Engineering, Operations & Technology
Boeing Research & Technology

Environment & Energy Perspectives

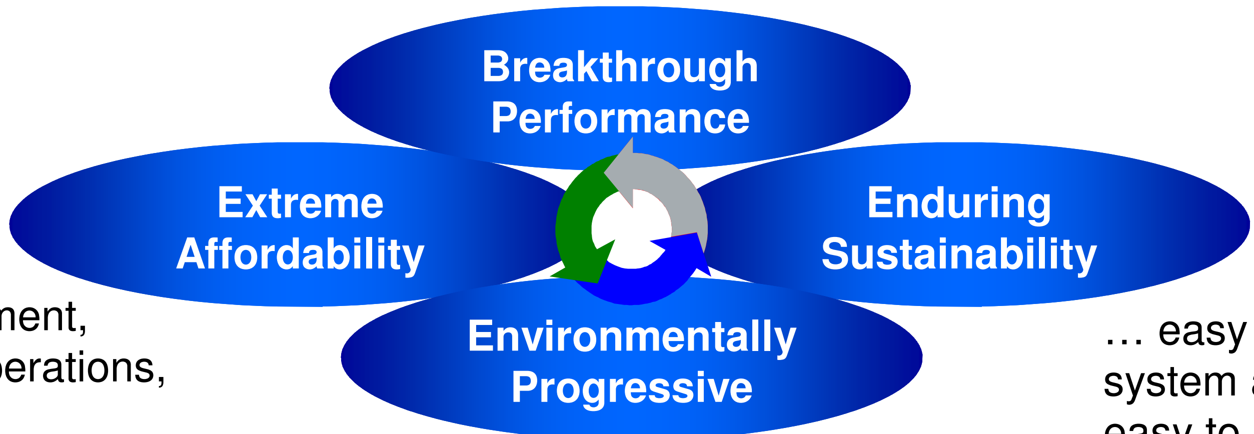
IEEE Region 5 – Green Technologies Conference
4-5 April 2013 – Denver, CO
George Roe

The Boeing Company 1916 ...

... to today

Customers' needs drive technology characteristics

…to meet the customer needs (range, payload, speed, mission effectiveness, availability, reliability, etc.)



… in development, production, operations, and support.

… easy to mod; open system architecture; easy to upgrade

… non-polluting in production; quiet; non-polluting & fuel efficient in operation; disposable/ recyclable at end of life

Our plan and commitments

Relentlessly pursue manufacturing and life cycle improvements

100%

100% of Boeing major manufacturing sites will maintain ISO 14001 certification.

Improve performance of worldwide fleet operations

25%

Focus on 25% efficiency improvements in worldwide fleet fuel use and CO_2 emissions by 2020.

Deliver progressive new products and services

15%

Improve CO_2 emissions and fuel efficiency by at least 15%

Pioneer new technology

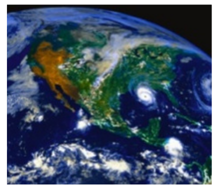
75%

Devote more than 75% of R&D toward benefiting environmental performance

Environmental performance measures

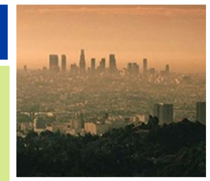
Global emissions

Emissions related to climate change concerns
CO_2 , NOx ,contrails



Local emissions

Emissions related to community air quality
NOx , SOx , particulates



Community noise

Noise related to aircraft
Ground and air operations

Hazardous materials

Materials with potential risks to human health or the environment
Toxics, VOCs, ozone depleters

Sustainable materials

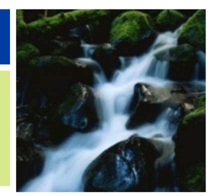
Materials that optimize the use of resources
Reduce, reuse, recycle, renew

Energy

Environmentally progressive management and use
Conservation, renewable

Water

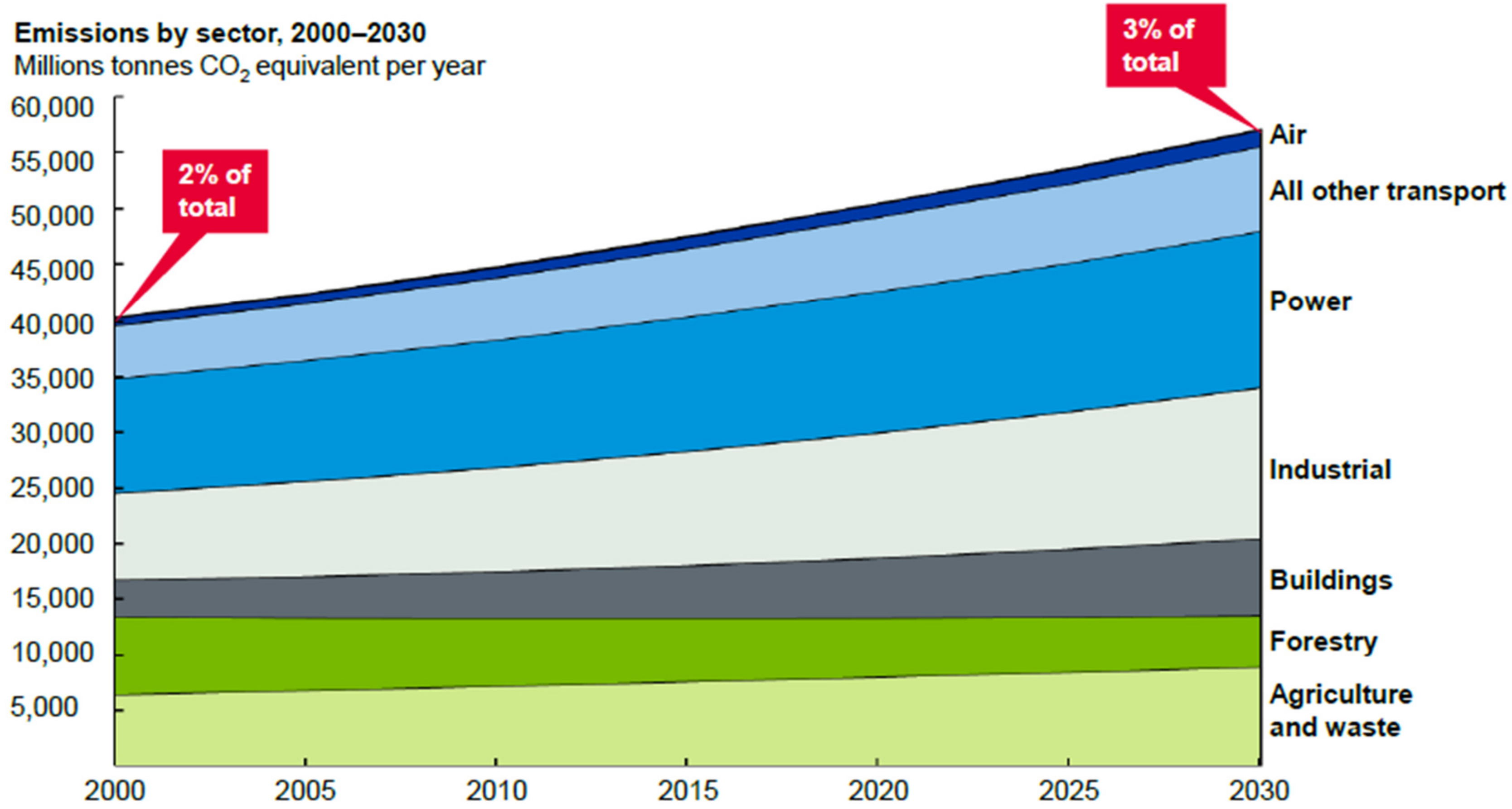
Environmentally progressive management and use
Conservation, quality



We are committed to improving Boeing's product lifecycle environmental footprint

(http://www.boeing.com/boeing/aboutus/environment/)

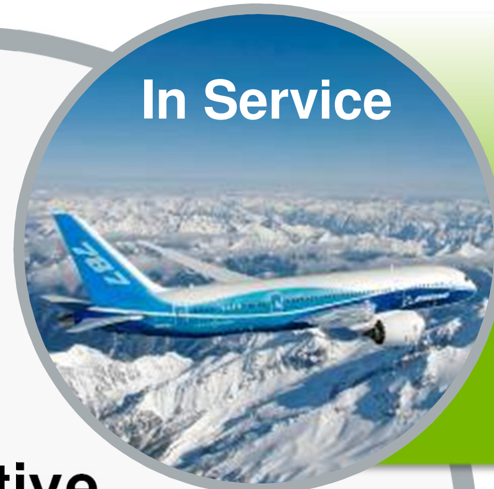
Aviation: 2% of global CO_2 emissions & growing



Source: WBCSD Mobility 2030 model; IPCC

Life cycle environmental footprint reduction

- **Minimizing manufacturing waste**
- **Conserving energy and water**
- **Reducing emissions**



- **Reducing emissions**
- **Minimizing noise**
- **Reducing fuel consumption**

Innovative Environmental Solutions

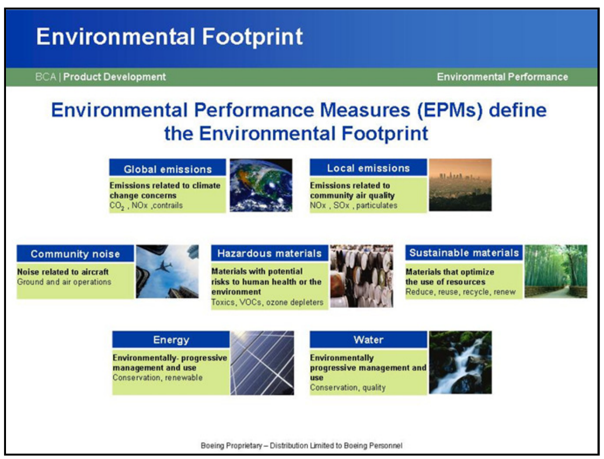
- **Stewardship, conservation and life cycle strategies**

- **Remarketing**
- **Reclaiming materials**
- **Recycling**

Design for environment

Phases of Design

Concept Development	Joint Definition	Detail Definition	In-production Improvements	Fleet Improvements



Operations
- Manufacturing

In Service

Suppliers
- Raw Materials

End of Service

Designing to Improve Environmental Performance

Improving the environmental efficiency and performance of world wide fleet

Opportunities to reduce fuel burn, emissions and noise

Airplane Modifications

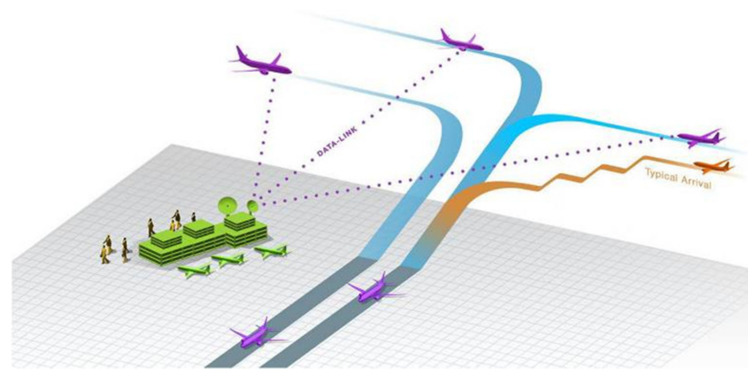
Airplane modifications for increased operational efficiency and environmental performance

Operational Efficiency

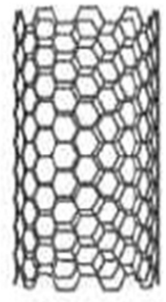
Work with airlines to offer and implement integrated operational efficiency solutions; on the ground and in the air

Airspace Efficiency

Collaborate with all stakeholders to optimize worldwide airspace efficiency and navigation



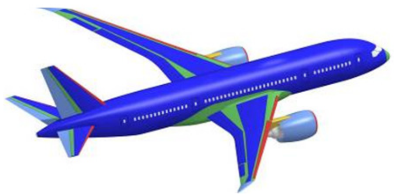
Actively pursuing technology research for fuel, CO_2 and noise efficiency



Researching next generation materials

Example: Next generation composites

Result: Reduces weight, which reduces fuel use and emissions



Designing aerodynamic improvements

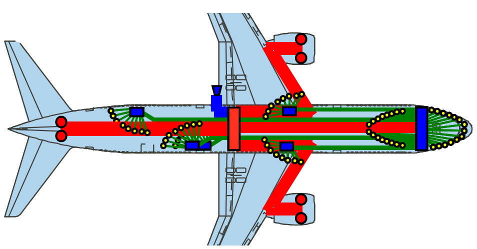
Example: Advanced wing design, raked wing tip

Result: Reduces drag which reduces fuel use and emissions

Researching improved propulsion systems

Example: Integrating new, more efficient engines

Result: Reduces fuel consumption and emissions and lowers noise



Researching less energy-intensive electric systems

Example: Reducing pneumatic systems

Result: Improving electrical efficiency improves fuel efficiency

Improving fuel efficiency

New Airplanes

787

20% more fuel efficient than airplanes it replaces

747-8

Double digit reduction in fuel consumption compared to airplanes it replaces

737 MAX

10-12% more fuel efficient than earlier models

Existing Airplanes

767

5.5% more fuel efficient with addition of winglets

777

1% more fuel efficient than earlier models

Each Gallon of Fuel Not Burned = 21 Pounds CO_2 Not Emitted

The 787 Dreamliner integrates advanced technologies to improve environmental efficiency

Cleaner, quieter and more efficient

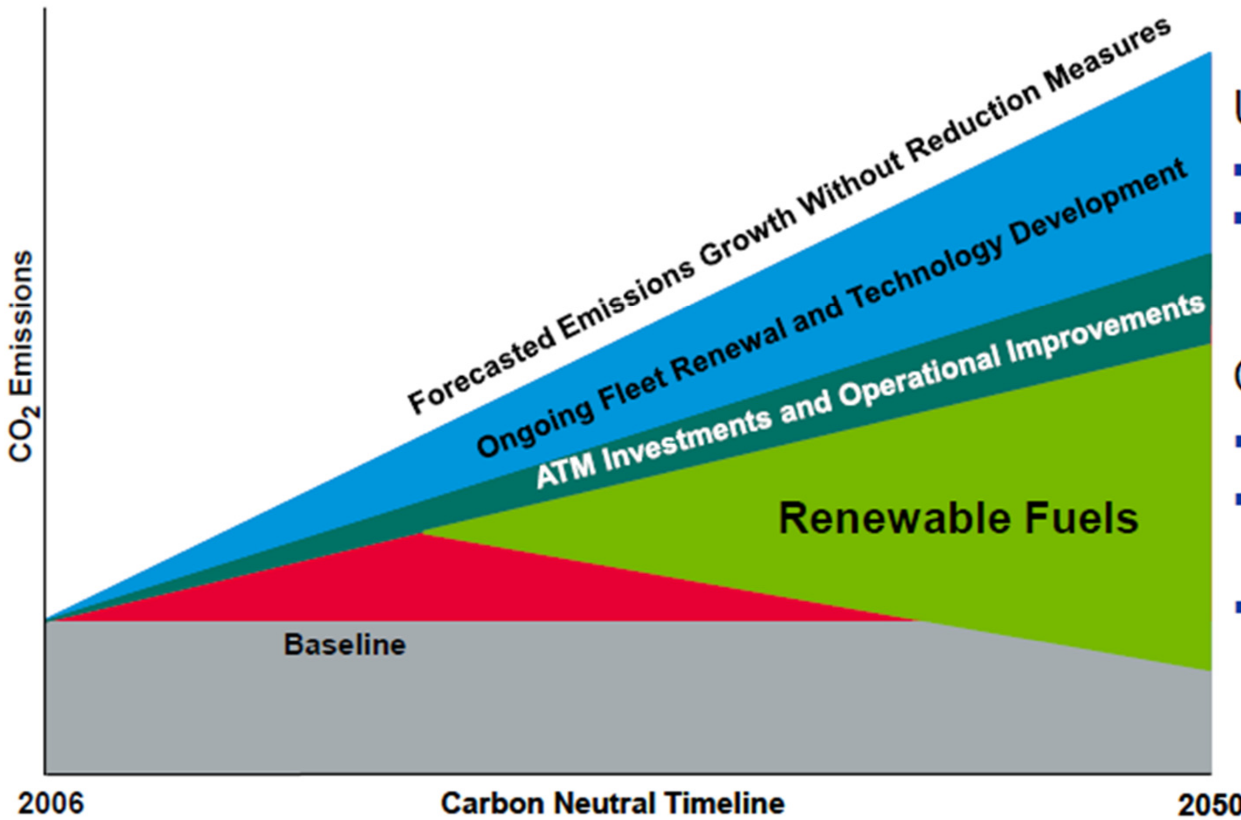
20%* Reduction in fuel and CO_2

28% Below 2008 industry limits for NO_x

60%* Smaller noise footprint

*Relative to the 767

The commercial aviation challenge: carbon-neutral growth



Presented to ICAO GIACC / 3 February 2009 by Paul Steele on behalf of ACI, CANSO, IATA and ICCAIA

Using less fuel:
- Efficient airplanes
- Operational efficiency

Changing the fuel:
- Lower life cycle CO_2
- No infrastructure modifications
- "Sustainable biofuels"

Sustainable Biofuels Enable Continued Growth

Technology readiness levels (TRL's)*

TRL 1 Basic principles observed and reported

TRL 2 Technology concept and/or application formulated

TRL 3 Analytical & experimental critical function and/or characteristic proof-of concept

TRL 4 Component and/or breadboard validation in laboratory environment

TRL 5 Component and/or breadboard validation in relevant environment

TRL 6 System/subsystem model or prototype demonstration in a relevant environment (ground or space)

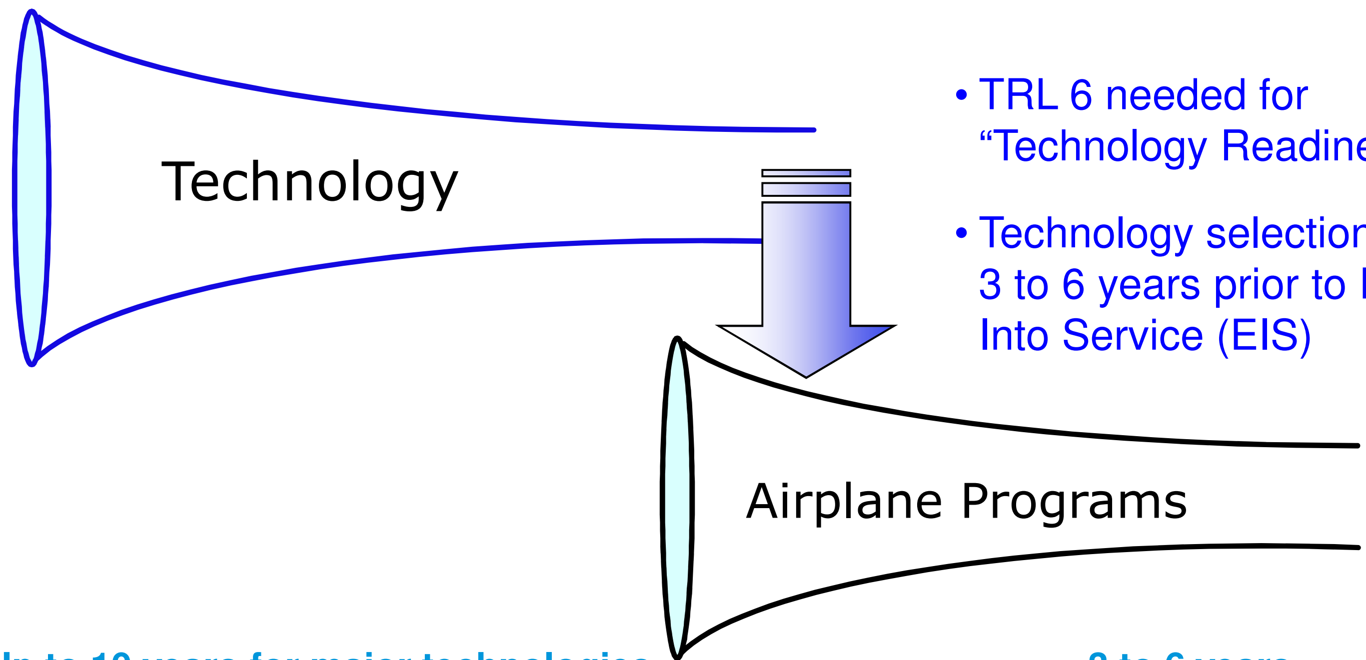
TRL 7 System prototype demonstration in a space environment

TRL 8 Actual system completed and "flight qualified" through test and demonstration (ground or space)

TRL 9 Actual system "flight proven" through successful mission operations

* Source: *TECHNOLOGY READINESS LEVELS - A White Paper* , John C. Mankins, 6 April 1995

Technology maturity levels
Timeline to airplane incorporation



- TRL 6 needed for "Technology Readiness"
- Technology selection occurs 3 to 6 years prior to Entry Into Service (EIS)

BASIC RESEARCH		TECHNOLOGY DEVELOPMENT			SYSTEM/SUBSYSTEM DEVELOPMENT				READINESS FOR PRODUCTION
TRL 1	TRL 2	TRL 3	TRL 4	TRL 5	TRL 6	TRL 7	TRL 8	TRL 9	TRL 10

Commercial Airplanes vs. Consumer Products

Production Volume in 2006

Apple iPods	~39.3 million sold	$240 ea / 9 B total
Toyota automobiles	7.711 million produced	$30K ea / 200 B total
Boeing commercial airplanes	398 delivered	$150M ea / 60 B total

- Development of New Product Line – 7+ years, $ Billions

- Product Line Life Cycle

First 747
Jan 1970

→

First 747-8
2009

\+ XX Years Future Production + 30+ Years In-Service = Very Long Product Life Cycle

- Long product life cycles and high cost of change drive need for <u>stable</u> & <u>long-lived</u> technologies and <u>open architectures</u>

Demonstrators accelerate implementation

Noise Reducing Chevrons Developed During Quiet Technology Demonstrator Program QTD2

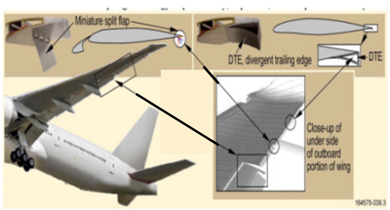
787-8

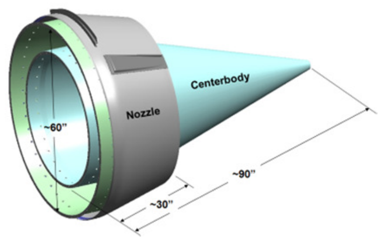
747-8

ecoDemonstrator - accelerating advances to improve environmental performance

N+1 FAA CLEEN
Continuous Lower
Energy Emissions Noise

N+2 NASA ERA
ISRP, SMAART, RTAPS
N+3





Vision:
- Accelerate technology maturation
- Build & integrate more rapidly

Result:
- To market faster
- Higher success rates
- Technology leadership

	2013	2014	2015	2016	2017	--------- 20XX

737 Platform

Twin Aisle

Environmentally Advanced Wing

Optimized Integration

Hybrid Power

Working together for a continuum of demonstrators to accelerate technology

Boeing Research & Technology

Flight & Systems Technology | **Boeing Research & Technology**

Systems & Electronics Technology

Boeing Commercial Airplanes

Boeing Defense, Space & Security

BR&T

Systems & Electronics Technologies

- **Platform Systems**
  - Electrical power
  - Thermal management
  - Actuation
  - Energy management
  - Counter CBRNE, Safety & Security Protection

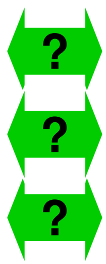
- **Electronics**
  - Avionics Systems Technology
  - Electronics, Prototyping & Integrated Center
  - Optical & Signal Processing
  - Radio Frequency & Microsystems
  - Solid State Electronics

- **Vehicle Systems**
  - Integrated system architectures
  - Intelligent autonomous systems
  - Fiber optic data networks
  - Human-system integration

- Components, subsystems & integration
- Modeling & simulation
- Prototyping, lab test, field eval

Terrestrial / Aerospace Energy Knowledge & Technology Transfer

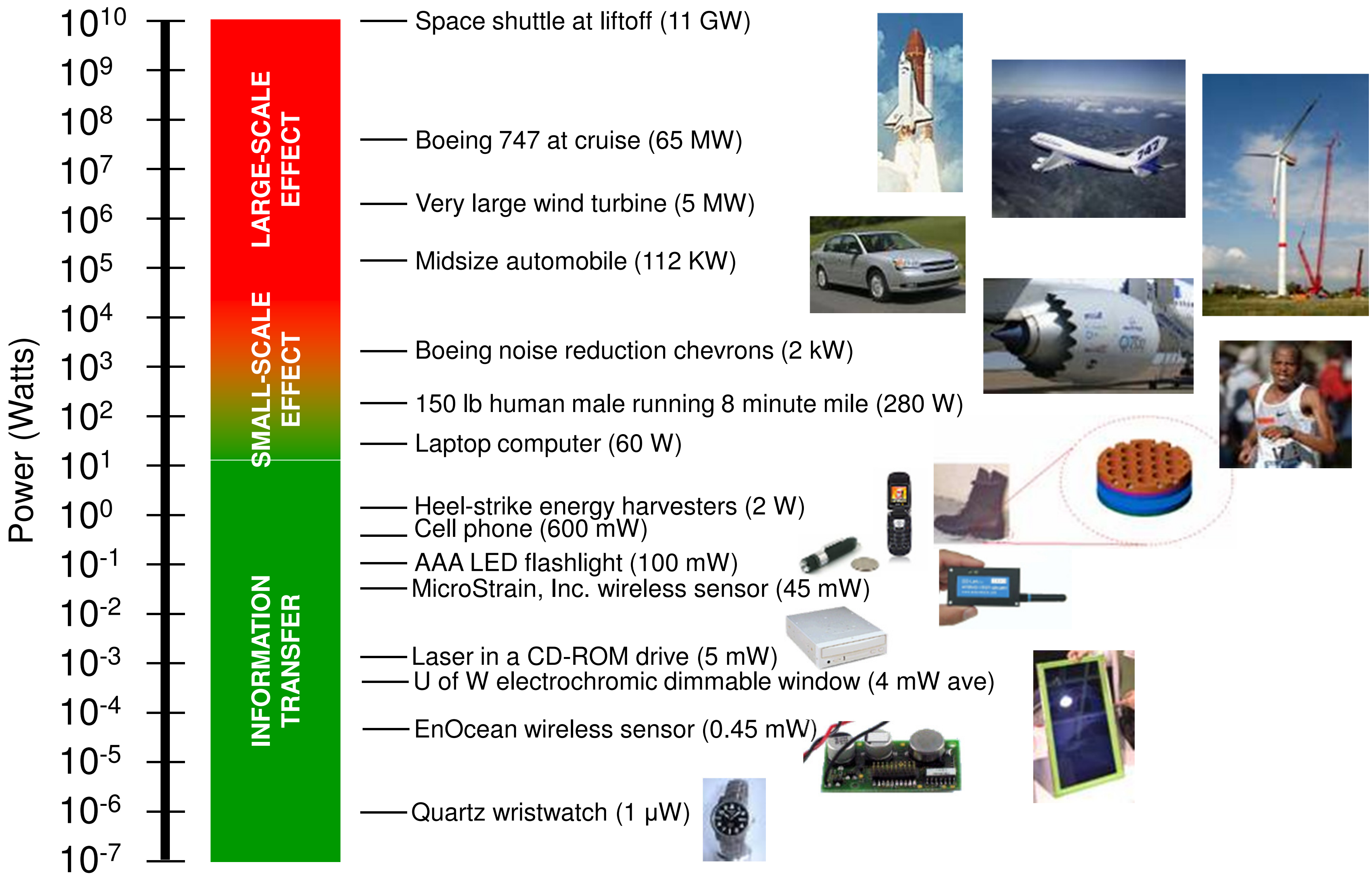

www.tripadvisor.com)




www.aerospaceweb.org

Really?

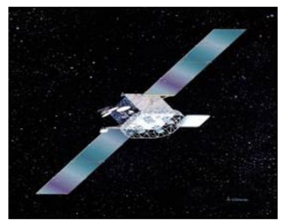
Power continuum



Energy management across value stream

Design → **Extended Enterprise** (**Internal Operations** / **Suppliers & Partners**) → **Product & Services In Use** → **Product End of Life**

- Materials
- Component / subsystem / system technologies
- Analysis tools
- Lessons-learned
- Needs & opportunities
- Sensors & control systems
- Life cycle assessment
- System management

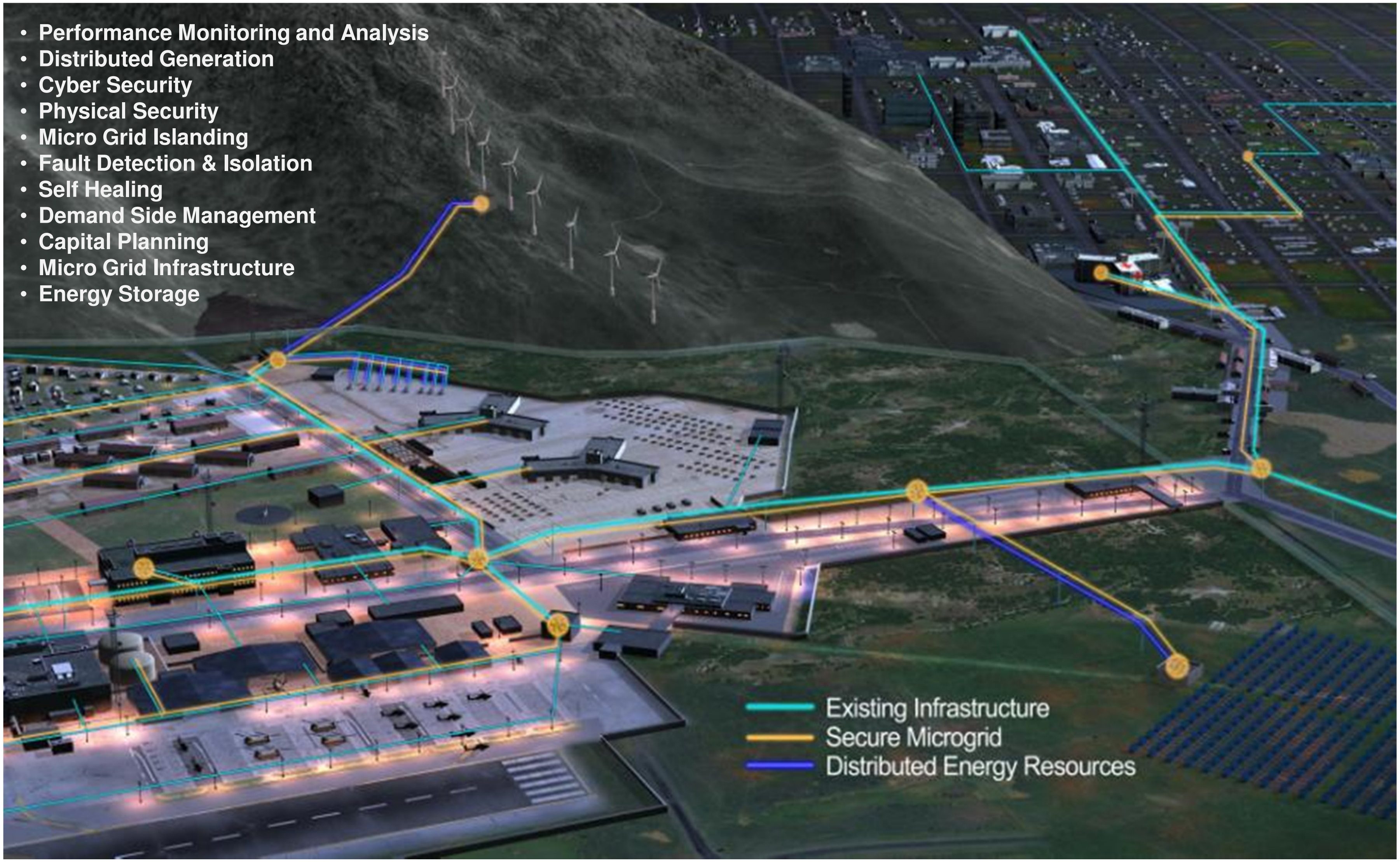





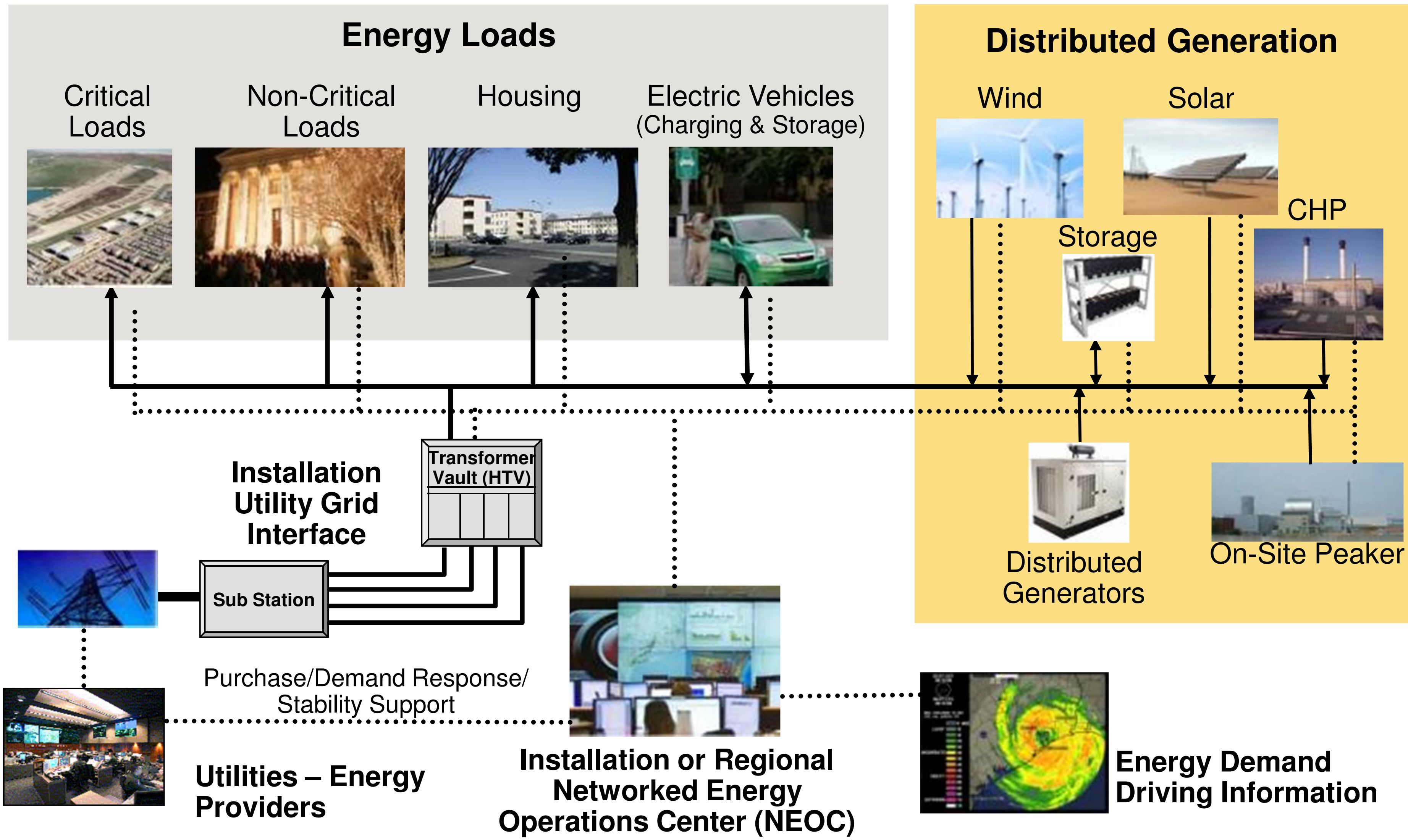


DoD energy security

- Performance Monitoring and Analysis
- Distributed Generation
- Cyber Security
- Physical Security
- Micro Grid Islanding
- Fault Detection & Isolation
- Self Healing
- Demand Side Management
- Capital Planning
- Micro Grid Infrastructure
- Energy Storage



Microgrid architectural elements



“More Electric” trend in transportation

POWER ELECTRONICS (Si, SiC, GaN

- SEMICONDUCTOR SWITCHES
- CAPACITORS
- CIRCUITRY
- OTHER COMPONENTS

ENERGY STORAGE

- BATTERIES
  - MAINTENANCE FREE
  - CHEMISTRIES
- FLYWHEELS
- SUPERCAPACITORS

THERMAL MANAGEMENT

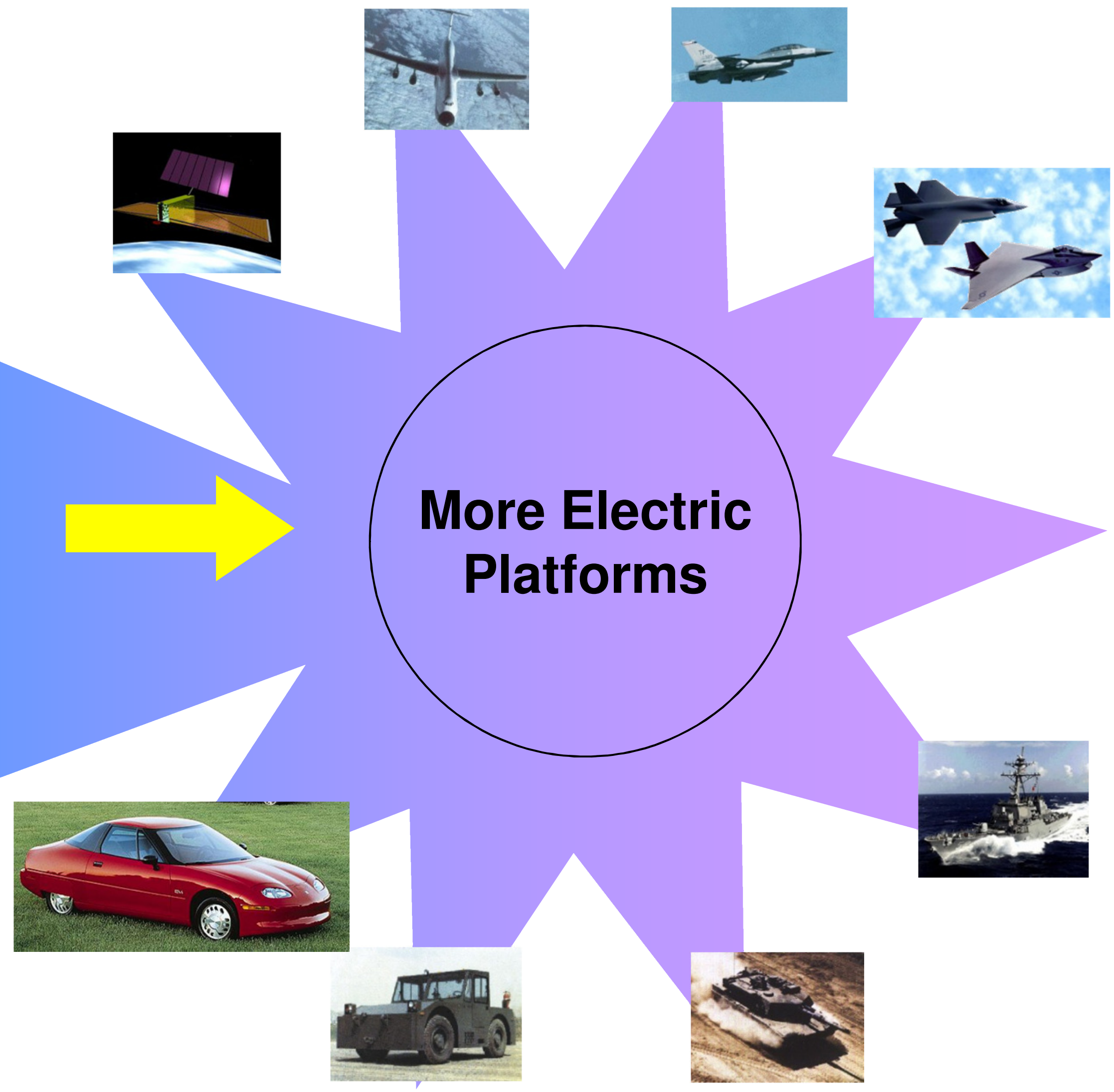
- ACTIVE VS. PASSIVE
- HEAT PIPES
- “ELECTRIC” AIR CONDITIONING
- STORAGE
- RECOVERY

POWER GENERATION / UTILIZATION

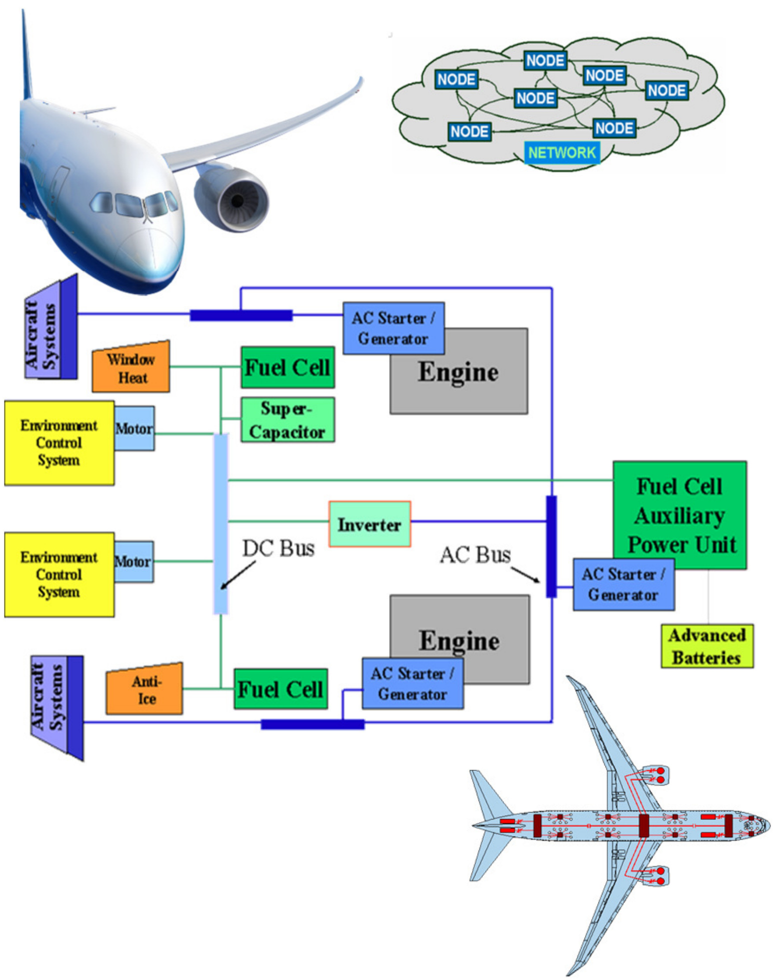
- MOTOR TYPES
  - SWITCHED RELUCTANCE
  - INDUCTION
- STARTER / GENERATORS
- COOLING
- MAG BEARINGS
- CONTROLLERS
- ELECTRIC ACTUATION

POWER DISTRIBUTION / SYSTEM INTEGRATION

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



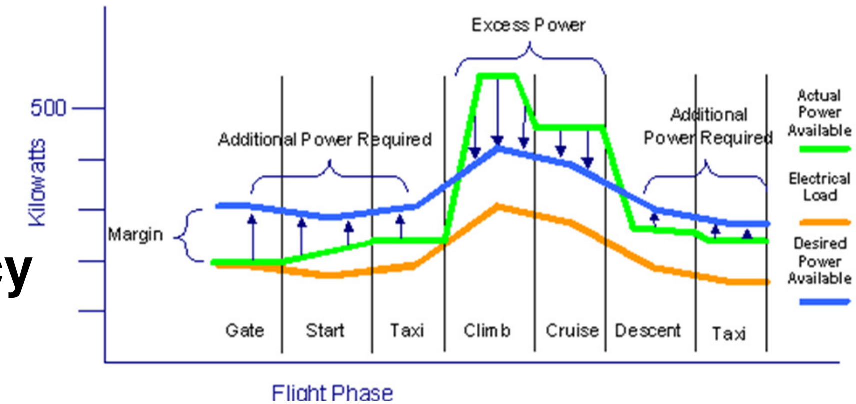
Grid-like power systems

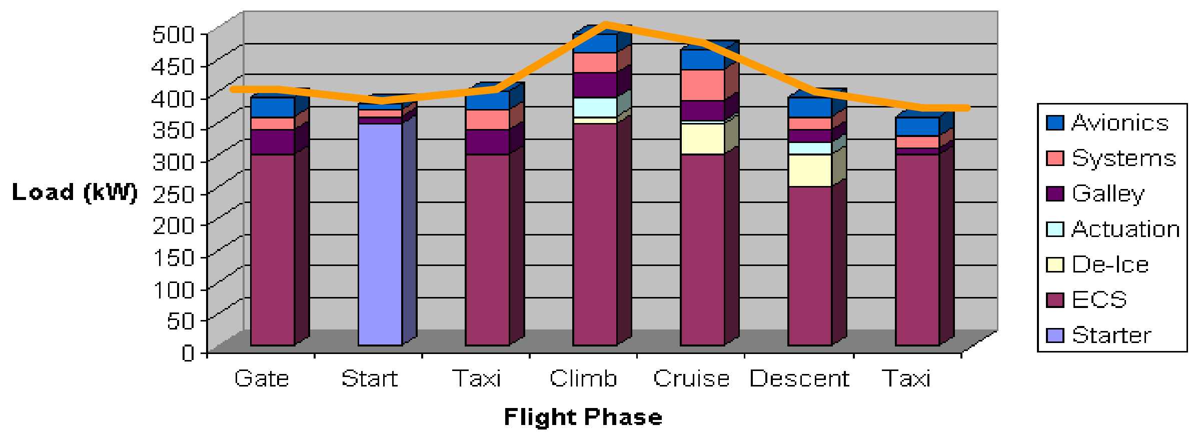


- Power system flexibility & utility
- Graceful, graduated failure modes
- Reduced power extraction
- Lower wire weight
- Improved efficiency
- Greater dispatch availability

Optimizing power management

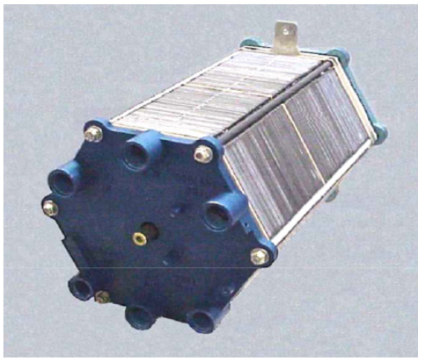
- **Lower power margin during idle descent**
- **Energy storage & load management opportunities**
- **Potential to improve airplane efficiency & reduce power system rating**





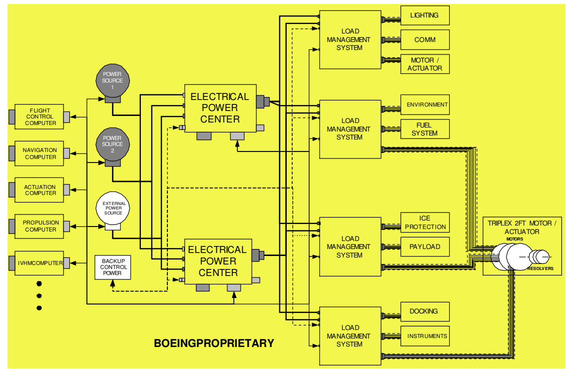
Electrical components improvement

Fuel Cells



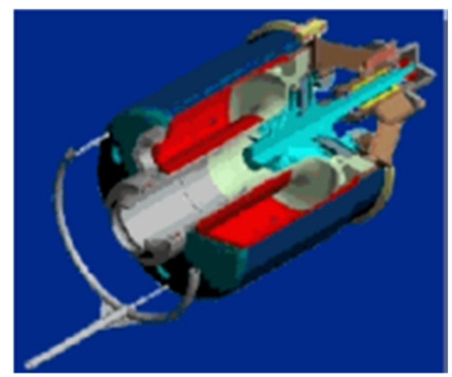
Batteries

New Capabilities in Power Management

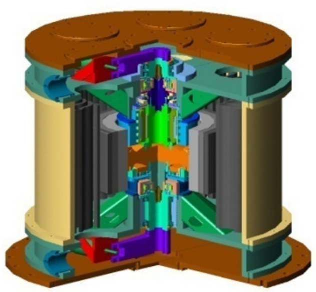


Actuators

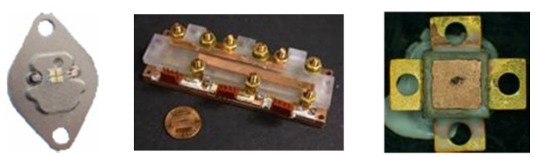
Generators



Circuit Protection

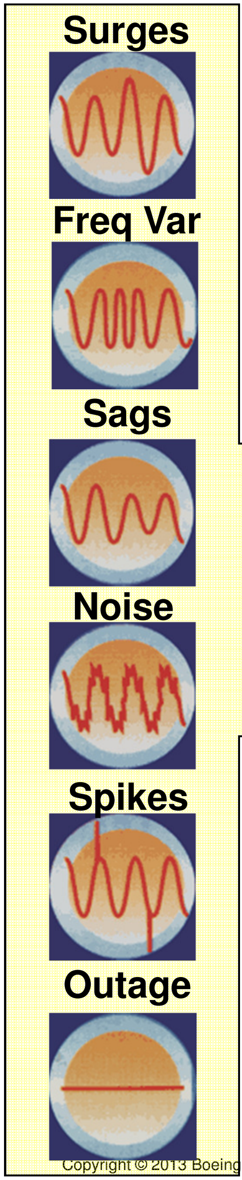


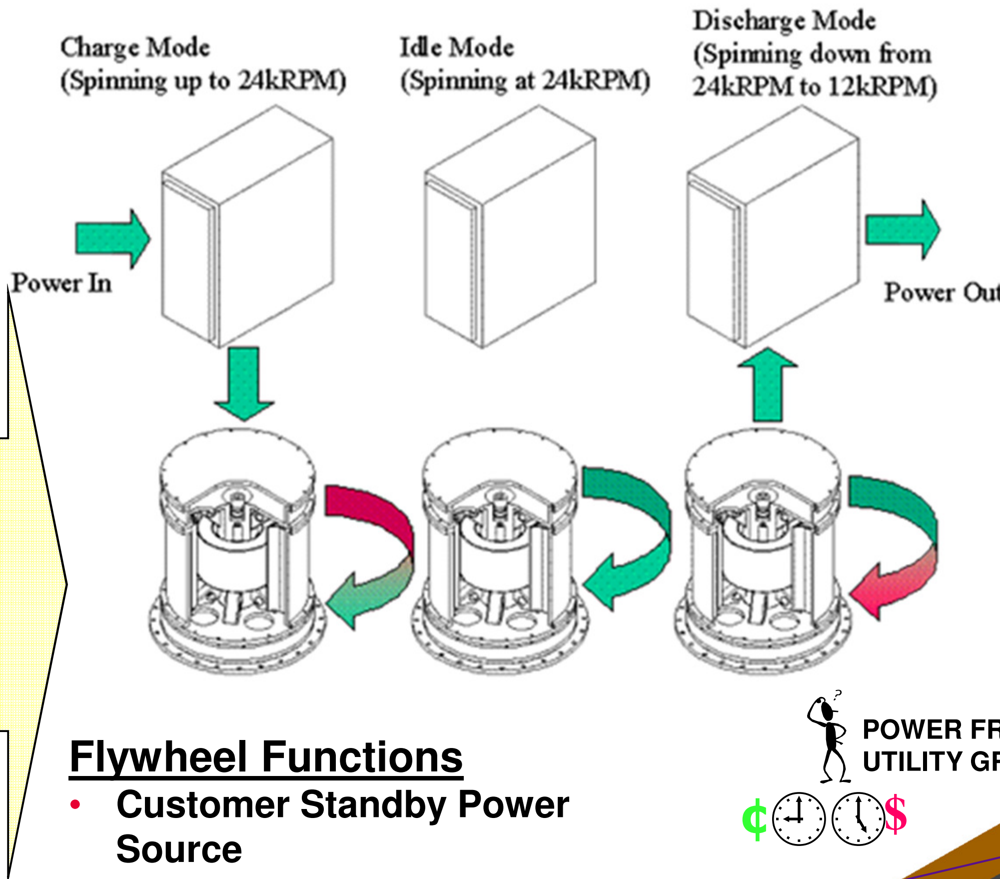
Flywheels

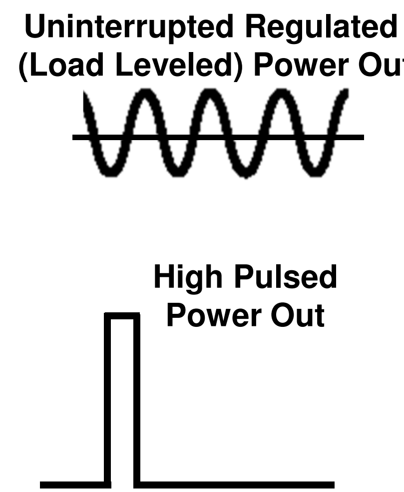


High Temperature Packaging

Flywheel electricity systems

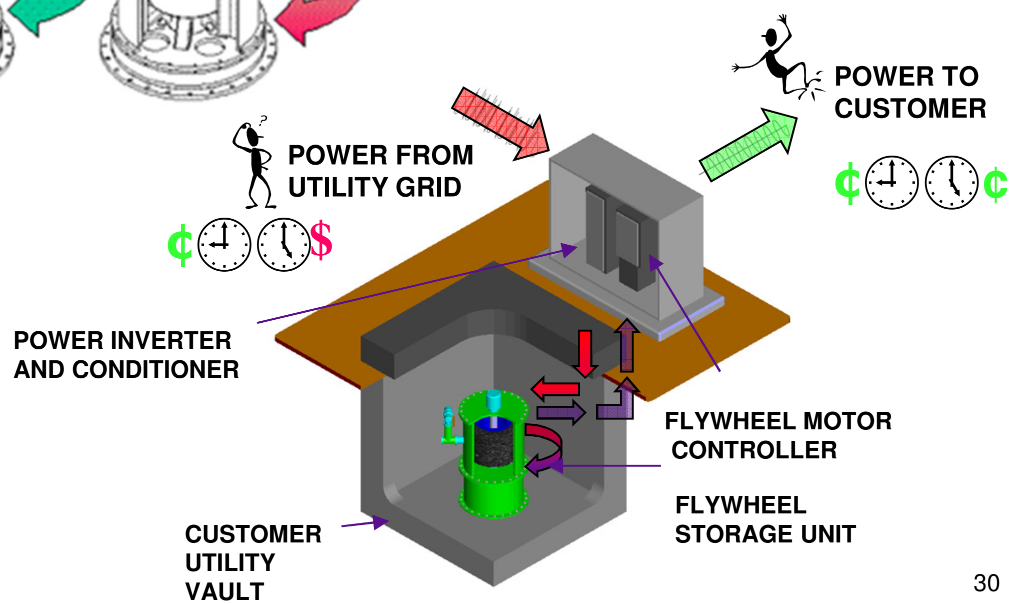






Flywheel Functions

- Customer Standby Power Source
- Power Quality
- Load Leveling
- Peak Shaving
- Reactive Power Support
- Voltage Support



Recovering & harvesting energy

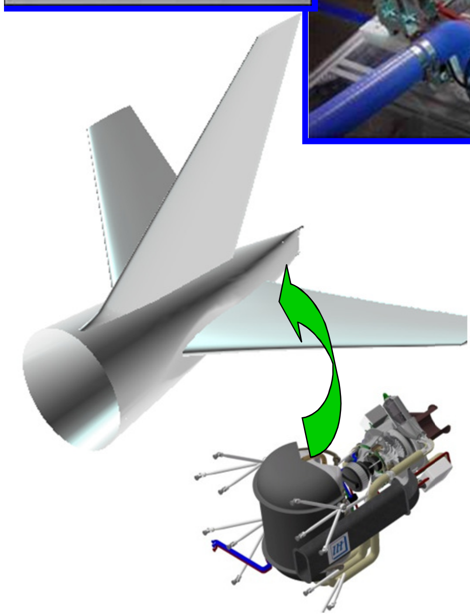
- **Characterize energy available in the airplane**
- **Explore various methods of accessing this energy**
- **Model & evaluate potential solutions**
- **Test prototypes in representative environments**

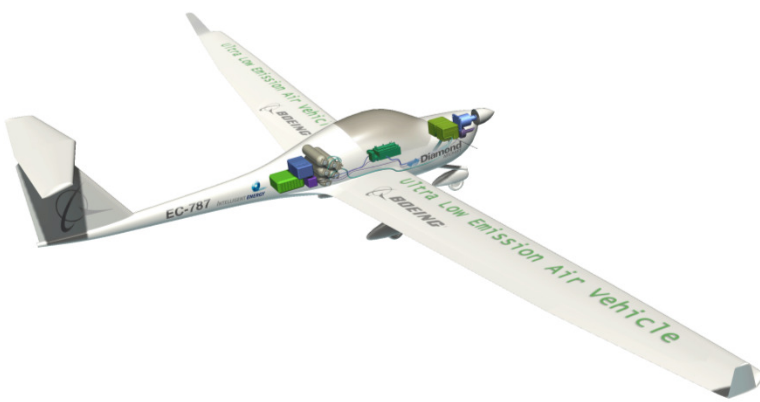
- **Reduce installation cost**
- **Reduce weight**
- **Increase modularity**
- **Enable introduction of new features & rapid reconfiguration**

Thermal, solar, vibration, … energy

Fuel cell energy solutions can significantly reduce emissions

- Greater system efficiency
- Lower CO_2
- No NO_x
- No SO_2
- No particulate matter





- Utility power source
- Re-generable battery
- Peak load alleviator
- Emergency power unit
- Auxiliary power unit
- Special purpose power
- Propulsion power

Observations

- **Multiple organizations / domains have energy-relevant technologies**
- **"More-electric" airplane and space power / thermal technology base is synergistic with terrestrial energy applications**
- **Ground-first-then-air technology spiral accesses adjacent markets for Boeing & partners**
- **Dual-use technology emphasis encourages industry investment**
- **Multiple ongoing efforts in technology development / integration labs / concept demonstration offer high leverage potential**
- **Detailed follow-up discussions focusing on technology and/or organization are recommended**

Shared technologies, tools & TPM’s

Technologies

- Power generation
- Power conditioning
- Power transmission
- Power conversion
- Energy storage
- Temperature control
- Heat transport
- Waste heat rejection

Tools

- Computer modeling
- Prototyping
- Demonstrations
- Field tests
- Path-to-market

Technical Performance Measures (TPM’s)

- Efficiency
- Reliability / maintainability
- Affordability
- Weight & volume
- Safety
- Environmental impact

Ground system applications can mitigate aircraft integration challenges

- Altitude
- Vibration
- Shock
- Sand/dust/moisture
- Thermal interface
- Operation timing
- Logistic fuel
- Performance

- Safety
- Volume
- Weight
- Reliability
- Maintainability
- Affordability
- Qualification
- Certification

Air / ground synergy: ➡ = High ⇨ = Moderate

Technology maturation opportunities

- **Technology maturation (typically to TRL 6)**

- **Criteria**
  - Consistent with established R&D strategies / plans
  - Synergy with business unit strategies / plans
  - Transition plan / exit strategy

- **Approaches**
  - Modeling & simulation
  - Lab evaluation
  - Prototyping
  - Demonstration
  - Technology industry networking
  - Intellectual property
  - Publication

- **Funding sources**
  - Utility grants
  - Government contracts
  - Industry consortia
  - Collaborative funding

Collaboration opportunities

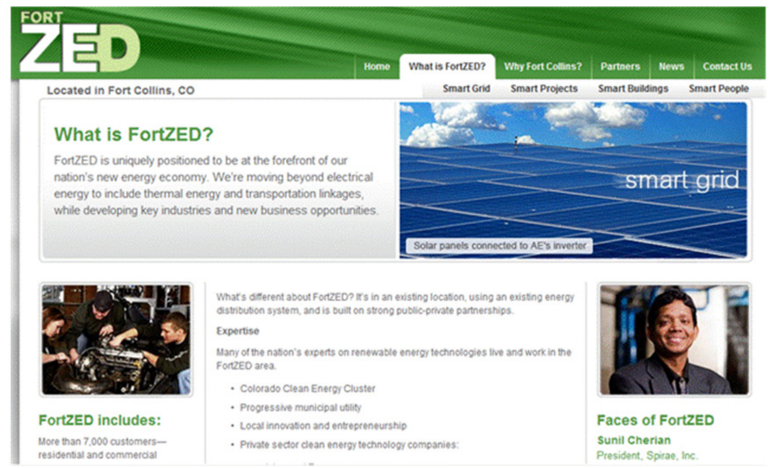
- **Technology development & demonstration**
- **Modeling & simulation tools / methodologies**
- **Performance / reliability data sharing**
- **Industry standards / pre-competitive design guidelines**
- **Focus areas include:**
  - Energy sources
  - Electrical power generation
  - Power conditioning & management
  - Wiring
  - Energy storage
  - Thermal management
  - Energy recovery & harvesting
  - Multi-function components / subsystems / systems
  - System health & operation monitoring / management

“Net zero” initiative synergies

Air Force – Army - Marine Corps - Navy

✓ DoD

✓ Communities



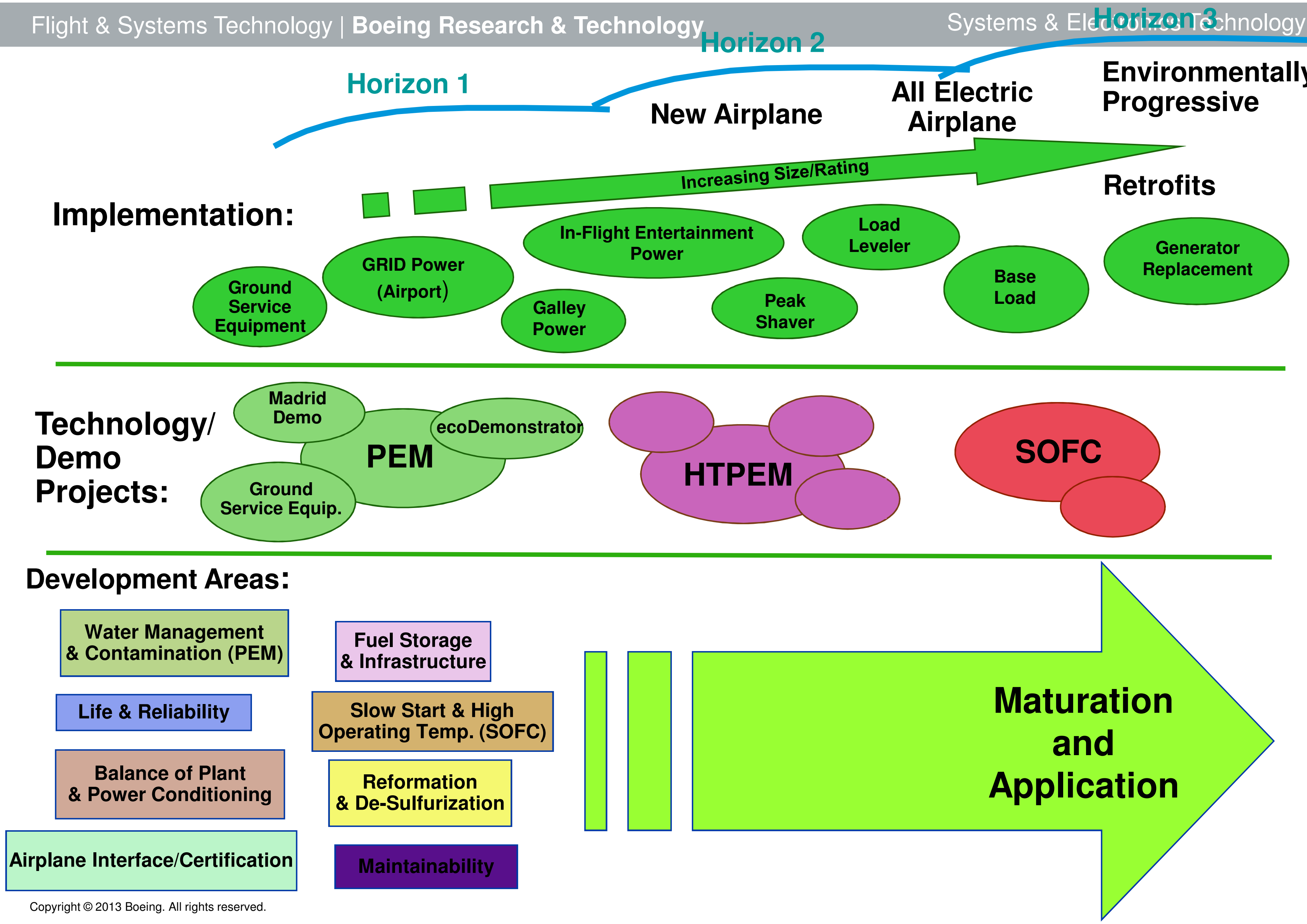
http://fortzed.com/

¿ Airports?

Fuel Cells

An Illustration of Multi-party Collaborative Technology Maturation

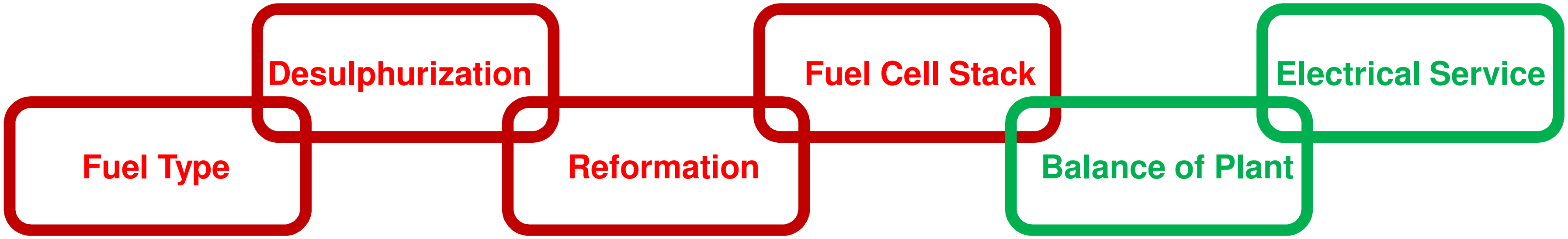
Fuel cell technology maturation

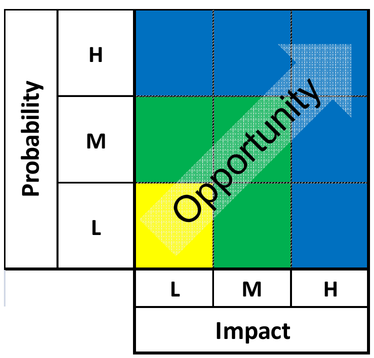


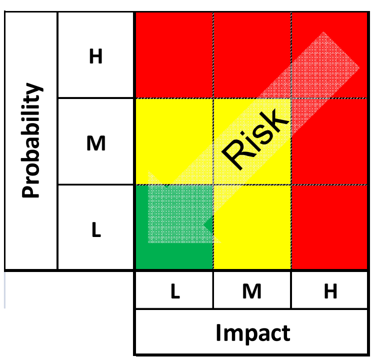
Situation assessment

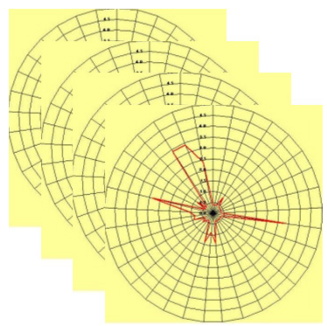
- **Fuel cells may contribute as part of a system-level total energy management architecture**
- **Key technical issues must be addressed**
- **“Pathfinder” focus area applications are being evolved**
- **System demonstrations provide high leverage for integration**
- **Funding resources are limited**
- **Collaboration – internally and externally – is desirable**

System capability & development needs assessment for priorities & staging









- Facility power
- Maritime
- Ground support
- Sensors
- Aircraft utility
- Power pod
- UAV / UGV / UUV

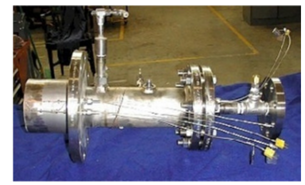
- Identify critical elements & associated attributes / risks / opportunities
- Evaluate elements to identify weakest and strongest "links" & possible "placeholder" surrogates
- Compare applications to identify synergies & situation-unique items
- Identify collaboration opportunities (funding, entities, transitions)

Many shared technologies

Red: Technology Maturation Needed
Black: Industry is Relatively Mature

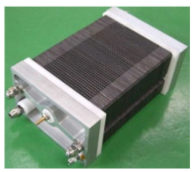
Hydrogen Storage

Fuel Tank

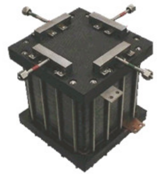


Fuel Reforming

SOFC Stack



PEM/HT PEM Stack



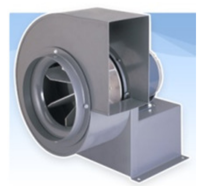
Electrolyzer Stack

Power Electronics and Controls

Batteries / Capacitors

Pumps

Turbo Compressor



Air Blower

Heaters

Sensors

Valves and Plumbing

Water Reservoir

Filters

Water Separator/Collector

Steam Generator HEX

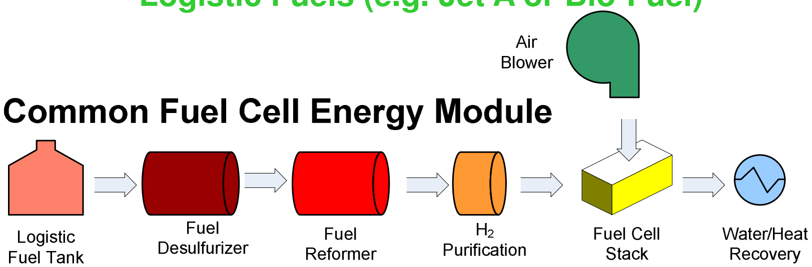
Heat Exchangers

Fuel Cell Energy Sources can Facilitate "Green" Ground Support Equipment (GSE)

Potential Fuel Options for "Green" GSE

With
Logistic Fuels (e.g. Jet A or Bio-Fuel)

Common Fuel Cell Energy Module



Option 2
Use Hydrogen

Hydrogen Could Be Generated Onsite by Electrolysis Using Solar/Wind/Grid Power

Photo by: Las Vegas Valley Water District

Examples of Airport GSE

Ground Power Unit

Aircraft Tractor (Tug)

Lower Deck Loader

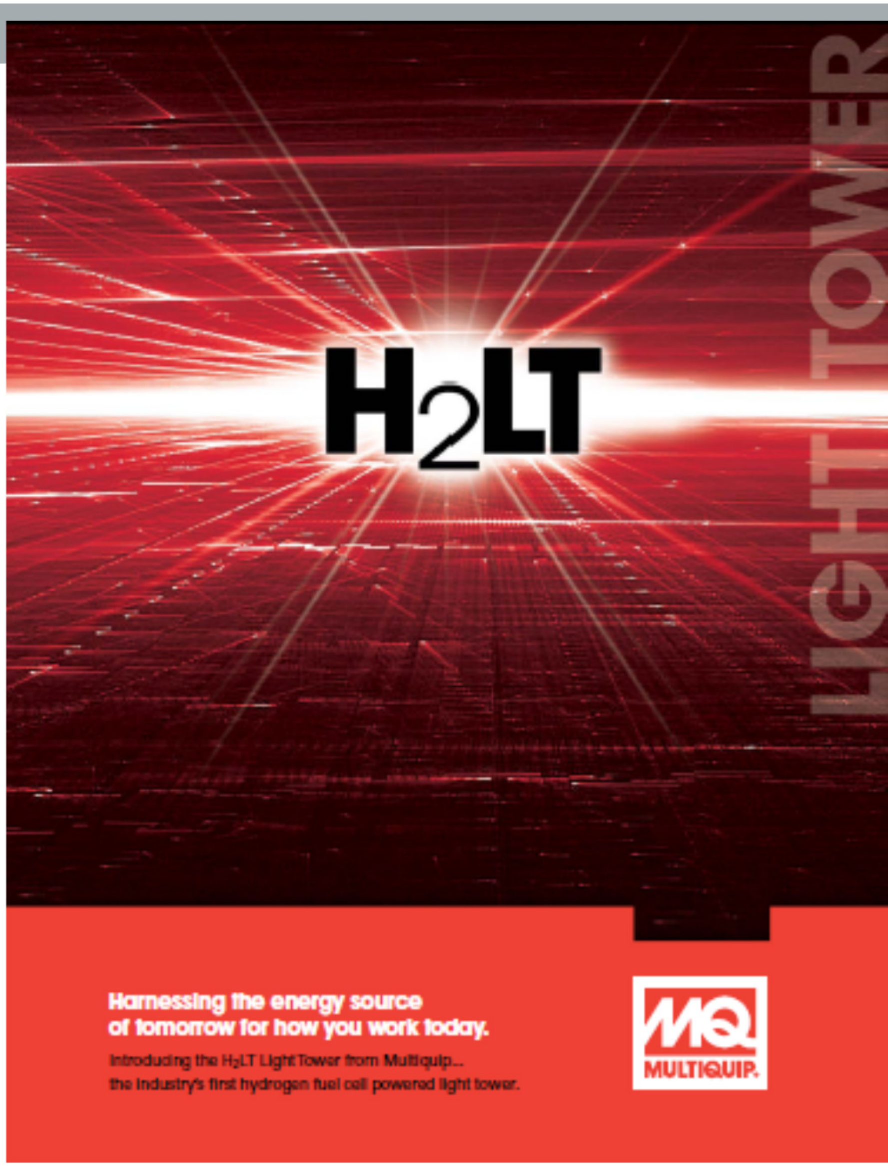
Airport Passenger Steps

Mobile Light Stands

Aircraft Heater

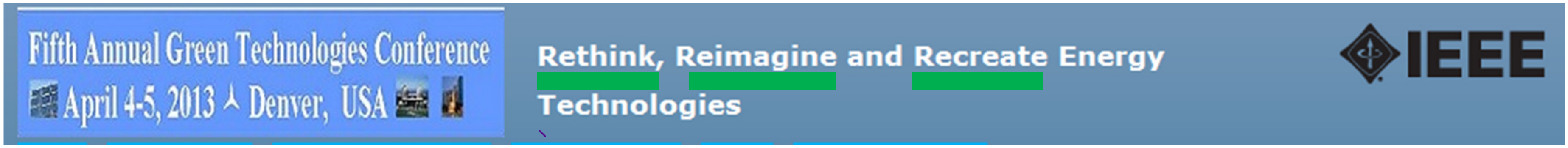
Airport Baggage Handling

A success story!



Links

RE: “Re …”



Reallocate
Rebound
Recall
Recover
Rededicate
Reevaluate
Refund
Regroup
Rehost

Reinforce
Rejuvenate
Rekindle
Release
Remember
Rendezvous
Reorient
Repurpose
Require

Rerun
Respond
Return
Reuse
Review
Reward
Re-examine
Reyoke
Rezone

“ Re” = “again”, “anew”, “back”
“Re” ← a prefix … a PRE … FIX

Organizational & application collaboration

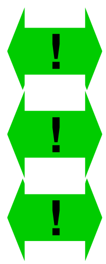
Flight & Systems Technology | **Boeing Research & Technology**

Systems & Electronics Technology

SYNERGY!

Terrestrial / Aerospace Energy Knowledge & Technology Transfer

www.tripadvisor.com)



www.aerospaceweb.org

Really!

Reflections & …

- **“First, do no harm.” (from the Physicians’ Oath)**
- **“If you want peace, work for justice.” (Pope Paul VI)**
- **“Without knowledge action is useless and knowledge without action is futile.” (Abu Bakr)**
- **“Action springs not from thought, but from a readiness for responsibility.” (Dietrich Bonhoeffer)**
- **“Where your talents and the needs of the world cross, there is your vocation.” (Aristotle)**
- **"You cannot do all the good the world needs, but the world needs all the good you can do." (Anonymous)**
- **“Do what you can, with what you have, where you are.” (Theodore Roosevelt)**

… Reminders

- **“We would like to live as we once lived, but history will not permit it.” (John F. Kennedy)**
- **“We did not inherit the land from our fathers. We are borrowing it from our children.” (Amish Proverb, per www.agros.org, 27 December 2010)**
- **"If you do not change direction, you may end up where you are heading." (Lao Tzu)**
- **“Twenty years from now you will be more disappointed by the things you didn't do than by the ones you did do. So throw off the bowlines, sail away from the safe harbor. Explore. Dream. Discover.” (Mark Twain)**

Thank you

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