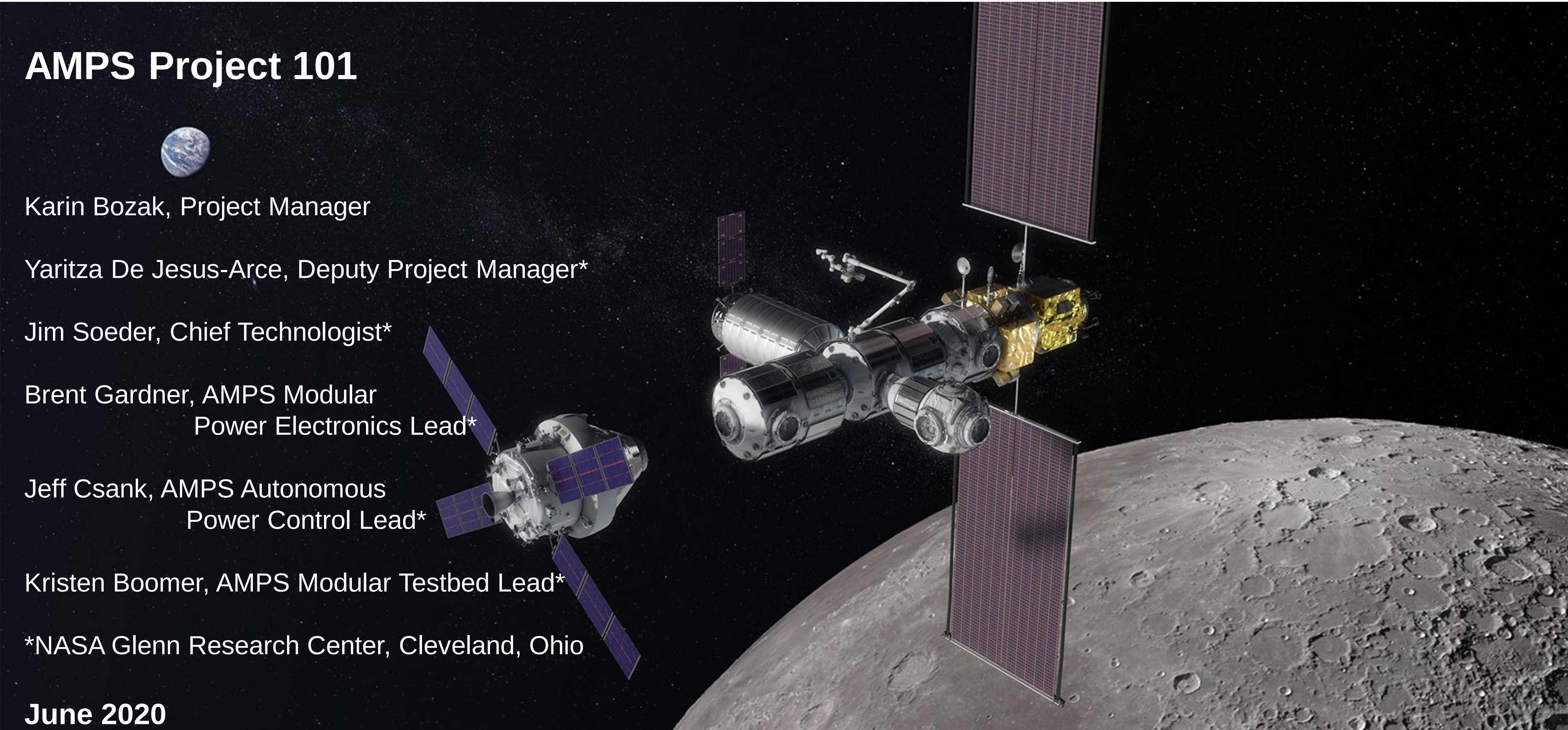
Advanced Exploration Systems (AES)
Advanced Modular Power Systems (AMPS)

National Aeronautics and Space Administration



AMPS Project 101

Karin Bozak, Project Manager

Yaritza De Jesus-Arce, Deputy Project Manager*

Jim Soeder, Chief Technologist*

Brent Gardner, AMPS Modular Power Electronics Lead*

Jeff Csank, AMPS Autonomous Power Control Lead*

Kristen Boomer, AMPS Modular Testbed Lead*

*NASA Glenn Research Center, Cleveland, Ohio

June 2020

AMPS 101 – Agenda

- **AMPS Project Overview – Karin Bozak (15 minutes)**
- **AMPS Modular Power Electronics – Brent Gardner (15 minutes)**
- **AMPS Autonomous Power Control – Jeff Csank (15 minutes)**
- **AMPS Modular Power Testbed – Kristen Boomer (15 minutes)**

Advanced Exploration Systems (AES)
Advanced Modular Power Systems (AMPS)

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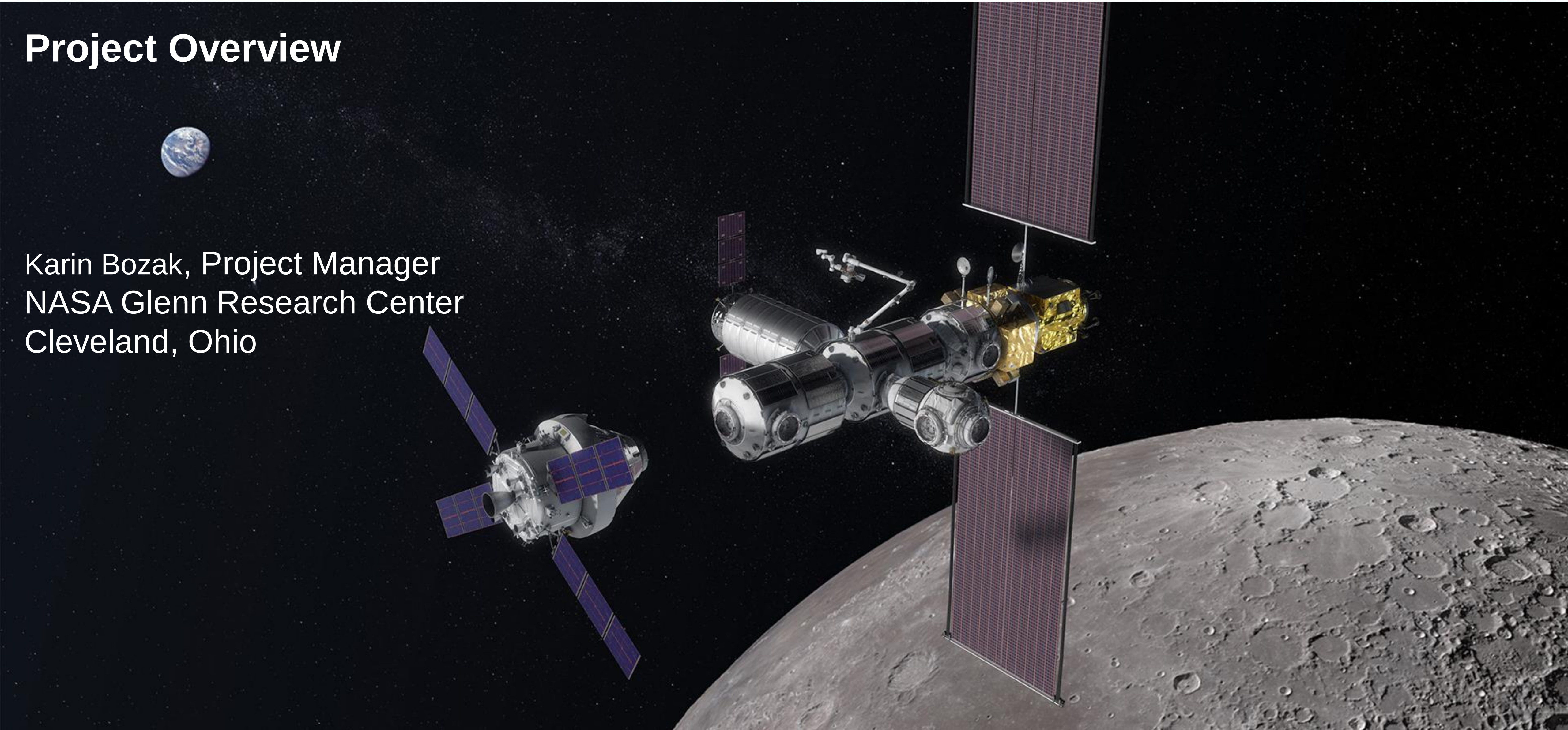
Project Overview

Karin Bozak, Project Manager
NASA Glenn Research Center
Cleveland, Ohio



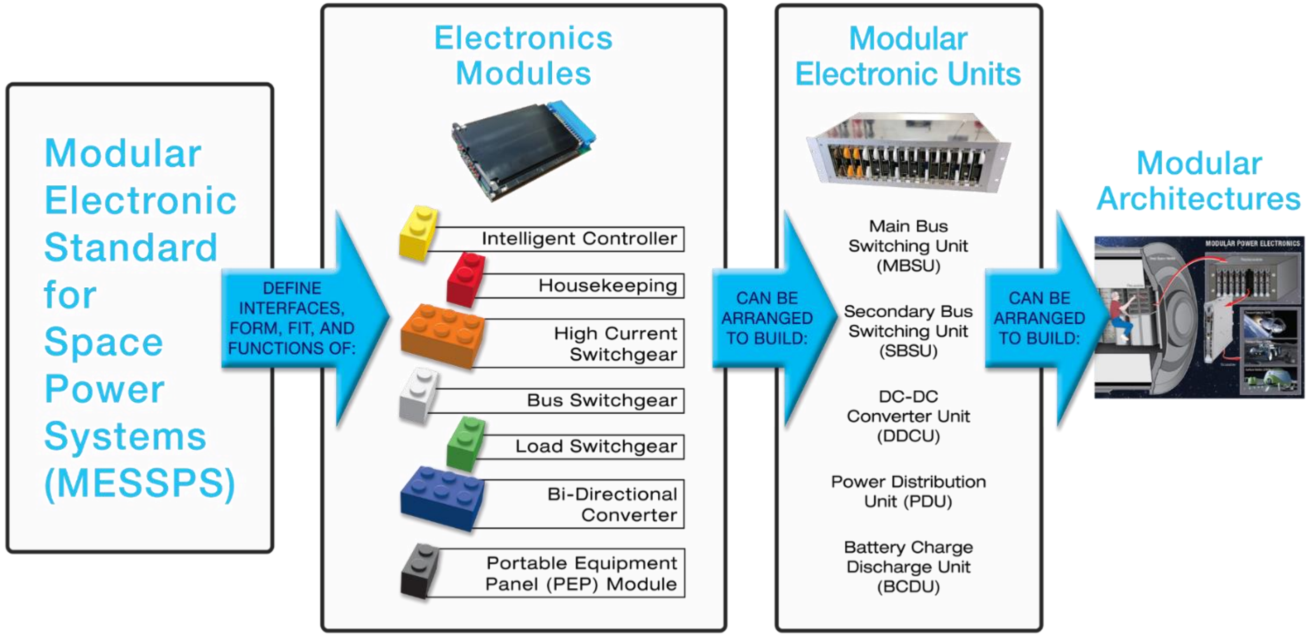
AES Modular Power Systems (AMPS) – Project Overview

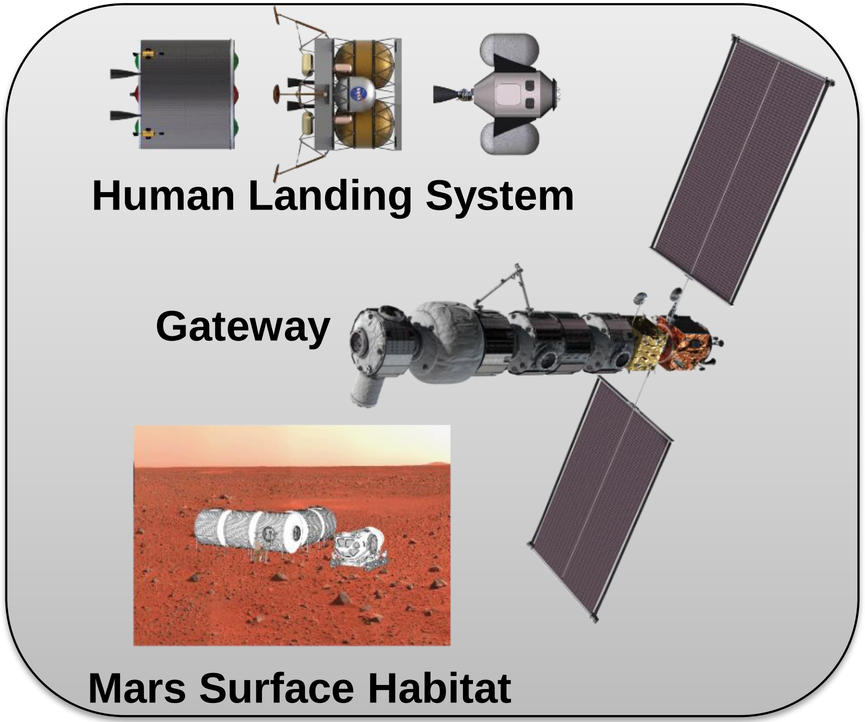
Why is the AMPS project important?

- Modular power system architectures provide opportunities to minimize maintenance operations, improve power system availability, and reduce the number of unique spare parts which is necessary to enable sustainable future exploration missions and systems.
- This project matures modular power system technologies, inclusive of modular power standards, modular power electronics, and autonomous power controls, in support of NASA lunar activities and deep space exploration.

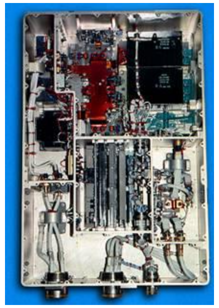
Objectives

- The AMPS project seeks to **transform future space power system architectures and operations** with a modular approach by standardizing the power system at the electronics module level, automating power management and distribution functions, and validating the approach through ground-based demonstrations.





Traditional versus Modular Power Architectures

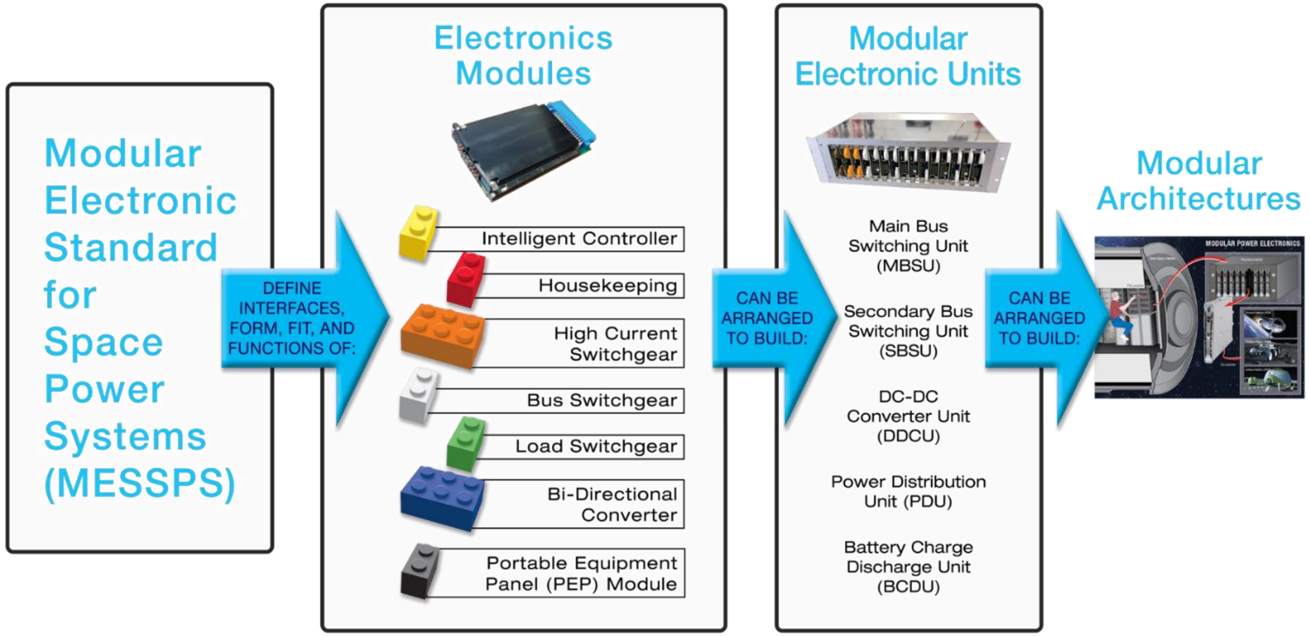


DC to DC Converter Unit

Main Bus Switching Unit

Remote Power Controller

Traditional ISS-Like Power Architecture



Benefits of AMPS Modularity and Commonality (1 of 2)

- **Promotes power system commonality across multiple systems for the Moon2Mars Campaign**
  - Provides a compatible set of common electronics modules (circuit boards or cards) that can be used to construct a variety of modular electronic units (MEUs)
- **Reduces the cost of hardware development and testing**
  - Once the Electronic Modules (Circuit Boards) are developed, they can be reused to build up multiple Modular Electronic Units (MEUs) within a program (i.e. Gateway) or across programs (i.e. Artemis missions)
    - Reduction in non-recurring engineering costs as the power electronics modules (i.e. Housekeeping Module) can be utilized for multiple modular electronic units (MEUs)
    - Reduction in build costs as a result of the standard mechanical interfaces between the electronics modules and the modular electronics units (MEU’s)

Benefits of AMPS Modularity and Commonality (2 of 2)

- **Improves sparing and logistics up mass impacts by making components interchangeable**
  - Power distribution and power converter electronic modules would be common across all Gateway modules – reducing number of unique spares and up-mass needed
    - Enables sharing of spares, which could result in on-orbit volume savings
    - For example, if a single Remote Power Controlled (RPC) switch fails:
      - ISS-like RPCM Switch Spare Mass: 4.7 kg
      - Modular Approach Switchgear Module Spare Mass: 0.5 kg
- **AMPS Electronics Modules can be used to develop Modular Electronic Units (MEUs) for future Exploration Elements – Mars Habitat, Mars Transport, etc.**
  - Minimize the need for power system redesign for future Exploration Programs
  - Improves logistics to enable a human mission to Mars
- **Enables certification of a common vendor(s) that can provide a long term supply of electronics modules and their supporting components (FETs, Drivers etc.)**
  - The AMPS standard-driven approach enables multiple vendor(s) or suppliers

Modular Power Systems Project - Technology Evolution

KEY:
- Relevant to Gateway
- Relevant to Surface Missions
- Relevant to Human Missions

FY12

Completed trade study to develop modular power concepts for future vehicles, such as Deep Space Habitat and the AES Multi-Mission Space Exploration Vehicle

FY13

Delivered a 120 VDC power hardware prototypes to JSC Testbed (iPAS) in June 2013. Hardware prototypes demonstrate the functions of modular electronic units

FY14

Delivered a 28 VDC Modular Battery to JSC for the EVA Project

FY15

Demonstrated modular primary fuel cell stack on SCARAB Rover at GRC

FY16

Released initial draft of the Modular Power Distribution Unit (PDU) Standard

Demonstrated first generation hardware prototype of modular PDU to validate Standard

FY17

Released initial draft of the Modular Bi-Directional Converter Unit Standard

Demonstrated the Autonomous Power Controller (APC)

FY18

Released an updated draft of the Modular PDU Standard, incorporating feedback from NextSTEP Contracts.

Delivered a single platform APC to JSC Testbed (iPAS)

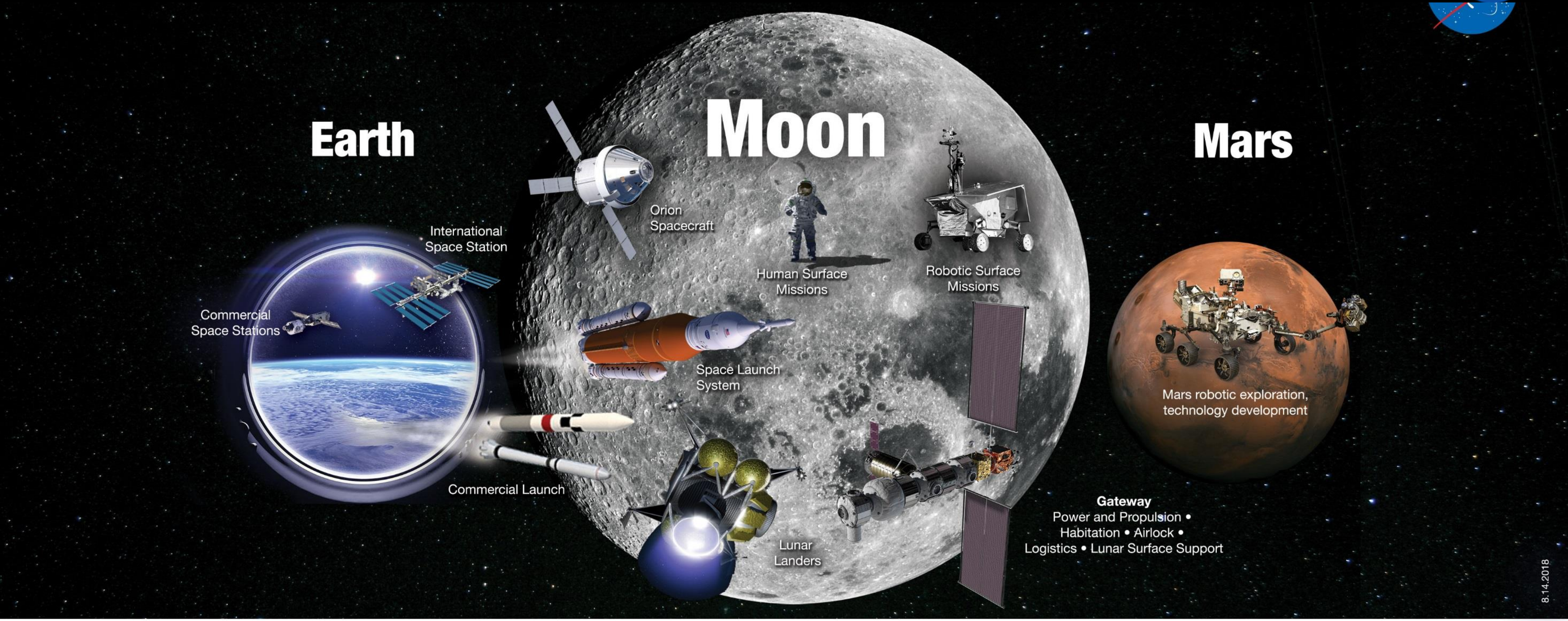
FY19

Demonstrated a single string of modular power prototype hardware

Demonstrated the Autonomous Power Controller (APC) with a Gateway Power Architecture

FY20

Why Now?

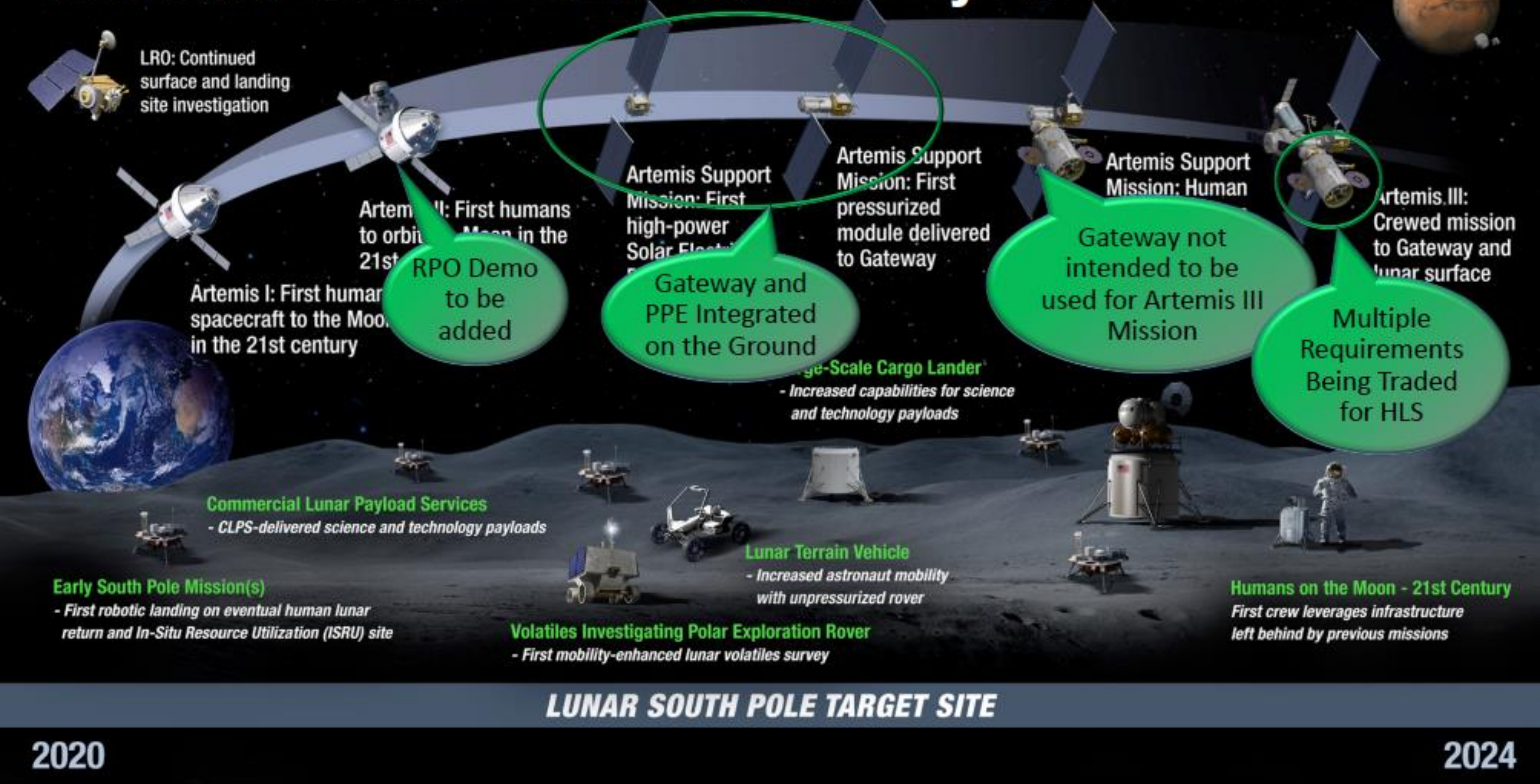


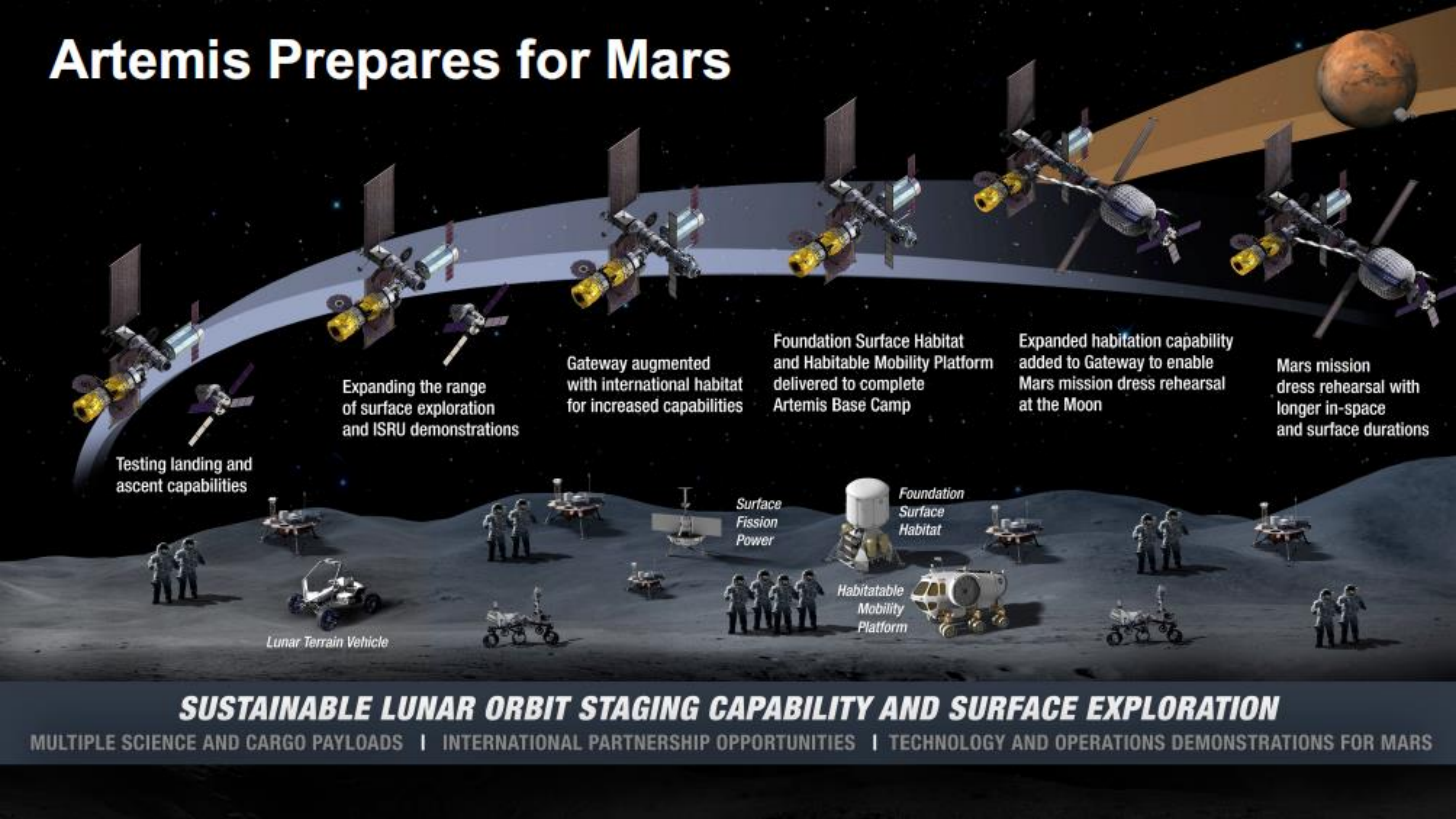
America Will Lead
Fly Astronauts on American Spacecraft
Develop New Commercial Space Stations

America Will Lead
Fly Astronauts Around the Moon
Establish the First Human Outpost Around the Moon
Develop American Landers to Return Humans to the Moon

America Will Lead
Return the First Scientific Collection from Mars
Practice a Round-trip Leading to Humans to Mars

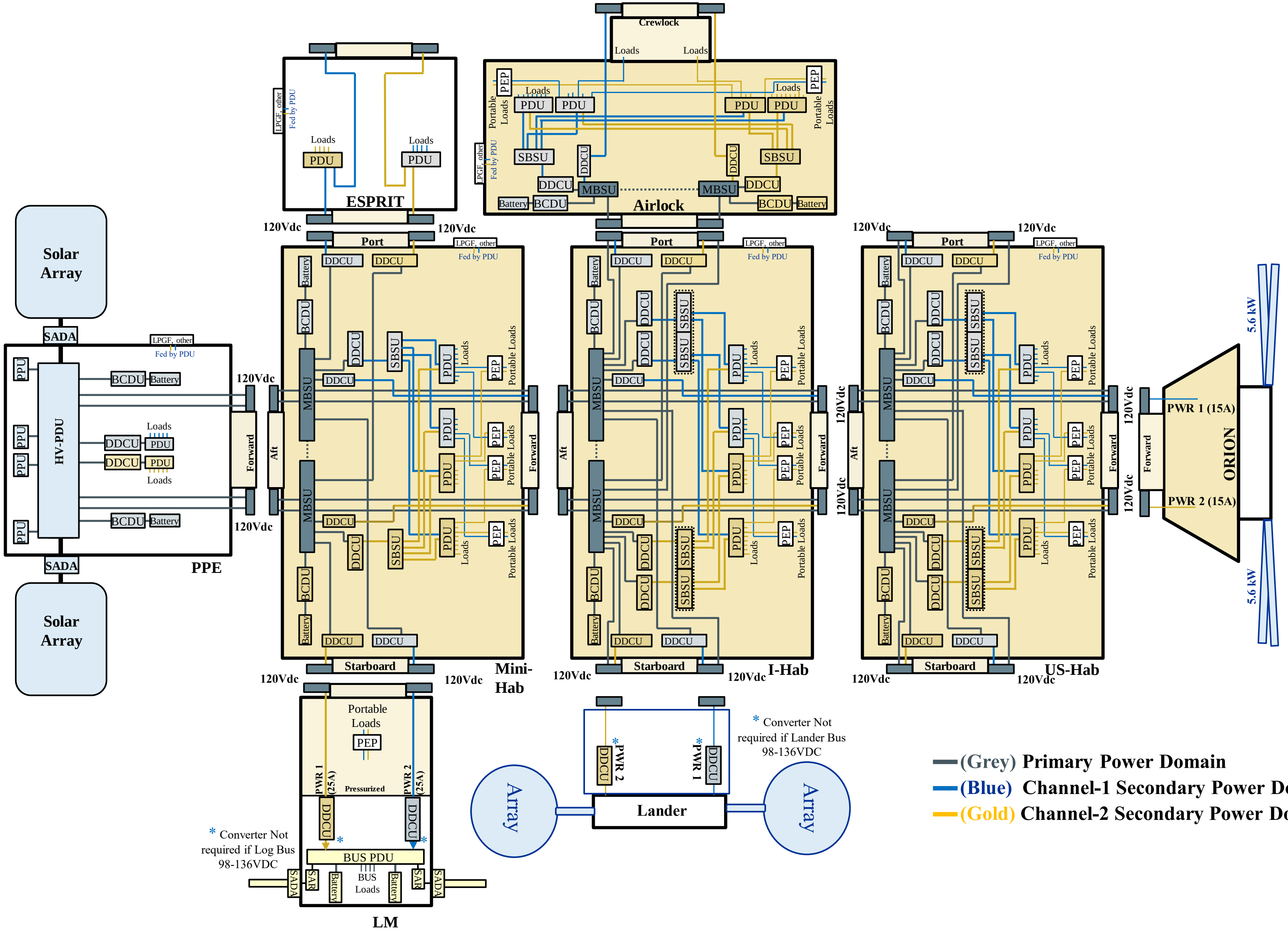
Artemis: To The Lunar Surface By 2024




Artemis Prepares for Mars
Testing landing and ascent capabilities
Expanding the range of surface exploration and ISRU demonstrations
Gateway augmented with international habitat for increased capabilities
Foundation Surface Habitat and Habitable Mobility Platform delivered to complete Artemis Base Camp
Expanded habitation capability added to Gateway to enable Mars mission dress rehearsal at the Moon
Mars mission dress rehearsal with longer in-space and surface durations
Surface Fission Power
Foundation Surface Habitat
Habitatable Mobility Platform
Lunar Terrain Vehicle
SUSTAINABLE LUNAR ORBIT STAGING CAPABILITY AND SURFACE EXPLORATION
MULTIPLE SCIENCE AND CARGO PAYLOADS | INTERNATIONAL PARTNERSHIP OPPORTUNITIES | TECHNOLOGY AND OPERATIONS DEMONSTRATIONS FOR MARS

Gateway Sustainable Power Architecture

Notional Gateway Integrated Power Architecture with visiting vehicles, Per Tim Lawrence 5/16/2019



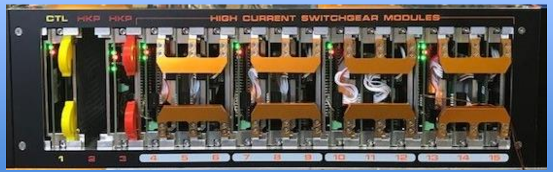
—(Grey) Primary Power Domain
—(Blue) Channel-1 Secondary Power Domain
—(Gold) Channel-2 Secondary Power Domain

DDCU – DC To DC Converter Unit
MBSU – Main Bust Switching Unit
PDU– Power Distribution Unit
BCDU – Battery Charge / Discharge Converter
PUP – Power Utility Panel

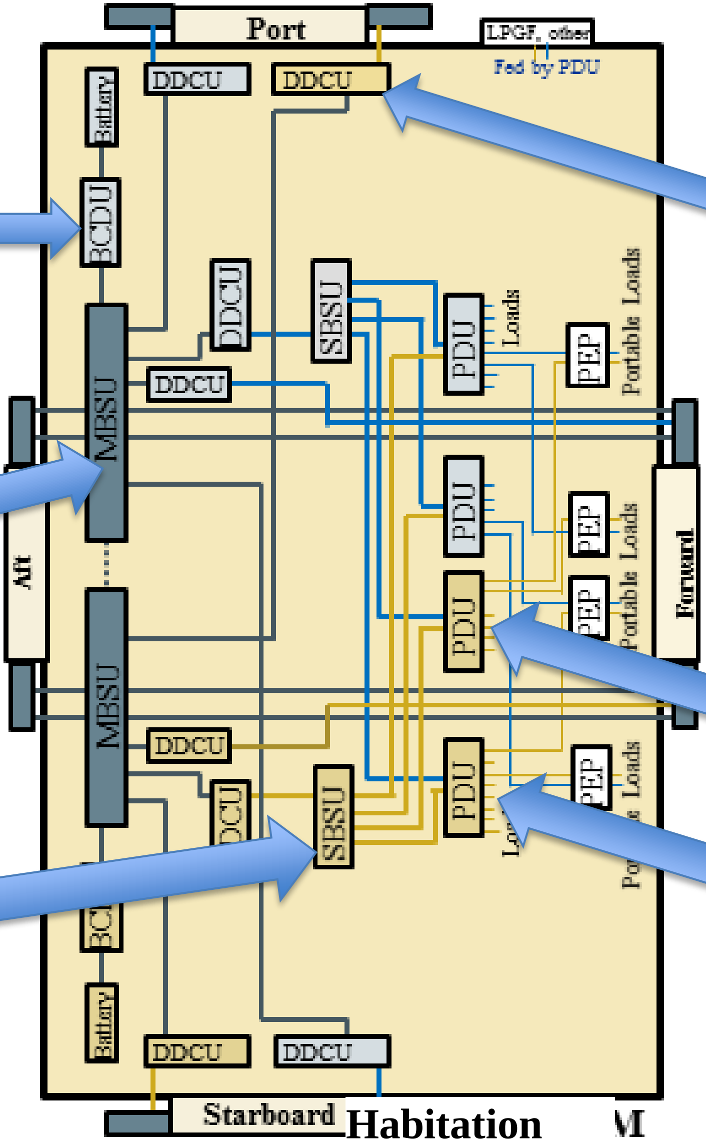
Modular Power System Units Proposed for a Generic Habitation Module

Battery Charge Discharge Unit (BCDU)

Primary Main Bus Switching Unit (MBSU)



Secondary Bus Switching Unit (SBSU)



Habitation Module

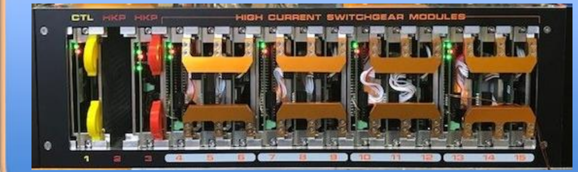
DC to DC Converter Unit (DDCU)

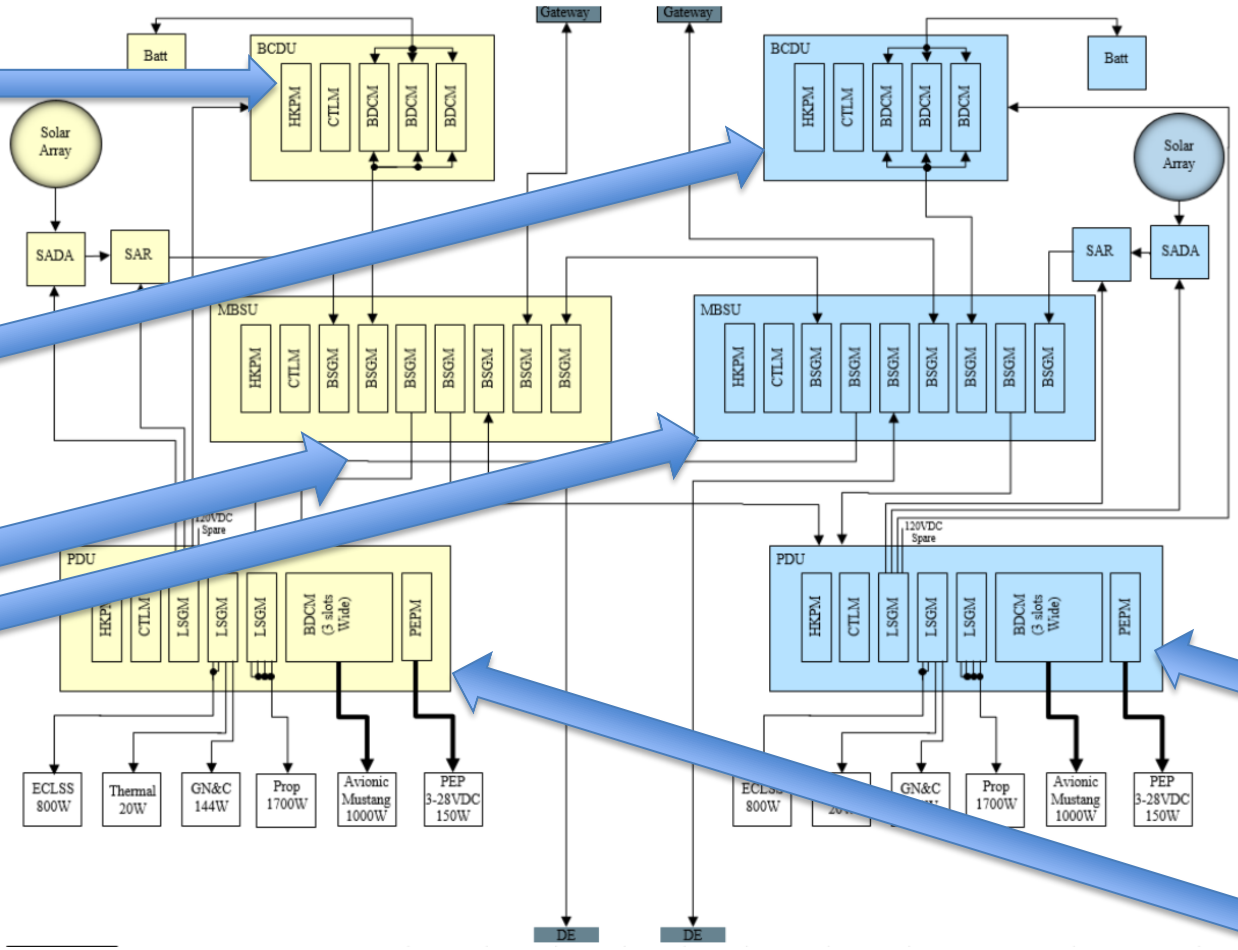
Power Distribution Unit (PDU)

Modular Power System Units Proposed for a Generic Human Lander

Battery Charge Discharge Unit (BCDU)

Main Bus Switching Unit (MBSU)

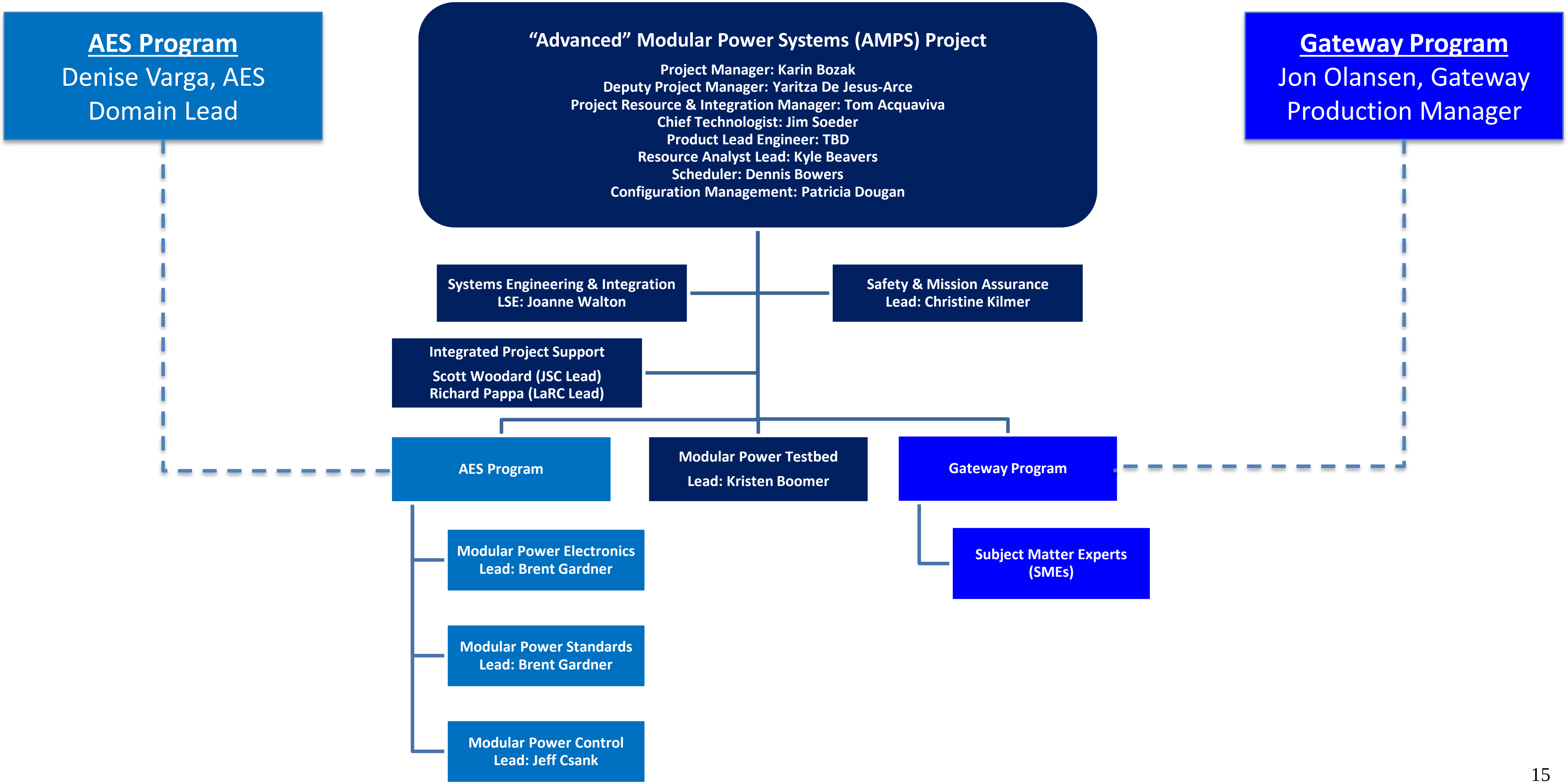




Lunar Lander – Crewed Element

Power Distribution Unit (PDU)

AMPS Project Organization



QUESTIONS?

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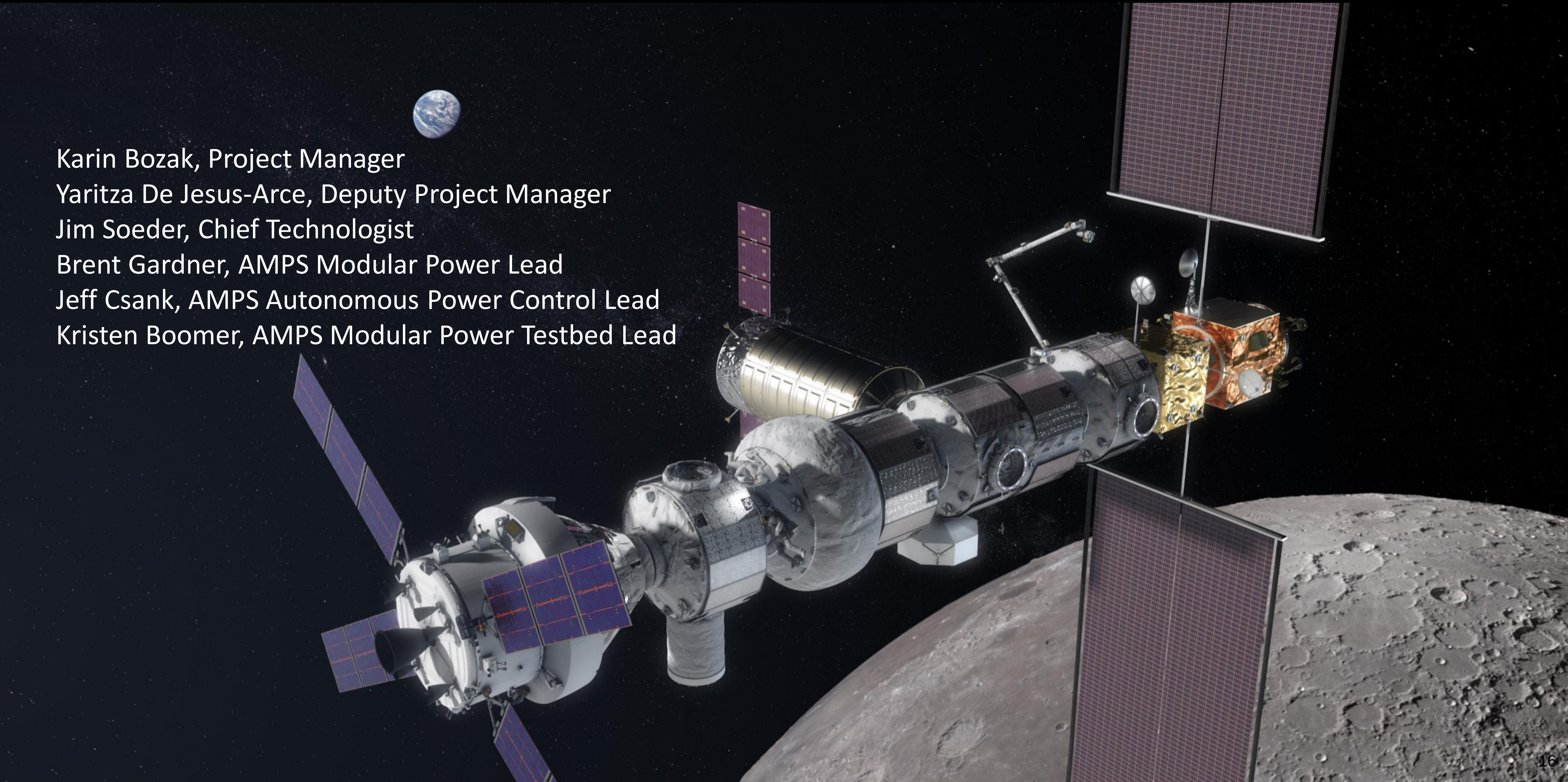
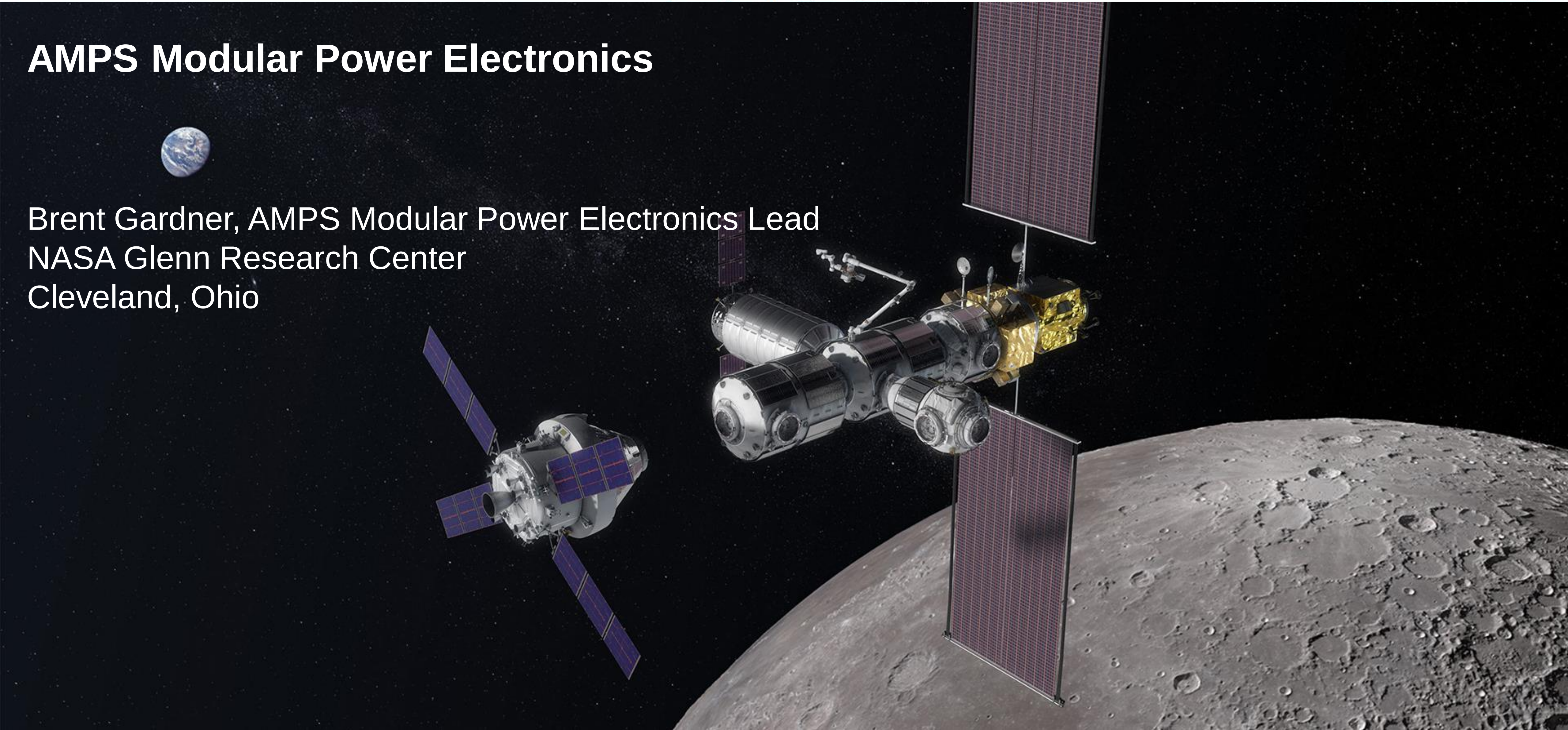


National Aeronautics and Space Administration

AMPS Modular Power Electronics

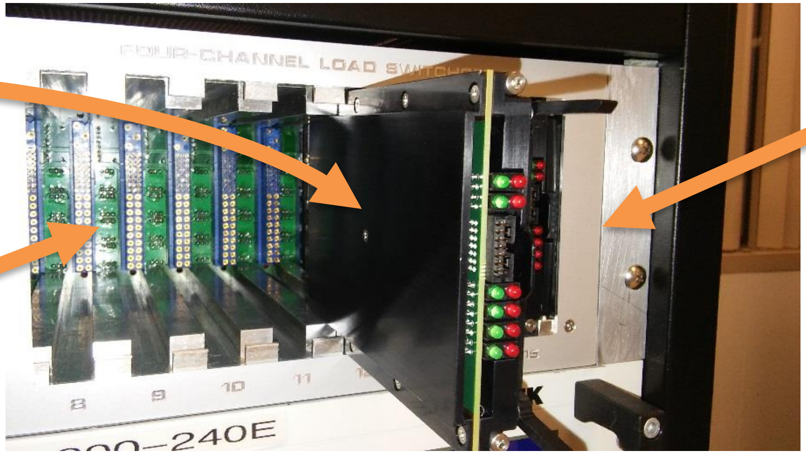


Brent Gardner, AMPS Modular Power Electronics Lead
NASA Glenn Research Center
Cleveland, Ohio

Definitions

Electronics Module

Backplane



Chassis

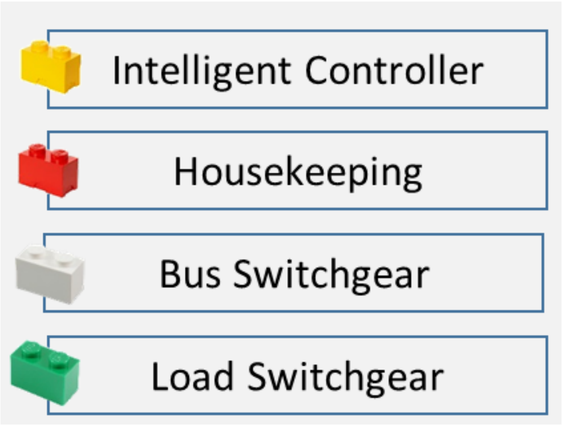
Modular Electronics Unit

Electronics Modules can be arranged into **chassis** to form **Modular Electronics Units** (MEU = ORU from ISS), such as Power Distribution Units (PDUs), Main Bus Switching Units (MBSUs), Battery Charge/Discharge Units (BCDUs), etc.

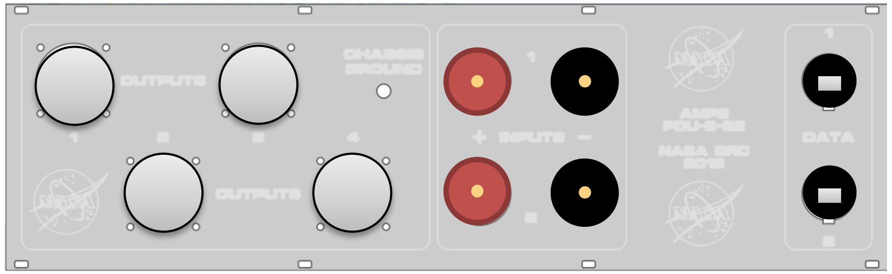
Example Power Distribution Unit

Chassis/Backplane

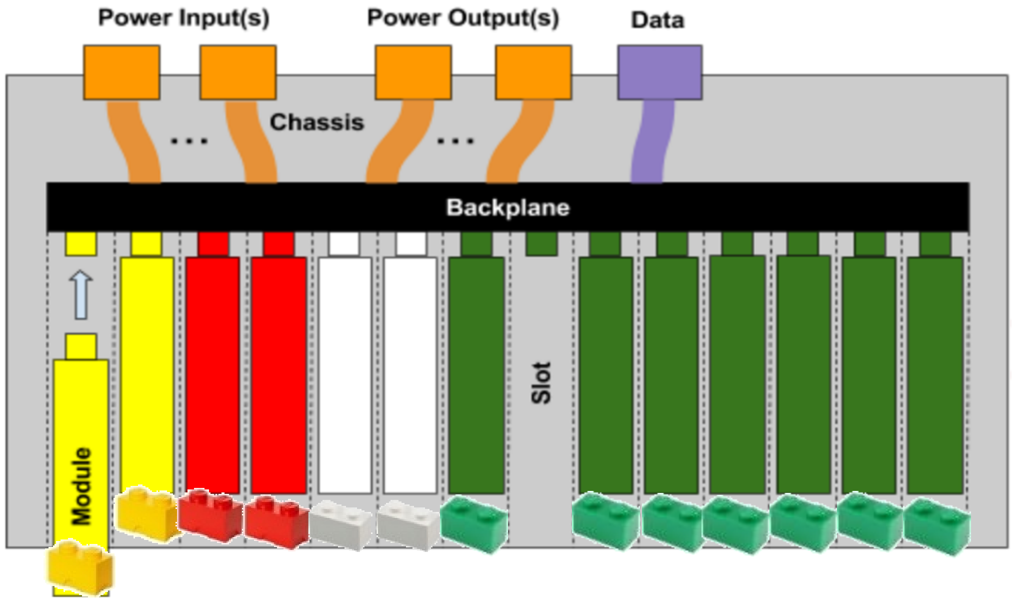
+



Electronics Modules



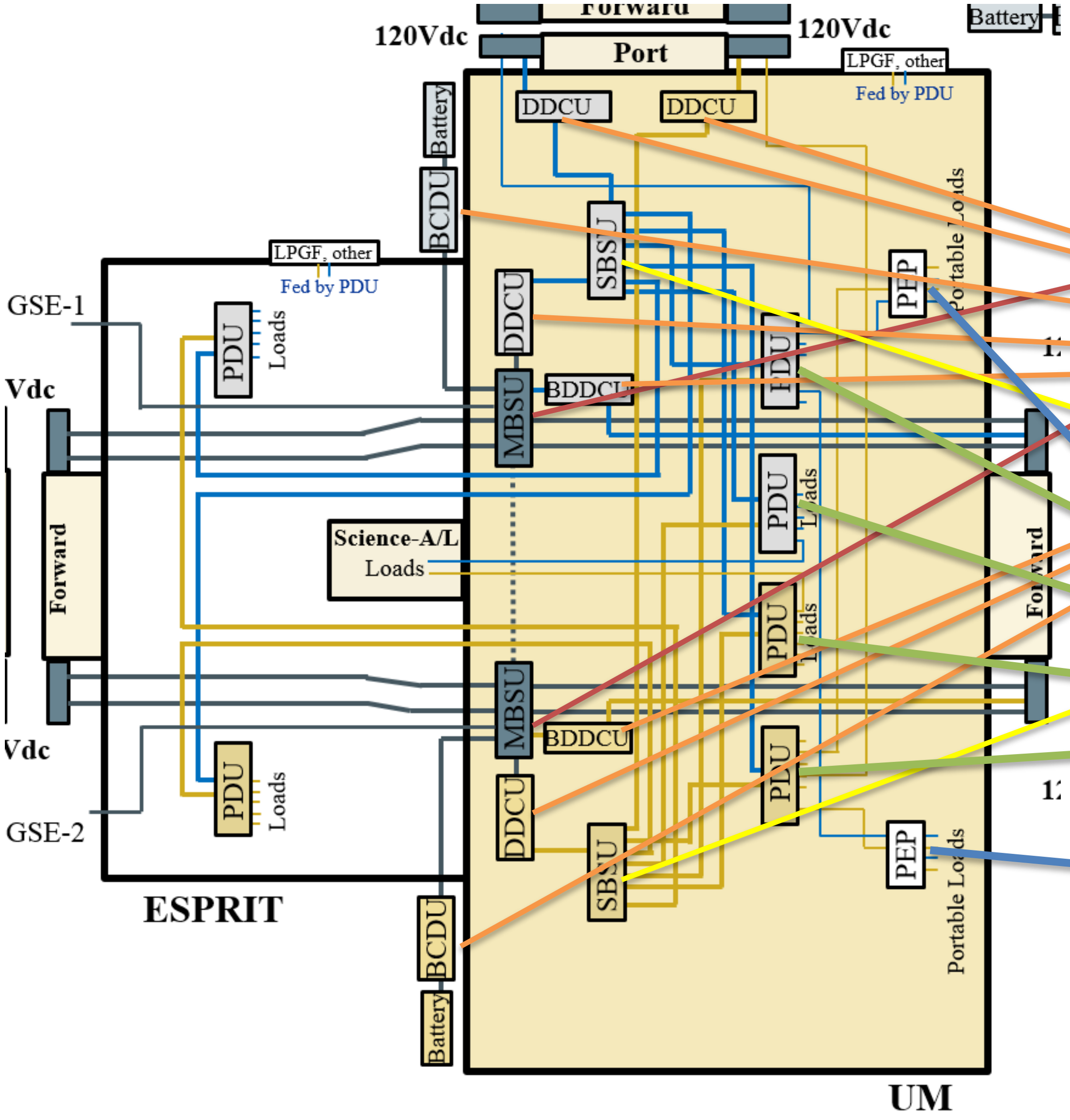
Rear



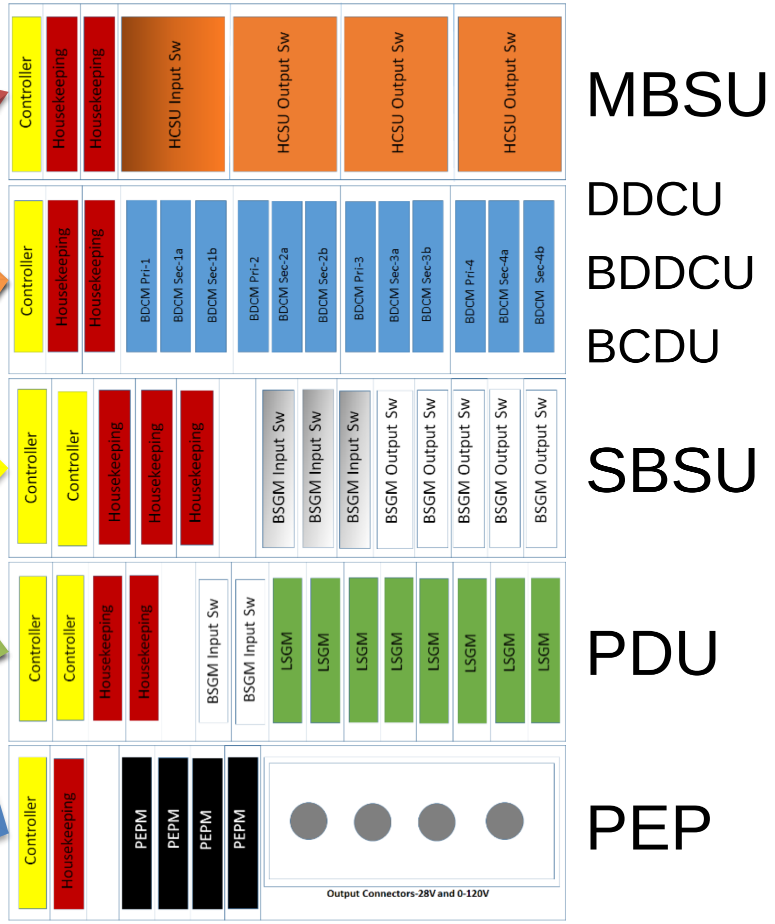
Top

Modular Electronics Unit

Utilization Module Power System



AMPS Modular Electronics Units

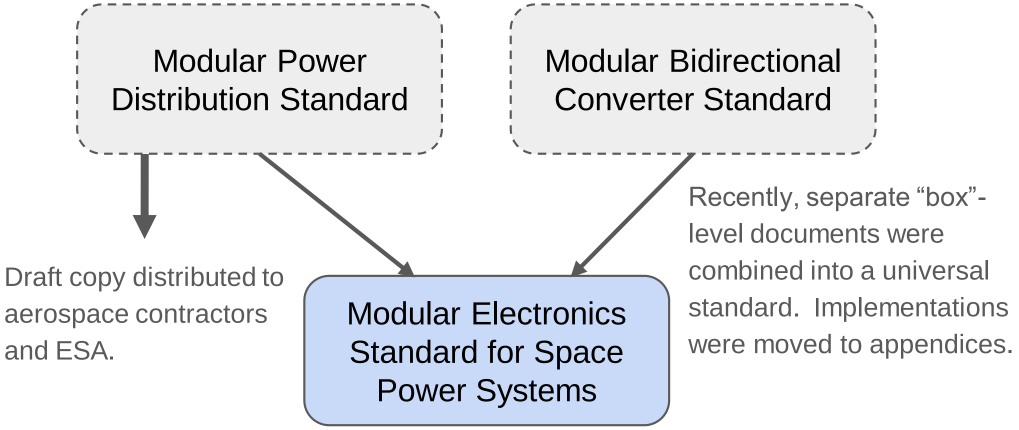


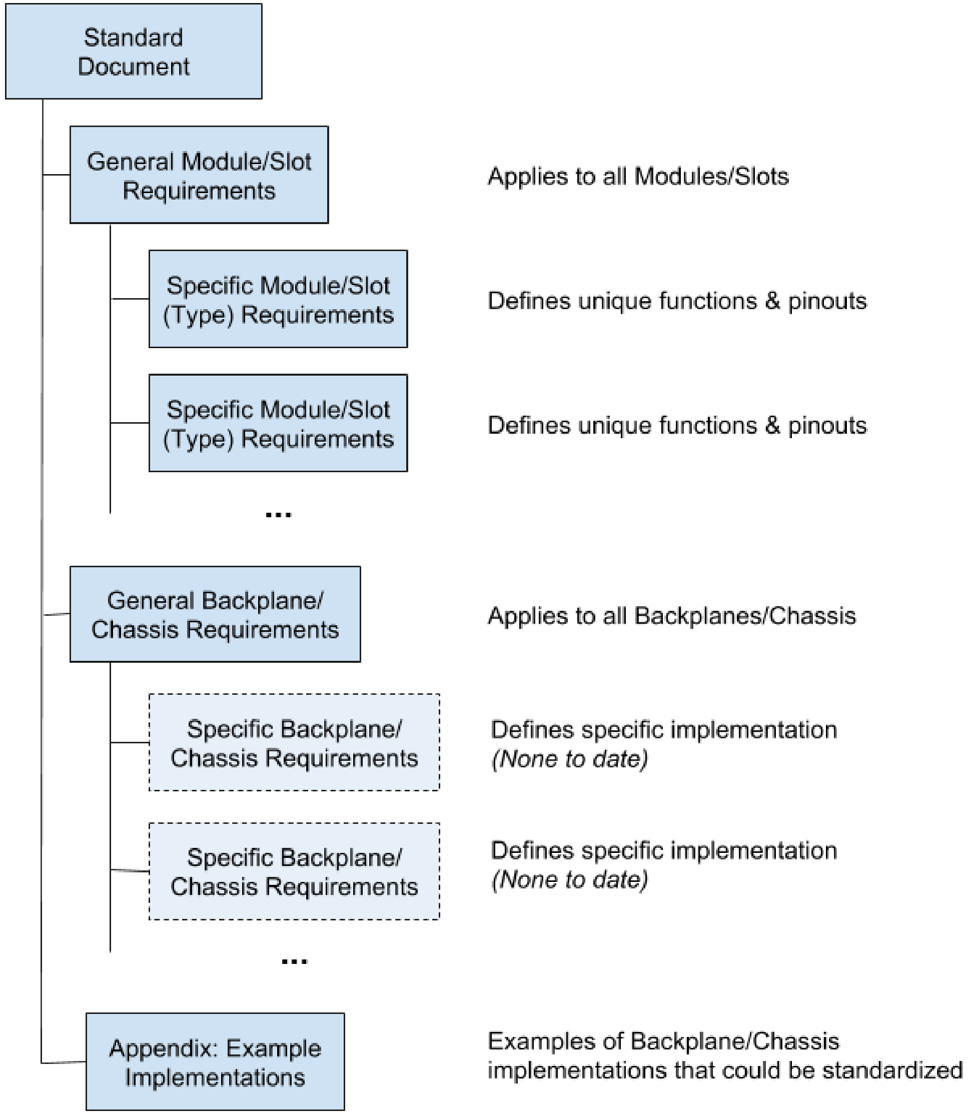
Standardizing the Electronics Modules

Two existing documents specify the electrical <u>power quality</u> for Gateway:

- International Space Power System Interoperability Standard (ISPSIS)
- Gateway Electrical Power Quality Specification Requirements for 120Vdc

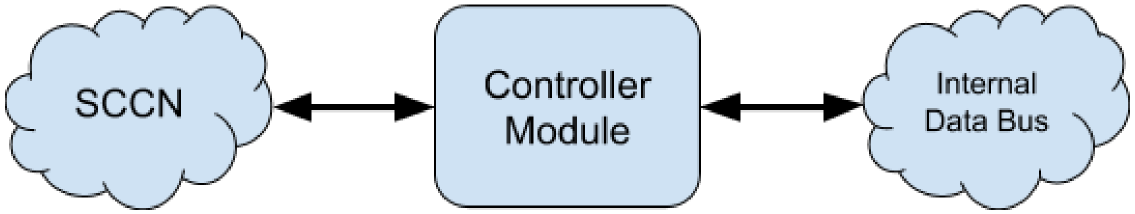
The **Modular Electronics Standard for Space Power Systems** was developed to define the <u>interfaces</u> and <u>functions</u> of the AMPS electronics <u>modules</u>. It is compatible with the existing power quality standards.





Controller Module (CTLM)

Functions:
- Spacecraft-to-internal network adapter
- Validates chassis configuration
- Monitors module status
- Translates commands & telemetry



SCCN: Spacecraft Communications Network

Inputs/Outputs:
- Spacecraft communication network (Ethernet)
- Internal data bus (CAN)

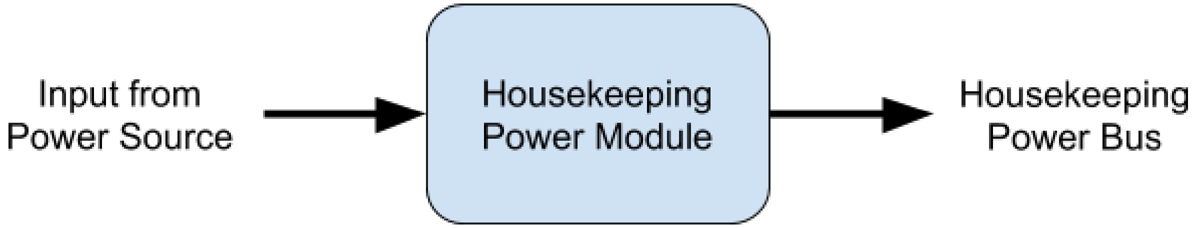
Size: 3U x 1 Slot
TRL: 4
Status: 3rd gen. prototype demonstrated in chassis

Design / Major Components:
- Raspberry Pi Compute Module running Raspbian operating system
- Ethernet & CAN controllers

Housekeeping Power Module (HKPM)

Functions:

- Generates Housekeeping Power Bus (5VDC) from 120VDC source



Inputs: 120VDC (nominal)
Outputs: 5VDC @ 30A

Size: 3U x 1 Slot
TRL: 4
Status:

- 3rd gen. prototype demonstrated in chassis

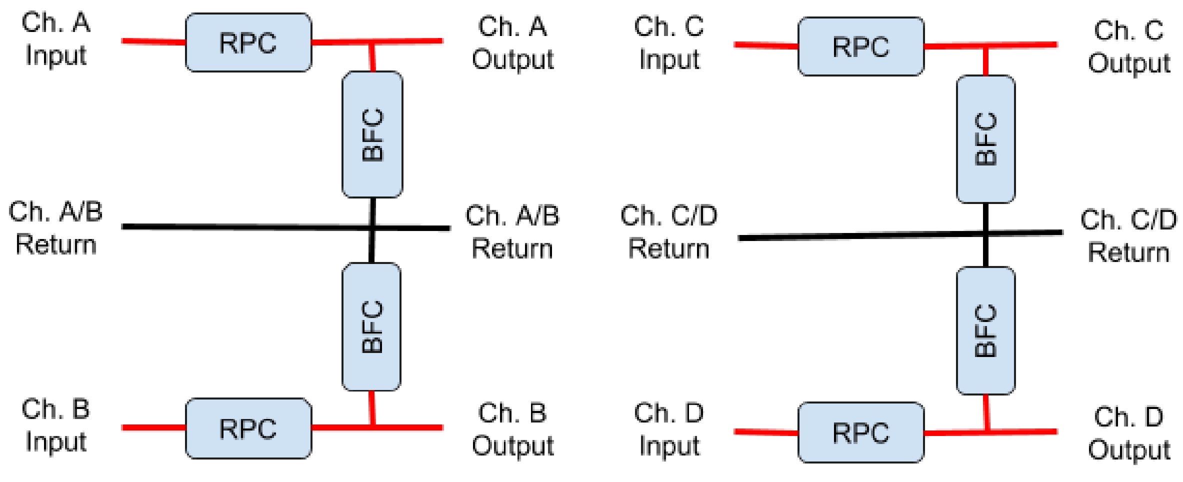
Design / Major Components:

- Digilent CmodA7 FPGA module
- 150W SynQor DC/DC converter

Load Switchgear Module (LSGM)

Functions:

- 4-channel unidirectional switch
- Current-limiting with configurable levels
- Resettable trip
- Parallelable channels can form "virtual power channels" (VPCs)
- Inductive load protection, safe discharge

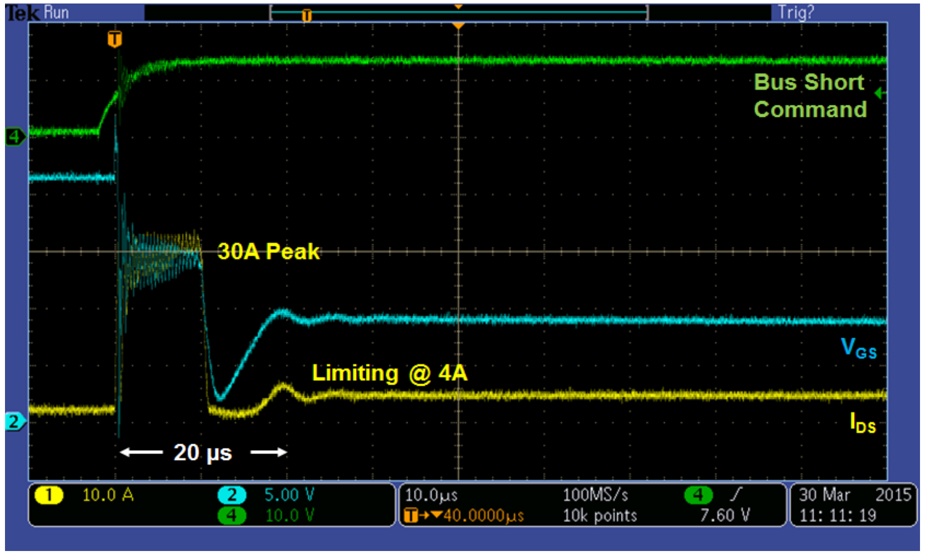


RPC: Remote Power Controller **BFC: Bleeder-Flyback Circuit**

Inputs: 4 @ 0-150VDC, 4A
Outputs: 4 @ 0-150VDC, 4A

Size: 3U x 1 Slot
TRL: 4
Status:

- 5th gen. prototypes demonstrated in chassis, paralleled 8 channels across 2 modules

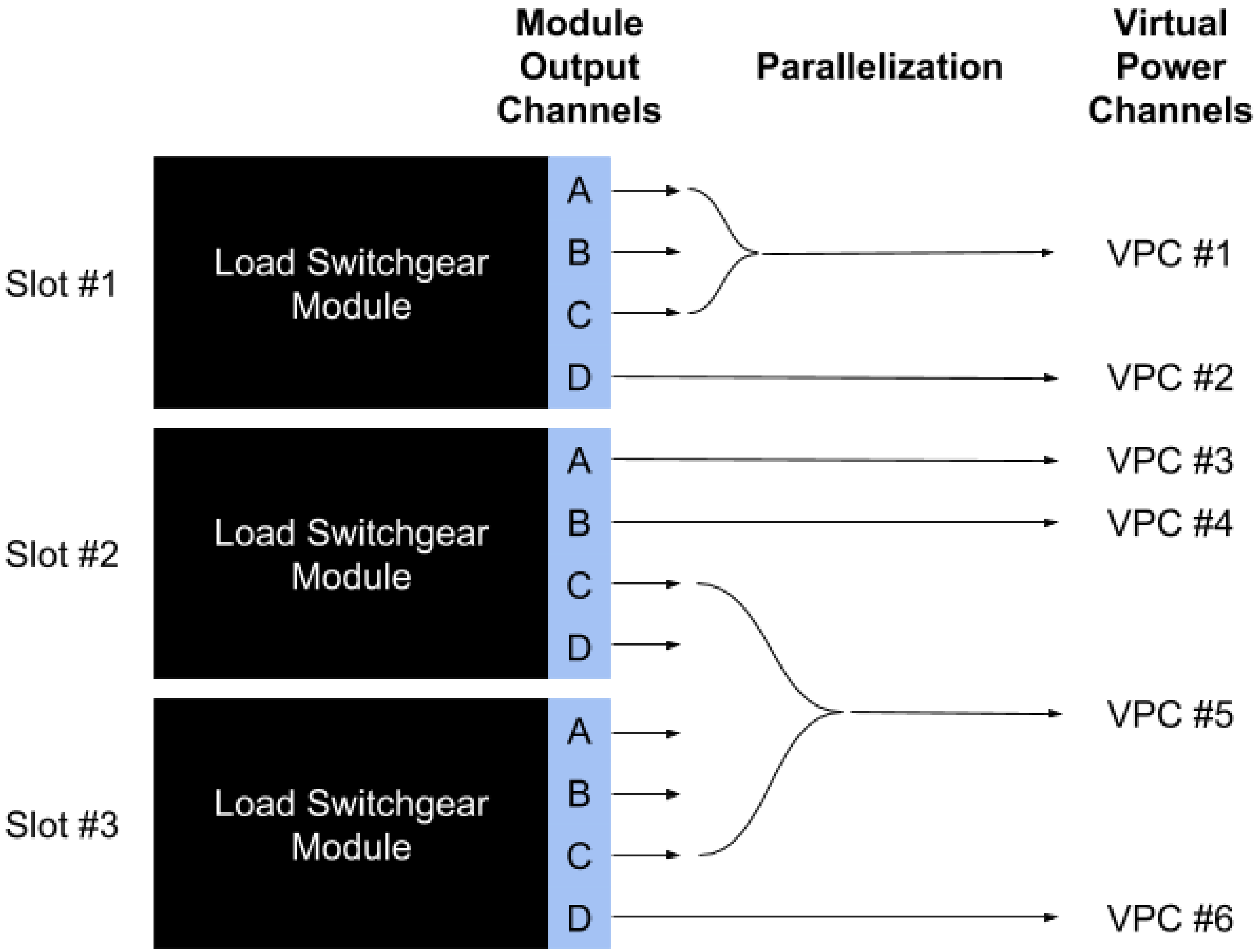


Short-Circuit Load Test (Current-Limiting)

Virtual Power Channels

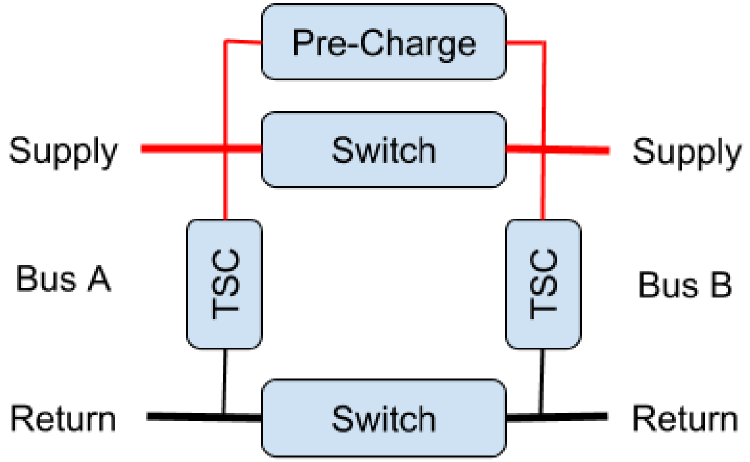
The 4x4A outputs of the Load Switchgear Modules (inside a single PDU) can be paralleled to form higher-current VPCs.

Current-limiting algorithms handle timing mismatches to prevent single-channel faults during transient events.



Bus Switchgear Module (BSGM)

Functions:
- Bidirectional bus switch (supply & return)
- Bidirectional pre-charge circuit
- Configurable, resettable trip
- Transient suppression



TSC: Transient Suppression Circuit

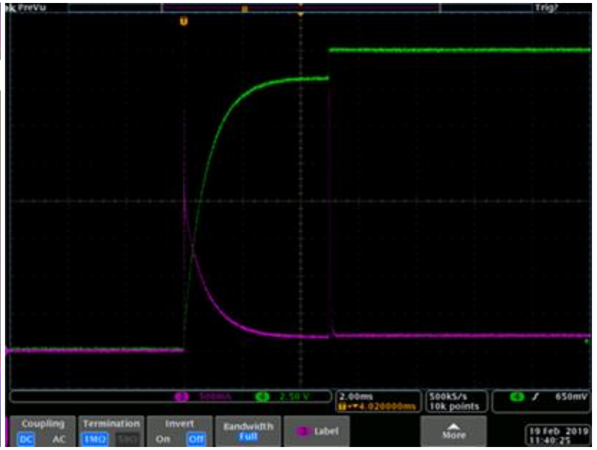
Inputs/Outputs: 2 ports @ 120VDC, 40A

Size: 3U x 1 Slot

TRL: 4

Status:
- 4th gen. prototypes demonstrated in chassis

Thermal Test

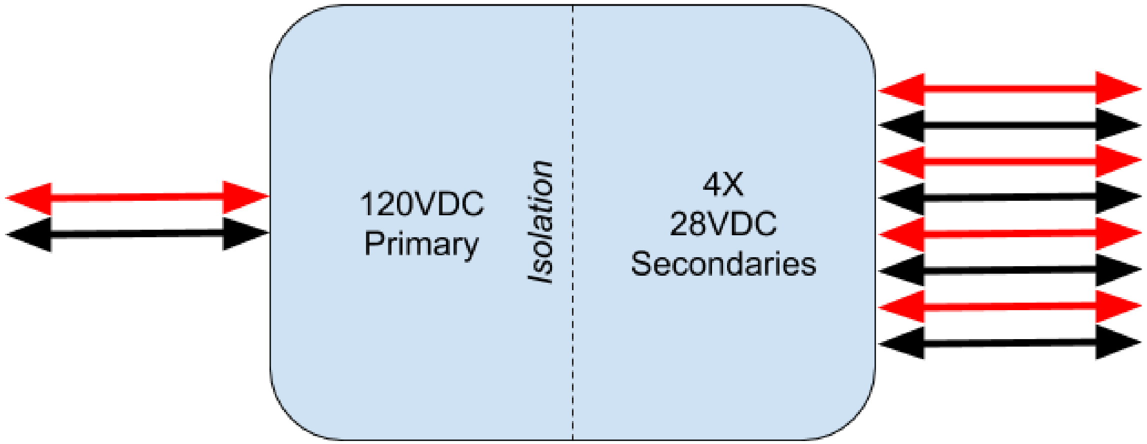


Pre-Charge/Make Test

Bidirectional Converter Module (BDCM)

Functions:

- Bidirectional DC/DC converter
- Configurable current & voltage setpoints
- Configurable, resettable trip
- Configurable secondary: 120VDC or 28V
- Synchronized, staggered switching



Inputs/Outputs:

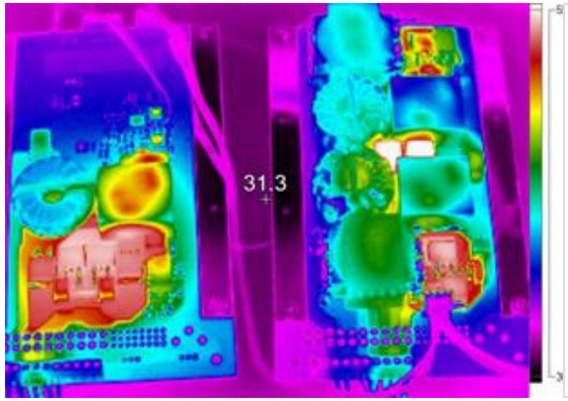
- "Primary": 120VDC @ 40A
- "Secondary": 120VDC @ 40A or 28VDC @ 160A

Size: 3U x 3 Slots

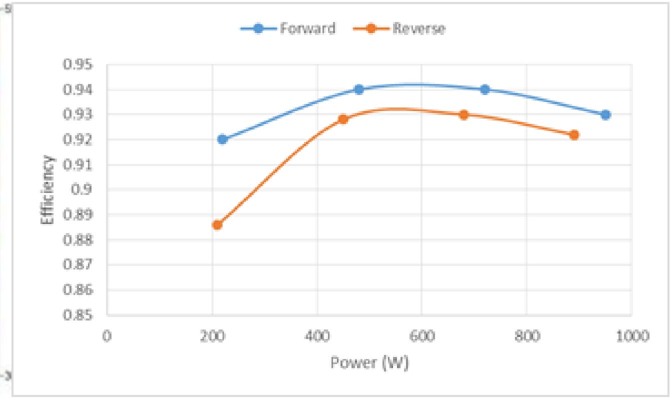
TRL: 4

Status:

- 2nd gen. prototypes demonstrated in chassis, paralleled 4 module sets @ 4kW

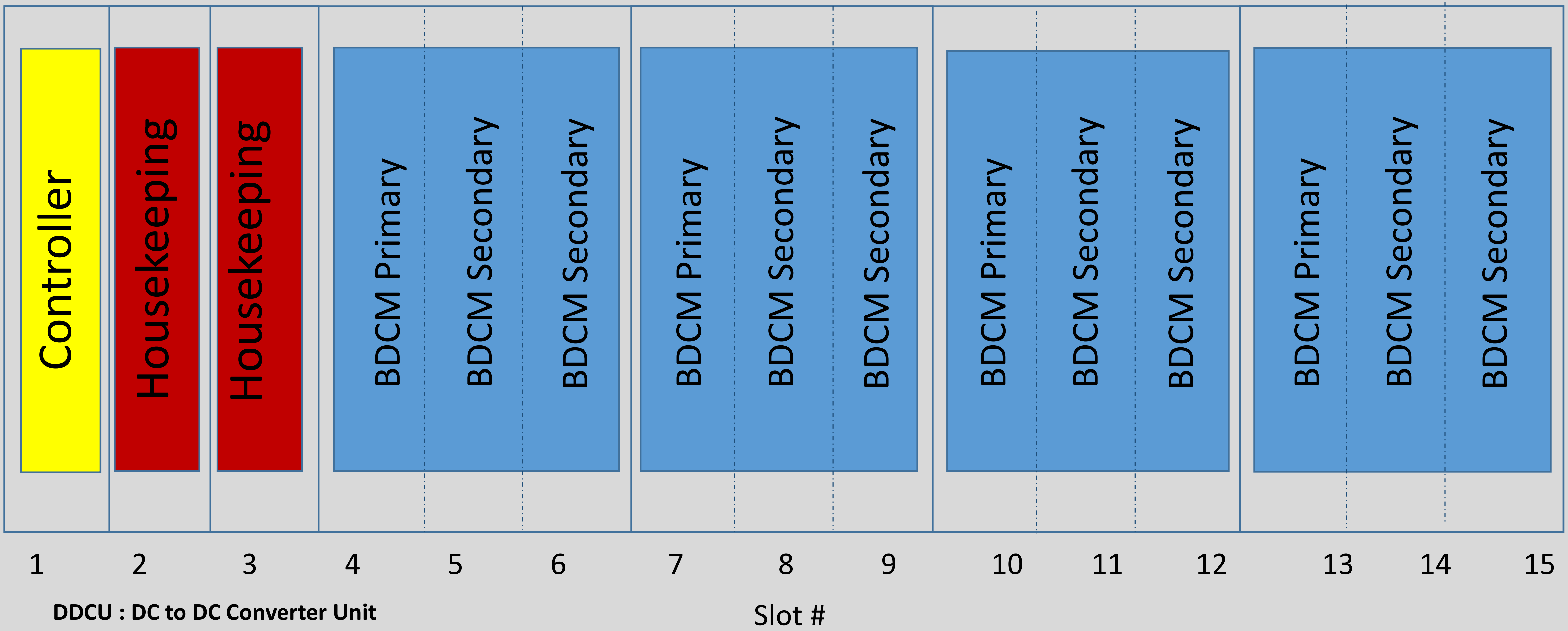


Thermal Test



Efficiency Test

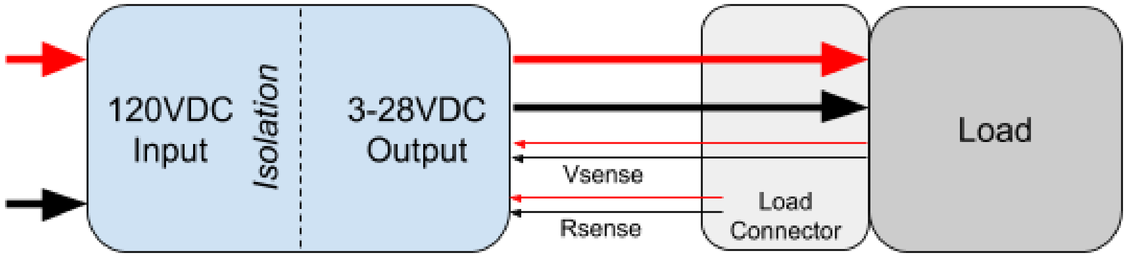
DDCU\BCDU\BDDCU Converter



DDCU : DC to DC Converter Unit
BCDU : Battery Charge Discharge Unit
BDDCU : Bidirectional Converter Unit
BDCM : Bidirectional Converter Module
2nd HKPM is Optional for DDCU Only

Portable Equipment Power Module (PEPM)

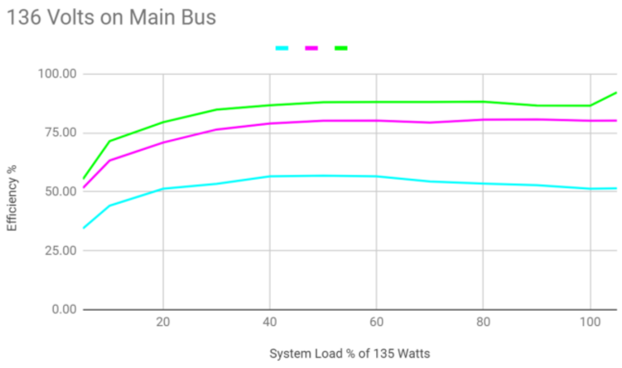
Functions:
- Variable output, isolating DC/DC converter
- Load cable or user programmable output
- Remote voltage sense



Input: 120VDC
Output: 3-28VDC @ 5.3A (up to 150W @ 28VDC)

Size: 3U x 1 Slot
TRL: 4
Status:
- Initial dev. jointly funded by JSC and GRC
- 3rd gen. prototypes demonstrated in chassis

Featured on Instagram @nasaglenn

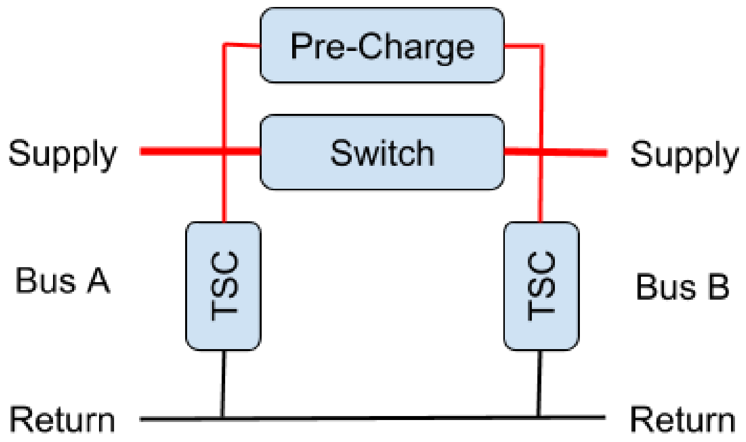


Efficiency Test

High Current Switchgear Module (HCSM)

Functions:

- Bidirectional supply-side switch
- Bidirectional pre-charge circuit*
- Configurable, resettable trip
- Transient suppression*



TSC: Transient Suppression Circuit

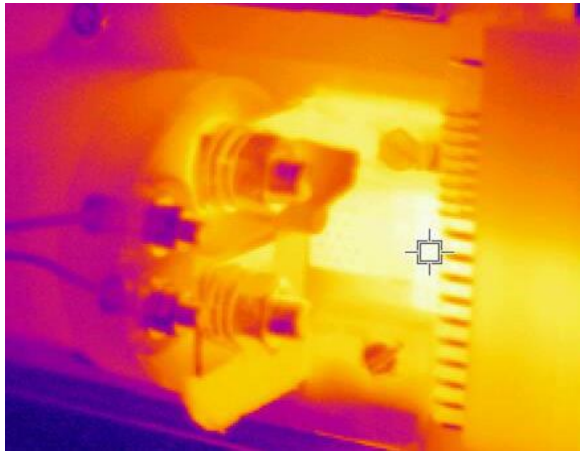
Input/Outputs: 2 ports @ 120VDC, 200A

Size: 3U x 3 Slots

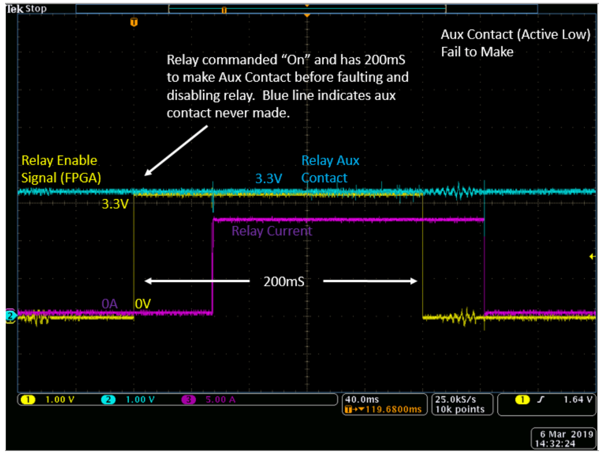
TRL: 4

Status:

- 2nd gen. prototype demonstrated



Thermal Test @ 200A



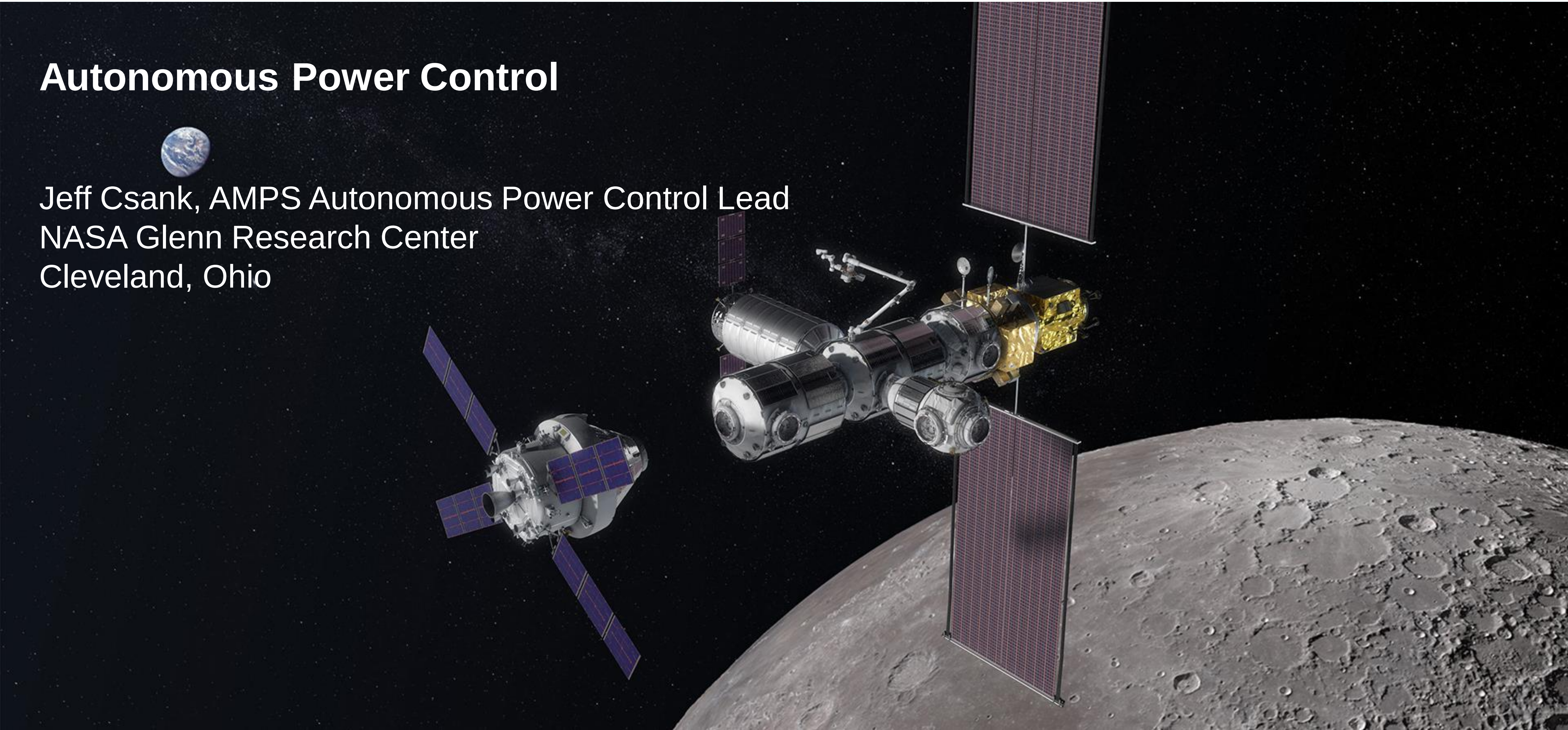
Electrical Test

Advanced Exploration Systems (AES)
Modular Power Systems (AMPS)

National Aeronautics and Space Administration

Autonomous Power Control

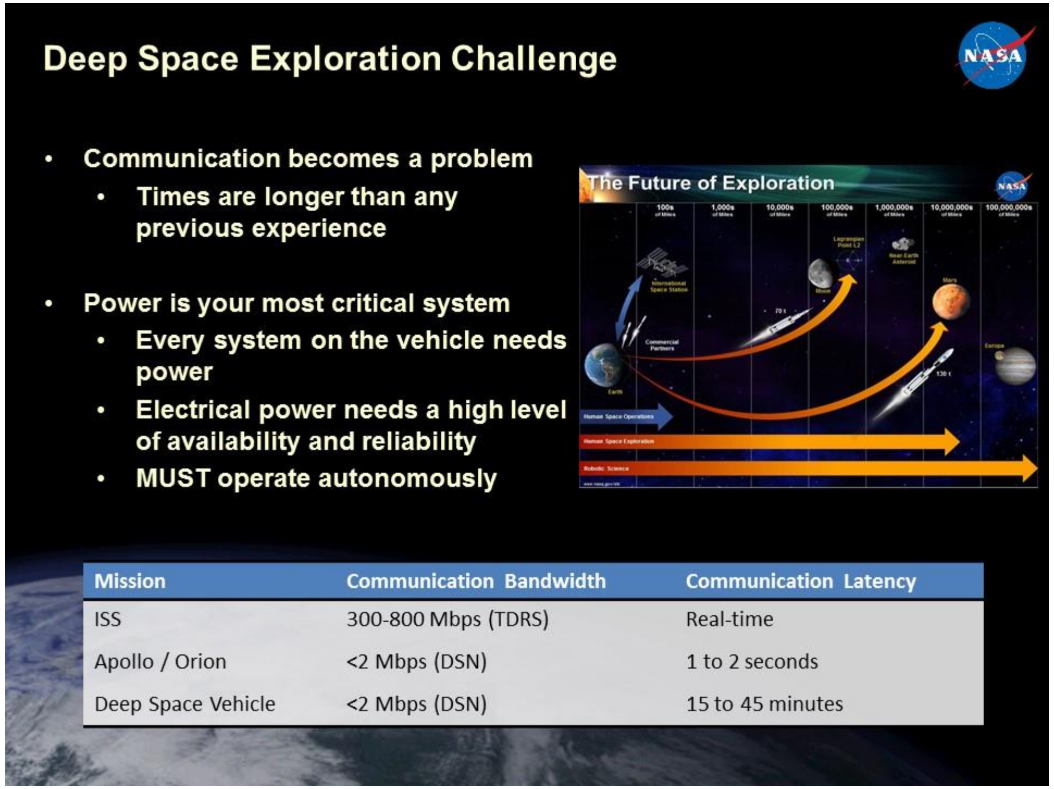
Jeff Csank, AMPS Autonomous Power Control Lead
NASA Glenn Research Center
Cleveland, Ohio



Why Autonomous Power Control

- **Deep Space Exploration Challenge**
  - Large communication latency reduces ability for ground control to safely operate vehicle subsystems in real-time.
    - Deep Space Vehicle = 15 to 45 minutes for round trip communication

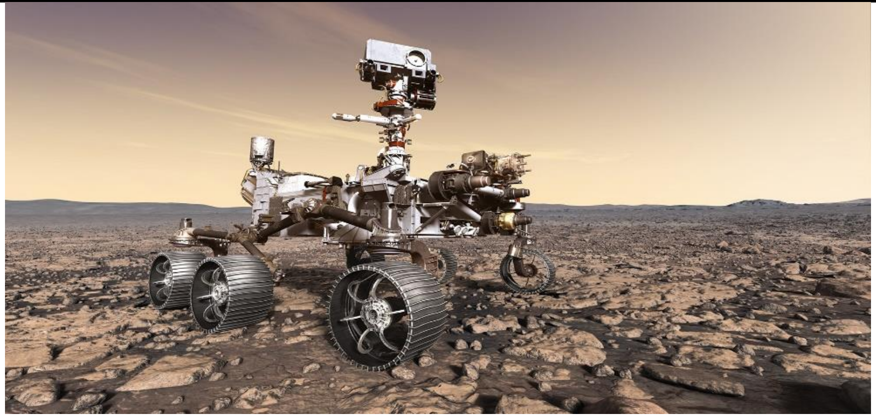
- **Gateway requirement for 21-day autonomous operation**
  - GTW-L2-0044: Independent Operations Requirement
    - *Modules shall provide for autonomous operations for up to 21 days independent of ground communications.*
    - Requirement driven by anticipated needs of a crewed Martian Mission
      - J. Badger, “Spacecraft Dormancy Autonomy Analysis for a Crewed Martian Mission,” NASA TM 2018-219965

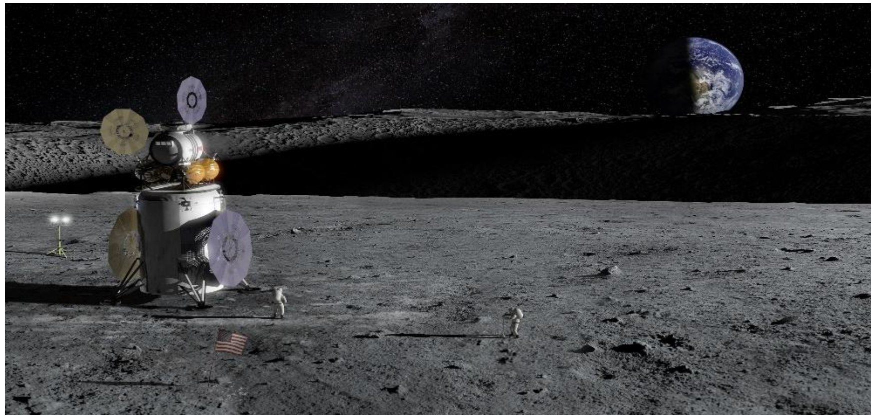


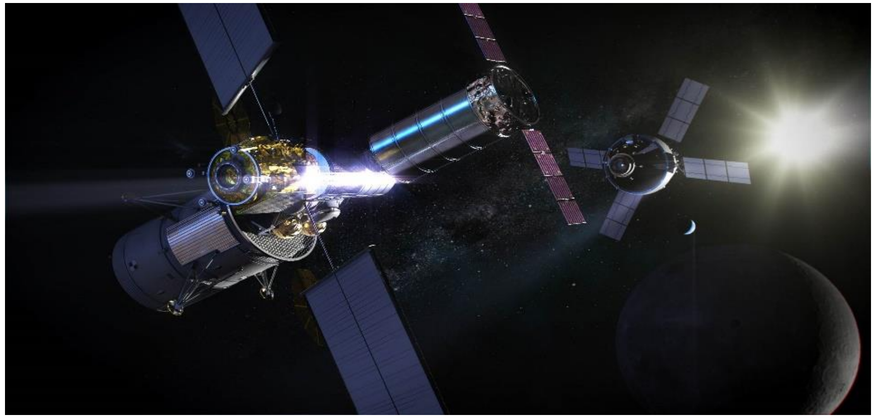
What is an Autonomous Power System?

- **Power System Functions**
  - Operate power system safely at all times
    - Protect from overloading, over discharging, etc.
  - Provide power to as many high priority loads as possible

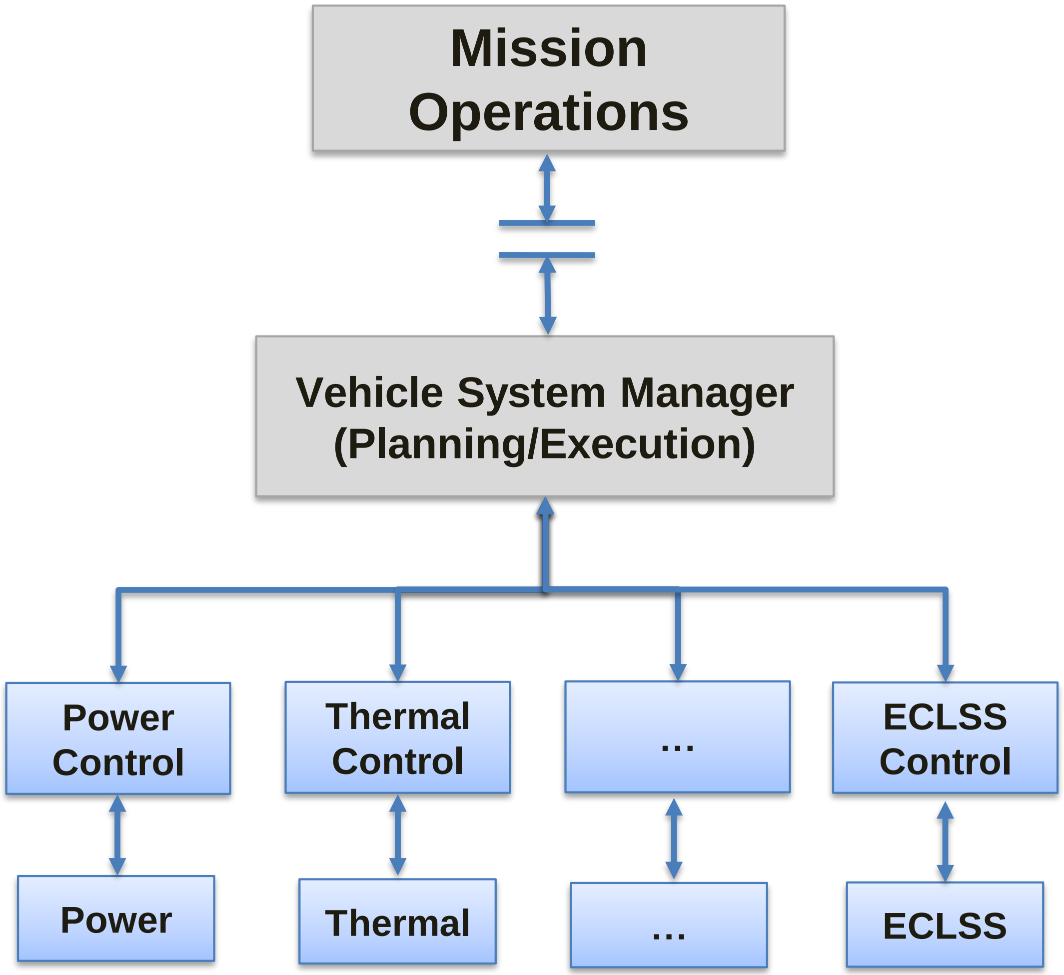
- **Autonomous Power System Control Functions**
  - Manage the power system without human intervention
    - Fault management
    - Energy management
    - Contingency Management
      - Maintenance, mitigation, and recovery
  - **Permit humans to consent to any operations / actions during habitation (manned spacecraft only)**







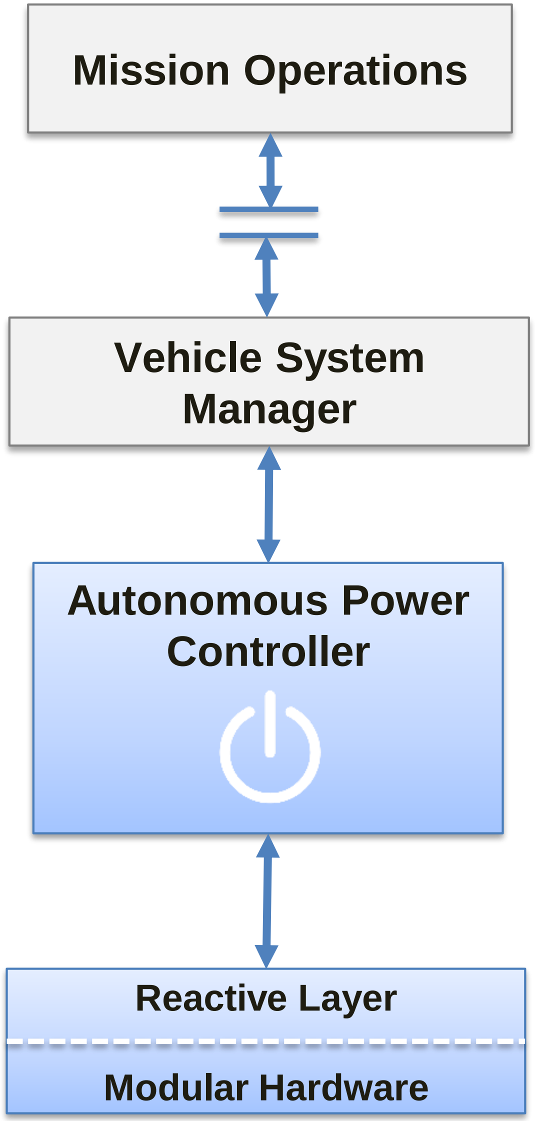
Autonomous Spacecraft Architecture



- **Spacecraft Autonomy**
  - Goal is to remove the human element from real-time operation of the vehicle.
  - Push functions/capabilities to the lowest level possible
  - Vehicle system manager responsible for the Planning and Execution of vehicle operations.
  - Autonomous subsystem controllers contains all the knowledge of the particular subsystem.
  - Could contain intermediate control layers for systems that are more complex.

Vehicle Autonomous Control Architecture

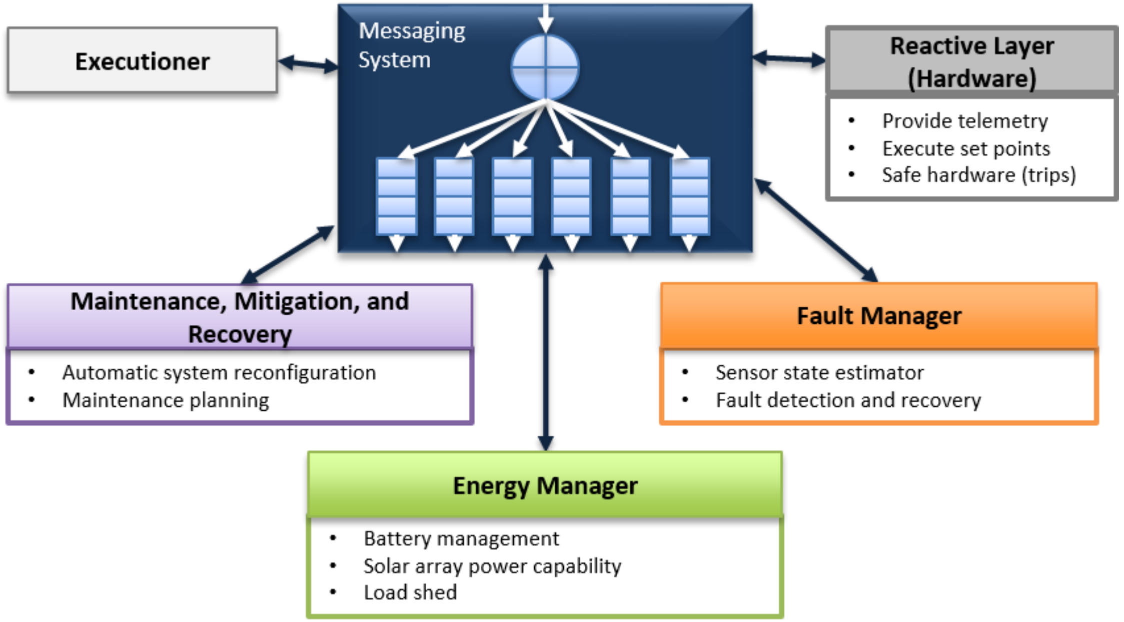
- **Mission Operations**
  - Monitors vehicle operations
  - Adjusts long term mission objectives
- **Vehicle System Manager**
  - Ensure mission operations are met
  - Resolve fault indications between subsystems
  - Schedule power usage by loads
- **Autonomous Power Controller**
  - Provide power to the highest priority loads
  - Forecast energy availability
  - Manage power/energy constraints for the vehicle
  - Safely operate the EPS hardware
  - Perform EPS fault management
    - Hard / Soft faults, Sensor faults, Communication Faults
- **Reactive Layer (Full Digital Control)**
  - Provides closed-loop control of the EPS hardware.
    - Circuit Trip, Voltage Control, battery charge, etc.
  - Protect EPS from hard faults (safe the system).



Autonomous Power Control Architecture

Energy Management

- Accurately forecast the power and energy available to the loads in the future
- Deliver power to as many as possible high priority loads as possible.
- Ensure power system constraints are not violated, including energy storage assets.
- Ability to shed loads to protect power system constraints.



Fault Management

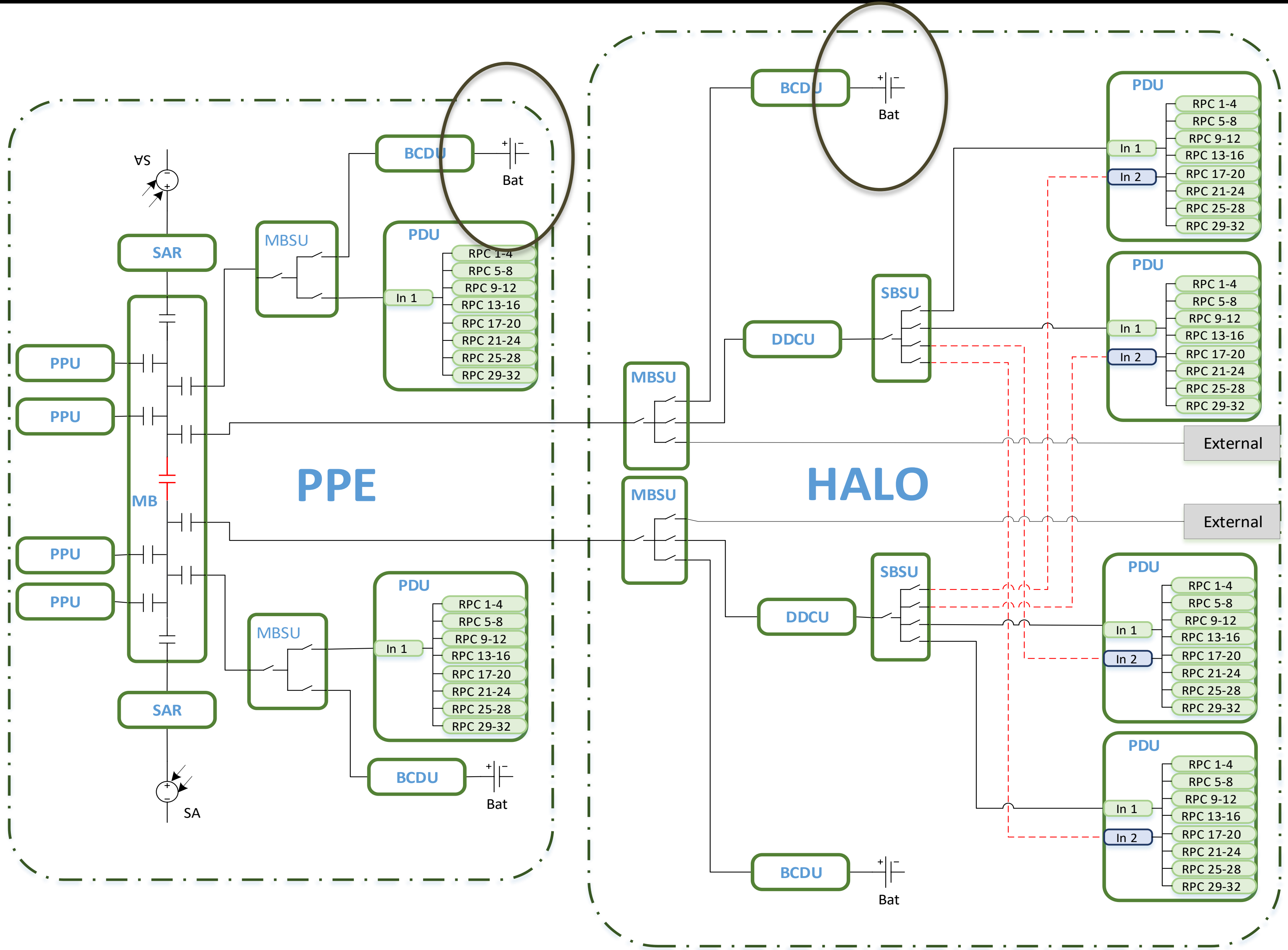
- Detect, isolate, and recover from faults without a human operator in the loop.
- Identifies hard failures (short to ground) and detect soft failures (high impedance faults), sensor failures and communication failures
- Rely on both model-based and rules-based fault management techniques.

Automatic Reconfiguration

- Ability to automatically reconfigure the power distribution system to deliver power to the loads.
- Use a shortest path first algorithm (Dijkstra's algorithm) to determine most efficient routing.

Energy Management

- **Forecast the amount of energy available from the Solar Array and batteries over the next planning period**
- **Developing capability to deal with distributed batteries**
  - Goal is to equally discharge all batteries on a single channel
  - Maximizes power availability in case of power system failure during eclipse

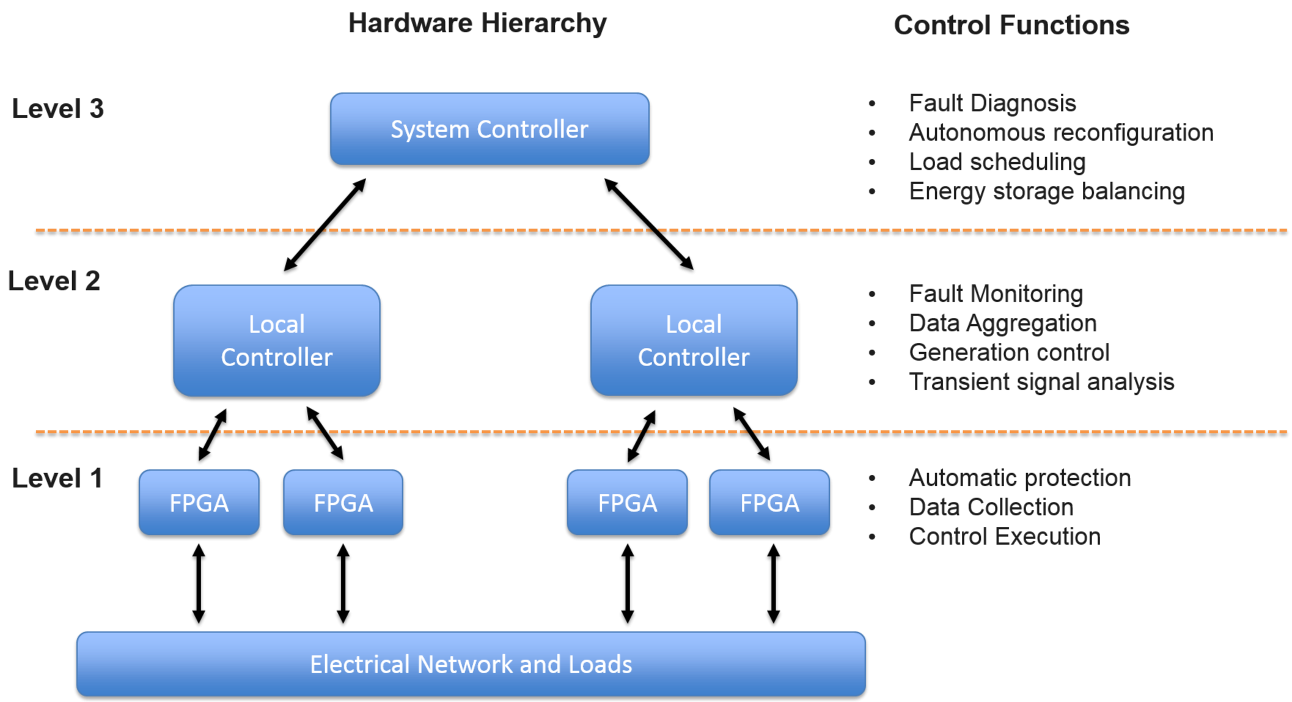


Fault Management

- **Detect, isolate, and recover from faults without a human operator in the loop.**

- **Fault Techniques Employed**
  - Classical hard protection (trip curve)
  - Heart beat for communication
  - Analytical redundancy
  - State estimation
  - Model based methods

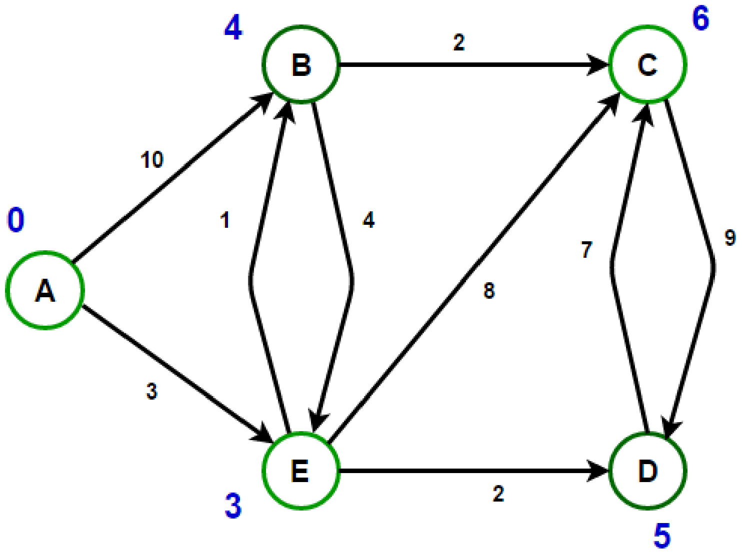
- **Multiple Fault**
  - Rely on blend of model based and rules based techniques
  - On average, can detect up to ~10 faults before fault manager stops detecting
    - System unobservable
    - Power system no longer functioning

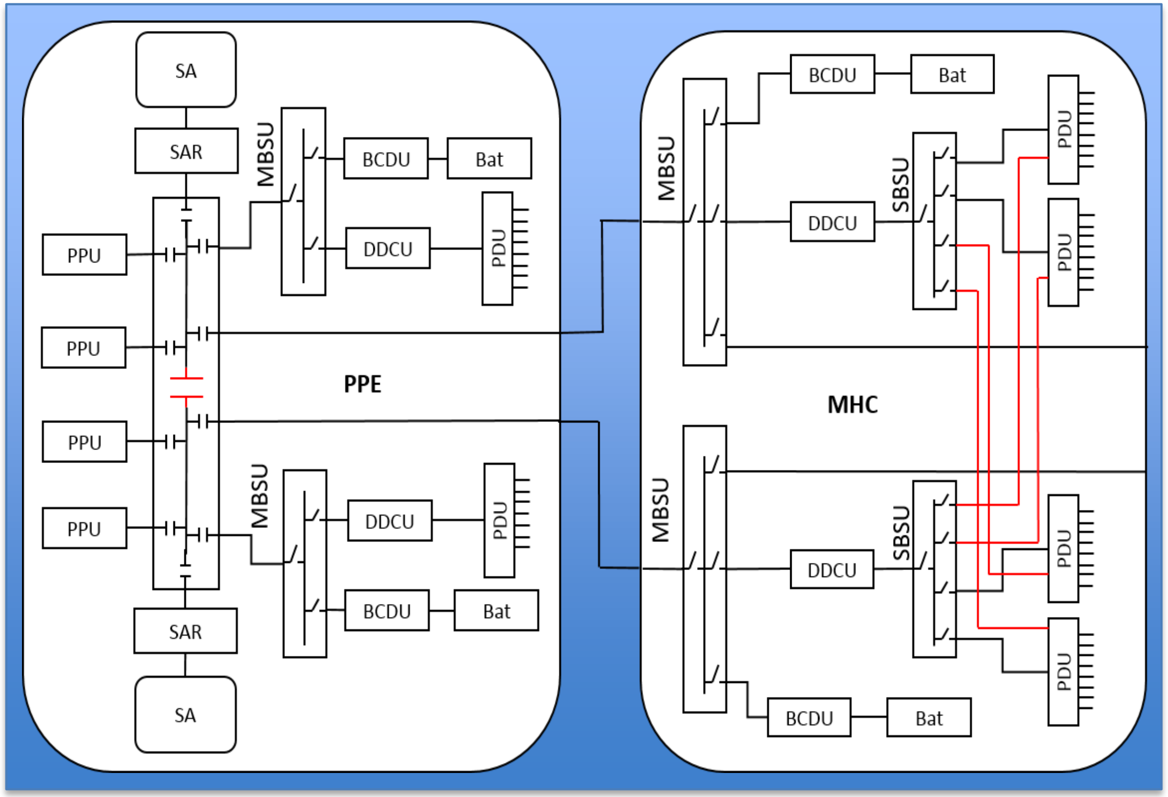


Current Fault Results
- Investigated and tested 380 individual faults
  - 76 hard faults
  - 132 switch faults
  - 24 communication faults
  - 148 sensor faults

Maintenance Mitigation and Recovery

- **Manages system reconfiguration**
  - Fault removes component from service and need to re-route power
  - *Need to repair equipment and schedule outage (future capability)*
- **Algorithm uses Dijkstra's algorithm**
  - Used in Google's Map
  - Find the optimal path by weighting every line.



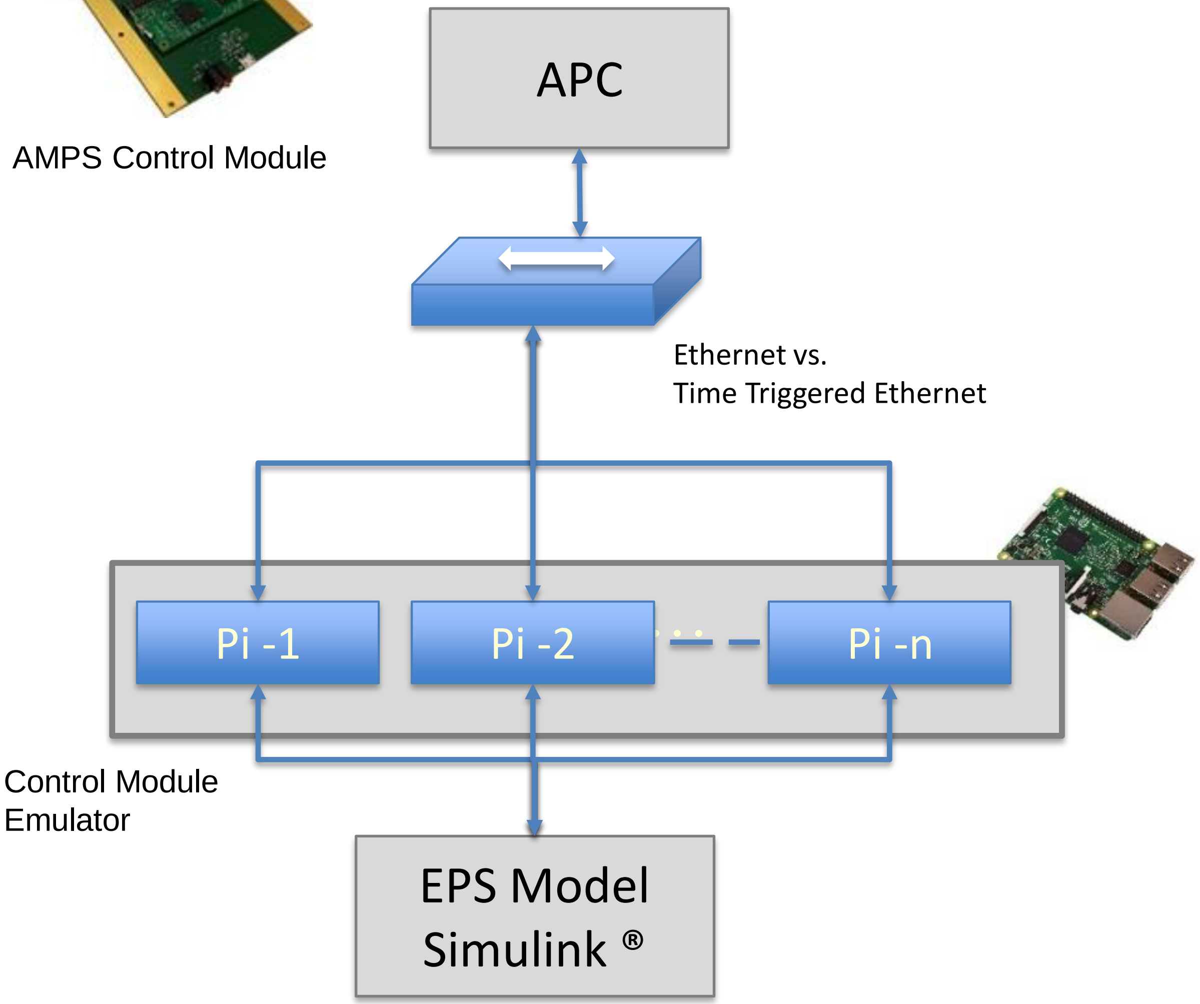


Gateway Modular Power System Emulator

Hardware Prototype

- **Modular Electronic Units (MEUs) are represented with single Raspberry Pi (Control Module)**
- **Actual MEUs are simulated in Simulink.**
  - Both commands and telemetry are sent through the interface (Pi /Control Module)
- **Allows the APC team to design a software interface that connects the modular hardware (control module) to the APC.**
  - Decreases future modular hardware integration effort
  - Allows for testing different communication technologies
    - Ethernet
    - Time Triggered Ethernet (TTE)

AMPS Control Module



Summary

- **The ability to manage a spacecraft’s electrical power system without a human in the loop is an enabling technology for human deep space exploration and required for the Gateway. This includes:**
  - Energy Management
  - Fault Management
  - Contingency Management or Reconfiguration

- **The Gateway program is interested in the energy management and reconfiguration capabilities that have been developed under AMPS.**
  - Actively working on demonstrating how those capabilities helps Gateway meet its mission objectives.

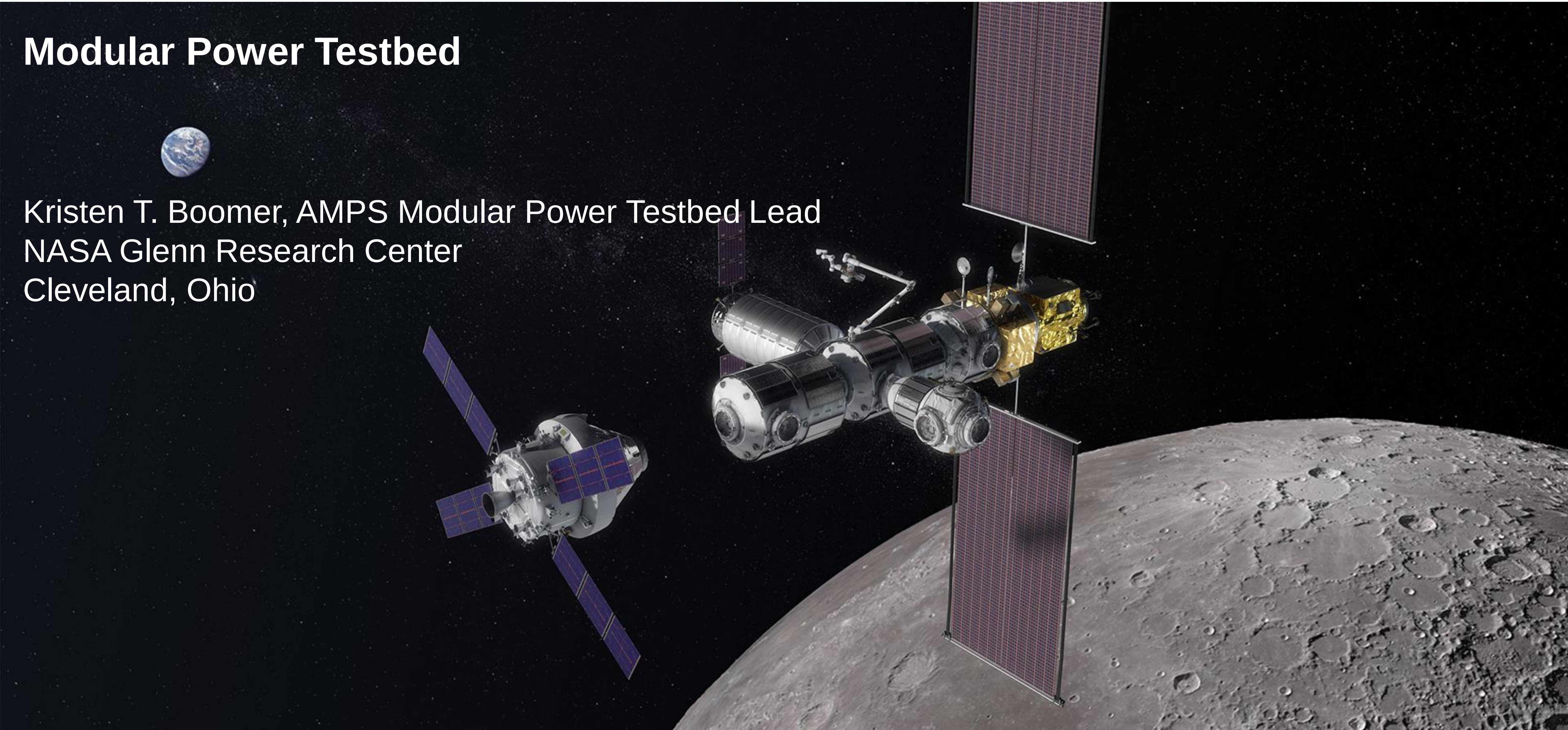
- **The APC provides essential power management and distribution control functions, which are critical to monitoring and controlling the <u>modular power hardware</u>, and therefore the APC is developing a method (interface) to integrate the module hardware together.**

Advanced Exploration Systems (AES)
Modular Power Systems (AMPS)

National Aeronautics and
Space Administration

Modular Power Testbed

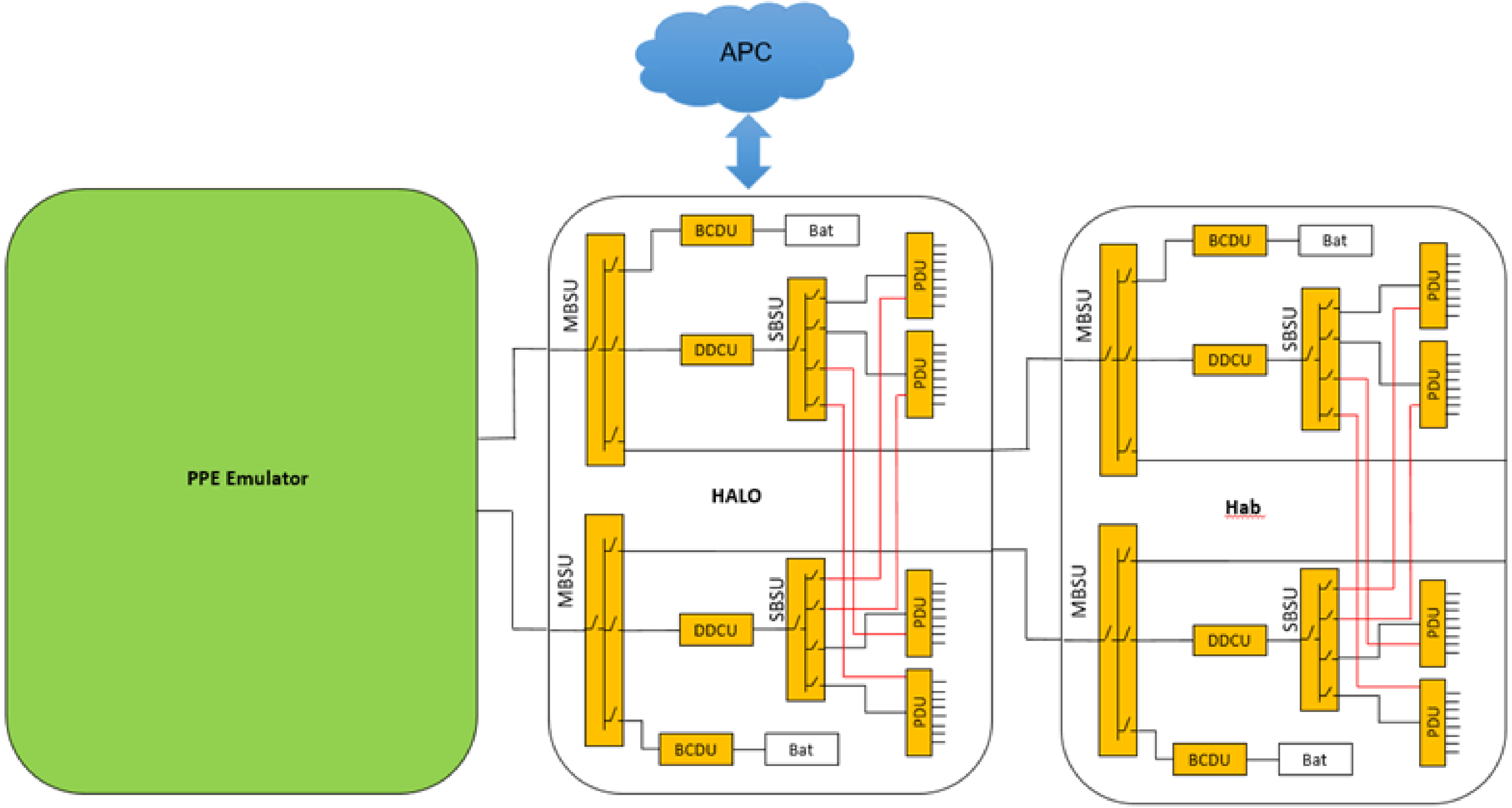
Kristen T. Boomer, AMPS Modular Power Testbed Lead
NASA Glenn Research Center
Cleveland, Ohio



Background

- The AMPS Modular Power Testbed is a three-year, three-phase effort to develop and demonstrate an end-to-end integrated modular power system testbed
- Testbed objectives:
  - Perform integrated testing of AMPS modular hardware
  - Provide a platform for collecting characterization test data on the power quality of a modular power architecture
  - Reduce risk of implementation for modular power systems on future NASA missions (e.g. Gateway, Landers)
  - Support modular standards development
  - Demonstrate the ability of the Autonomous Power Controller (APC) to monitor and control MEUs, perform electrical power system fault management, and system studies

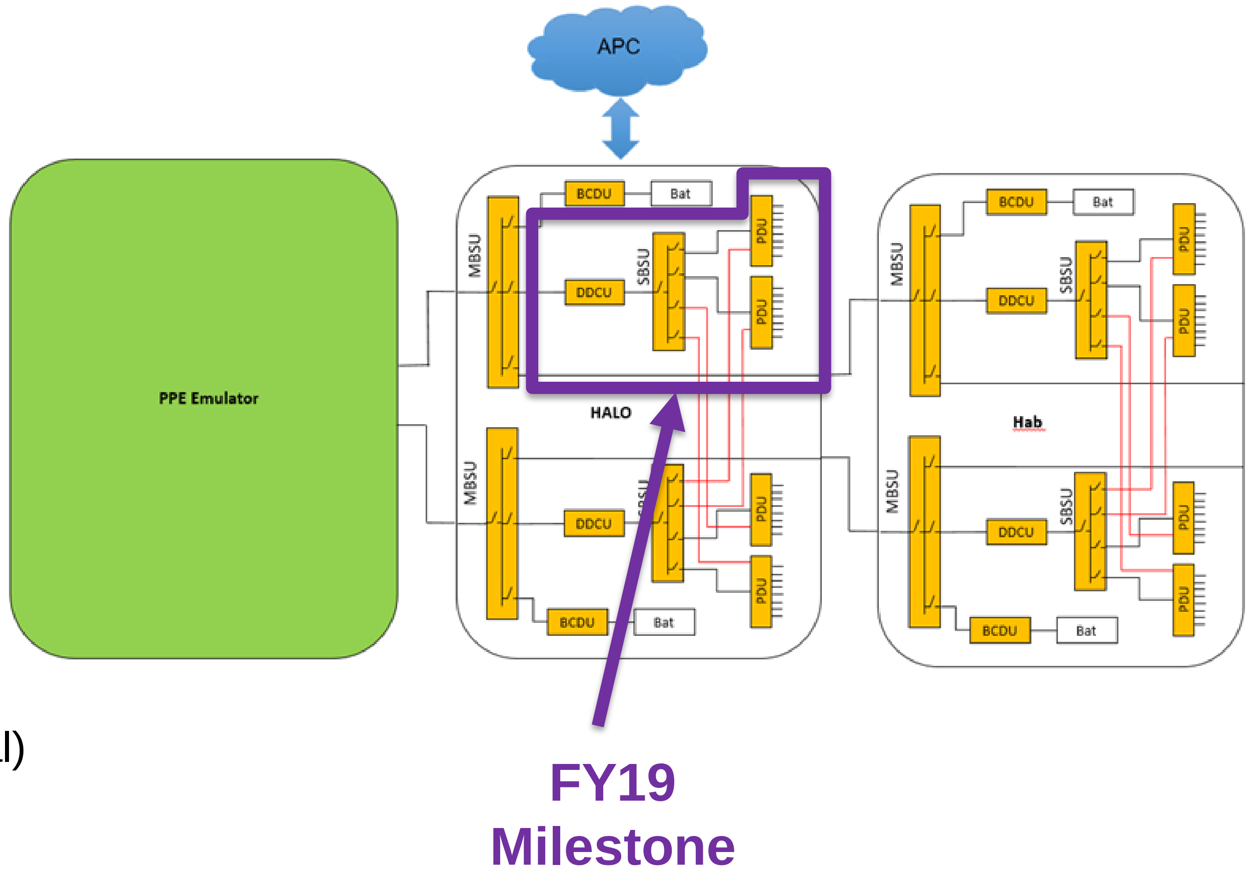
AMPS Modular Power Testbed – 3 Year Vision



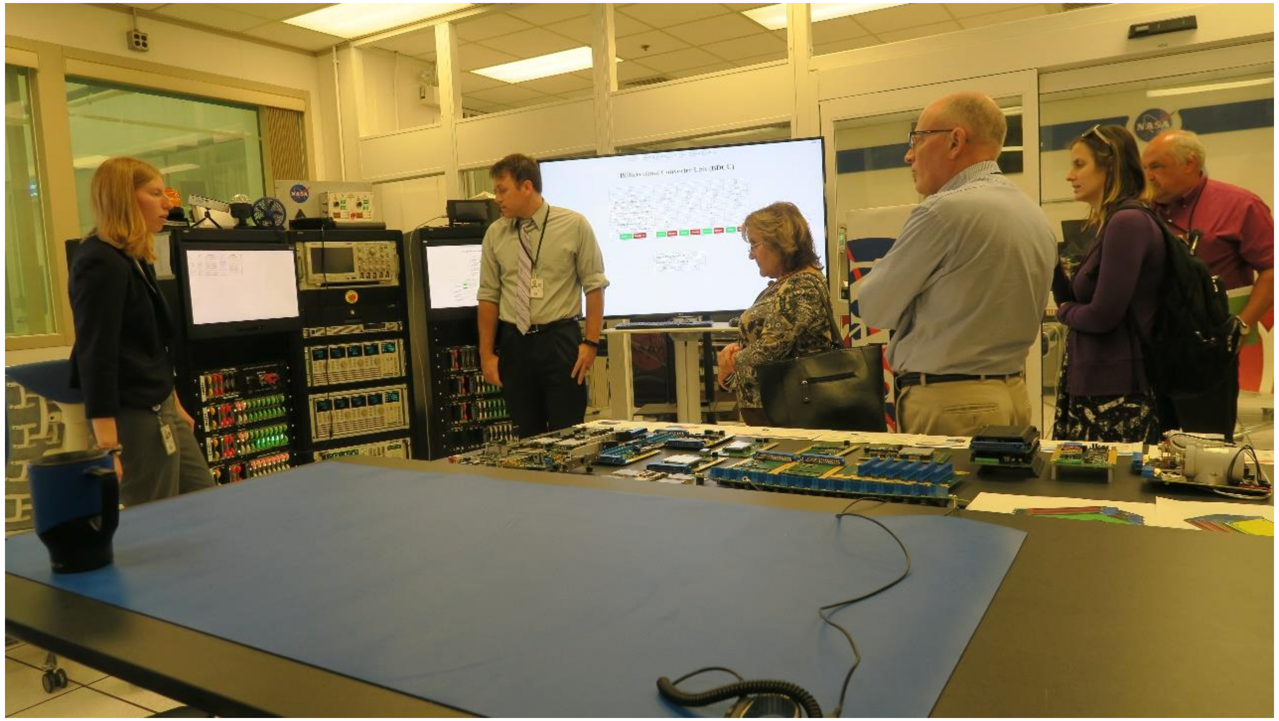
Acronyms:
APC: Autonomous Power Controller
Bat: Battery
BCDU: Battery Charge Discharge Unit
DDCU: DC-to-DC Converter Unit
HAB: Habitat Module
HALO: Habitation and Logistics Outpost
MBSU: Main Bus Switching Unit
PDU: Power Distribution Unit
PPE: Power and Propulsion Element
SBSU: Secondary Bus Switching Unit

Phase 1 – FY19

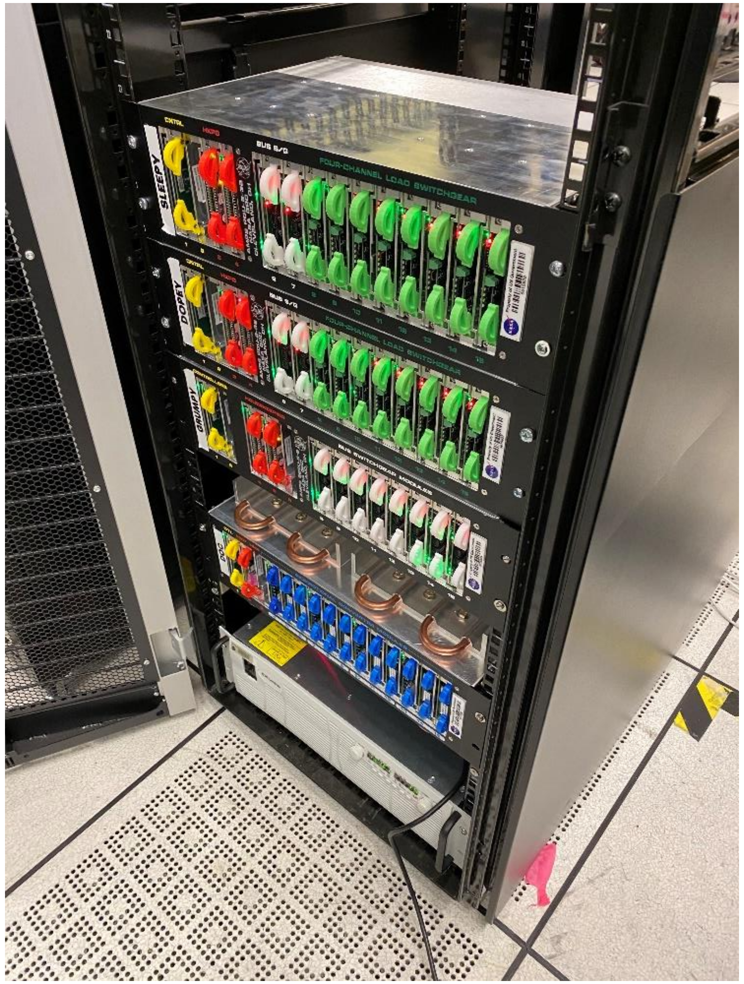
- **Initiated Build Up of Modular Power Testbed**
  - Facility modifications
  - Lab design and build up
  - Load build up
  - Cables
  - Data system
- **Integrated Modular Power Hardware into Testbed**
  - 4kW string consisting of:
    - 1 DDCU
    - 1 SBSU
    - 2 PDUs
  - Facility interfaces (cooling, electrical, data, mechanical)
  - Load interfaces
- **Developed Test Plan**
- **Demonstration of Single String completed in October 2019**
- **Delivered string to JSC**



Testbed Milestones



FY19 AES Demonstration



Hardware Delivery to JSC

Testbed Location

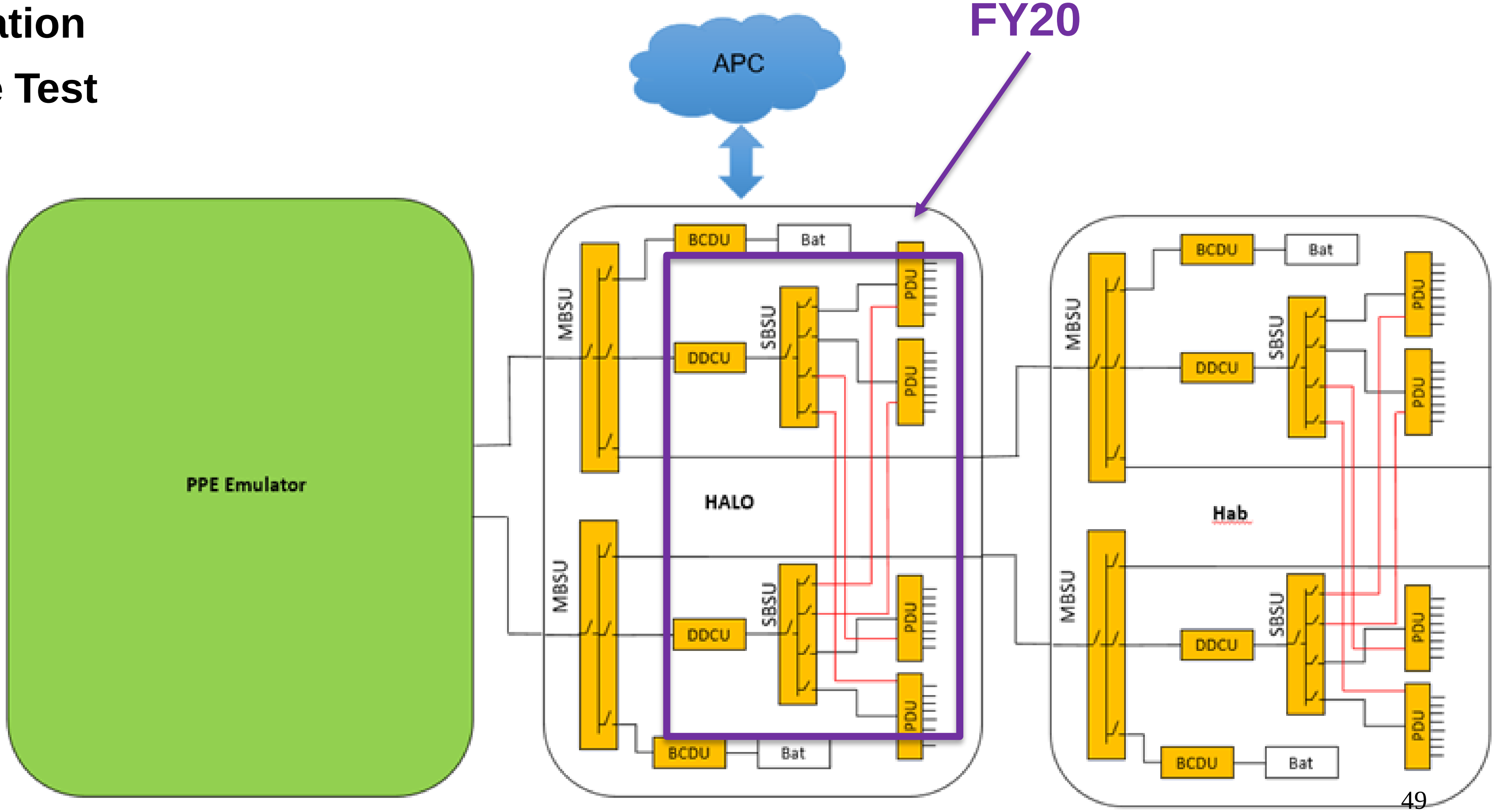
- Testbed to be built up in Building 333, Room 130
- Currently working on facility upgrades

Proposed Testbed Concept

Phase 2 – FY20

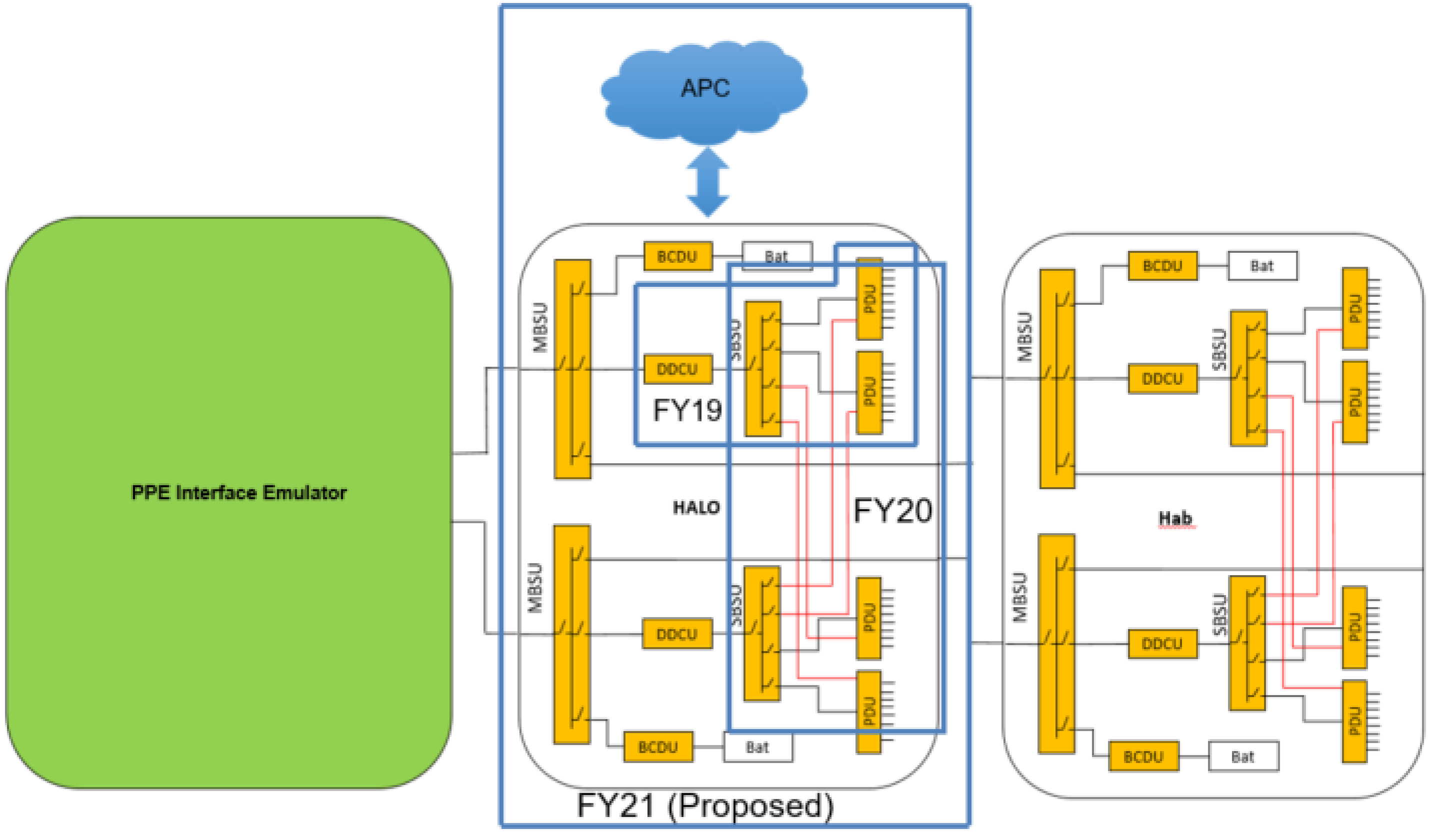
- **Second String Hardware Buildup**
  - Build a second string identical to hardware built in FY19
- **Build 2 primary MBSUs**
- **Second String Hardware Integration**
- **Integrated Two-String Hardware Test**
  - Max 8kW
- **Planning for Gateway testing**

Completed through FY20



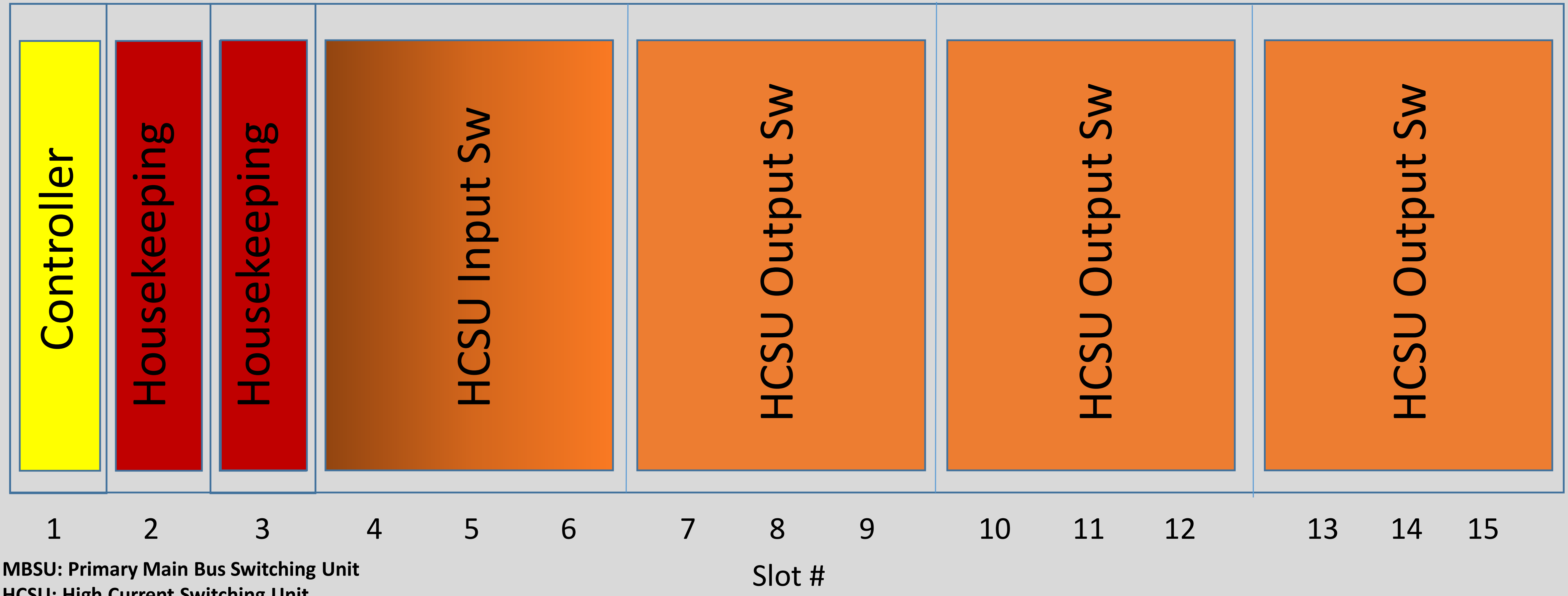
Phase 3 – FY21

- APC Integration
- MBSU Testing and Integration
- Gateway Power Quality Testing
- AMPS-ACO Fuel Cell Demonstration



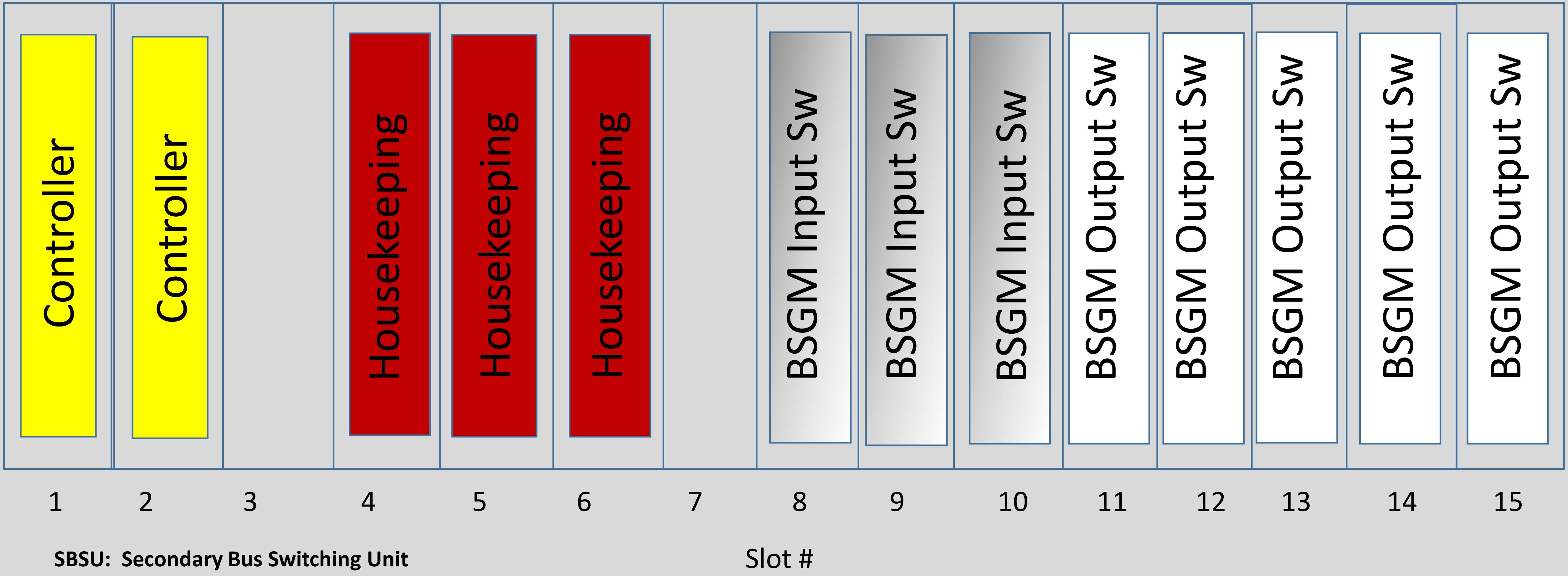
MODULAR POWER ELECTRONICS - BACKUP

MBSU



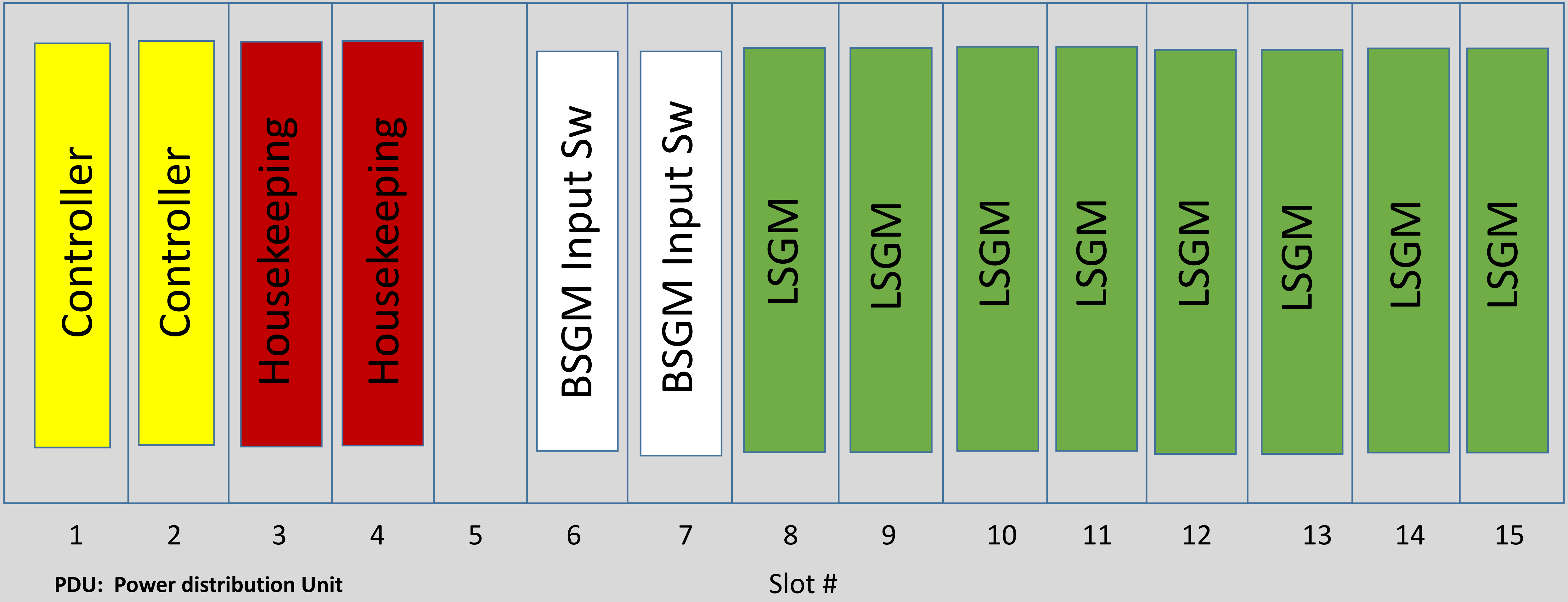
MBSU: Primary Main Bus Switching Unit
HCSU: High Current Switching Unit
The 2nd Housekeeping Module is Optional

SBSU



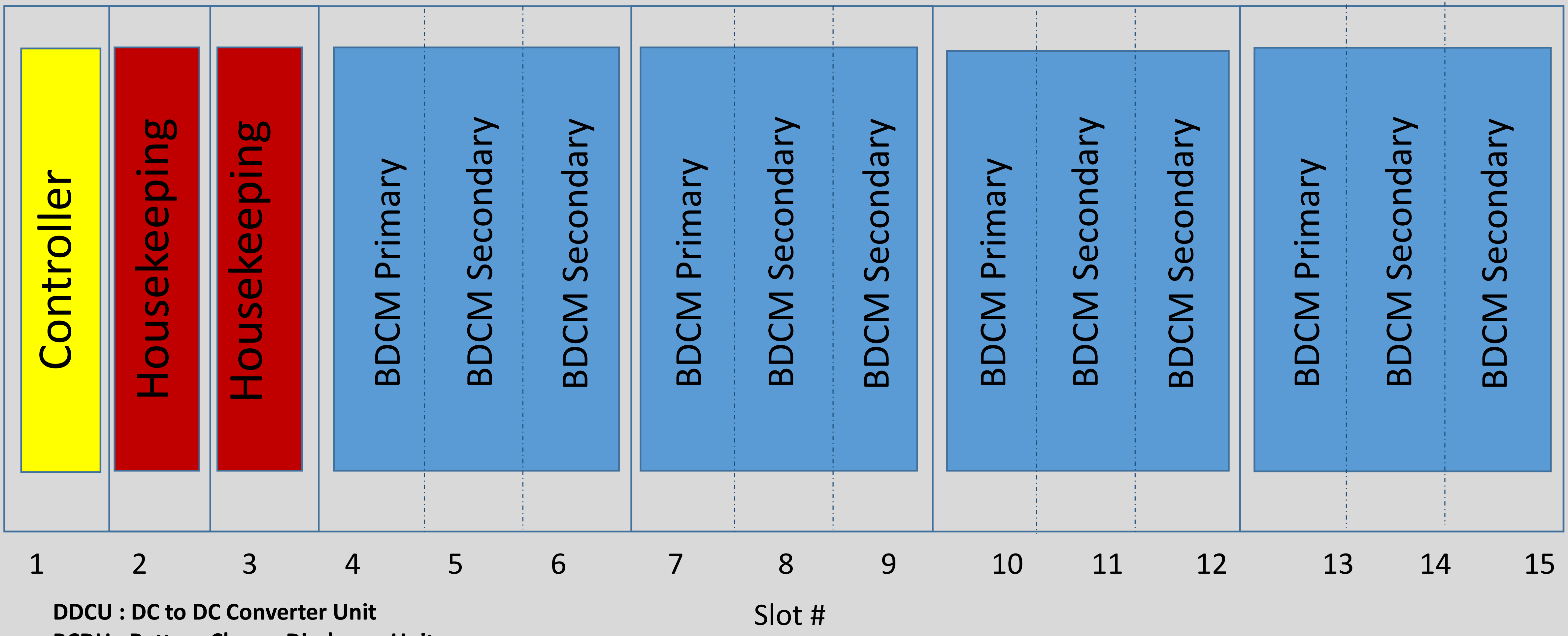
SBSU: Secondary Bus Switching Unit
BSGM: Bus Switchgear Module
2nd CTLM Optional
2nd and 3rd HKPM and BSGM Input Modules Optional

PDU



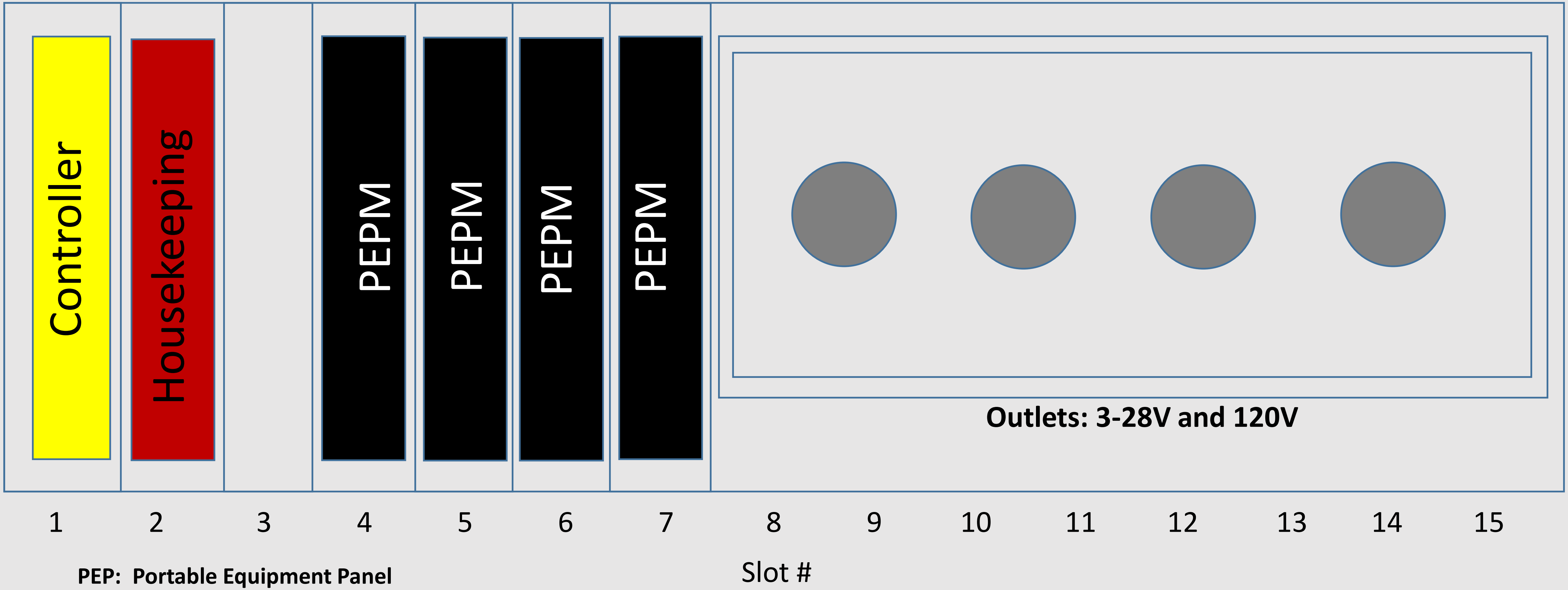
PDU: Power distribution Unit
BSGM: Bus Switchgear Module
LSGM: Load SwitchGear Module
2nd CTLM Optional

DDCU\BCDU\BDDCU Converter



DDCU : DC to DC Converter Unit
BCDU : Battery Charge Discharge Unit
BDDCU : Bidirectional Converter Unit
BDCM : Bidirectional Converter Module
2nd HKPM is Optional for DDCU Only

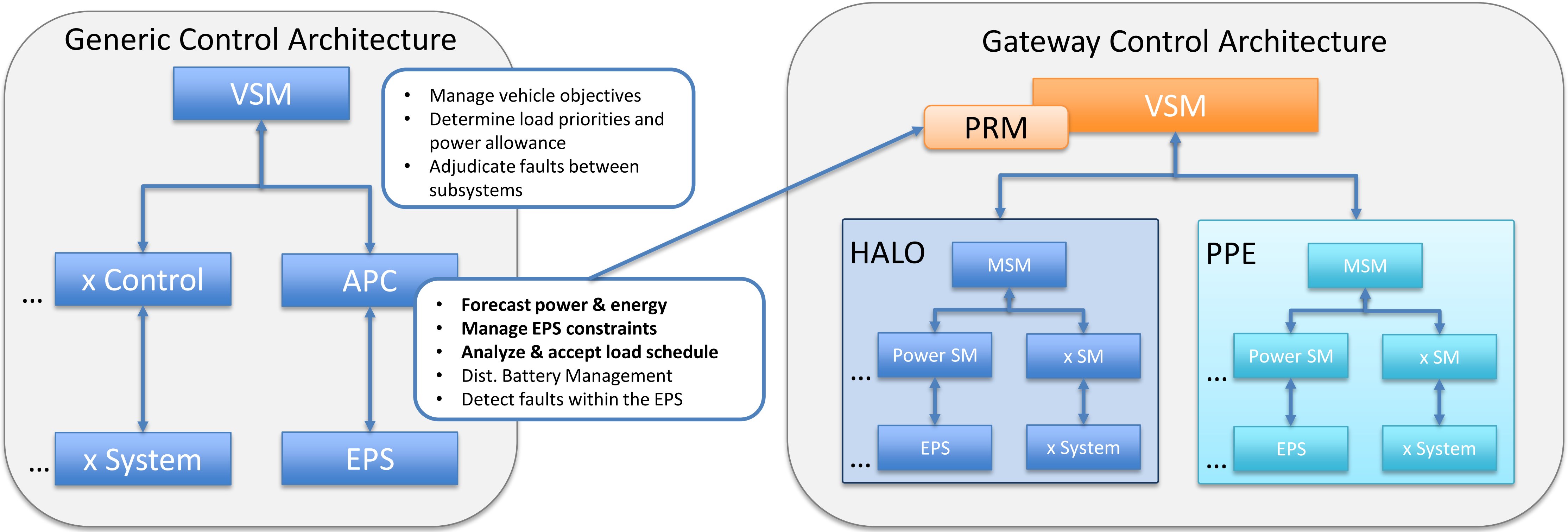
PEP



PEP: Portable Equipment Panel
PEPM: Portable Equipment Power Module
Each PEPM is fed by one LSGM channel.
Each outlet is fed by one PEPM and one LSGM channel (for 120V), totaling two LSGM channels per outlet.
Front panel connectors could be rear and cabled to single outlets, allowing more PEP channels.

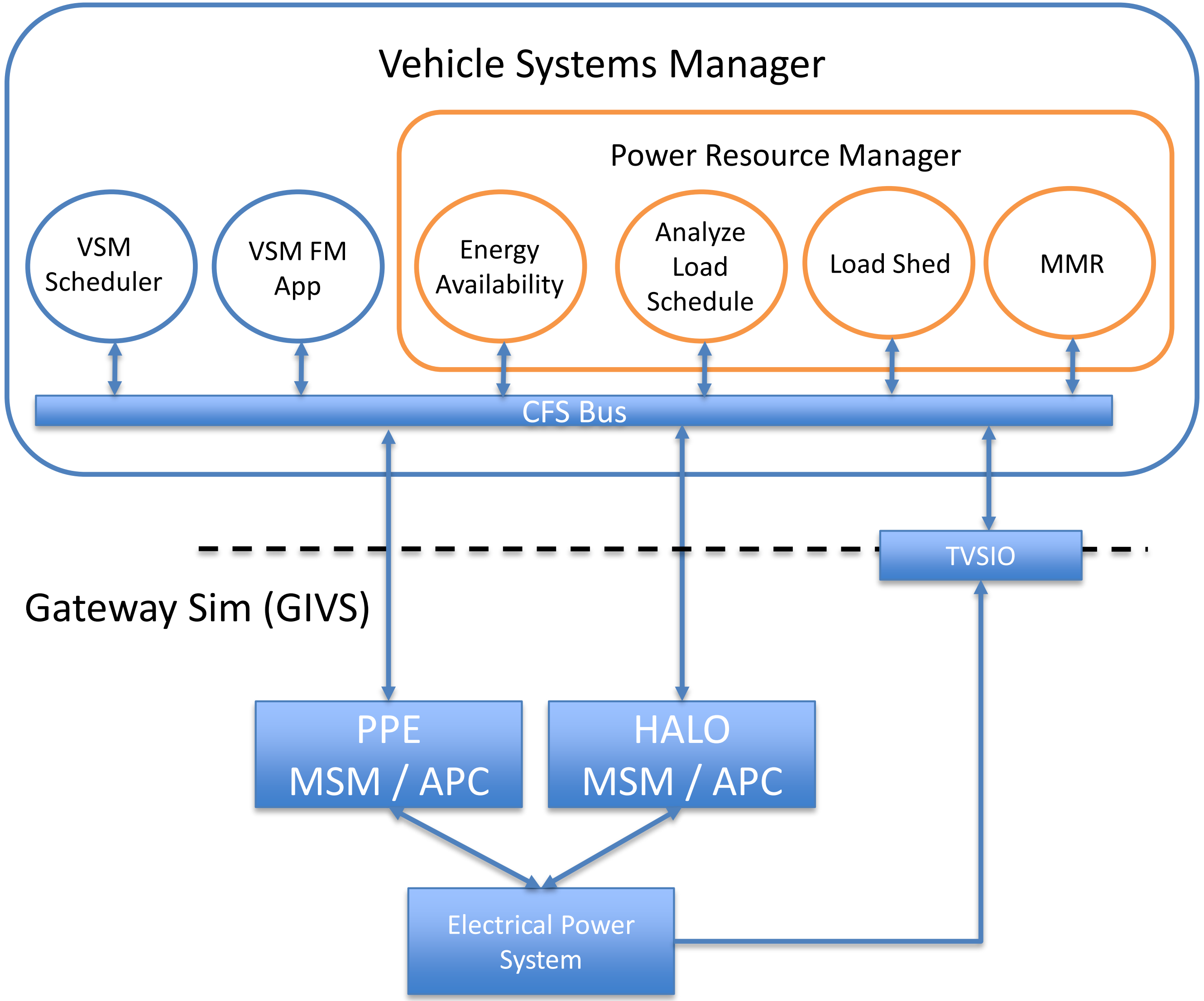
AUTONOMOUS POWER CONTROL - BACKUP

Gateway Vehicle System Manager Work



- **Gateway Power**
  - Gateway is more complex than a traditional space vehicle
  - Modules developed by different contractors and each module has its own power system manager
  - **Defining the power management and distribution functions required at the vehicle level**

Gateway Vehicle System Manager Work

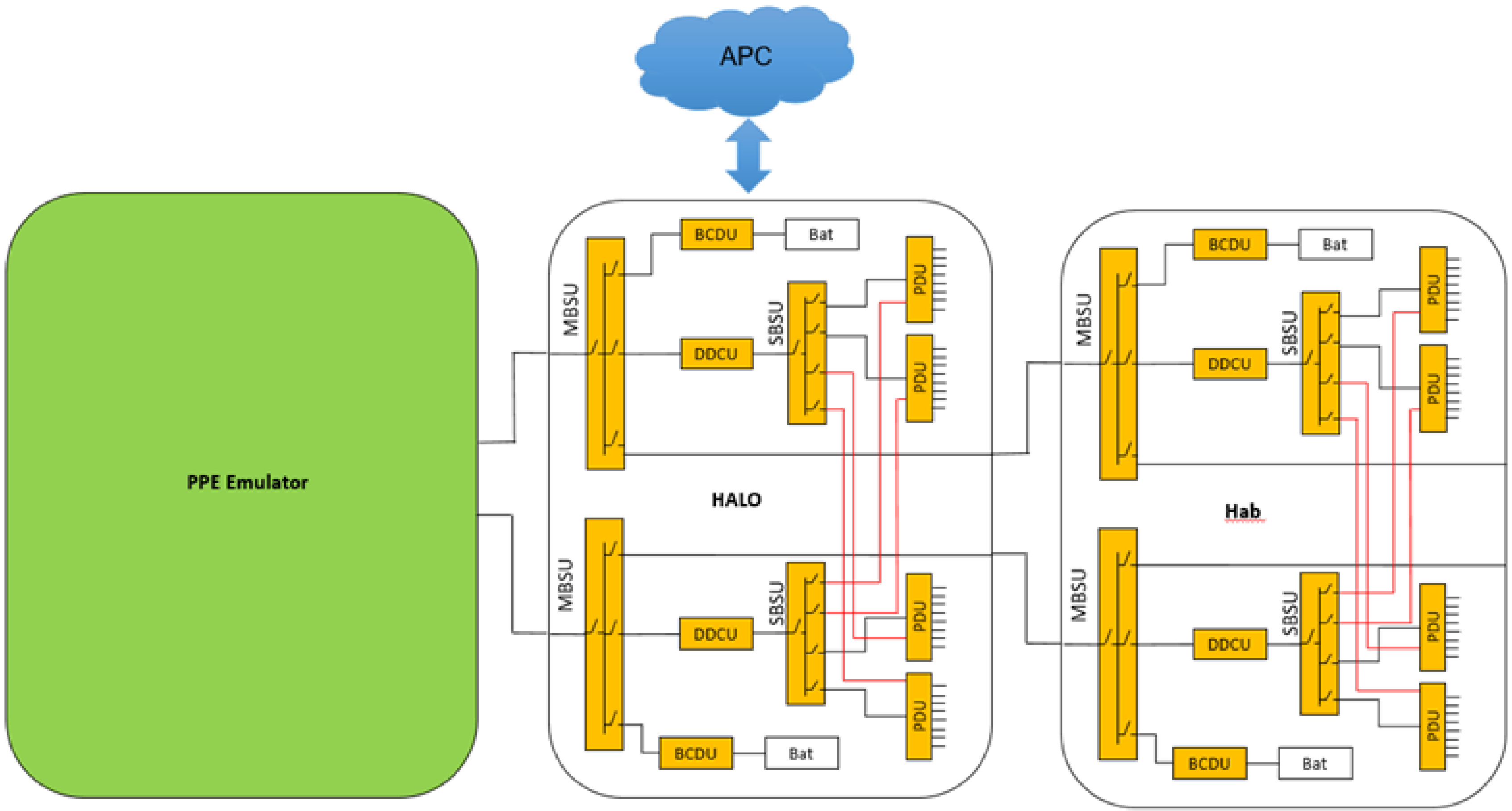


- **Developing and demonstrating capability on prototype software**
  - Develop software in-house at GRC
  - Deliver to JSC for integration, testing, and demonstration to Gateway program.
- **Delivered Power Resource Manager and demonstrate response to an electrical bus failure**
- **Starting developing additional capability for an eclipse planning demonstration**
- **Power Resource Manager**
  - Energy Availability
  - Load Shed
  - MMR
  - Analyze Load Schedule

MODULAR POWER TESTBED - BACKUP

Integration with APC

- **Currently APC uses Raspberry Pis and Simulink blocks to simulate modular hardware**
- **Plan to integrate with Testbed hardware during FY21**
  - Combination of Testbed single string hardware and APC emulators to demonstrate an entire system



Integration with iPAS Testbed

- iPAS testbed at JSC currently has AMPS hardware that is several generations old
- Plan to send JSC new modular hardware for integration during FY20
- AMPS Testbed could be run remotely from iPAS using SNRF network

Integration with SEP Testbed

- **Testbed built at GRC FY16-FY18 to test SEP Power Systems end-to-end**
- **Simulates PPE architecture**
  - Includes solar array simulator, high voltage power distribution unit, EP string loads (power processing units + load banks)
- **Located in Building 333, Room 112**
  - Allows for easy access for integrating testbeds together