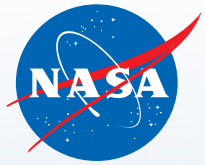
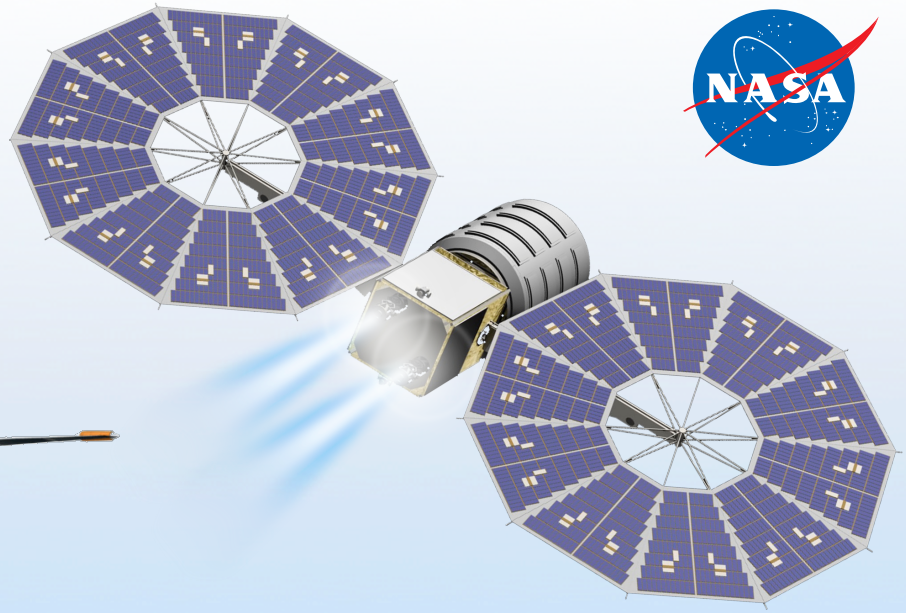



*"Anything one man can imagine, other men can make real."*

—Jules Verne, 1873

National Aeronautics and Space Administration



# NASA Propulsion and Power Technologies for Multiple Applications

**James M. Free**
Director, Glenn Research Center
Cleveland, Ohio

# Who is NASA Glenn?

## Lewis Field (Cleveland)

- 350 acres
- 1626 civil servants and 1511 contractors
- 66% of workforce are scientists and engineers

## Plum Brook Station (Sandusky)

- 6500 acres
- 11 civil servants and 102 contractors

# Glenn Awards and Recognition


## R&D 100 Awards (1966 to 2014) Glenn has 118, highest in the Agency in these disciplines

- Aeropropulsion systems
- In-space propulsion systems
- Aerospace communications
- Power and energy conversion

## Colliers

- Contributions to airline accident reduction (2008)
- Advance turboprop technology (1988)
- Thermal ice prevention systems (1946)

## Emmy

- Contributions to the Communications Technology Satellite (1987)

## Patents

- 43 to Glenn
- 38 to Glenn partners (fiscal years 2010 to 2013) as of July 25, 2013


## NASA Software of the Year

- 5 Glenn awards in the past 15 years

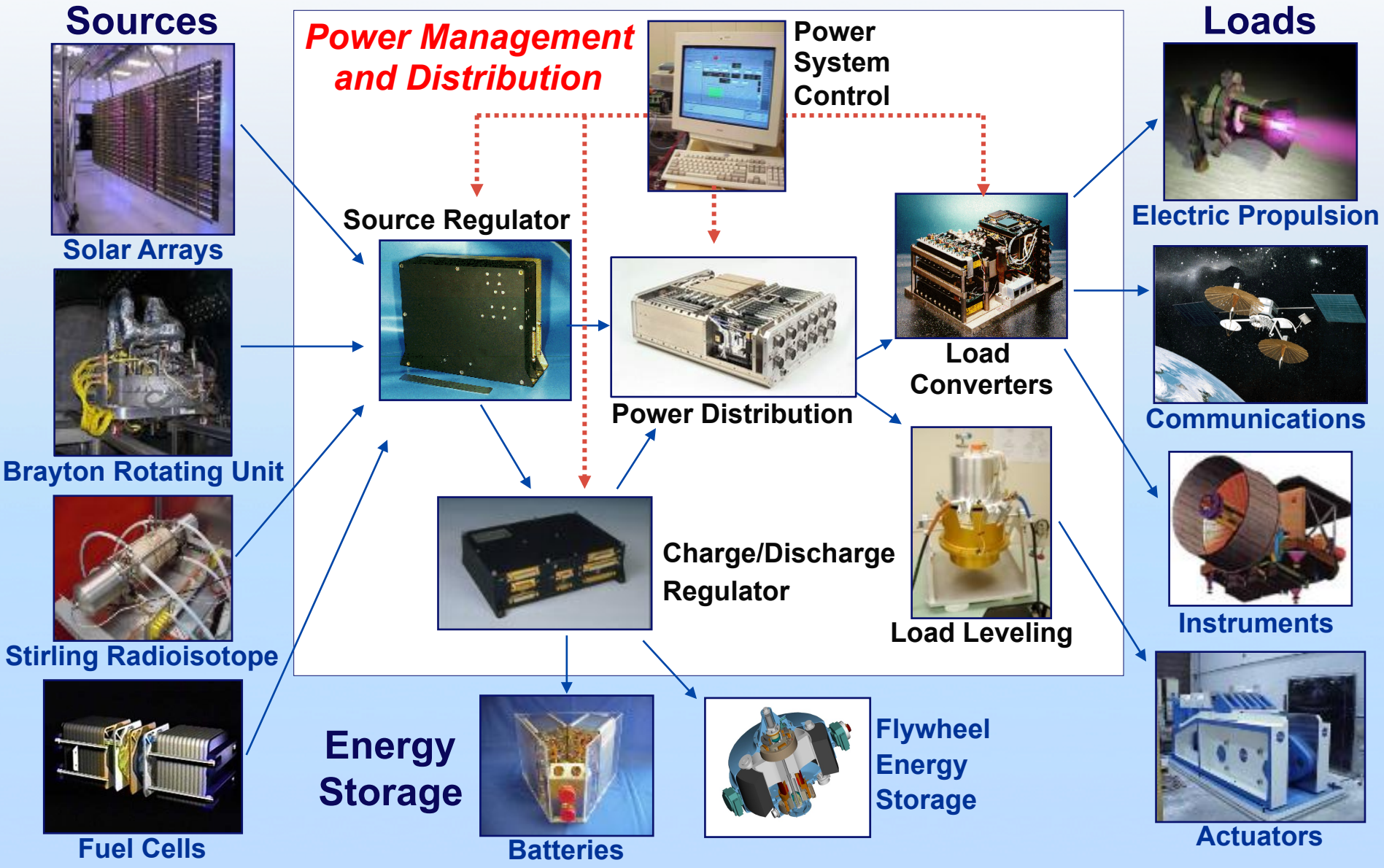

## FLCs

- Federal Laboratory Consortium (FLC) Excellence in Technology Transfer (2009 and 2011)

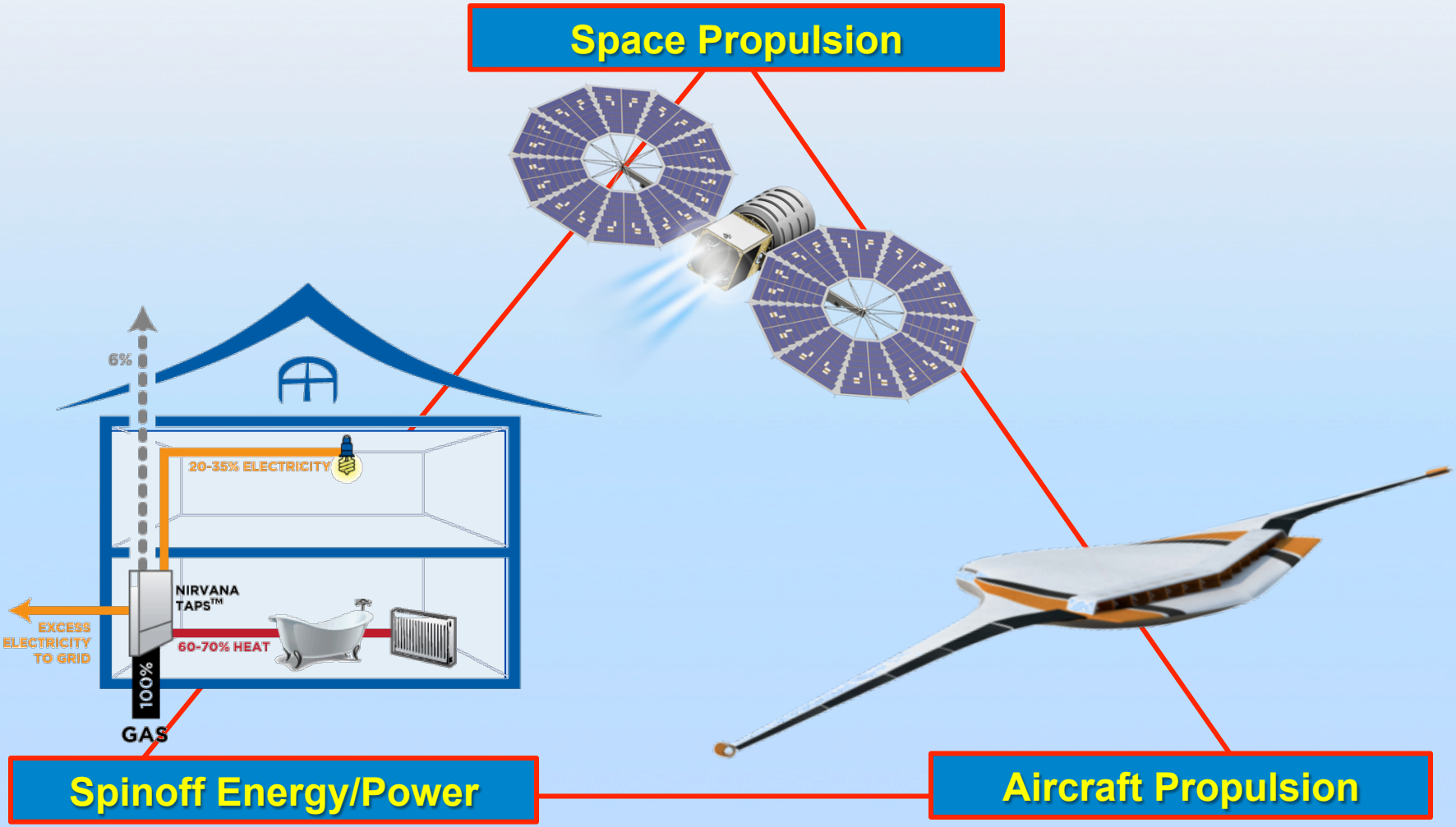
## Presidential Rank (2005 to 2011)

- 17 Meritorious
- 4 Distinguished

# Power System Elements—Broad Spectrum



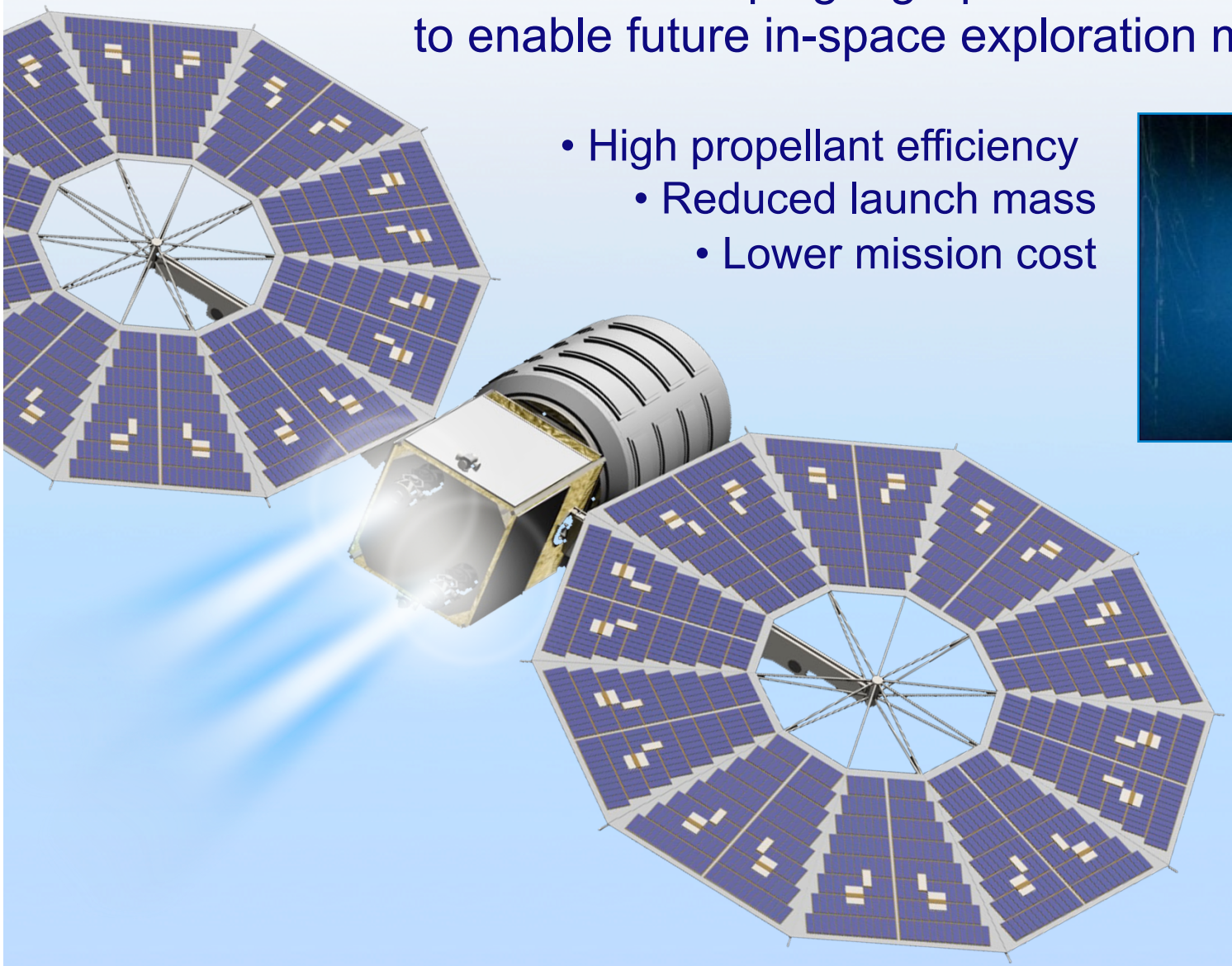
# Leveraging Glenn Aerospace and Energy Technology Synergies To Address Future Challenges

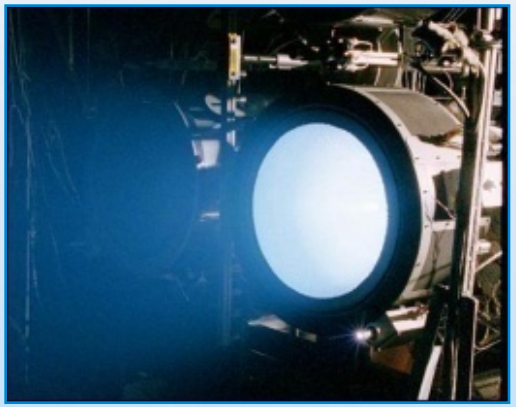


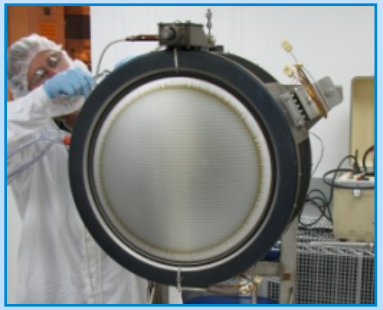
# Leverage Point #1—Solar Electric Propulsion (SEP)

NASA is developing high-performance SEP capability to enable future in-space exploration missions.

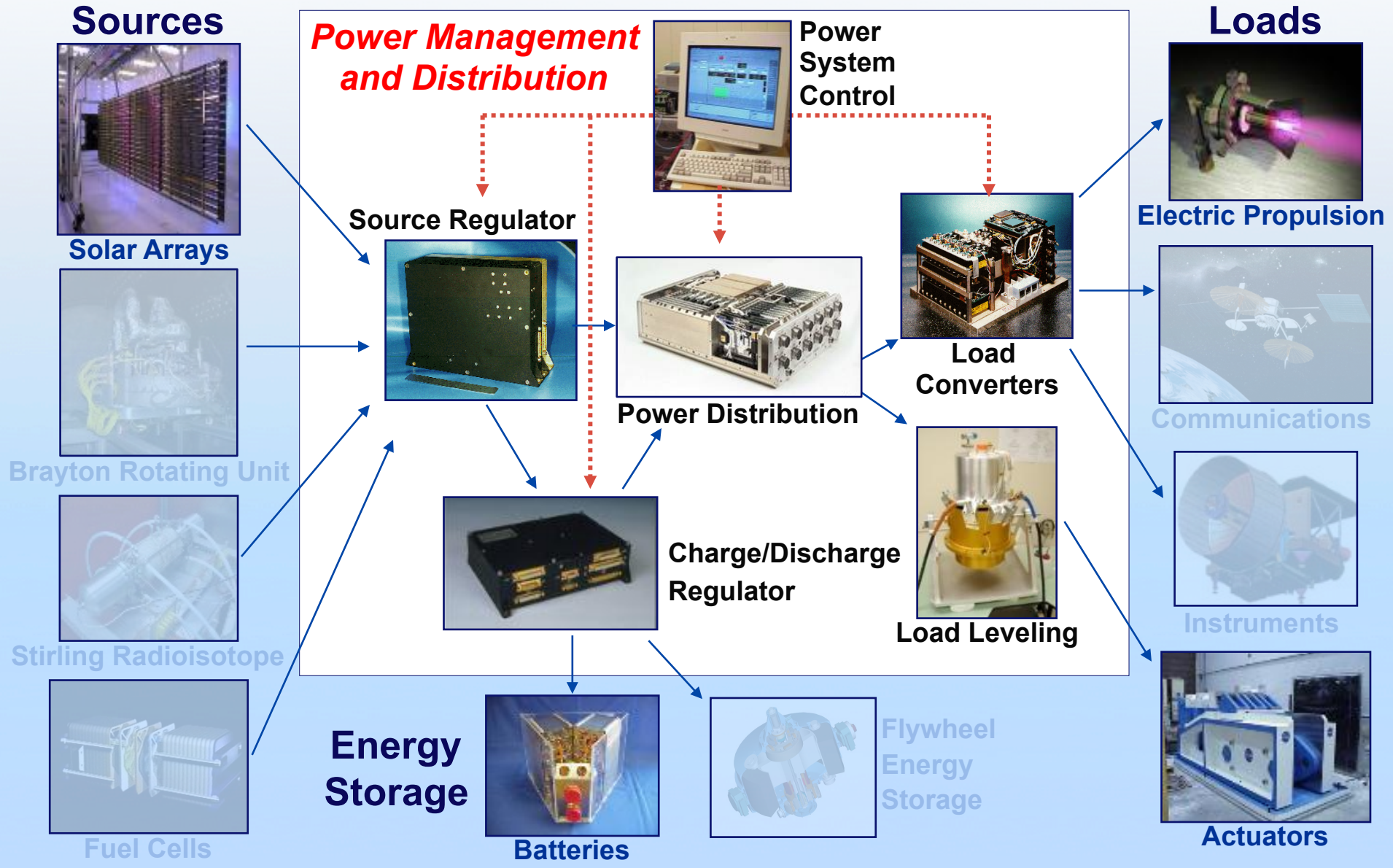
- High propellant efficiency
- Reduced launch mass
- Lower mission cost







# Power System Elements—Solar Electric Propulsion



# Leverage Point #2—
# Aircraft Turboelectric Propulsion

**Projected Timeframe for Achieving Technology Readiness Level (TRL) 6**

Power Level for Electrical Propulsion System

Spinoff Technologies Benefit More/All Electric Architectures:
- High-power density electric motors replacing hydraulic actuation
- Electrical component and transmission system weight reduction

- Turboelectric and hybrid electric distributed propulsion 300 PAX

>10 MW

5 to 10 MW

- Hybrid electric 737–150 PAX
- Turboelectric 737–150 PAX

2 to 5 MW class

- Hybrid electric 100 PAX regional
- Turboelectric distributed propulsion 150 PAX

1 to 2 MW class

- Hybrid electric 50 PAX regional
- Turboelectric distributed propulsion 100 PAX regional

kW class

- All-electric and hybrid-electric general aviation

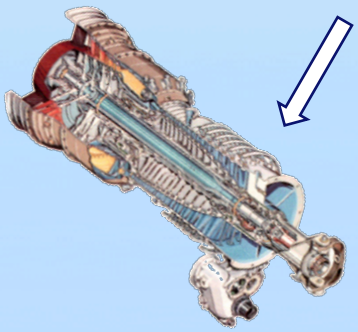
**(Power level for single engine)**

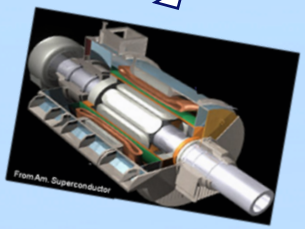
Today 10 Year 20 Year 30 Year 40 Year

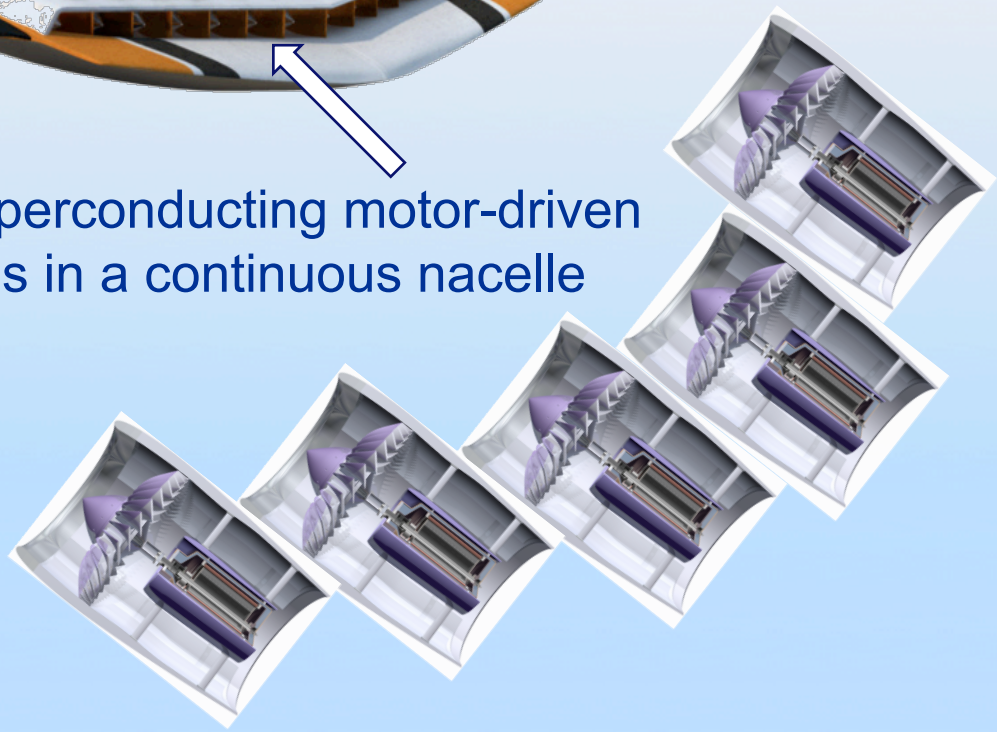
# Leverage Point #2—
# Aircraft Turboelectric Propulsion

Wingtip mounted superconducting turbogenerators

Superconducting motor-driven fans in a continuous nacelle

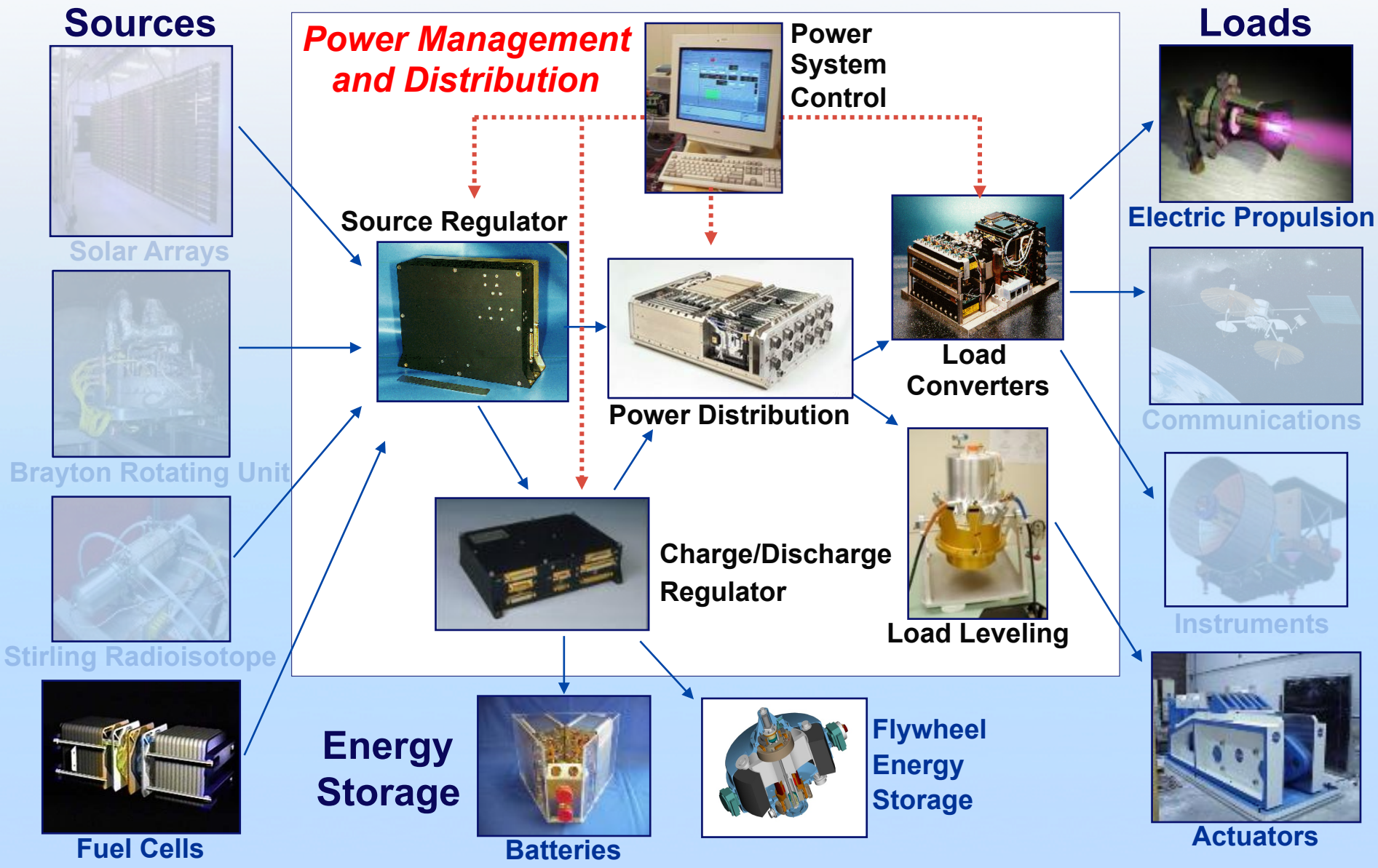




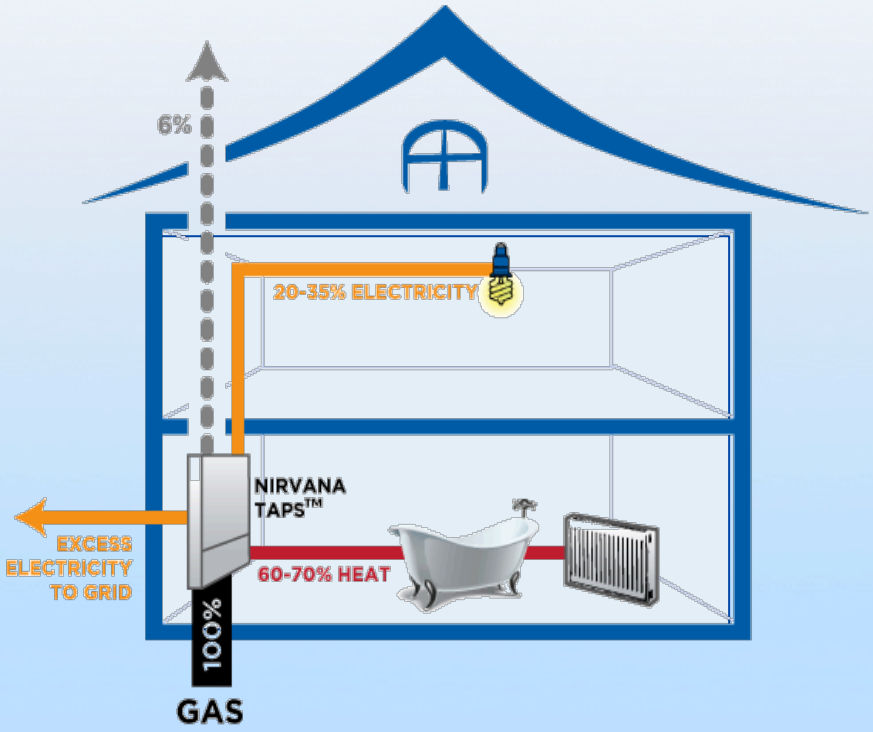



Power is distributed electrically from turbine-driven generators to motors that drive the propulsive fans.

# Power System Elements—Aircraft Turboelectric Propulsion



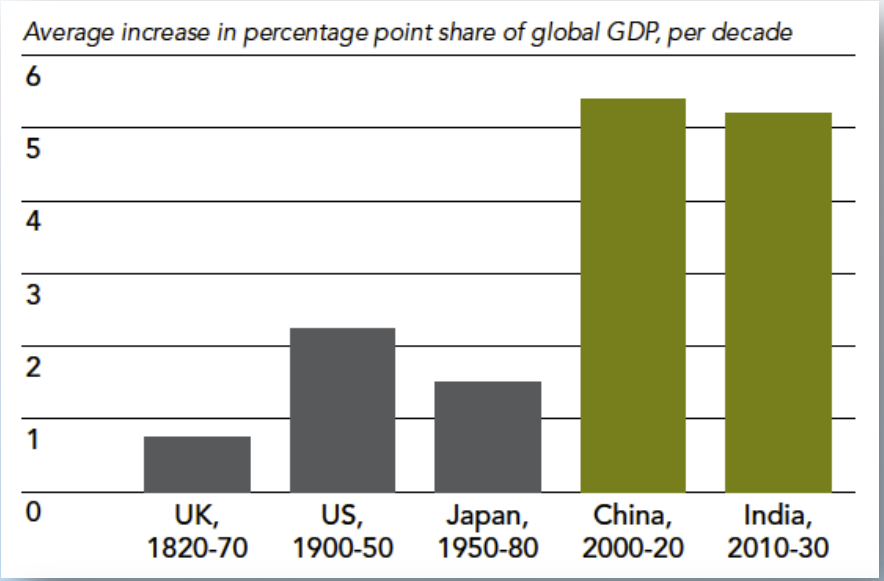
# Leverage Point #3—Energy/Power Spinoffs

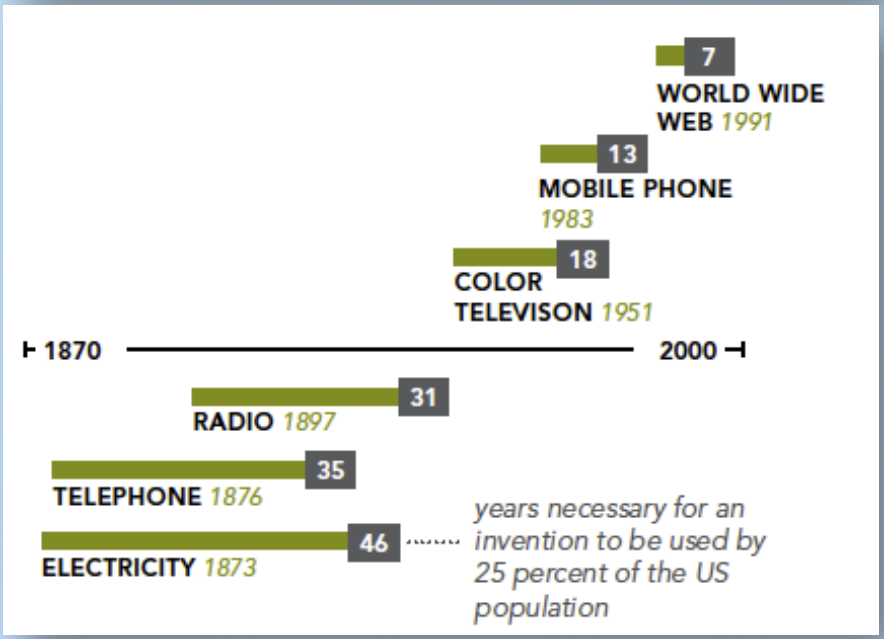



NASA is finding markets and applications for its technologies to address rising trends.

- Trends push demand for both aviation-related power technologies and non-aerospace.
- NASA has been tasked to enhance our technology transfer.
- NASA Glenn is focused on closing the loop on taxpayer investment.

# What do emerging global trends reveal?




China and India are growing economically at unprecedented rates.

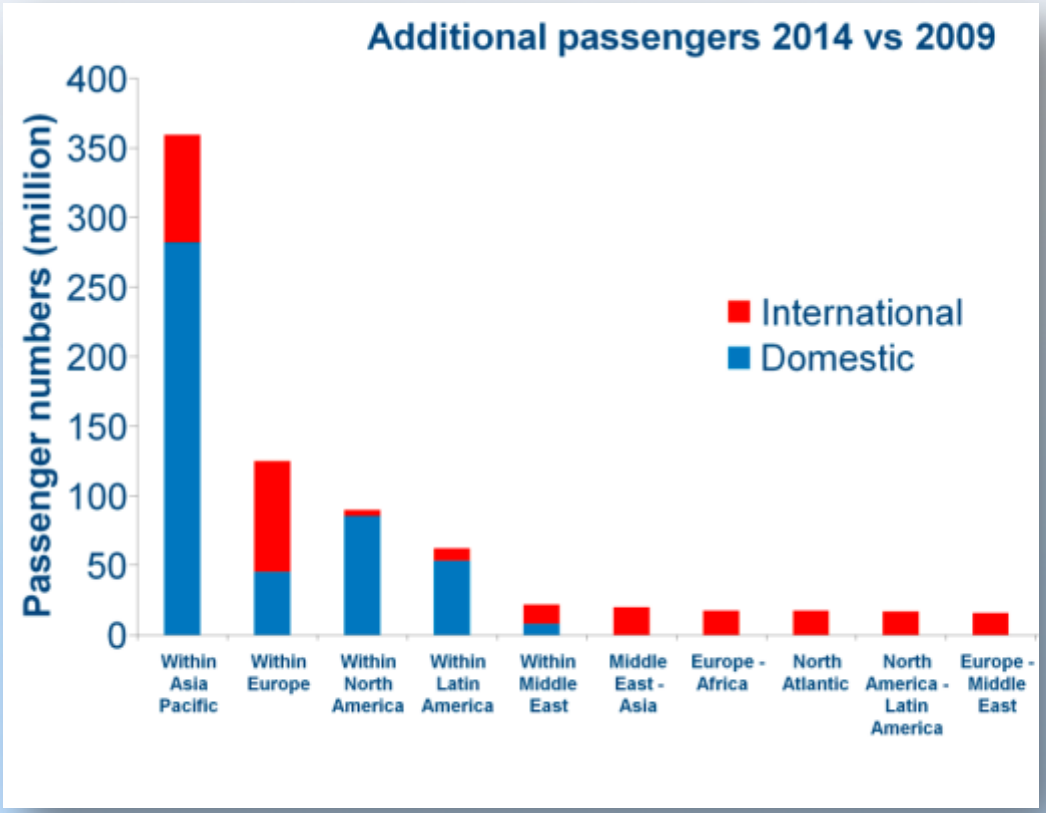
Asia-Pacific will have the largest middle class.

The world will be predominantly urban.

Revolutionary technology development and adoption are accelerating.

Source: National Intelligence Council

# Why are these trends important?




They drive global demand for air travel…

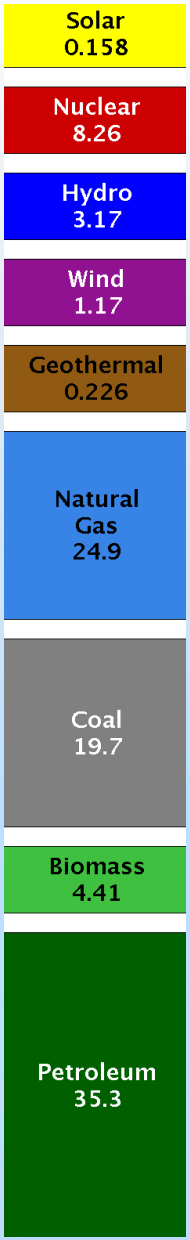
They drive expanding competition for high-tech manufacturing…

They drive“leapfrog” adoption of new technology and infrastructure…

They drive resource use, costs, constraints, and impacts…

They drive need for alternative energy technologies…

# Domestic Energy Use Trends




Source: LLNL 2012

## Energy sources:

- Fossil fuels (petroleum, natural gas, and coal) account for more than 80% of all U.S. energy production
- Nuclear provides about 8%
- The balance is renewable fuels (biomass, hydro, wind, geothermal, and solar)

## Energy consumption:

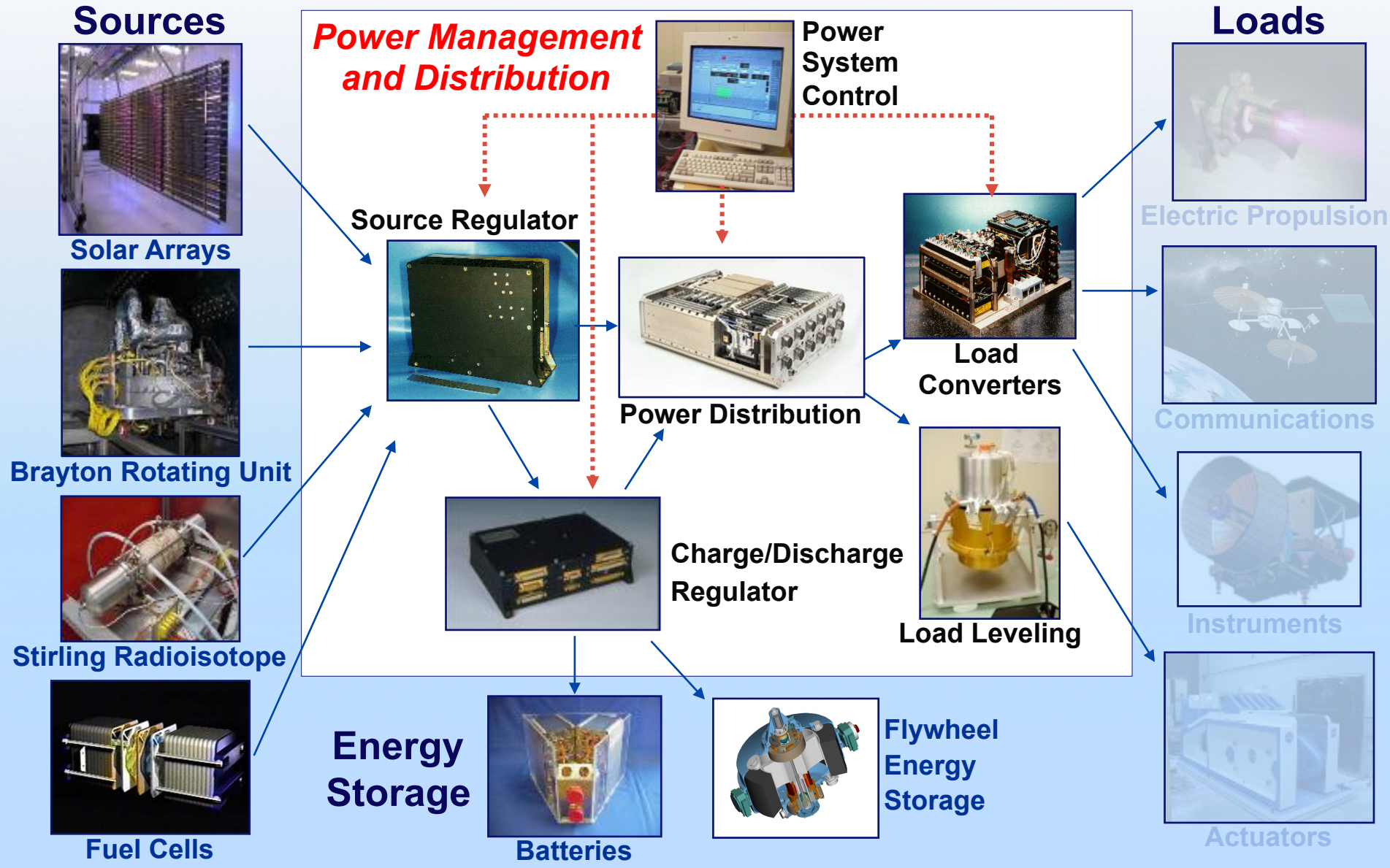
- ~40% of all U.S. energy is used for generating electricity
- ~28% is used in transportation
- The remainder is used for other residential, commercial, and industrial needs (e.g., heating)

## Energy efficiency:

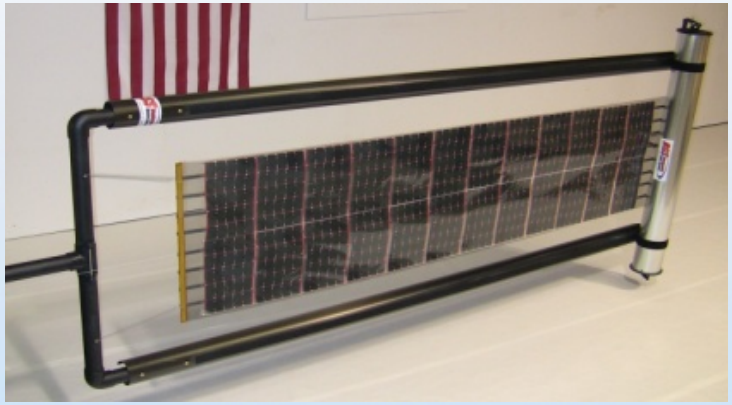
- More than half of all energy produced is rejected due to inefficiencies (e.g., waste heat)

***NASA can contribute to changing these trends.***

# Power System Elements—Energy/Power Spinoffs



# NASA-Driven Energy Advancements: Renewables



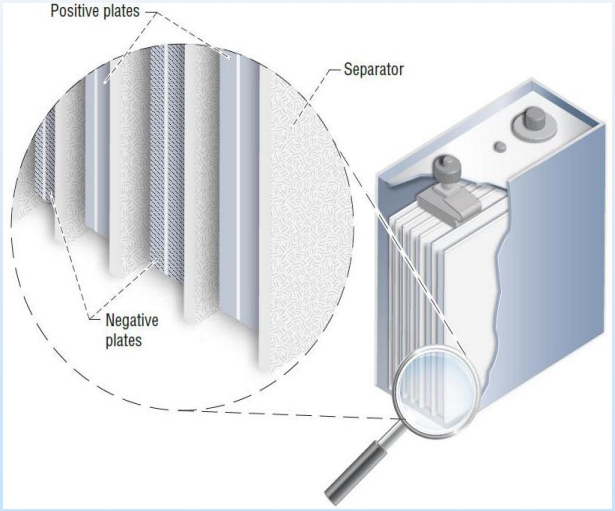
***Solar: Higher Performance and More Applications***

- Improved solar cell performance, measurement, and calibration
- Higher efficiency, lighter weight, and flexible solar cells
- Improved design and fabrication techniques
- Solar array technology advancements

***Wind: Enhanced Efficiency, Capacity, and Siting***

- Aeroelasticity analysis and vibration reduction
- Advanced rotating components and tribology research
- Ice accretion testing, analysis, and mitigation
- Improved composite blade manufacturing

# NASA-Driven Energy Advancements: Storage




### *Batteries: Safer, Better, and Lighter*

- Safer high-performance Li-ion chemistries
- Compact, lighter weight Li-ion architectures
- Performance advancements using carbon nanotubes, metal and metal oxide nanocatalyst processes, and engineered ceramic microstructures

### *Storage and Fuel Cells: Longer Life and More Reliable*

- Advanced flywheel systems for energy storage and frequency regulation
- Compact, high-power, and low-cost architectures
- Improvements in balance of plant components via life testing and evaluation
- Basic materials and electrochemistry research

# NASA-Driven Energy Advancements: Controls and Alternatives

***Power Management: Smart, Robust, and Resilient***

- Intelligent power systems
- Long-term autonomous operation
- Hierarchical control
- Distributed algorithm computation
- Agent-based software

***Alternatives: Improved Efficiency, Integration, and Flexibility***

- Higher efficiency energy conversion (e.g., Stirling, Brayton, motors, and electronics)
- Integration of renewable sources
- Improved combustion modeling, simulation, and testing
- Alternative fuels research, testing, and evaluation

# Moving Forward

- Technologies to advance power and propulsion
  - Exist
  - Are highly advanced
  - Have multiple applications

- NASA Glenn drives research, technology, and systems with power and propulsion at our core.

***NASA Glenn is Leveraging Aerospace and Energy Technology Synergies To Address Future Challenges.***