Smart Grid Development Issues for Terrestrial and Space Applications

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The development of the so called "Smart Grid" has as many definitions as individuals working in the area. Based on the technology or technologies that are of interest, be it high speed communication, renewable generation, smart meters, energy storage, advanced sensors, etc. they can become the individual defining characteristic of the "Smart Grid." In reality the smart grid encompasses all of these items and quite at bit more. This discussion attempts to look at what the needs are for the grid of the future, such as the issues of increased power flow capability, use of renewable energy, increased security and efficiency and common power and data standards. It also shows how many of these issues are common with the needs of NASA for future exploration programs. A common theme to address both terrestrial and space exploration issues is to develop micro-grids that advertise the ability to enable the "load leveling of large power generation facilities. However, for microgrids to realize their promise there needs to a holistic systems approach to their development and integration. The overall system integration issues are presented along with potential solution methodologies.

Smart Grid Development Issues for Terrestrial and Space Applications

University Clean Energy Alliance of Ohio
Building and Sustaining Partnerships

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Discussion Topics

- Background
- Developmental Vision
- Smart Grid Vision for Terrestrial and Space Applications
- Smart Grid Demonstrator
- Technology Needs
- Wrap Up

National Aeronautics and Space Administration

Glenn Research Center Power Systems Technologies

Power technology development in sources, storage, distribution, analysis, test and management from concept to flight

Power Systems Architecture and Engineering

System Power Analysis for Capability Evaluation

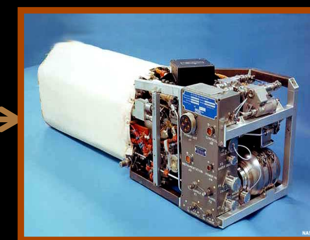
SPACE

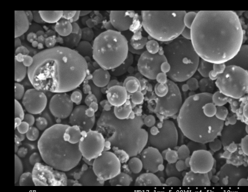
A Computer Code Developed at NASA Glenn Research Center, Cleveland, Ohio

Design, Analysis, Test and Verification

Energy Storage

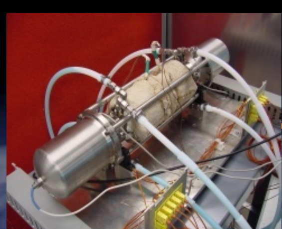
Fuel Cells



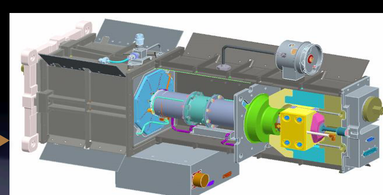


Batteries

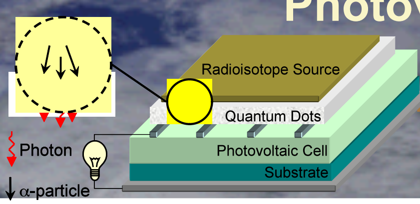
Power Generation

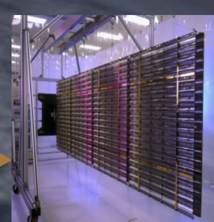


Stirling Convertors

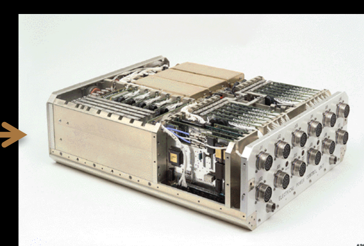


Photovoltaic's



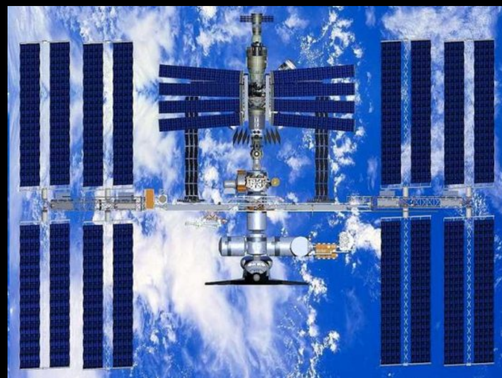


Power Management and Distribution

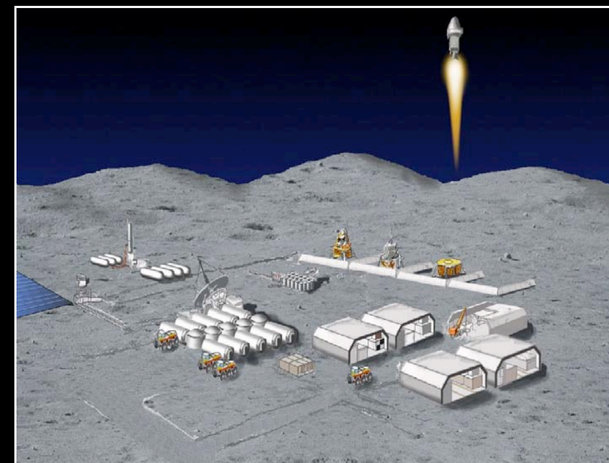


Power Controllers

What is NASA’s Interest In Smart Grid?



ISS Automation

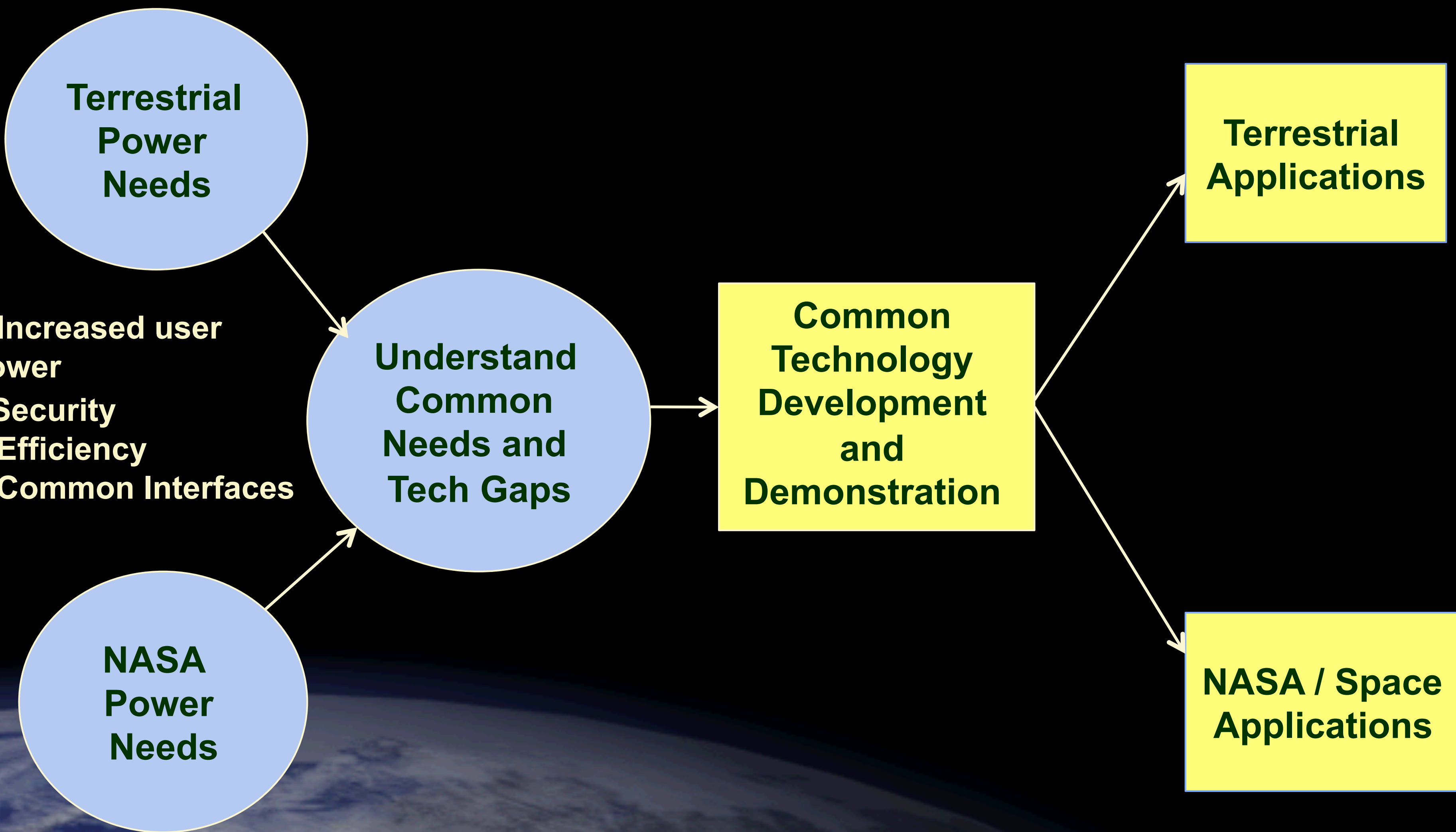


Planetary Surface Power Systems

Facility Sustainability

NASA’s interest is in the development of technologies that enable the Smart Grid

Developmental Vision



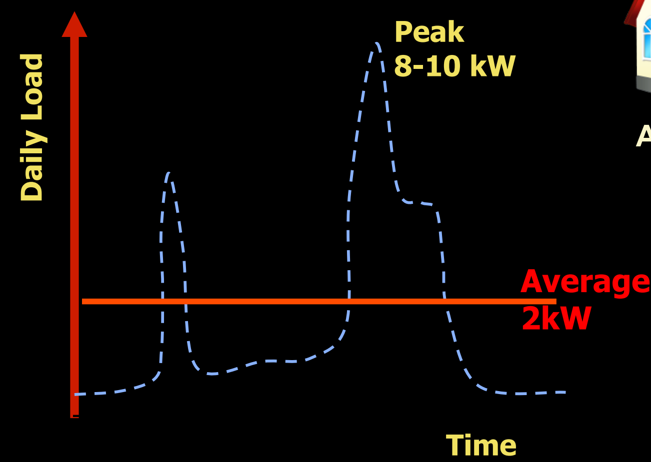
- Increased user power
- Security
- Efficiency
- Common Interfaces

Smart Grid Vision for Terrestrial and Space Applications

Advanced Power Grid Needs

- Accommodate the increase in user power requirements
  - New conventional power generating capability
  - Renewable generation
  - Distributed energy storage
  - Incorporate intelligent energy islands
- Security
  - Improve grid observability
  - Rapid fault detection and reconfiguration to minimize brownouts / blackout
  - Operator aids for intelligent power decision making
  - Failure diagnostics and prognostics for power components
- Efficiency
  - Provide peaking power while minimizing contingency -- (spinning) reserve
  - Incorporate user decision making
  - Load management under variable load demand & constrained capacity
  - Optimize generation and distribution assets
- Common power / data interface standards

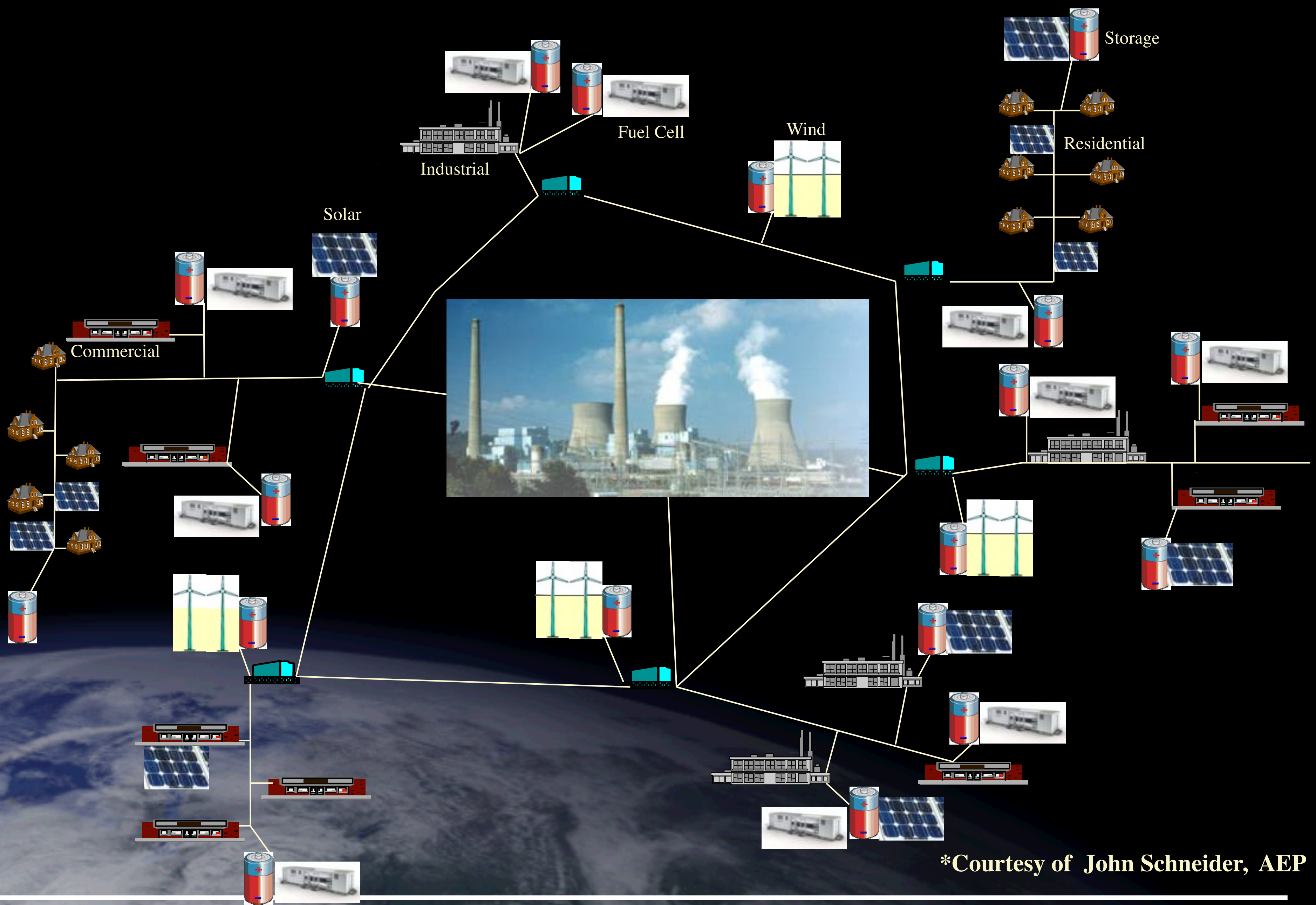
Key Need: Meet peak power requirements from generation to load at all times



Average House

Solution: Introduce distributed generation & storage to enable base load operation of grid assets

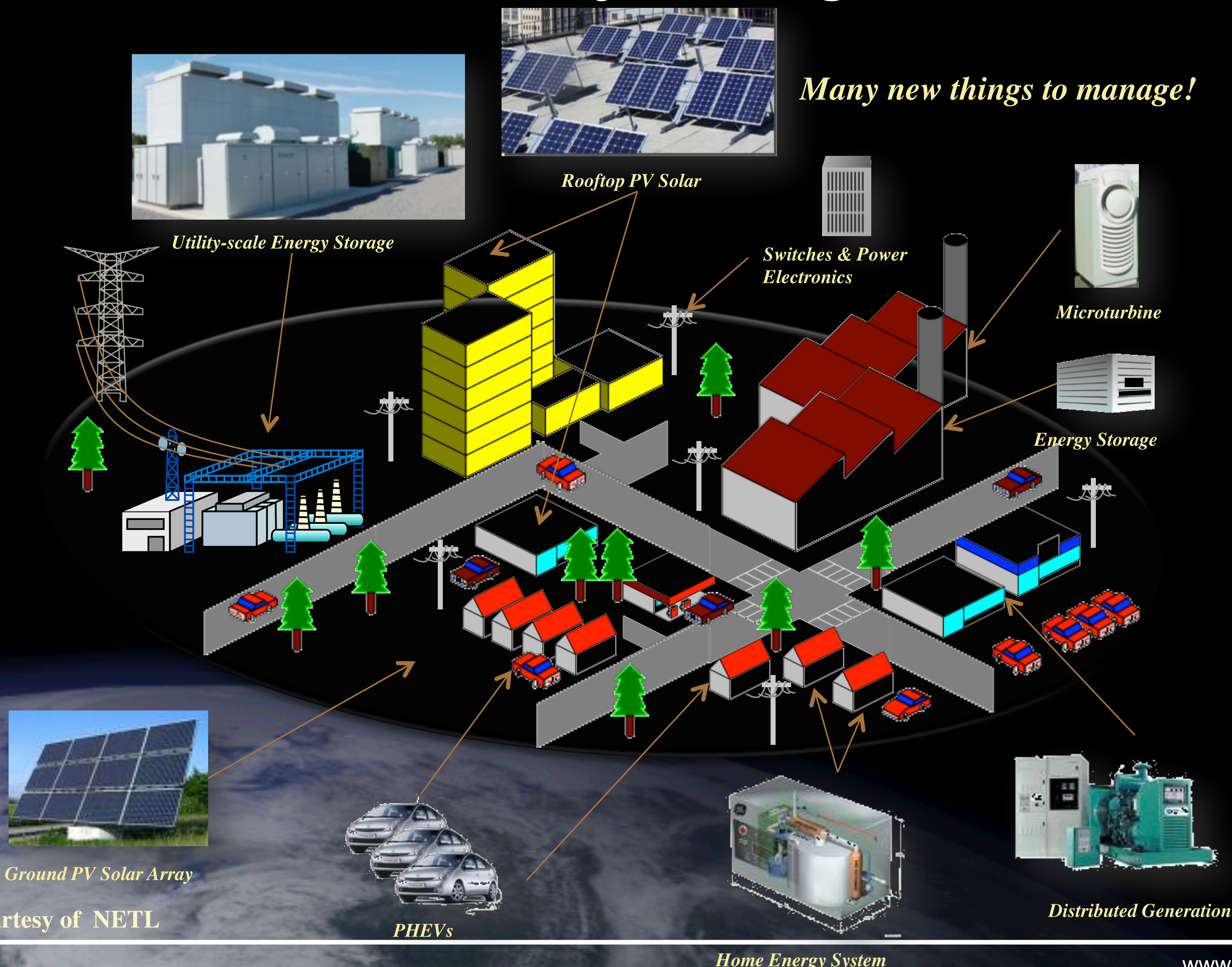
…the Grid of the Future?*



*Courtesy of John Schneider, AEP

National Aeronautics and Space Administration

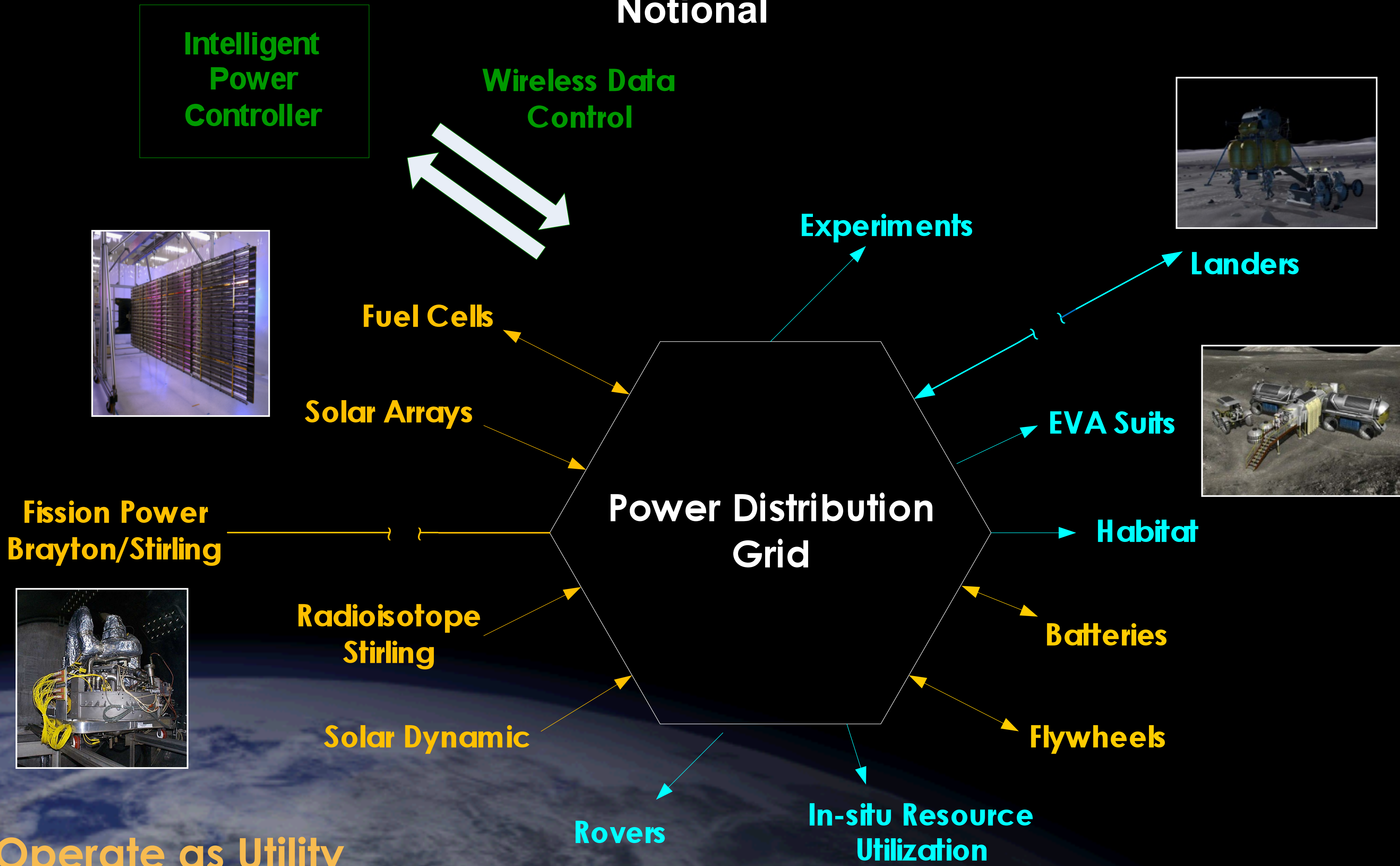
Community Micro-grid*



* Courtesy of NETL

Utility Based Surface Power System

Notional



Operate as Utility

International Space Station

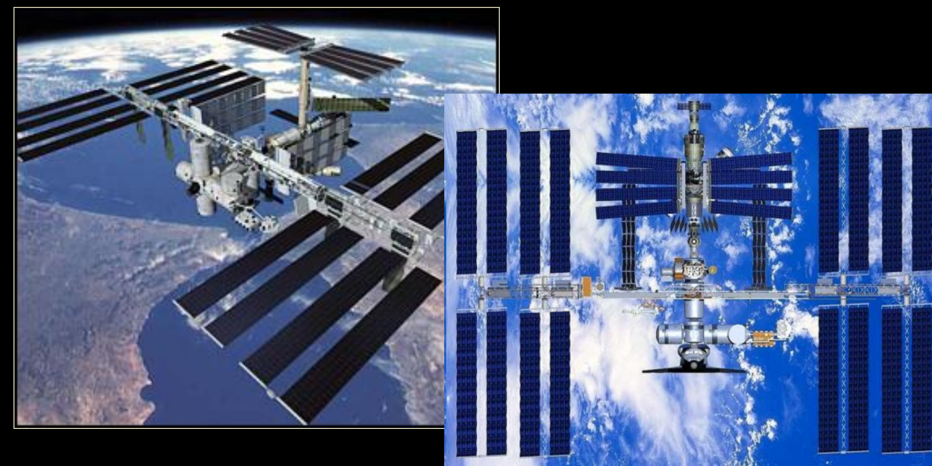
Power System Characteristics

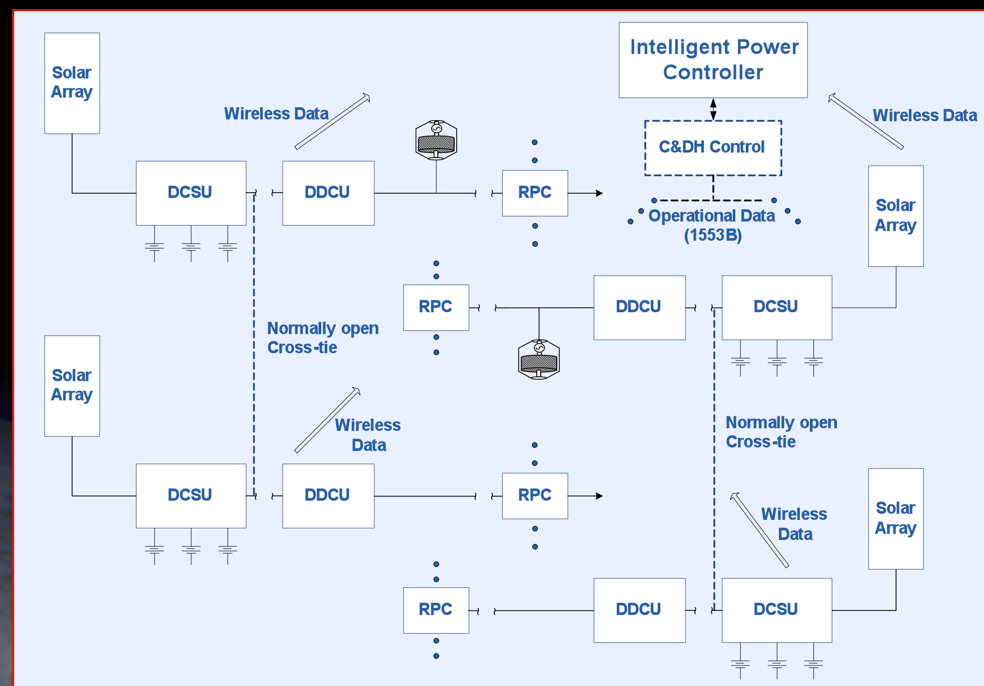
- Power 75 kW average
- Solar array power 125 kW
- Eight independent power channels -- 9.75 kW
  - Planar silicon arrays
  - NiH battery storage – 6 per channel
- Distribution
  – 116 - 170 V primary
  – 120 V secondary
- Contingency power > 1 orbit
- System lifetime of 15+ years

ISS Intelligent Power Demonstration

Power System Needs

- Long Term operation with minimal human intervention -- operational autonomy
- Rapid fault detection and reconfiguration
- Failure diagnostics and prognostics for power components
- Load management under variable load demand & constrained capacity
- Accommodate peak power demands while minimizing contingency – primary source
- Optimize generation and distribution assets
- Incorporate distributed energy storage





Technologies

- Automation Technologies
- Modeling and simulation
- Fault diagnostics
- Wireless sensors
- Renewable storage integration
- Power Systems Engineering

Commonality of Needs

Terrestrial Power

- Accommodate increased user power needs
  - New conventional power generating capability
  - Renewable generation
  - Distributed energy storage
  - Incorporate intelligent energy islands
- Security
  - Improve grid observability
  - Rapid fault detection and reconfiguration to minimize brownouts / blackout
  - Operator aids for intelligent power decision making
  - Failure diagnostics and prognostics for power components
- Efficiency
  - Provide peaking power while minimizing contingency -- (spinning) reserve
  - Incorporate user decision making
  - Load management under variable load demand & constrained capacity
  - Optimize generation and distribution assets
- Common power / data interface standards

Exploration Power

- Accommodate increased user power needs
  - Renewable power sources
  - Incorporate distributed energy storage
  - Permit incremental build-up and seamless growth.
- Security
  - Grid Observability
  - Long Term operation with minimal human intervention -- operational autonomy
  - Rapid fault detection and reconfiguration
  - Failure diagnostics and prognostics for power components
- Efficiency
  - Load management under variable load demand & constrained capacity
  - Accommodate peak power demands while minimizing contingency – primary source
  - Optimize generation and distribution assets
- Common power / data interface standards

Smart Grid Systems Technology Development

What is the Smart Grid?

- Secure Data Comm.
- Renewable Generation
- Energy Storage
- Asset Optimization
- Autonomous Controls
- Smart Meters
- Enhanced Decision Making Tools
- Advanced Sensors
- Increased Observability

Blind Men Describing the Elephant

Smart Grid Universe

Evolves with the integration of all these elements and more

- Secure Data Comm.
- Renewable Generation
- Energy Storage
- Increased Observability
- Enhanced Decision Making
- Advanced Sensors
- Autonomous Controls
- Asset Optimization
- Smart Meters

Smart Grid Technology Development

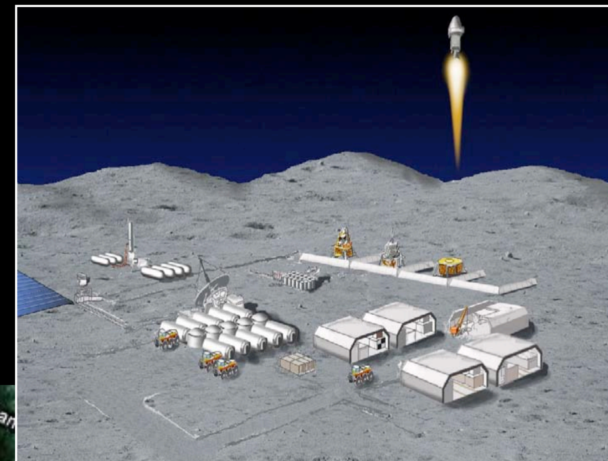
- The key to Smart Grid implementation is successful system integration of the new underlying component and control technologies
  - Stable and reliable operation issues with power grids having a high percentage of renewable generation and energy storage
  - Integration of "Micro-Grids" or "Micro Energy Islands" with large power grids
  - Incorporation of a high degree of automation and fault tolerance for reliable / secure operation
  - Ability to utilize large amounts of data to optimize grid operation

Smart Grid Demonstrator Overview

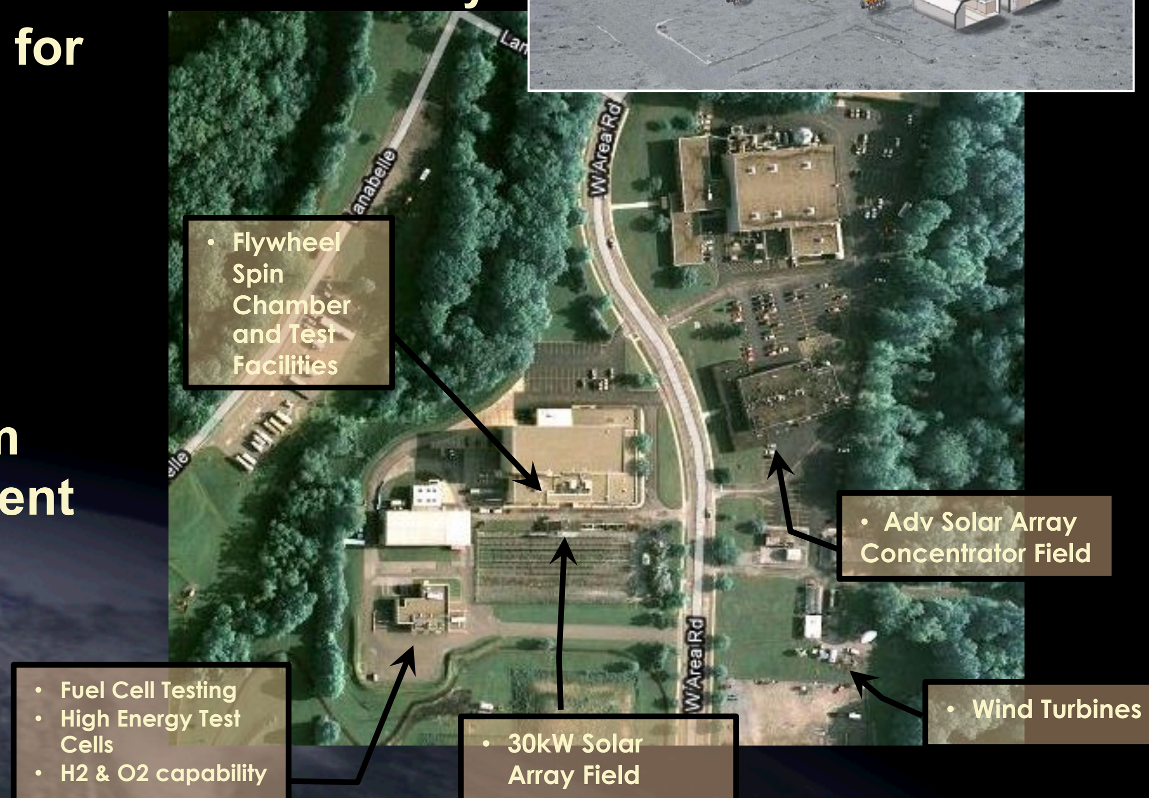
Objectives

- Leverage capabilities that already exist at on the Power Campus at NASA GRC
- Scalable test platform for research
- Decoupled from the main grid for “edge of the envelope” demonstration and testing
- Provide results applicable to both terrestrial and space systems
- Provide a system test platform for new technology development and deployment (example: flywheels)

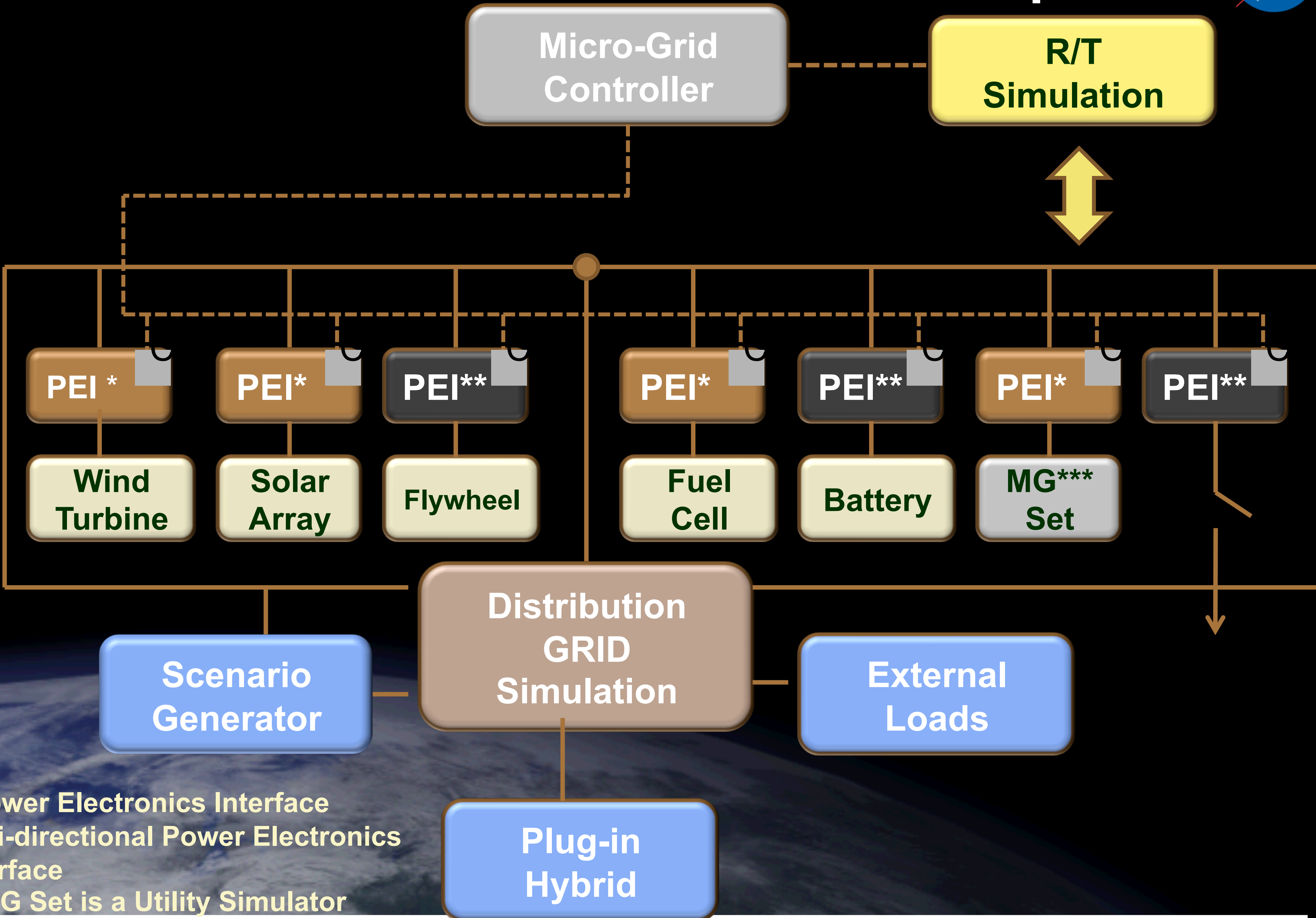
Future Lunar Base



NASA Facility



Smart Grid Demonstrator Concept



* Power Electronics Interface
** Bi-directional Power Electronics Interface
** MG Set is a Utility Simulator

Technology Needs

- Systems Technology
  - Routine operation with a high percentage of energy storage
    - Demonstrate real and reactive power control using energy storage
    - Distributed vs centralized energy storage for renewables
  - Understand the benefits of DC vs AC interconnections for sources and storage
- Simulation Technology
  - Load flow / dynamic models for technology development and operation
  - Analytical models of micro-grids that can be replicated and run in real time and faster than real-time
  - Hardware in the loop operation with analytical models

Technology Needs

- Automation and Controls
  - Economic negotiation of load demand
  - Optimization algorithms
    - Loss reduction,
    - Reliability and risk
    - Operating margins – component, circuit, system
  - Automated fault recovery
  - Adaptive control algorithms for changes in plant and input parameters
  - Prognostics to identify faulty sources and loads
- Intelligent Distribution / Interface Hardware
  - Power Electronics for bi-directional power flow techniques for real and reactive power
  - Bi-directional fault control
  - Intelligent switching centers to enable distributed hierarchical control

Technology Needs

- Communication
  - Wireless data transmission
  - Secure data interchange
- Decision support tools
  - Data Fusion
  - Autonomous and human-agent operations in high information density environments for advanced data integration and presentation
- Intelligent Interface Standards – Data
- Intelligent Interface Standards – Power
- Sensors
  - Intelligent Sensors with integrated data transmission and energy harvesting

Wrap-up

- There are common needs in Smart Grid both for terrestrial and NASA exploration applications
- Systems integration is the key to being able to realize the potential of the Smart Grid
- Technology demonstration in a facility decoupled from the main grid and incorporating real-time simulation is necessary for successful implementation