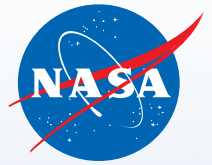
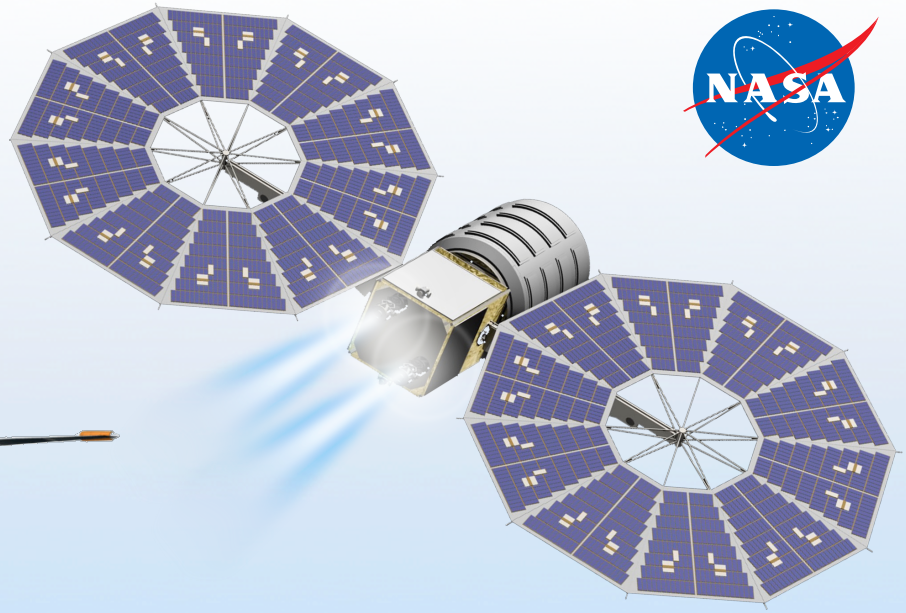


"Anything one man can imagine, other men can make real."

—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

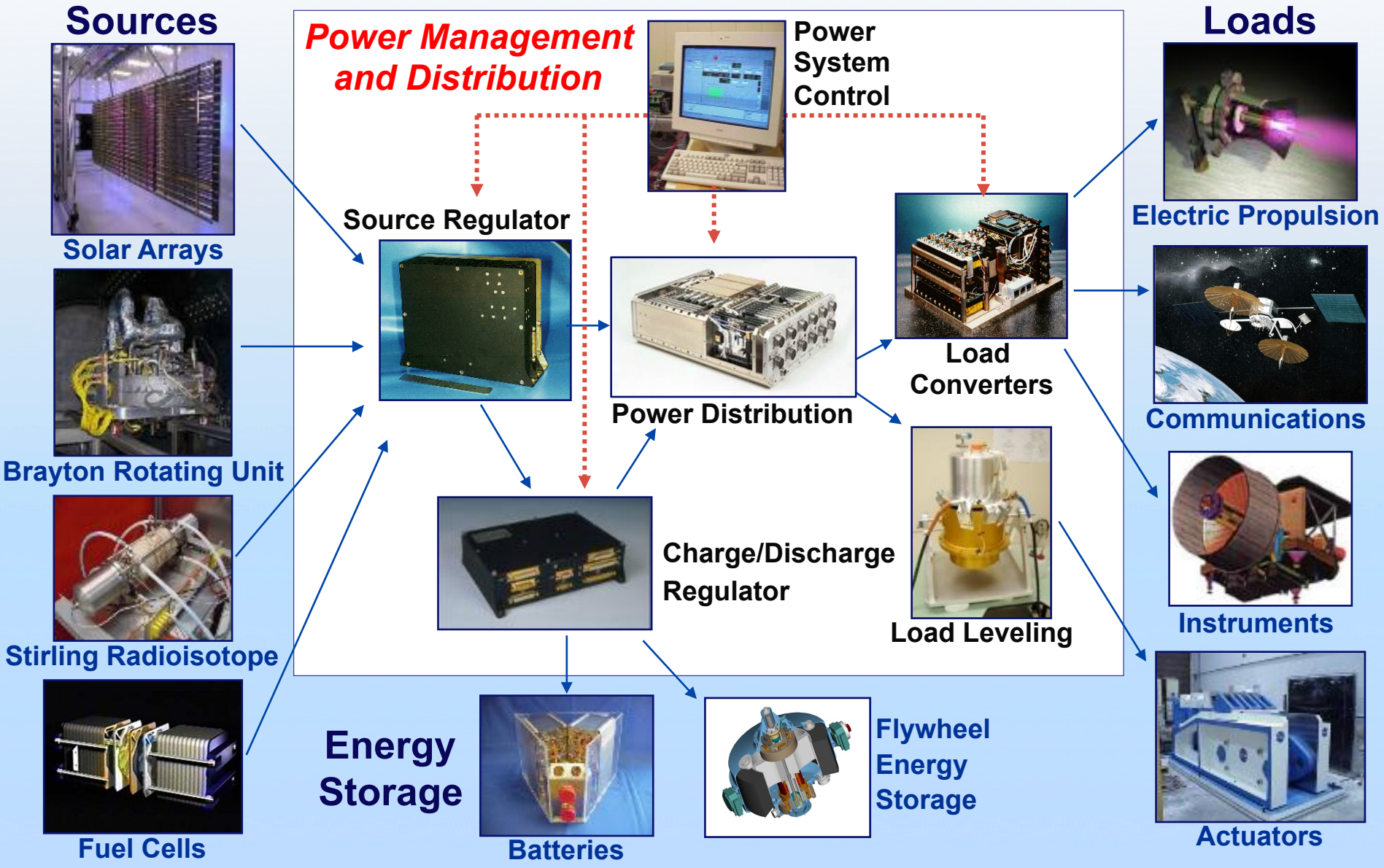
FLCs

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

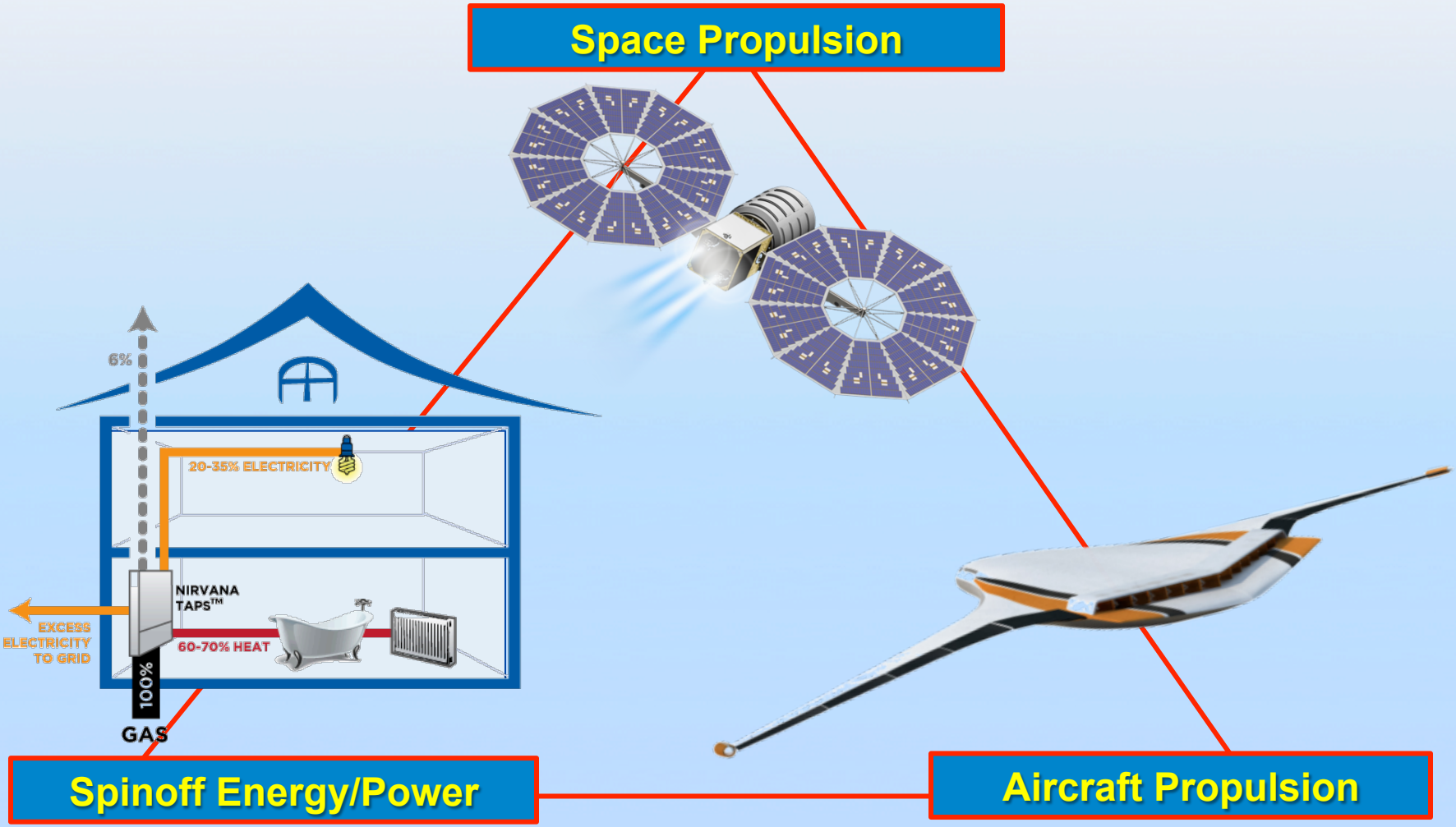
Presidential Rank (2005 to 2011)

- 17 Meritorious
- 4 Distinguished

Power System Elements—Broad Spectrum



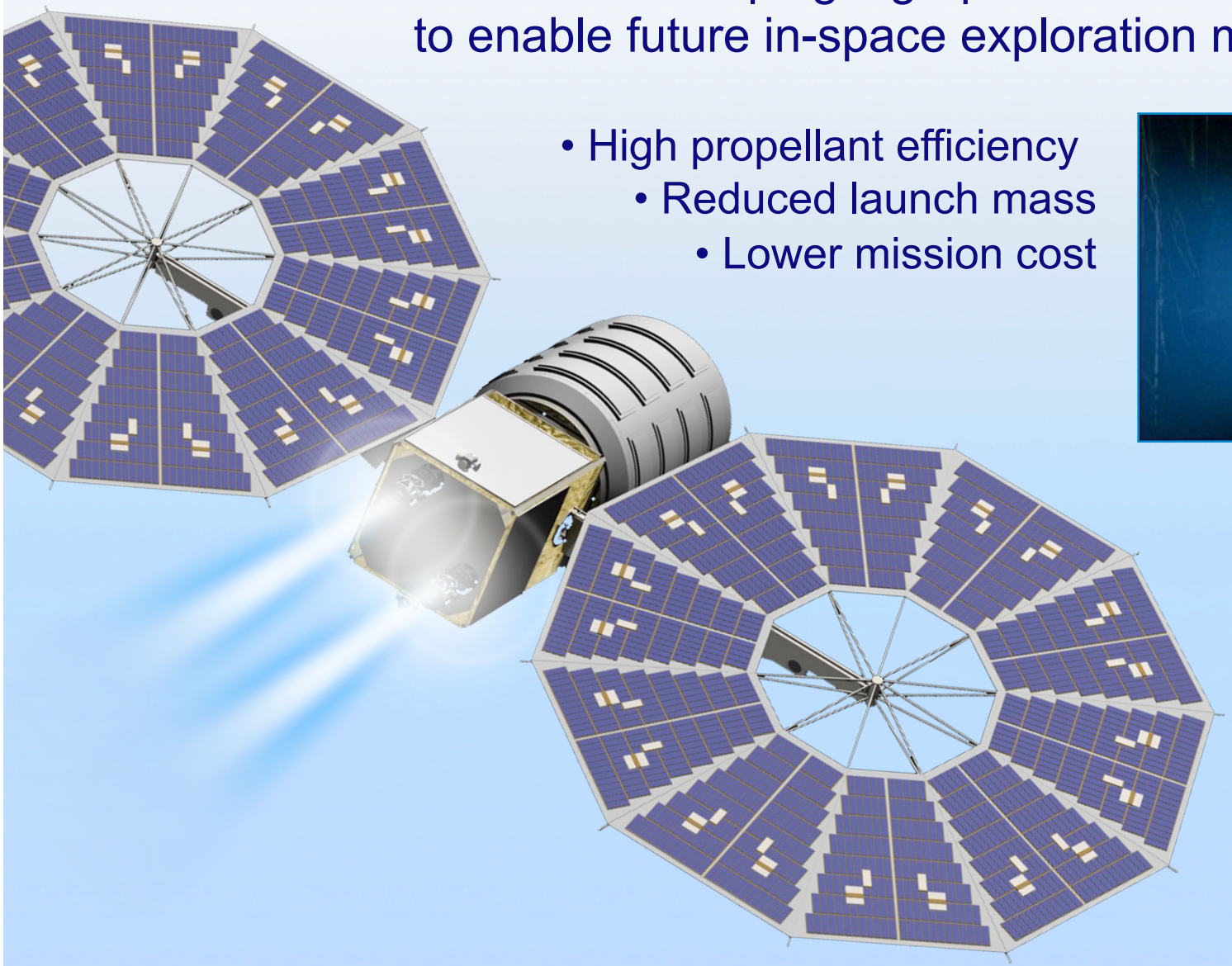
Leveraging Glenn Aerospace and Energy Technology Synergies To Address Future Challenges

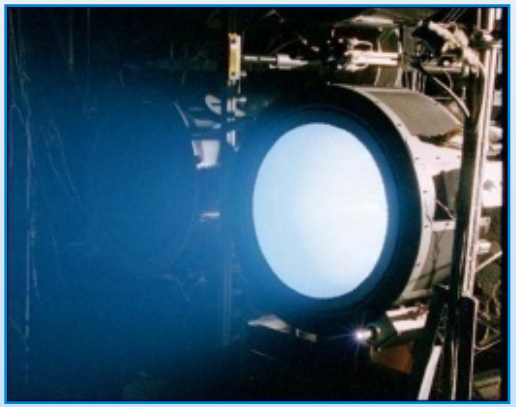


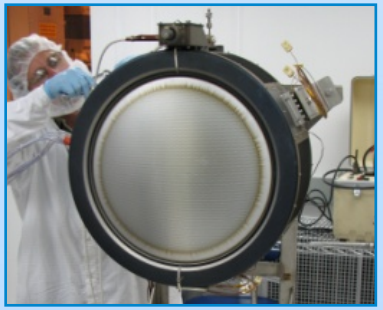
Leverage Point #1—Solar Electric Propulsion (SEP)

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

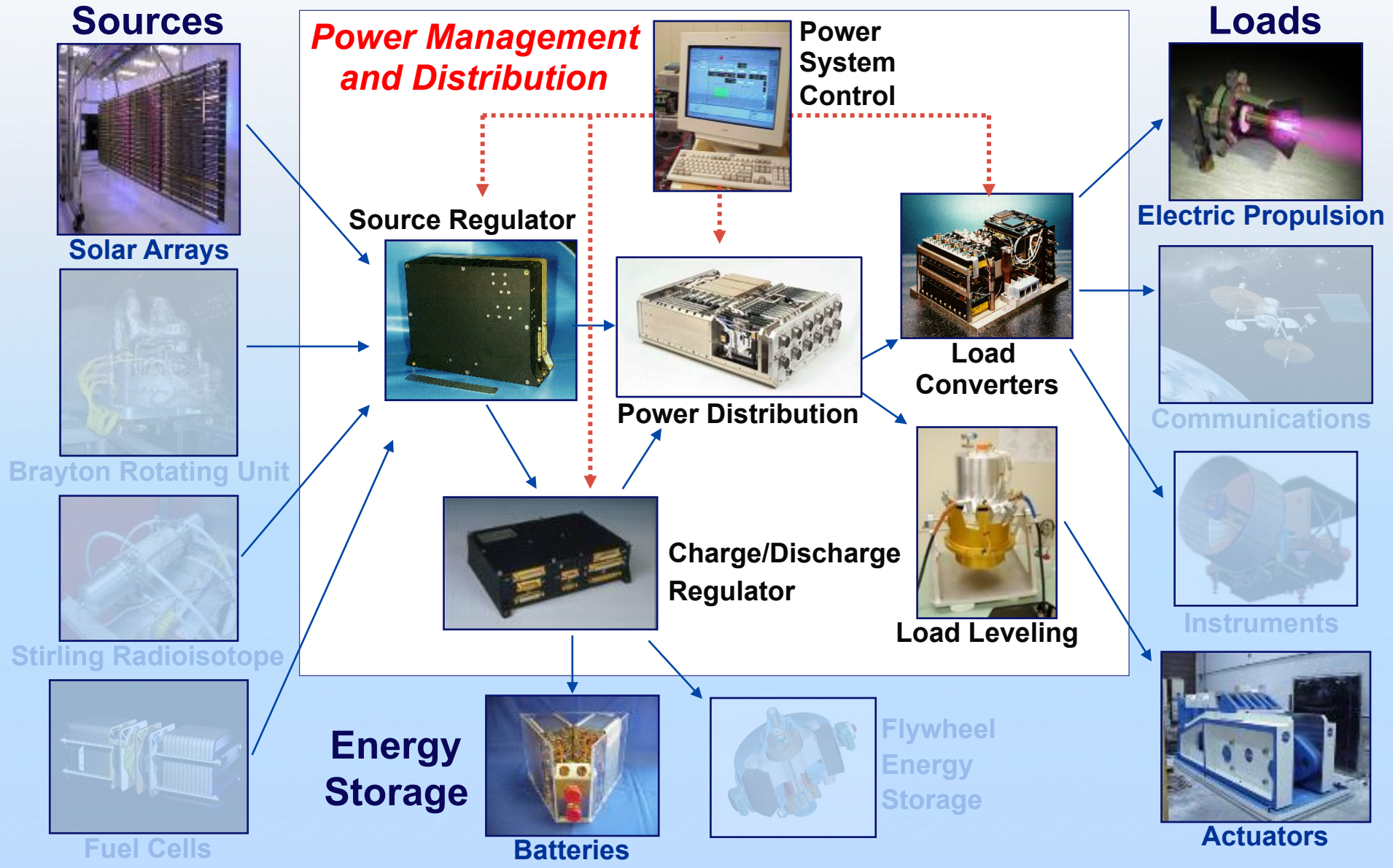
- High propellant efficiency
- Reduced launch mass
- Lower mission cost







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

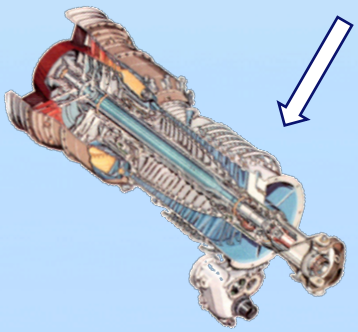
(Power level for single engine)

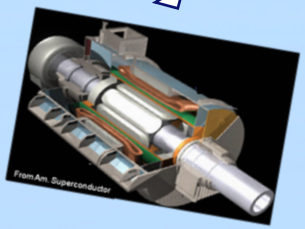
Today 10 Year 20 Year 30 Year 40 Year

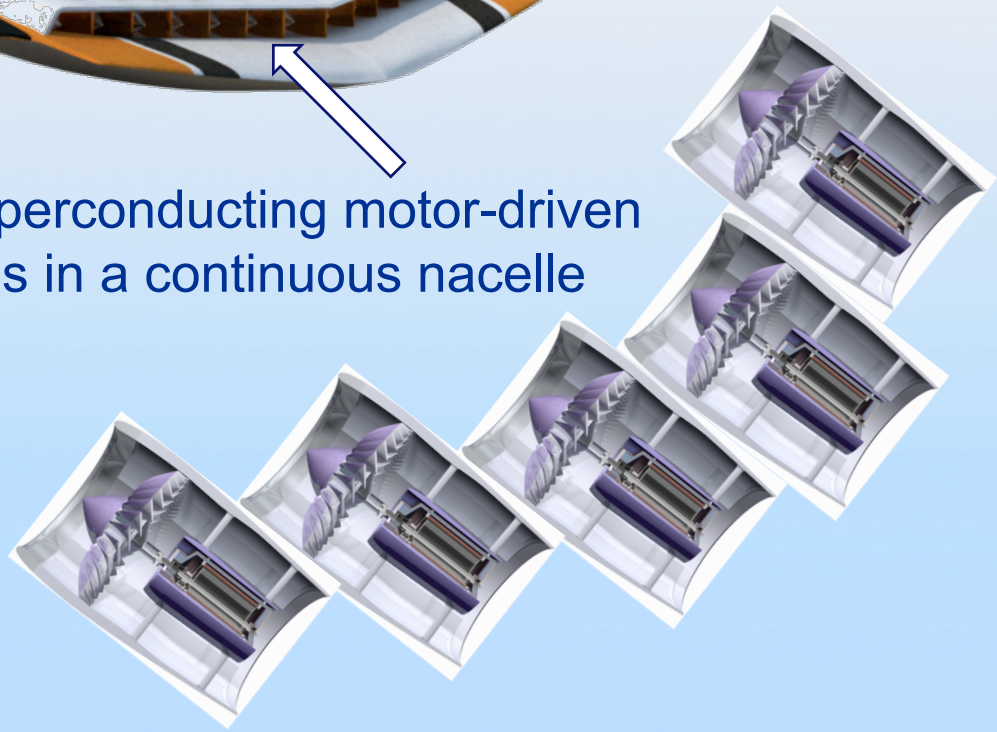
Leverage Point #2—
Aircraft Turboelectric Propulsion

Wingtip mounted superconducting turbogenerators

Superconducting motor-driven fans in a continuous nacelle

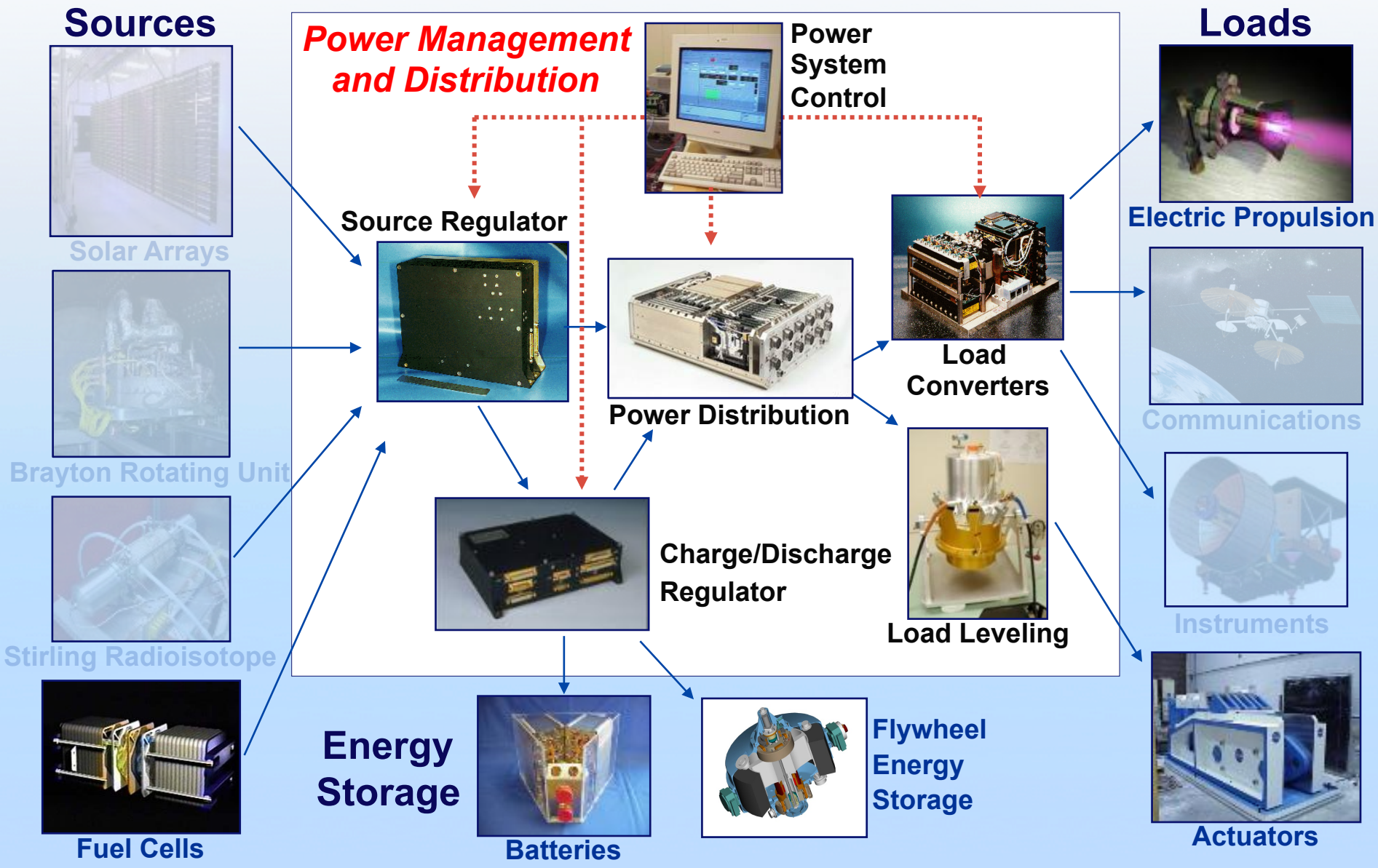




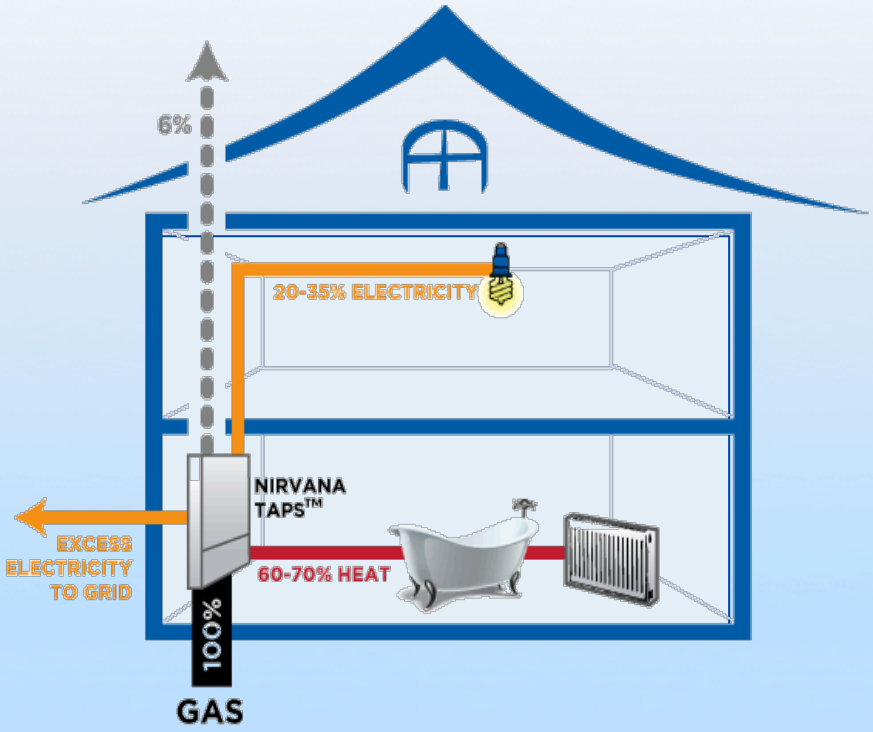


Power is distributed electrically from turbine-driven generators to motors that drive the propulsive fans.

Power System Elements—Aircraft Turboelectric Propulsion



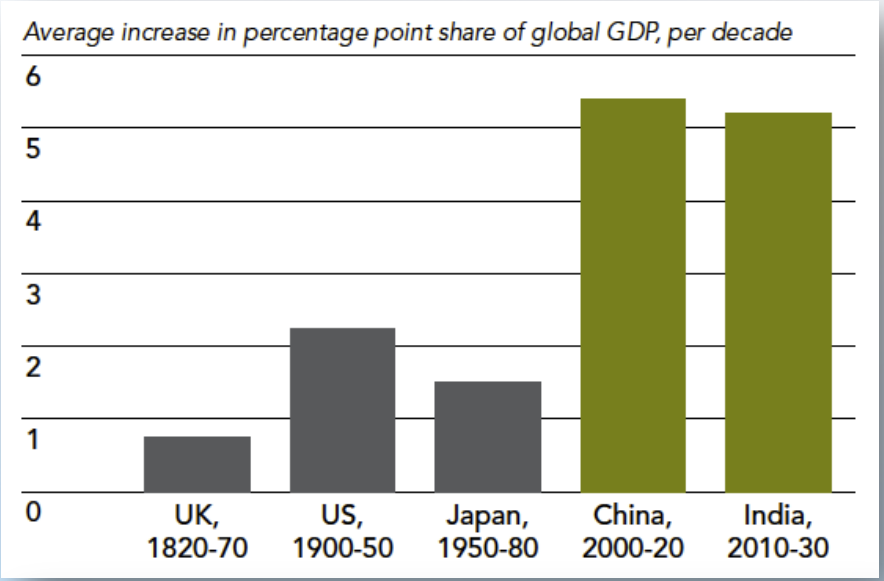
Leverage Point #3—Energy/Power Spinoffs

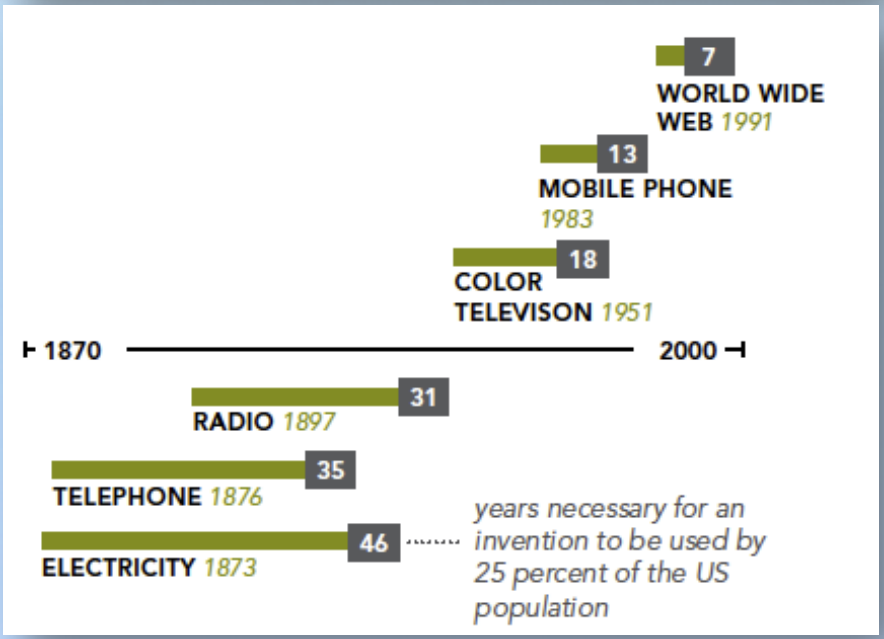


NASA is finding markets and applications for its technologies to address rising trends.

- 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.

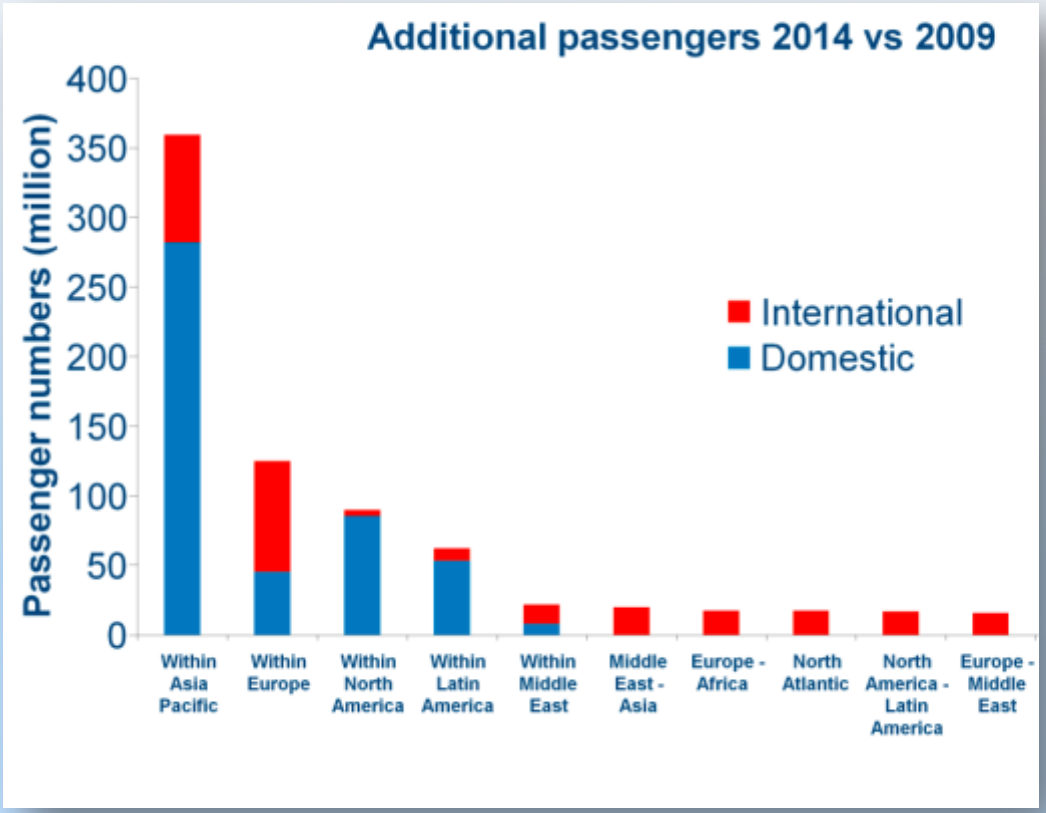
Asia-Pacific will have the largest middle class.

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…

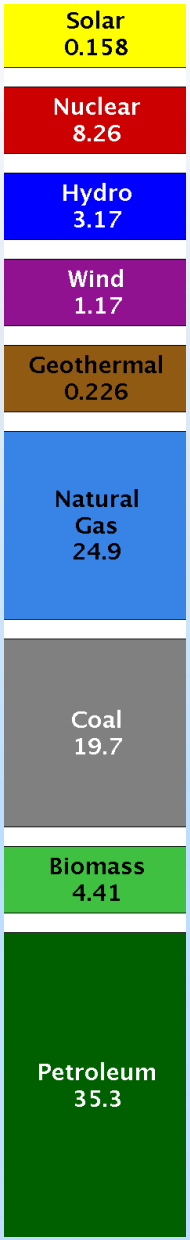
They drive expanding competition for high-tech manufacturing…

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:

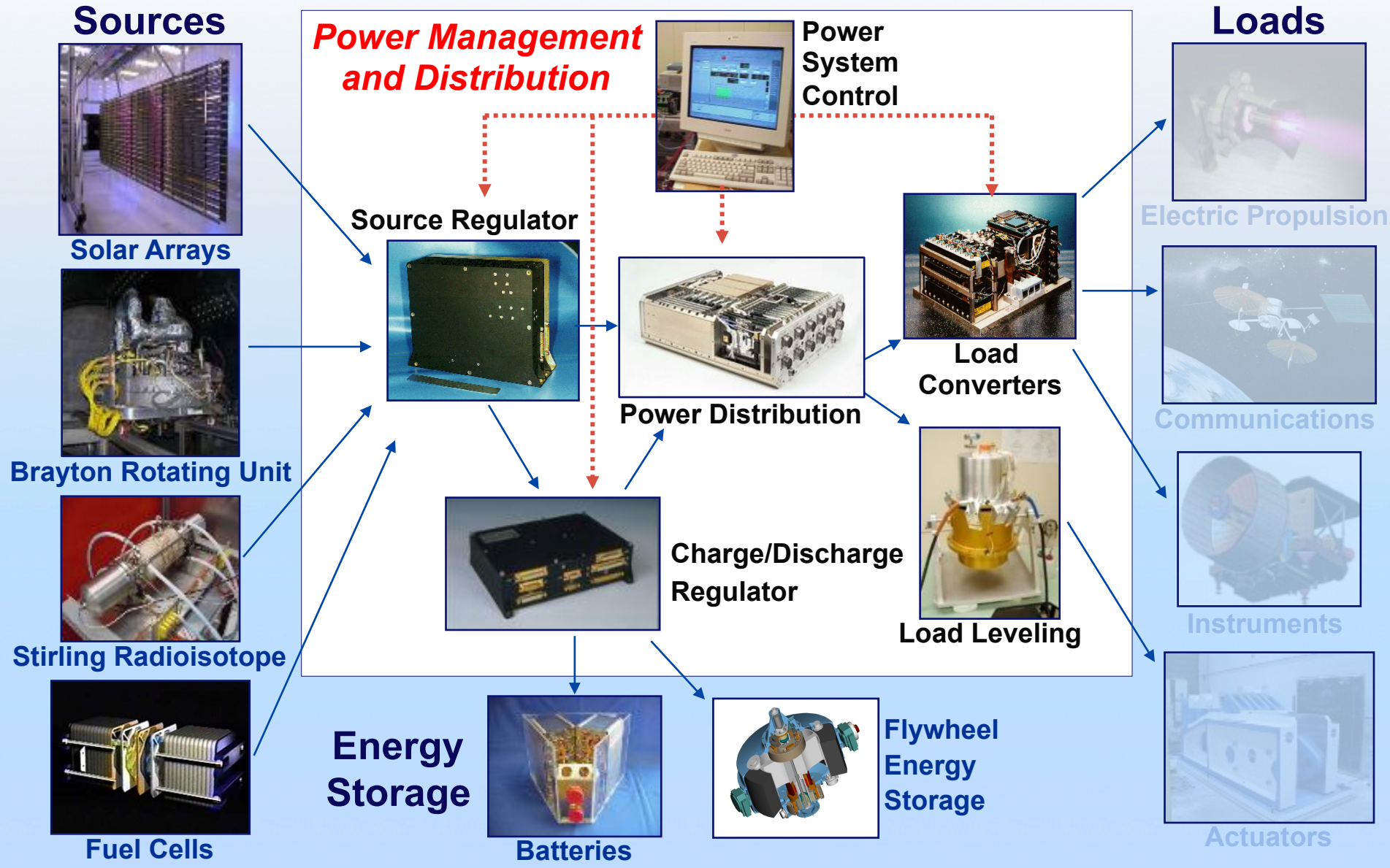
- ~40% of all U.S. energy is used for generating electricity
- ~28% is used in transportation
- The remainder is used for other residential, commercial, and industrial needs (e.g., heating)

Energy efficiency:

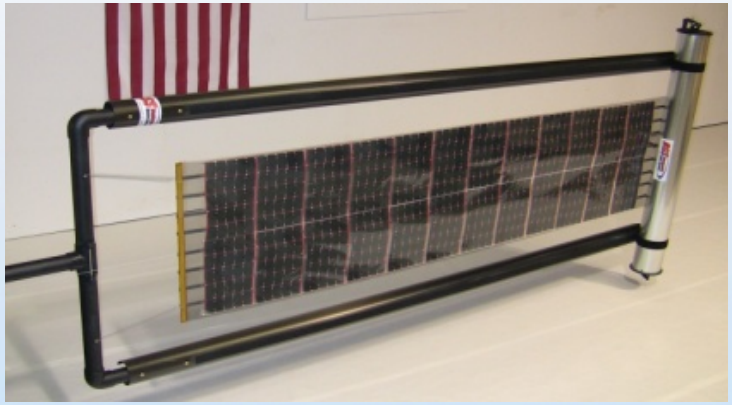
- More than half of all energy produced is rejected due to inefficiencies (e.g., waste heat)

NASA can contribute to changing these trends.

Power System Elements—Energy/Power Spinoffs



NASA-Driven Energy Advancements: Renewables



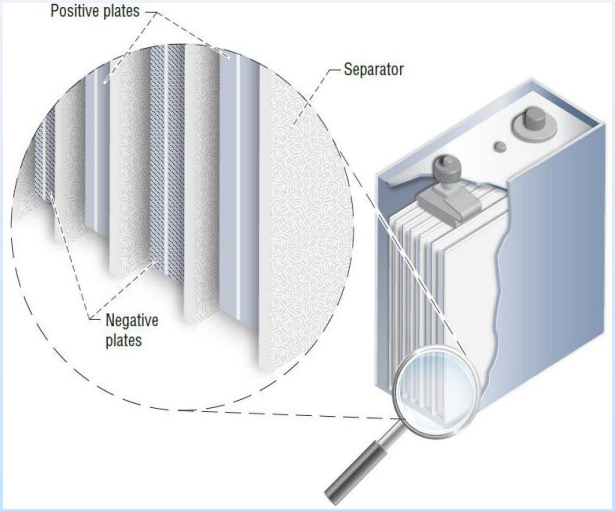
Solar: Higher Performance and More Applications

- 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.