National Aeronautics and Space Administration

Overview of Intelligent Power Controller Development for Human Deep Space Exploration

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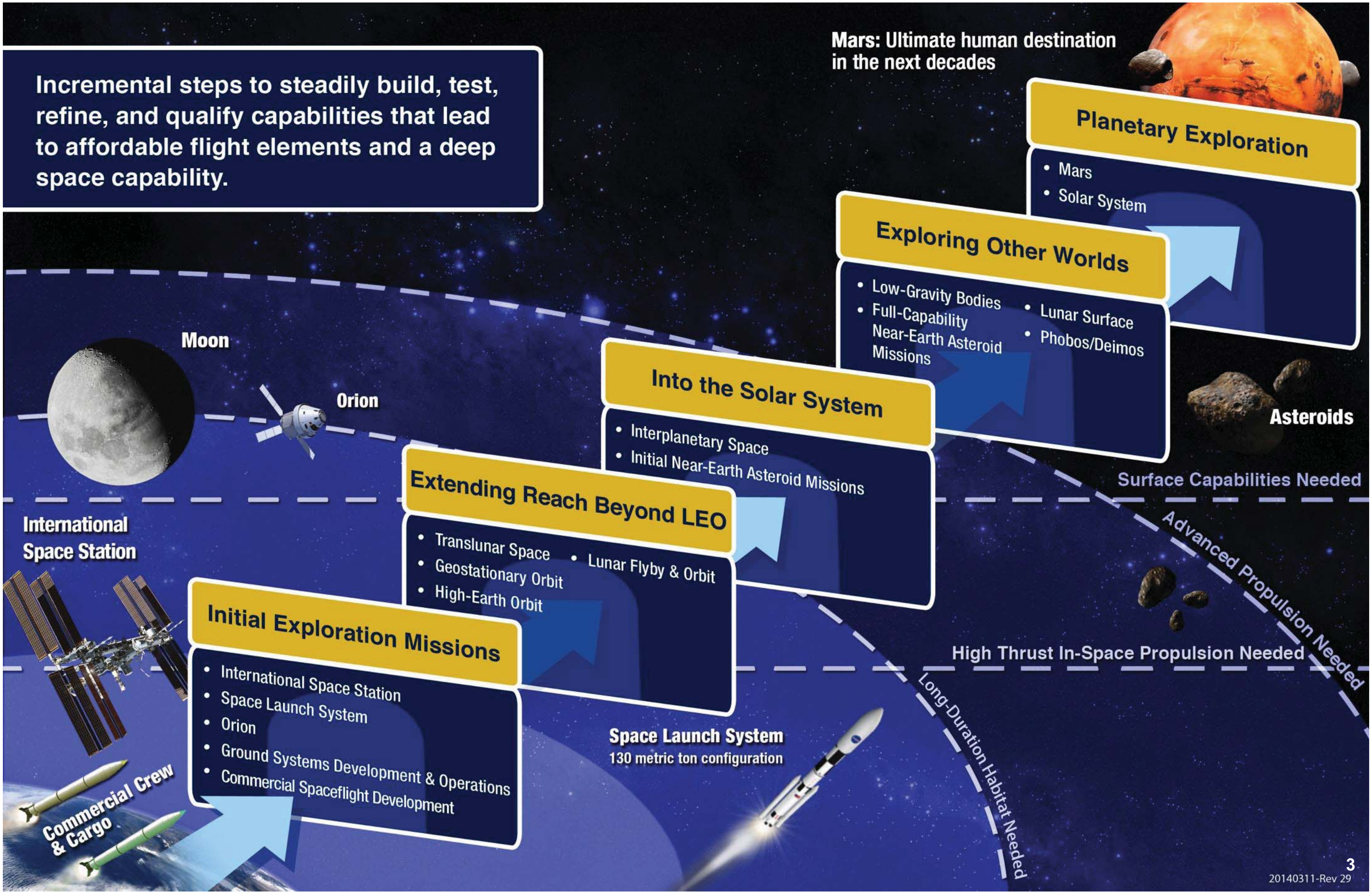
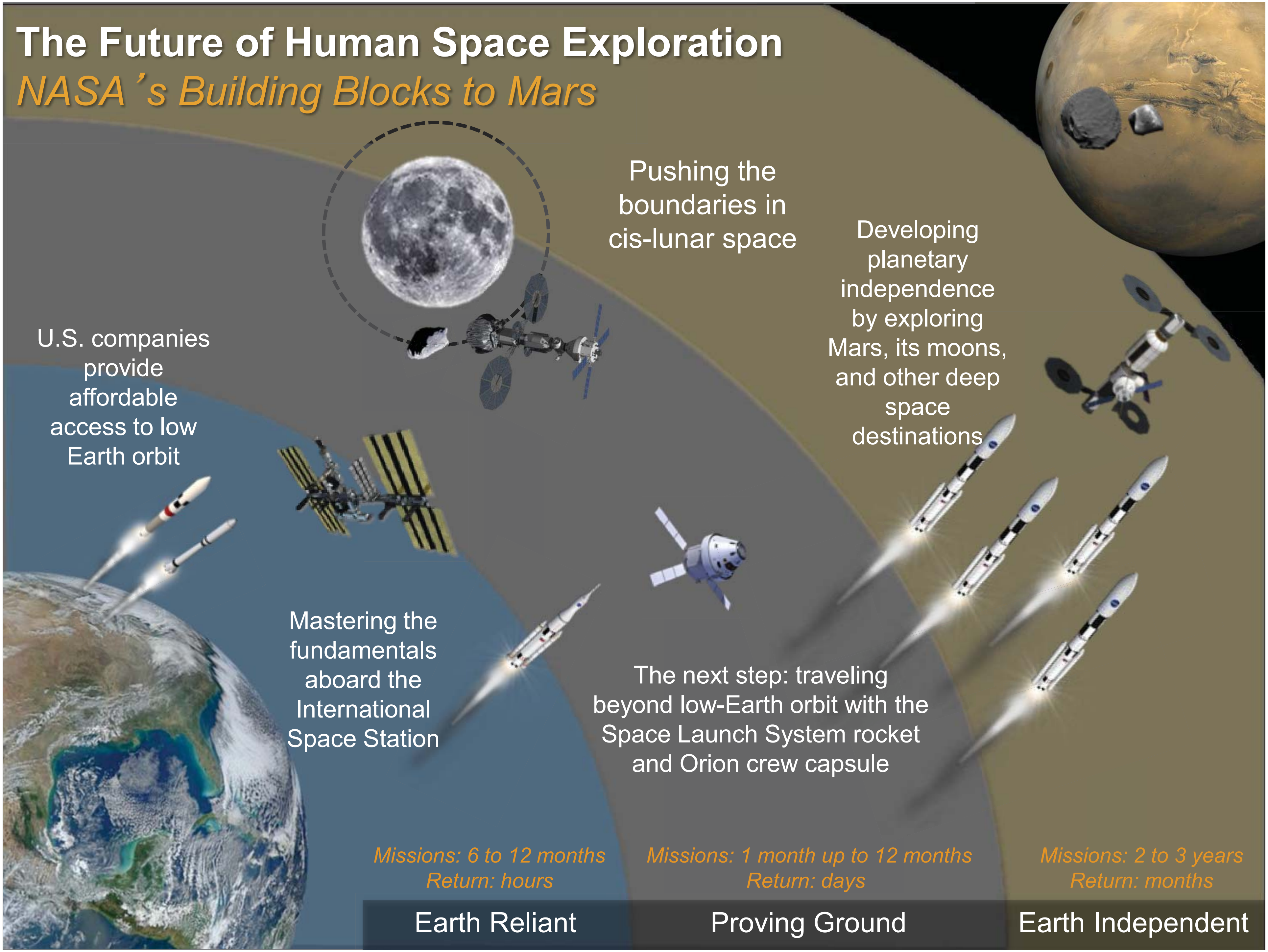
Agenda

- Overview of NASA Vision
- Deep Space Vehicle Power Architecture
- Traditional Space Vehicle Control Architecture
- Intelligent Control Architecture
- Power System Simulations for Test & Verification
- Applicability of Controls to Terrestrial Micro-grids
- Wrap-up

The Capability Driven Framework




The Future of Human Space Exploration
NASA's Building Blocks to Mars
U.S. companies provide affordable access to low Earth orbit
Mastering the fundamentals aboard the International Space Station
Pushing the boundaries in cis-lunar space
The next step: traveling beyond low-Earth orbit with the Space Launch System rocket and Orion crew capsule
Developing planetary independence by exploring Mars, its moons, and other deep space destinations
Missions: 6 to 12 months
Return: hours
Missions: 1 month up to 12 months
Return: days
Missions: 2 to 3 years
Return: months
Earth Reliant
Proving Ground
Earth Independent

What is the problem?

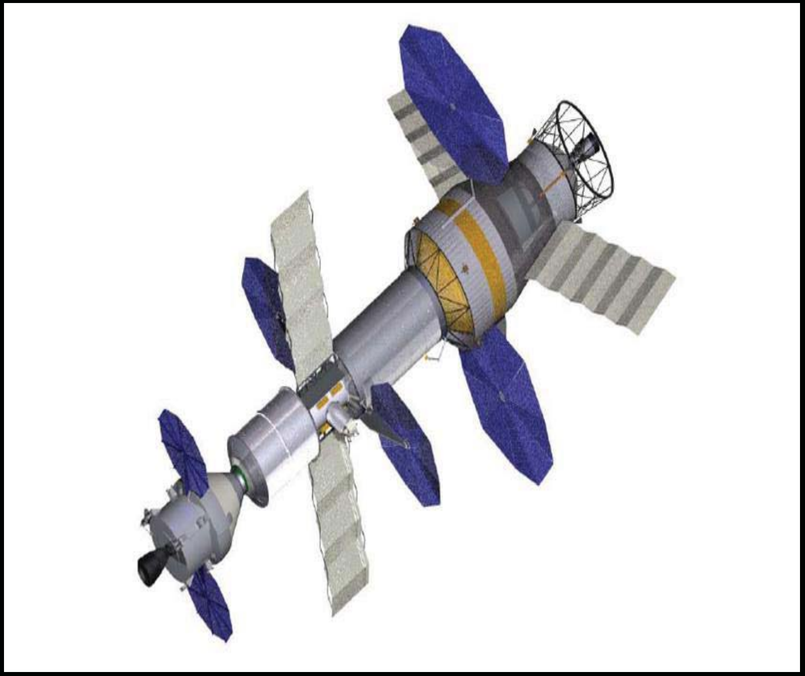
- **Communication and recovery times are longer than any previous experience**

Mission	Duration of Mission After Incident	Communication Latency Time
Deep Space Habitat	9 months to 1 year	15 to 45 mins.
Apollo/Orion	3 – 5 days	1 to 2 sec.
Mount Everest	1 – 2 days	Real time
Deep Sea Submersible	8 hours	Real time
Shuttle	2 – 5 hours	Real time
Submarine	1 – 2 hours	Real time

- **Power Is Most Critical System On Board Vehicle**
  - **System will need a high level of availability**
  - **System will need to operate autonomously for long periods of time**

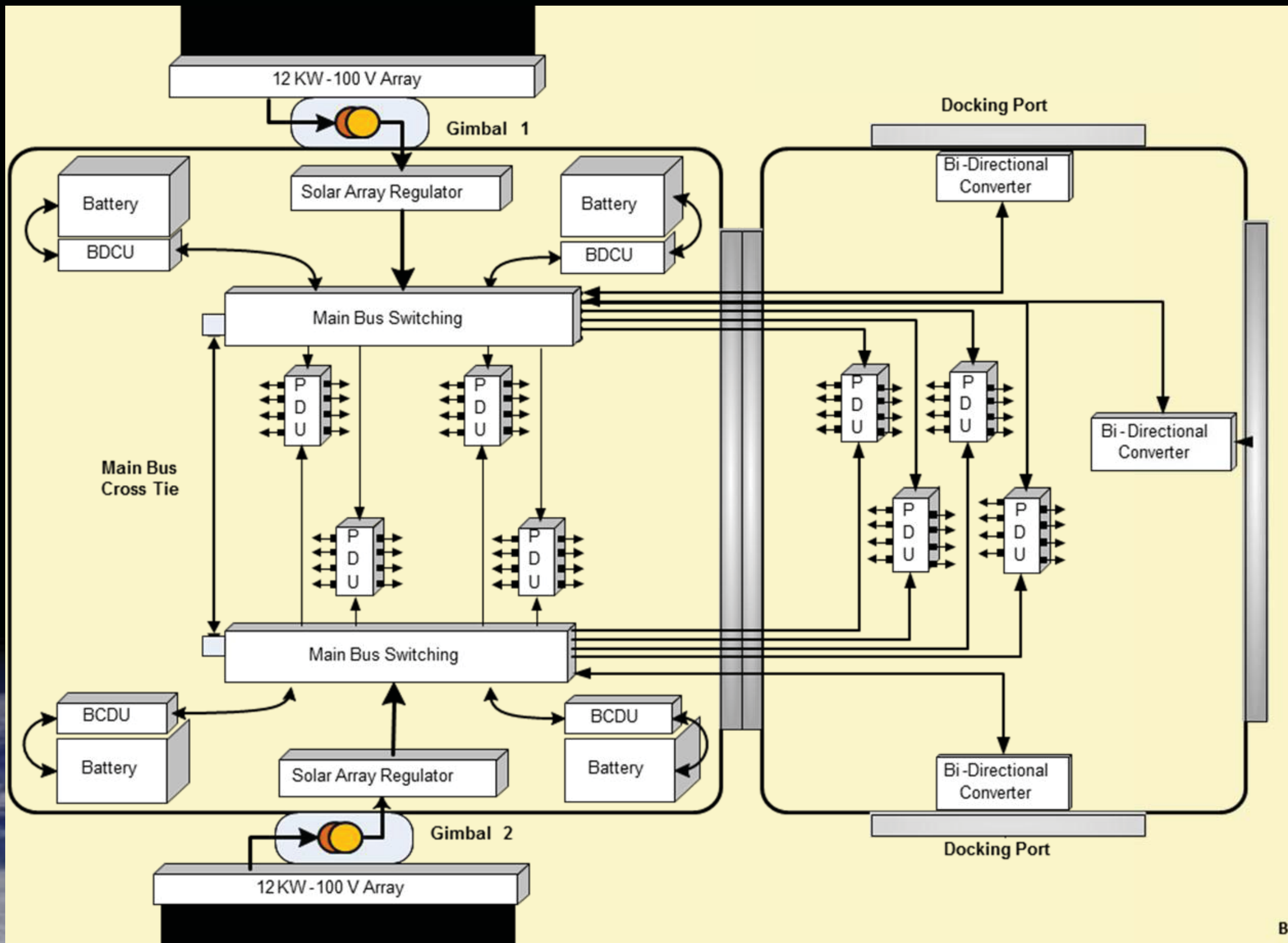
Potential Deep Space Vehicle Power System Characteristics

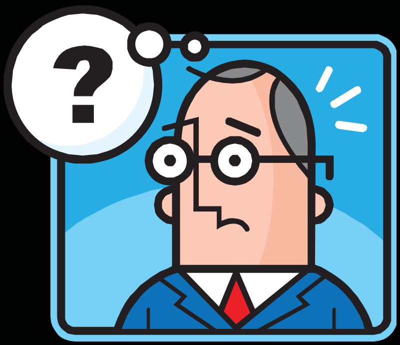
- Power 10 kW average
- Two independent power channels with multi-level cross-strapping
- Solar array power
  - 24+ kW Multi-junction arrays
- Lithium Ion battery storage
  - 200+ amp*hrs
  - Sized for deep space or low lunar orbit operation
- Distribution
  - 120 V secondary (SAE AS 5698)
  - 2 kW power transfer between vehicles



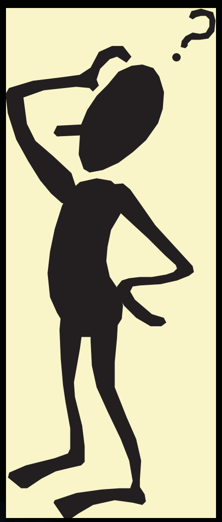
Deep space vehicle concept

Notional Deep Space Vehicle Power Architecture

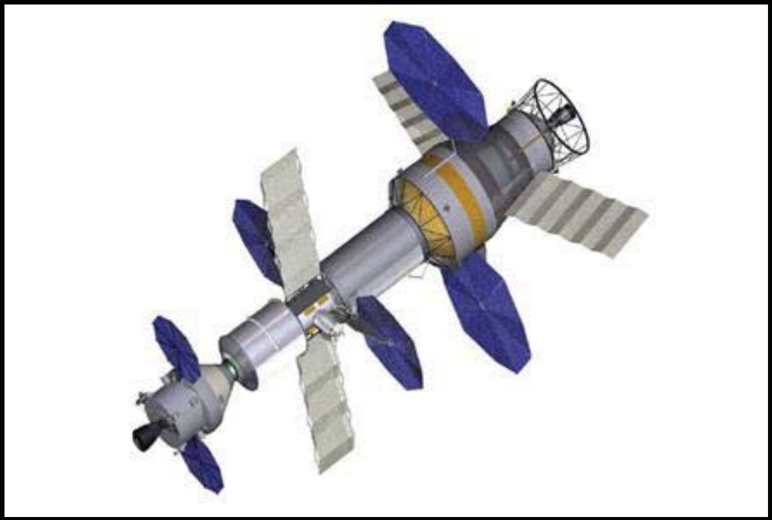




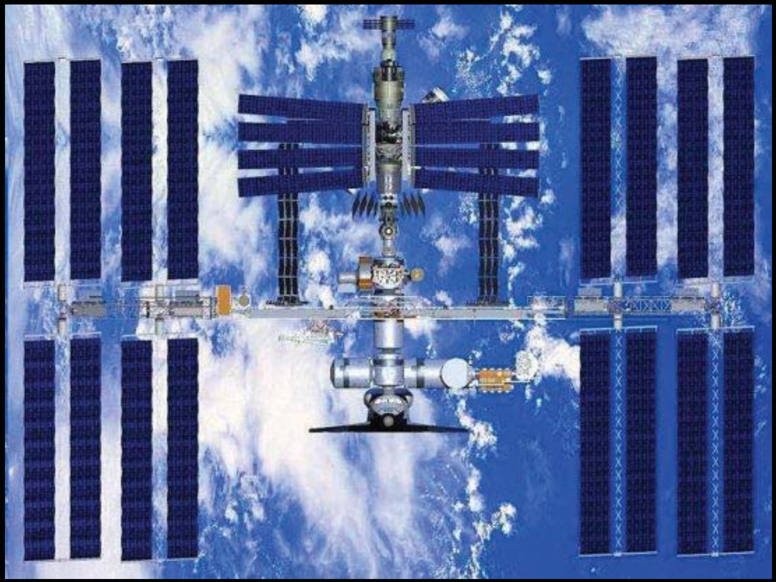
So What is Intelligent Power?



What is Intelligent Power?

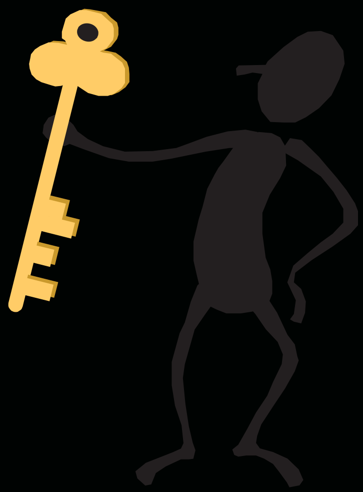


Exploration Systems



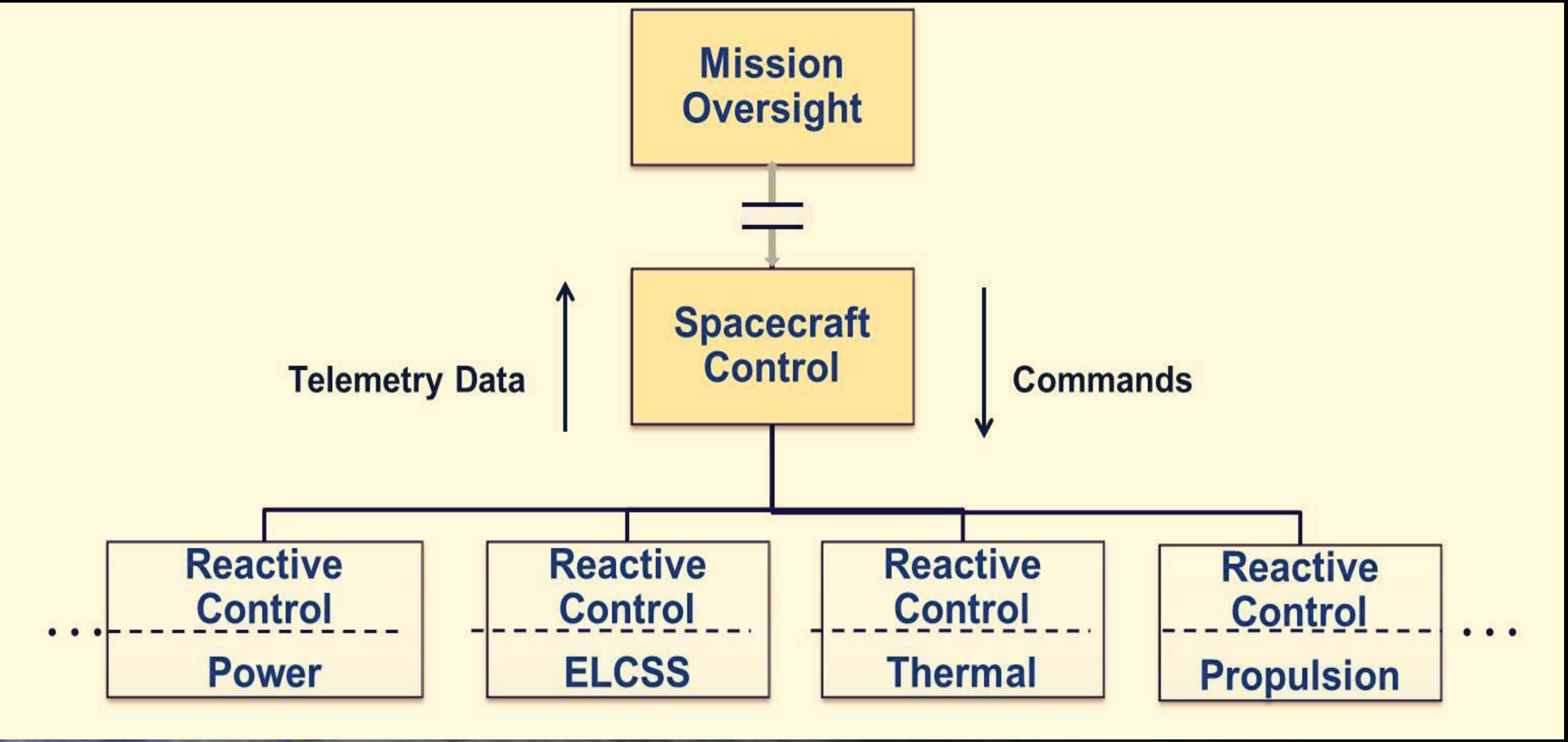
Near Earth Systems

An Intelligent Power Controller utilizes advanced hardware and control technology and works in conjunction with the space craft mission manager to autonomously manage and control distributed power generation and storage assets, power distribution networks, and loads for both near earth and space exploration systems.

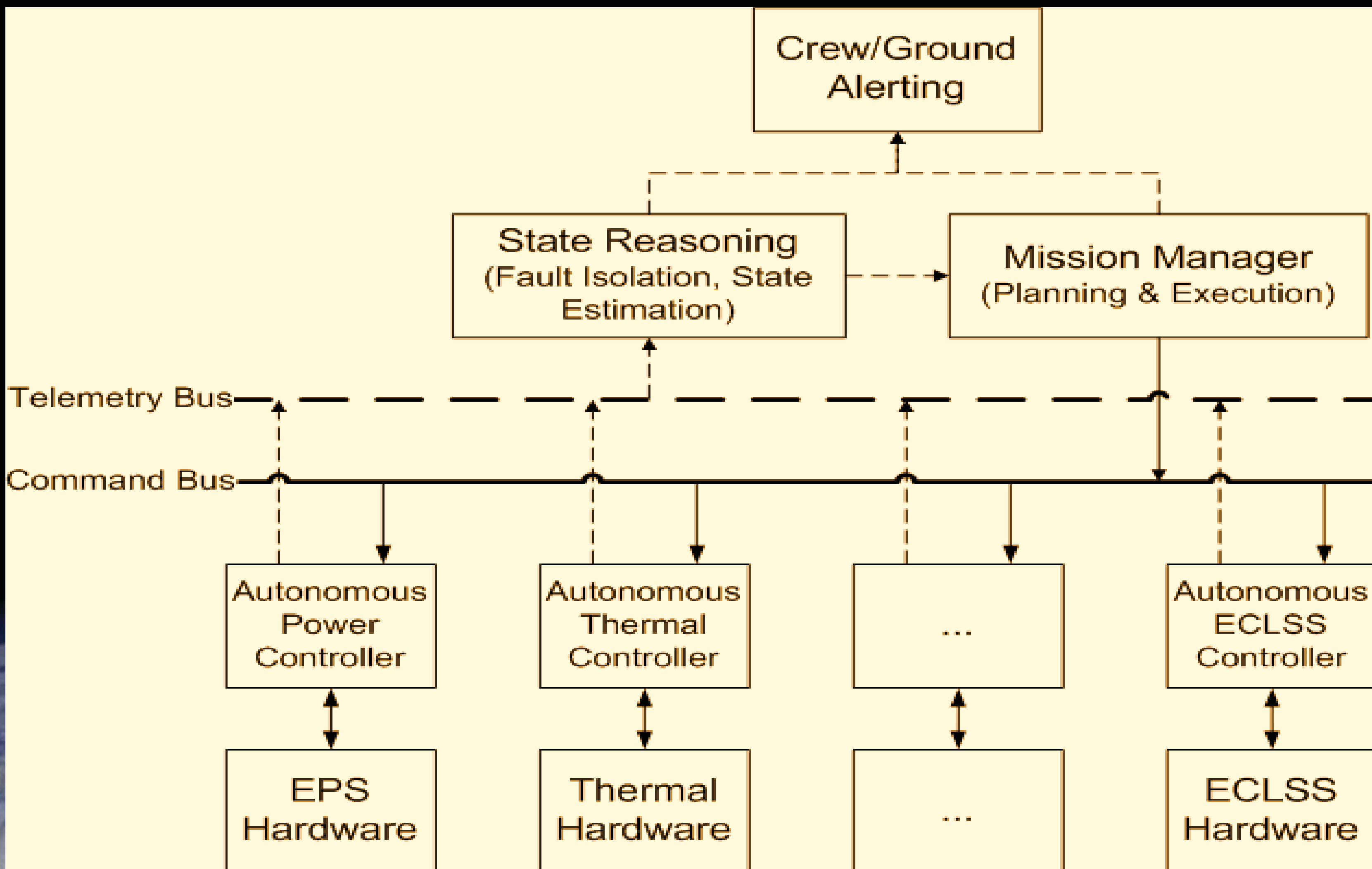


Intelligent Power Architecture

Simplified Space Craft Control Architecture



Intelligent Space Craft Controller Architecture



Mission Manager Intelligent Power Control Interface

- Navigation Vectors
- Traffic / Array Pointing Constraints
- Spacecraft (other subsystems) Operations State
- Proposed load profile

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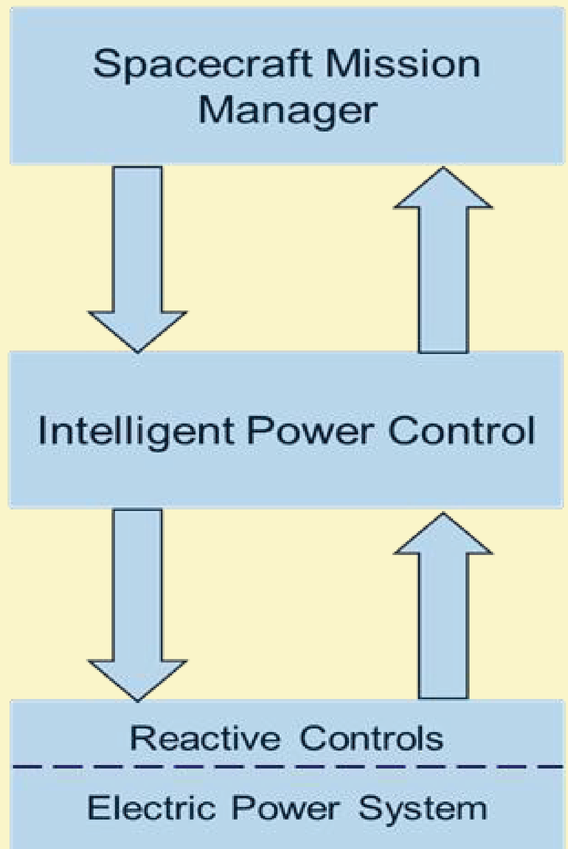

- Energy Availability
- Load Profile Evaluation
- EPS Operating State
- EPS ORU State of Health
- Caution/Warning Alarms
- Proposed Corrective Action(s)

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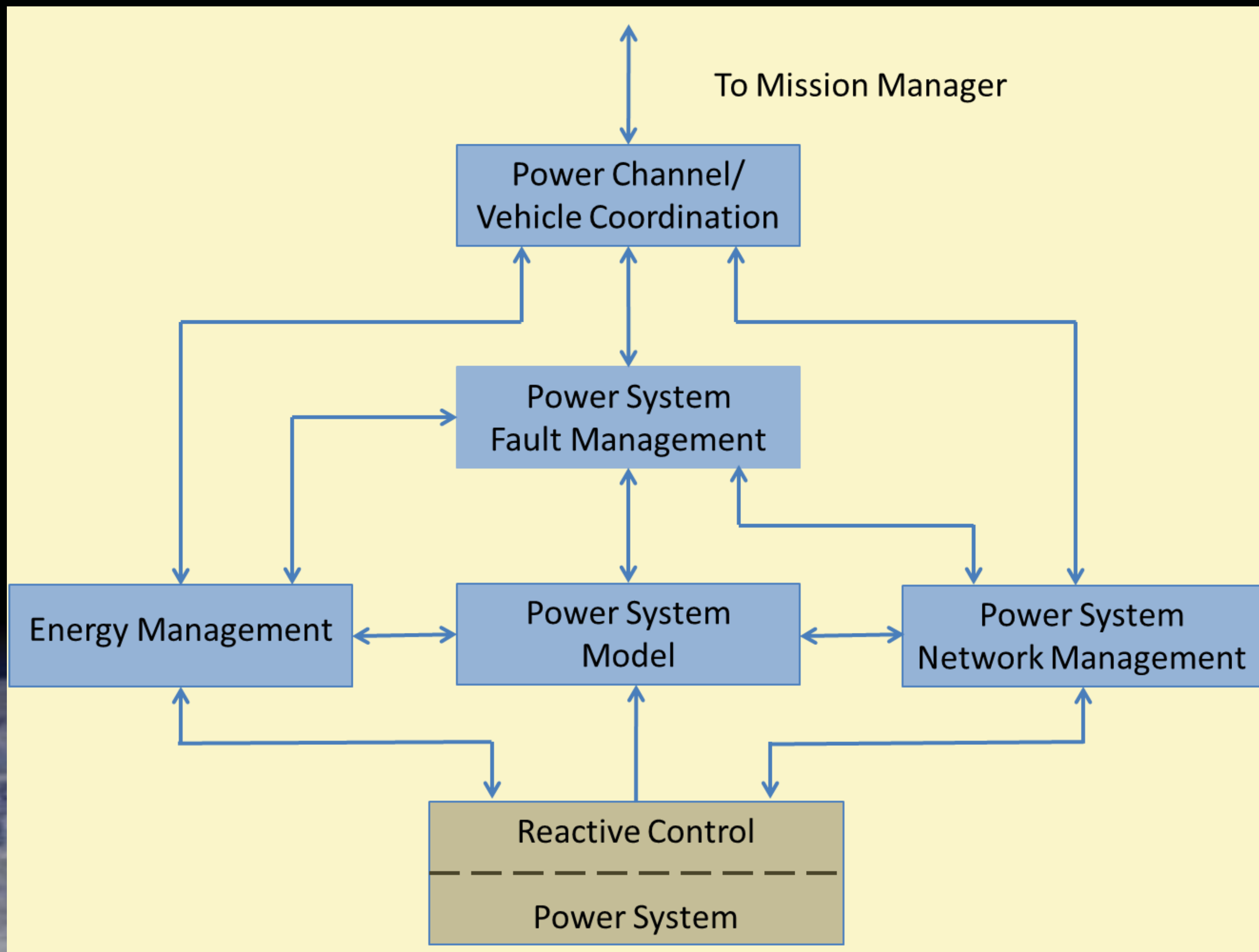
- Array Pointing
- Array Voltage S.P.
- Battery Charge/Discharge SP.
- Switchgear Positions

- Array Voltage
- Battery Voltage
- Battery Current
- Main Bus Currents
- Main Bus Voltages
- Secondary Bus Voltage
- Secondary Bus Currents
- Switch States

Intelligent Control Function Architecture



Intelligent Control Functions

- Energy Management
  - Power availability timeline
  - Set points for array regulation, battery charging / discharging,
  - Detect generation and storage failures
- Power System Model
  - Generation model using orbital parameters
  - Energy storage model
  - Power load flow
  - State Estimator
- Power System Network management
  - Power network security
  - Power quality
  - Detect soft faults
  - Report hard faults
  - Configure switchgear
- Power System Coordination
  - Communicate with Manager
  - Coordinate with identical power channel entities and/or vehicles

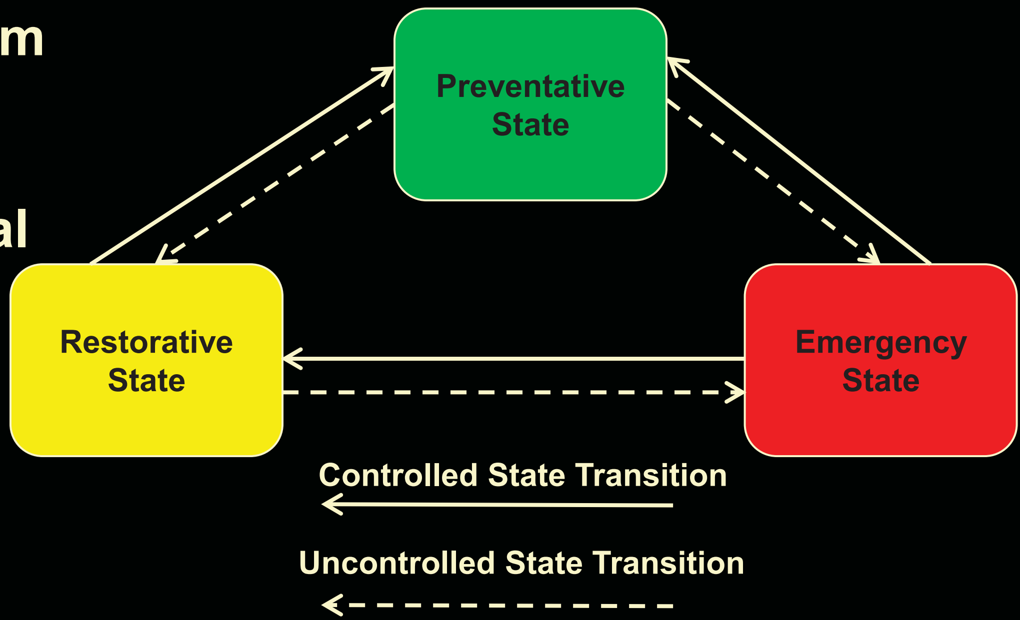
Power System Fault Management

Assess / Manage Power System State

- Preventative state -- Normal operation, continue indefinitely without interruption

- Emergency State – Fault occurs – relieve system stress and prevent further deterioration

- Restorative State – System is degraded but safe – restore power flow to all loads in a safe manner in minimum time

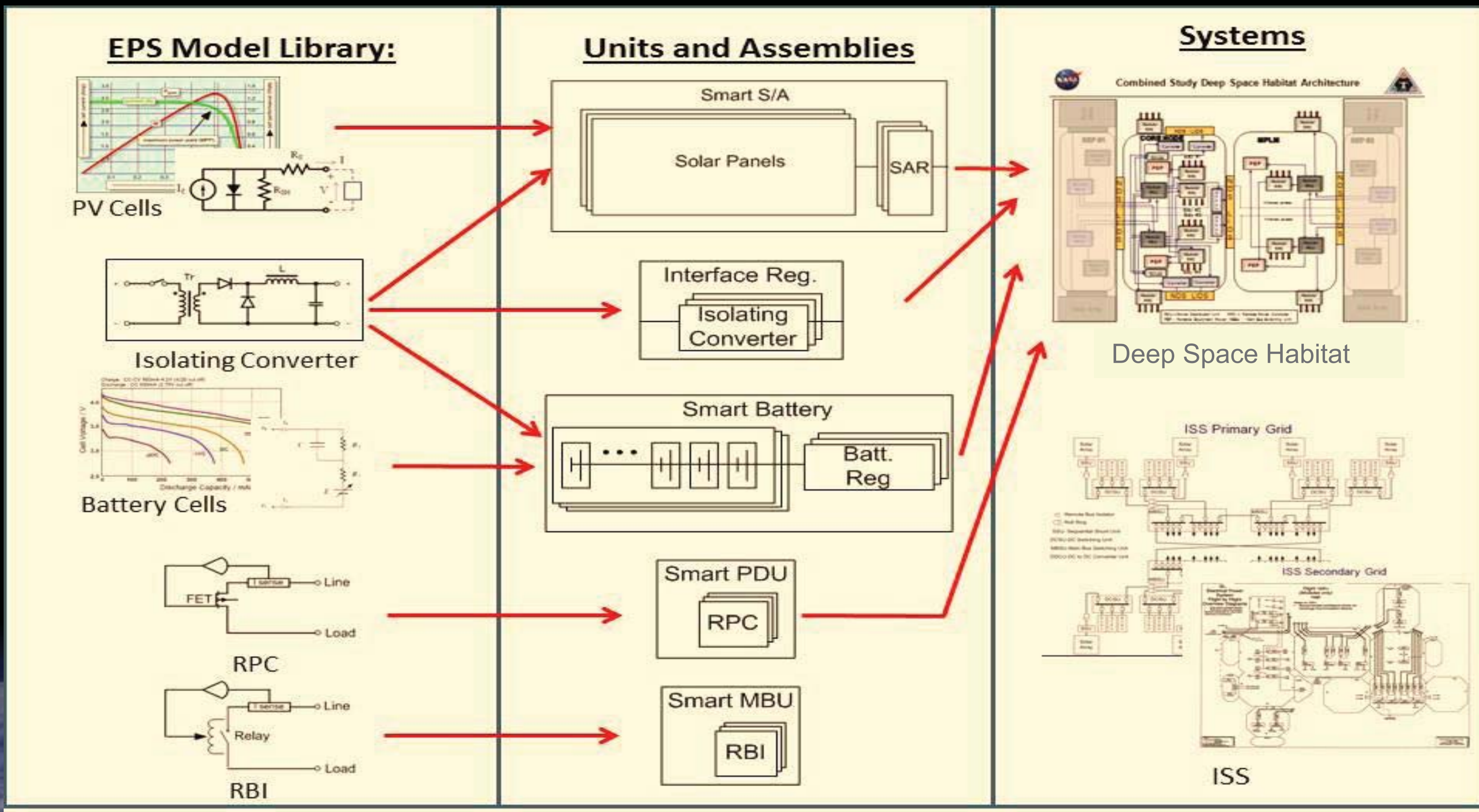


Additional Functions

- Contingency Analysis
- Develop corrective actions
- Component Health Monitor

Intelligent Power Controller Verification Approach

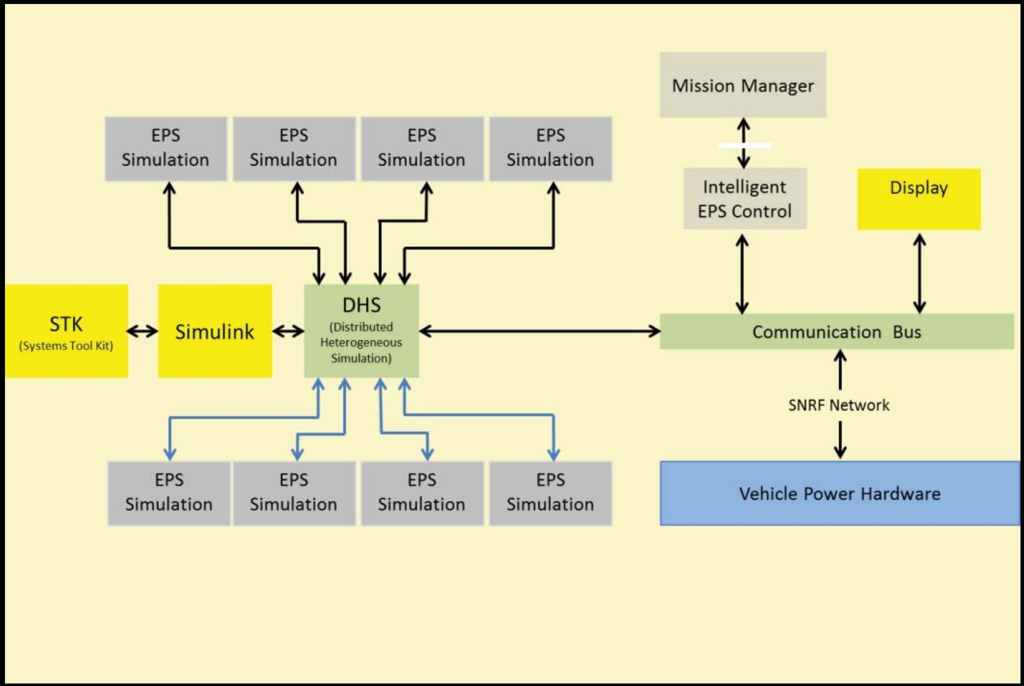
Power System Simulation Development



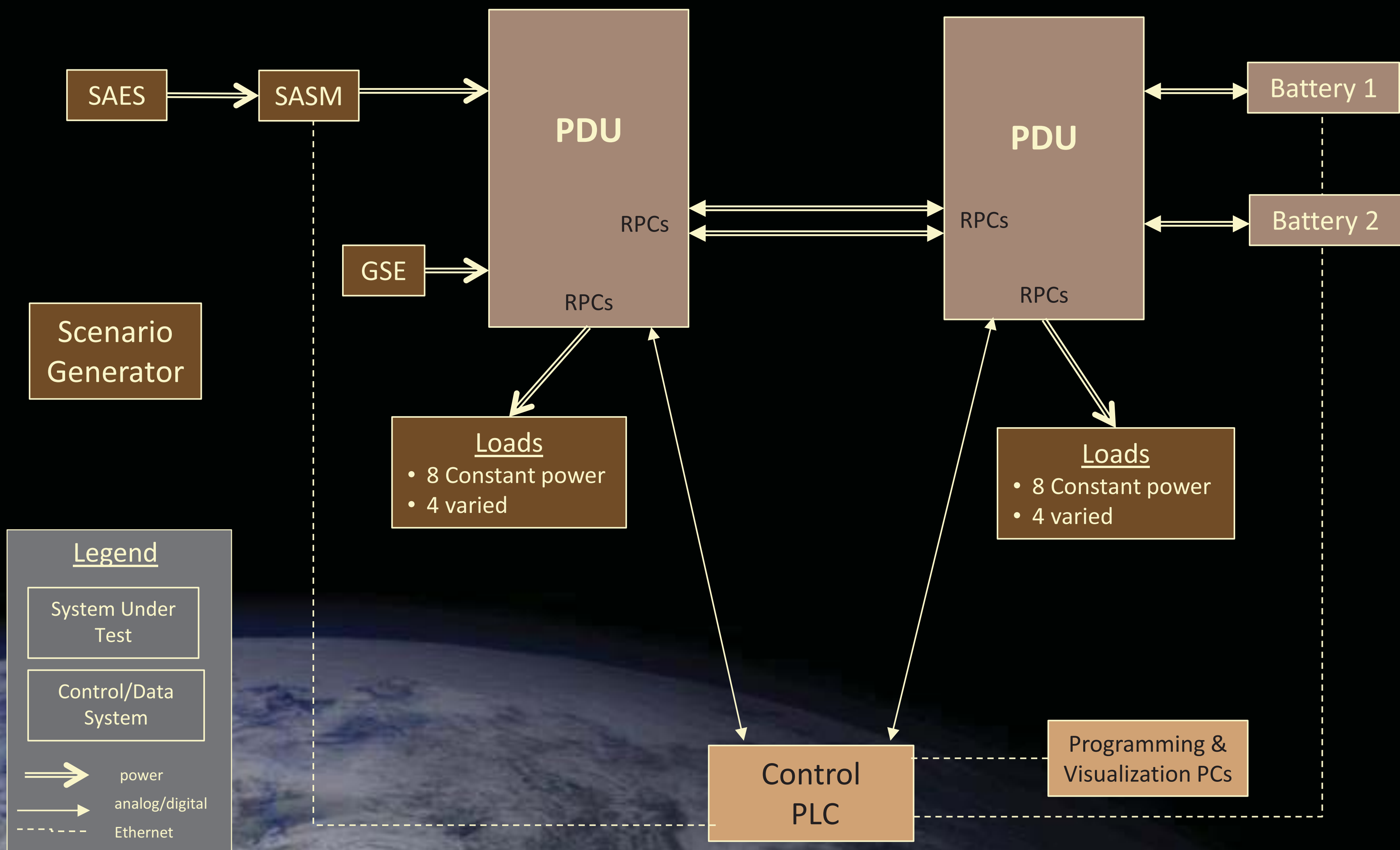
Intelligent Control Simulation Architecture

Distributed Heterogeneous Simulation Platform

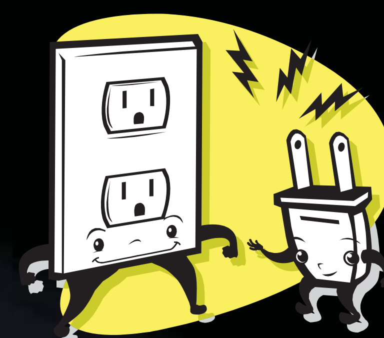
- 6 High speed multi-core PC's with 8 processors each
- Total of 48 processors
- PC's interconnected through high speed Ethernet
- Middleware provides synchronized interconnection of any number of dynamical subsystem simulation processors
- DHS-enabled to support time synchronization and real-time execution



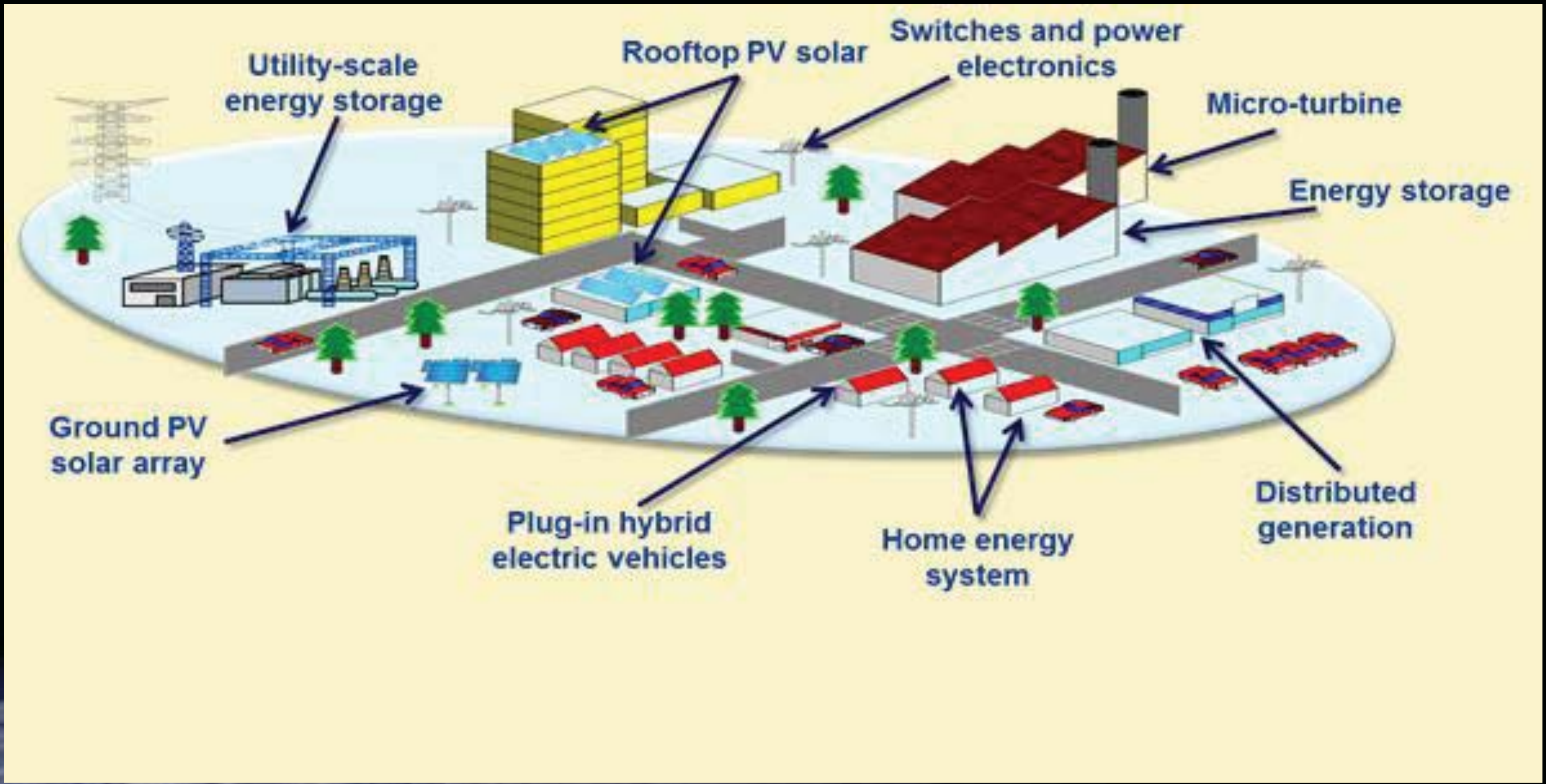
Hardware In the Loop Verification



Application to Terrestrial Micro-Grids



Terrestrial Micro Power Grid



Islanded micro-grids have higher level control needs that are very similar to deep space vehicle power systems

Wrap-up

- We need Intelligent Power Systems for long term operation far from earth

- Utilization of real-time simulations, hardware in the loop and power system test beds can achieve this development goal

- Technology to operate proposed deep space exploration vehicles can be utilized to operate terrestrial micro grids

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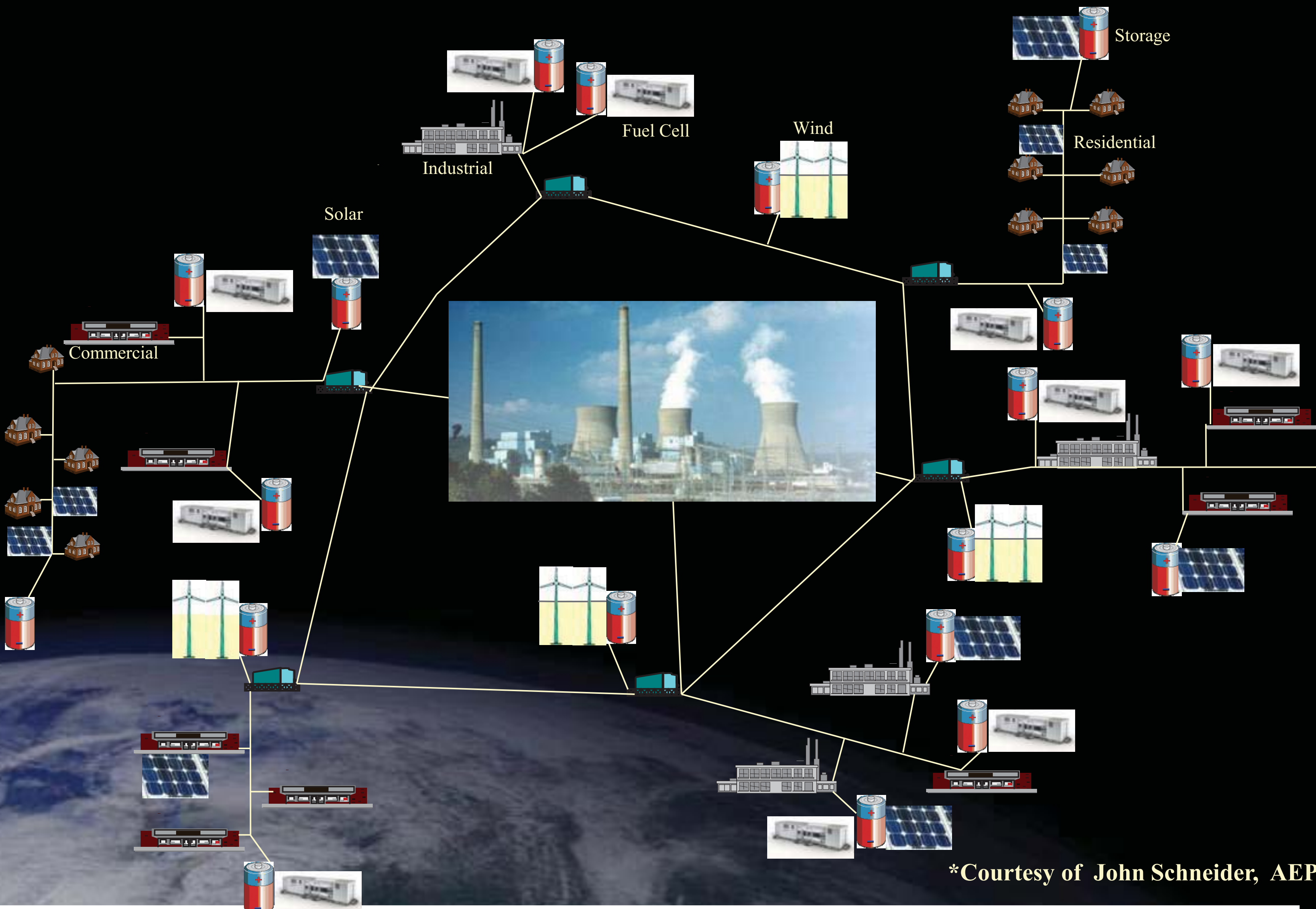
…the Grid of the Future?*



*Courtesy of John Schneider, AEP

Terrestrial Micro Grids

Islanded micro-grids have very similar needs to space vehicle power systems

- Both need to function autonomously for extended periods of time
- Both need to manage distributed energy resources
- Both need to manage loads over constrained capacity and time horizons
- Both need to guarantee that the network is safely managed
- Both need to detect, isolate, reconfigure and accommodate faults