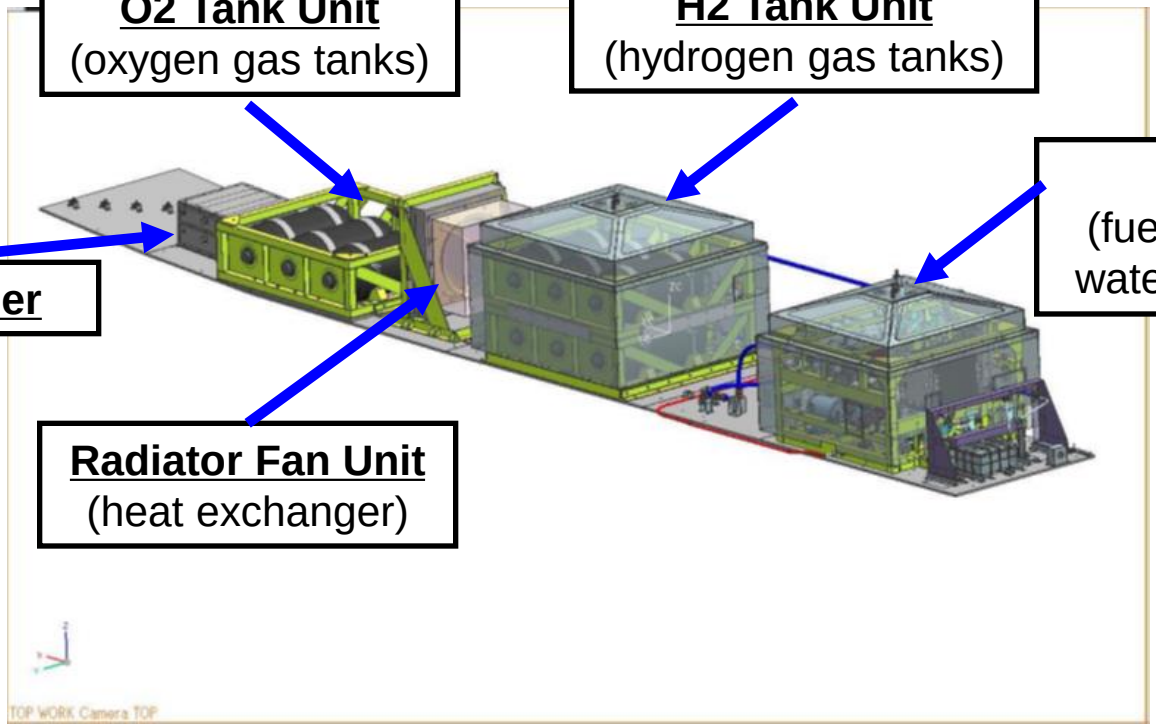
Active Engine Vibration Reduction (EVRN- AVC)



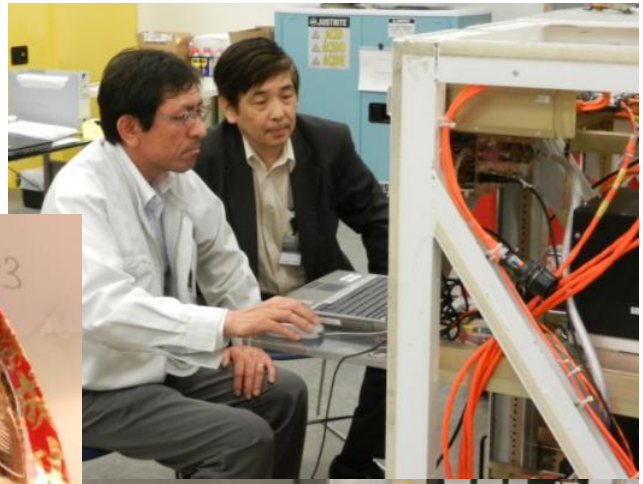
Variable Area Fan Nozzle

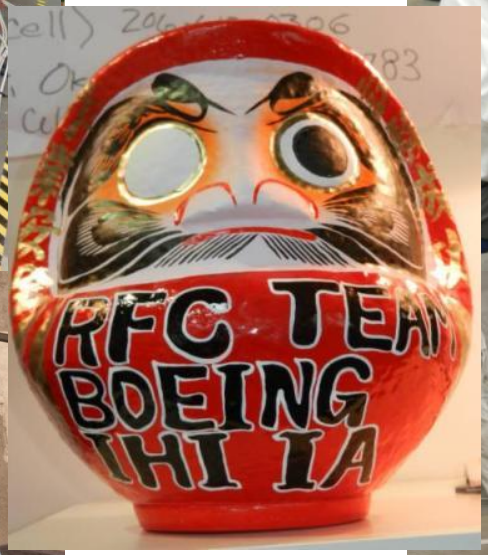
RFC System Configuration

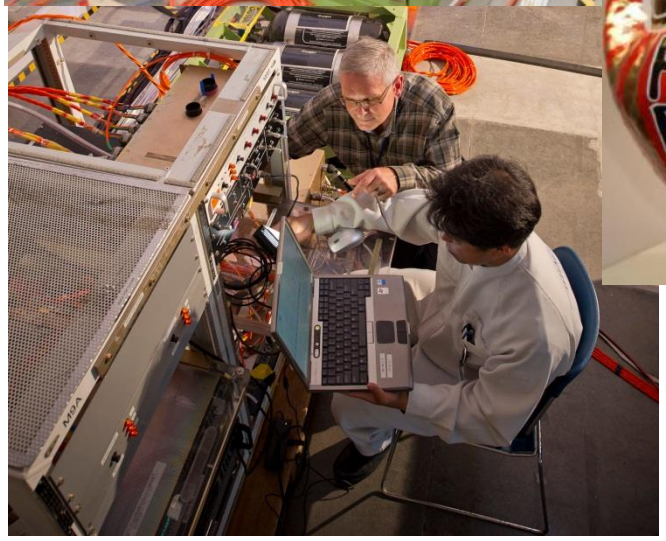
- Five(5) modules were located in B737-800 aft cargo area
- Control switches/power converters were located in cabin



RFC System Was Fully Checked In The Lab In Seattle Prior To Installation In The Airplane







RFC System Installed In The Aft Cargo Bay Of ecoDemonstrator 2012

Summary

- **The More Electric Airplane (MEA) is expected to play a significant role in the future of overall airplane system design, operation and performance**
- **The MEA is a technology enabler for energy generation, storage and conversion systems**
- **Some of the MEA-associated technologies (such as fuel cells) require significant R&D to bring them to the level of development so that industry can then make them commercially viable for airplane application**