



2021 TDM Review: CPE-NASA PPUP

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Moderator: LEX / Todd Peterson

NASA Glenn Research Center

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PPUP Team Members

Colorado Power Electronics

- *PPU Development / Fabrication / Testing*
 - Geoff Drummond
 - Kevin O'Connor
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 - Vlad Shilo

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- *MSFC (Mission Management)*
 - Andrew Schnell
- *GRC (Project Management)*
 - Eric Pencil (MT)
- *GRC (Project / Technical Guidance)*
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- *GRC (PPU Environmental Testing Liaisons)*
 - Mike Garrett (LED)
 - Kenneth Pederson (LMD)
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CPE-NASA Public-Private Partnership (1/2)

- Since 2003, NASA has awarded Colorado Power Electronics (CPE) 11 SBIR (Small Business Innovation Research) grants to **develop and mature power processing unit (PPU) technologies** for a variety of electric propulsion (EP) needs.
- In 2005, CPE began work on a high-performance PPU architecture that would support missions utilizing a **variety of NASA and commercial Hall-effect thrusters (HET) in the popular 5-kW power class**, including the NASA HiVHAc (High-Voltage Hall Accelerator).

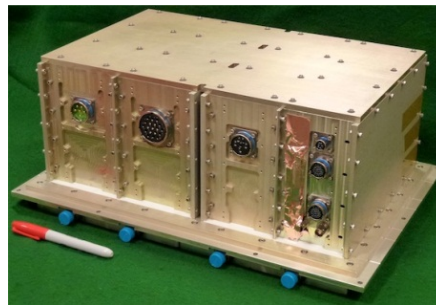


1-kW Breadboard Discharge Module

1st application of full-resonant power converter to kW-class EP



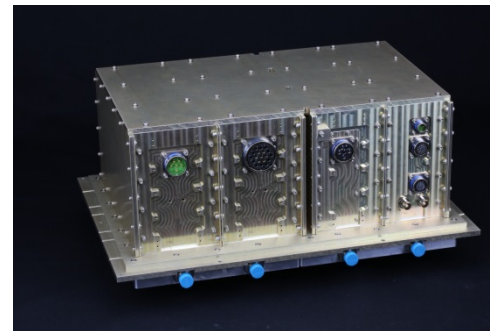
Brassboard PPU #1



Brassboard PPU #2

Tested for >1,000 hr in vacuum environment at GRC

Performance characterized at GRC in thermal-vacuum tests with integrated demonstrations using HiVHAc and Maxar SPT-140



Engineering Model (EM) PPU



PDU PPU

Mechanical, thermal, radiation, worst-case, and reliability analyses completed

CPE-NASA Public-Private Partnership (2/2)

- Now nearing the end of a SBIR Phase III effort with NASA GRC and JPL, CPE is ready to deliver a **high-fidelity, flight-like Prototype Development Unit (PDU) PPU** to NASA.
- At GRC, the PDU PPU will undergo **functional / performance checkouts, integrated system tests (IST), and qualification-level environmental testing** (i.e., electromagnetic interference / compatibility, vibration / pyroshock, and thermal-vacuum) to verify that the CPE design meets anticipated NASA mission requirements.

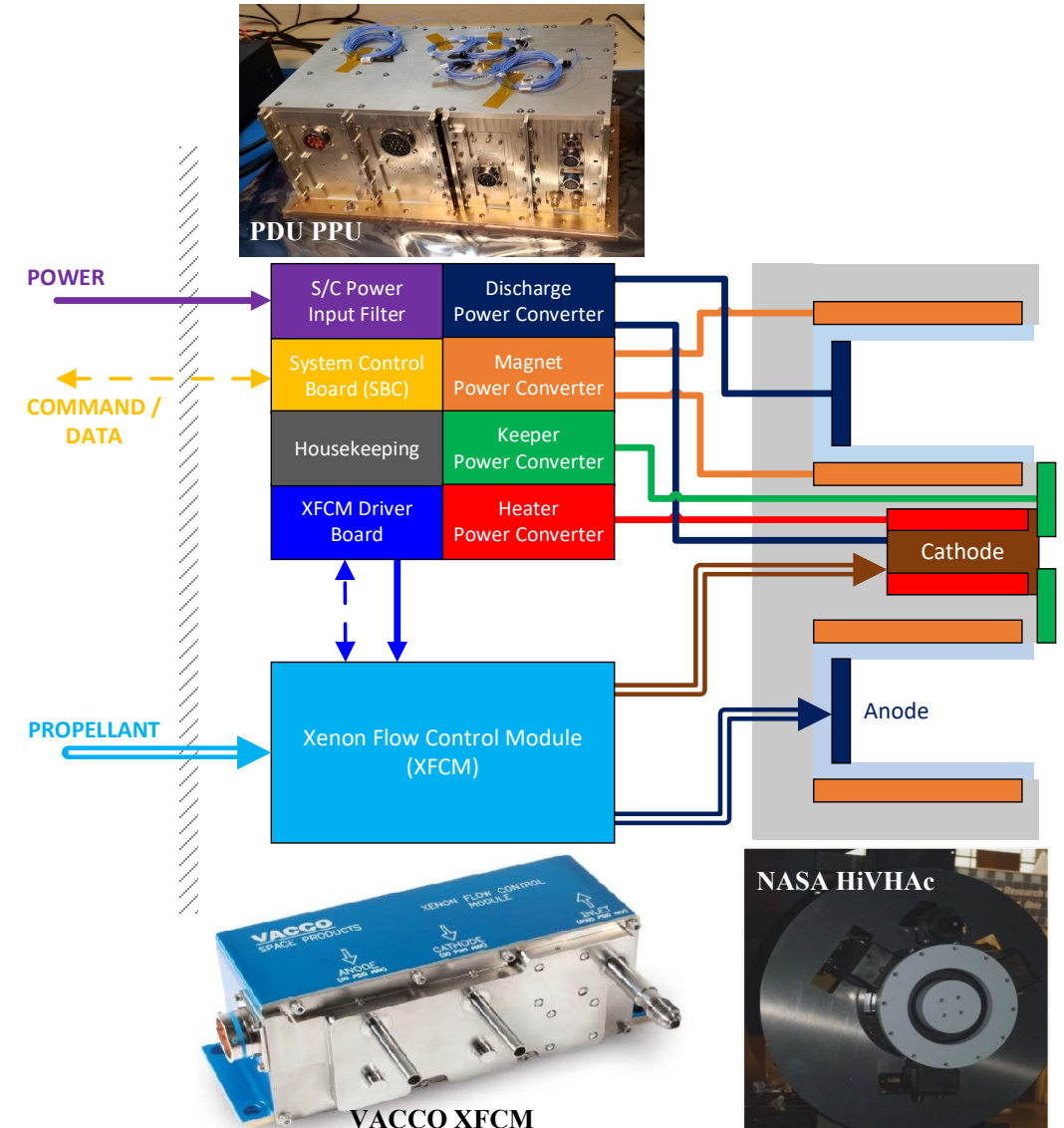
CPE-NASA PPUP



ACO Objectives (1/4)

The ACO (Announcement of Collaborative Opportunity) effort will utilize GRC EP test facilities to:

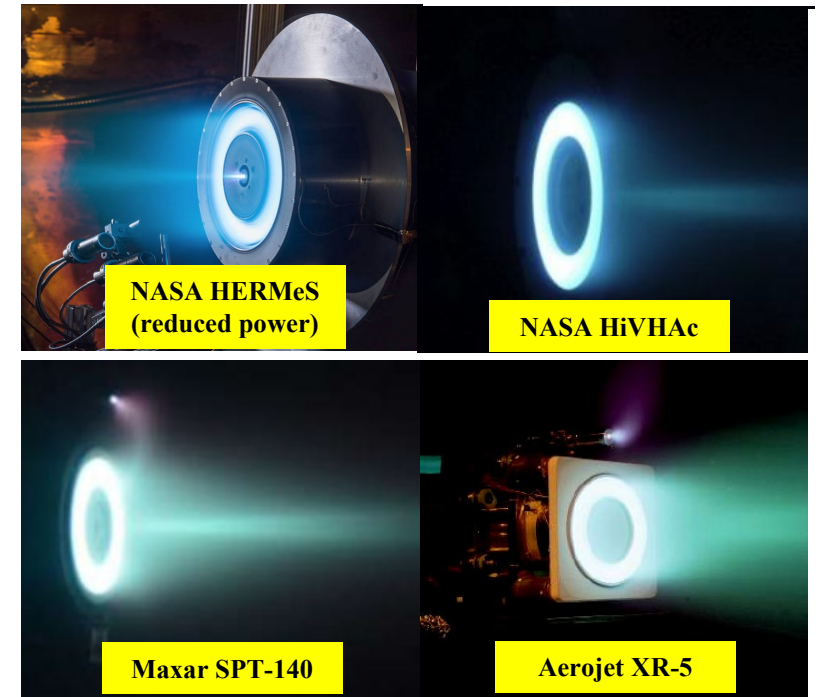
- Verify CPE PDU PPU integrated performance when operated as part of a complete HET system
- Demonstrate CPE PPU compatibility with thrusters from NASA and prospective commercial customers
- Advance the CPE HET PPU technology readiness level (TRL) to ~TRL 6 to encourage mission infusion
- Provide CPE with PDU PPU performance data and operational lessons learned to refine technology's commercialization plan and to showcase the technology to prospective NASA and commercial end-users



ACO Objectives (2/4)

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PPU Features

- ❖ Wide output ranges to enable operation of multiple thrusters
- ❖ Modular construction with parallel discharge modules scalable to higher powers
- ❖ Independent discharge module control for high efficiency at low power



ACO Objectives (3/4)

The ACO (Announcement of Collaborative Opportunity) effort will utilize GRC EP test facilities to:

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PDU PPU	Discharge	Magnet (x2)	Keeper	Heater
Output Voltage	200 – 700 V	2 – 20 V	5 – 40 V	1 – 13 V
Output Current	1.4 – 15 A	1 – 7.5 A	1 – 2 A	3.5 – 21 A
Output Power Max	4.5 kW	108 W	80 W	210 W
Regulation Mode	Voltage or Current	Current	Current	Current
Output Ripple	≤ 5%			
Line/Load Regulation	≤ 2%			
High Voltage Input	68 – 140 V (main power)			
Low Voltage Input	24 – 34 V (housekeeping)			

PPU Features

- ❖ Wide input ranges to satisfy power requirements for both commercial spacecraft buses and NASA missions
- ❖ Discharge supply delivery of full power with >95% peak efficiency at all input / output voltage settings



ACO Objectives (4/4)

The ACO (Announcement of Collaborative Opportunity) effort will utilize GRC EP test facilities to:

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PPU Features

- ❖ Digital control interface unit (DCIU) with space-qualified, rad-hard, reprogrammable FPGA (field-programmable gate array) and autonomous system control algorithms
- ❖ Power, telemetry, and control interfaces for VACCO XFCM
- ❖ Discharge ripple current telemetry to assess thruster stability
- ❖ Magnet reversal relay to allow for roll torque cancellation
- ❖ Safety interlocks and lockouts for discharge and heater supplies
- ❖ Rad-hard components rated to total ionizing dose (TID) of 100 krad and linear energy transfer (LET) of 37 MeV-cm²/mg
- ❖ Assembly via flight parts with flight processes and procedures



Key 2020 Challenge: COVID-19

Schedule delay for PDU PPU assembly

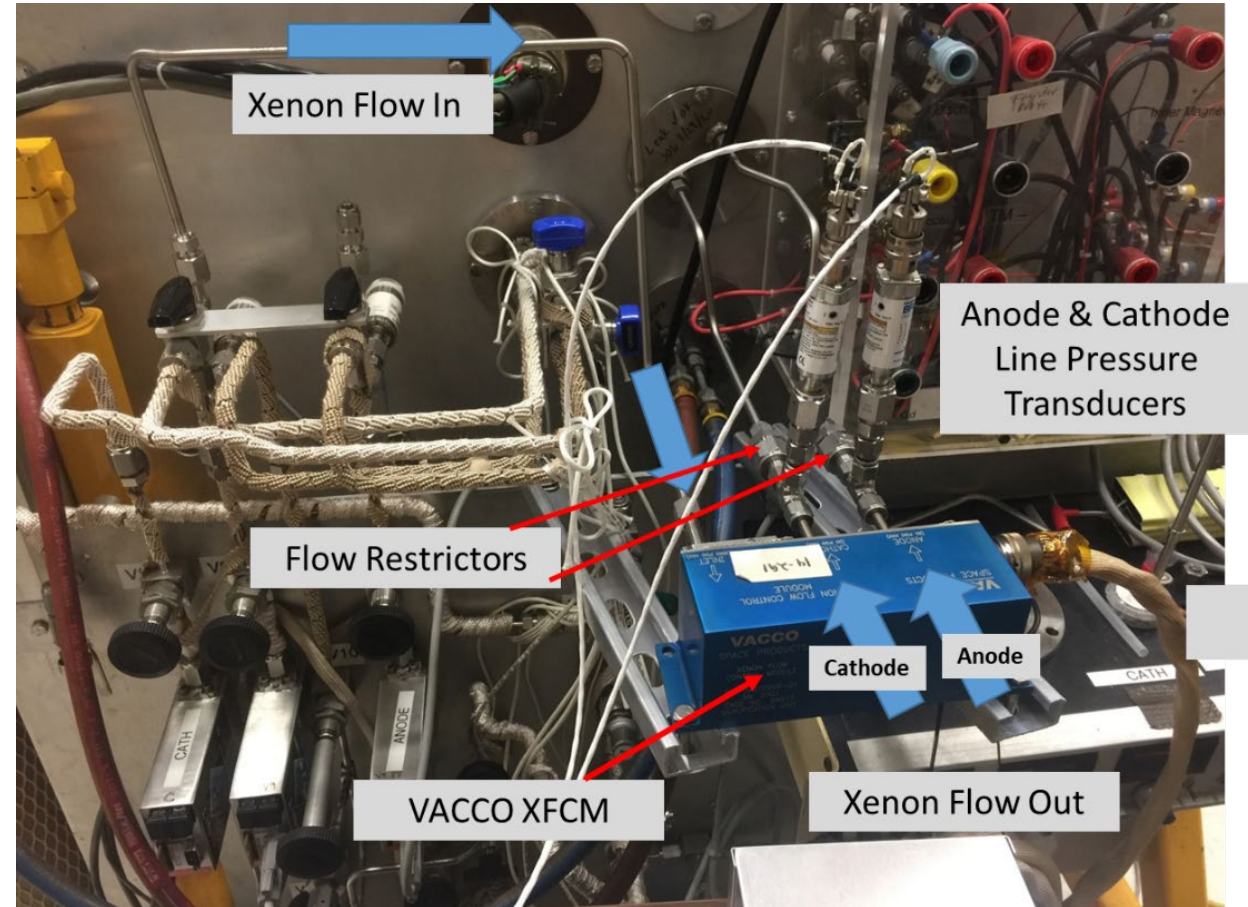
- Status: **Resolved in November 2020 (schedule impact: ~7 months)**
- ❖ COVID-19 disruptions led to supply chain delays for various PDU PPU components.
- ❖ PDU PPU has now passed all CPE checkouts and is awaiting NASA approval for delivery to GRC.

Schedule delay for PDU PPU delivery and test activities at GRC

- Status: **Unresolved (schedule impact: ~3+ months; budget impact: ~10+ months of NASA labor)**
- ❖ PPUP is awaiting GRC Executive Council's approval for return to onsite work (RTOW).
- ❖ CPE is unable to invoice for SBIR hardware delivery until GRC completes acceptance testing.
- ❖ PPUP, like other NASA STMD (Space Technology Mission Directorate) projects at GRC, had been instructed to continue maintaining nominal labor charge rates on the project despite no onsite access for a test-centric project.

Key 2020 Accomplishments (1/2)

- ✓ [GRC] Performed EM PPU calibration tests of the VACCO XFCM for CPE to update the PDU PPU's control algorithms / sequences
- ✓ [GRC] Developed RTOW plans for onsite test activities and facilitated CPE's environmental test planning with other GRC labs
- ✓ [CPE/GRC] Developed and executed PDU PPU component spares mitigation plan to reduce potential schedule risk during testing
- ✓ [CPE/GRC] Completed PDU PPU algorithm refinements based on prior test experience with the EM PPU



Key 2020 Accomplishments (2/2)

- ✓ [CPE] Completed component, board, and assembly-level functional testing of PDU PPU
- ✓ [CPE] Integrated accelerometers into PDU assembly and assessed thermocouple placement to support environmental and integrated system test planning
- ✓ [CPE] Installed multi-chip modules (MCM) into the to-be-delivered PDU PPU to improve capability for ISTs and partially offset a later delivery date
- ✓ [CPE] Incorporated firmware updates based on PDU assembly checkouts to improve PPU functionality



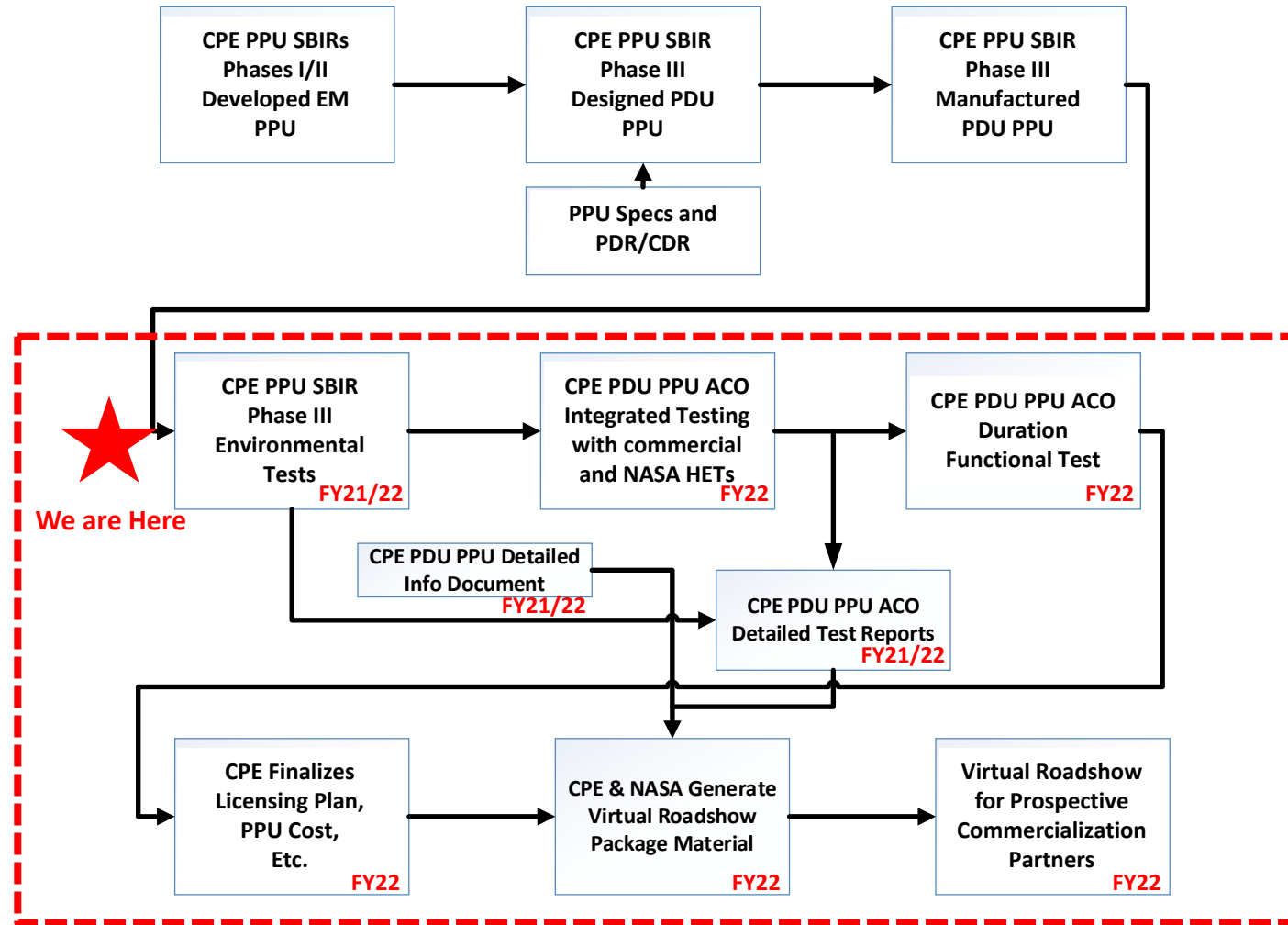
PDU DCIU board with MCM installed



CPE PPU Commercialization Roadmap

CPE-NASA PPU

- ❖ CPE designed the PPU, performed all parts selection, and procured all components.
- ❖ CPE sub-contracted flight-certified contractor (DBM Technologies) to assemble the PPU in accordance with IPC-A-610 standards.
- ❖ CPE performed functional testing of the PDU PPU prior to delivery to NASA GRC.



- ❖ NASA GRC is supporting functional, performance, environmental, and integrated tests of the PDU PPU.
- ❖ CPE and NASA will jointly complete all analyses and test reports to prepare “roadshow” package to brief prospective end-users.



Commercialization Plan Activities

- ❑ CPE to formulate a licensing / partnership strategy with potential partners
- ❑ CPE and NASA to identify any “gaps” that remain to flight-qualify the CPE PPU design and build
- ❑ CPE to develop its projected schedule and cost for manufacturing a flight-unit PPU
- ❑ CPE and NASA to prepare a full set of “key” documents, including requirements, specifications, bill of materials, analyses, qualification test reports, and integrated test reports
- ❑ CPE and NASA to compile presentation material for a “Virtual Roadshow” with non-disclosure agreements (NDA) required from interested parties:
 - “Key” documents
 - Main CPE PPU design features
 - Summary of select commercial and NASA design reference mission (DRM) studies implementing the CPE PPU
 - Etc.
- ❑ CPE and NASA to engage commercial companies that have already indicated interest in the CPE PPU technology, including prime contractors, spacecraft bus providers, and electric propulsion developers



2021 Project Outlook

Fiscal Year 2021 (FY21)

- **Key Risk:** PPUP RTOW access approval by GRC's Executive Council remains delayed.
- ❖ GRC's Executive Council is tentatively expected to approve the project RTOW in March / April.
- ❖ PPUP anticipates completion of pre-environmental integrated testing and most of environmental testing (CPE under SBIR work) by end of FY21, but post-environmental integrated testing (including with commercial thrusters) will not begin until FY22.

Fiscal Year 2022 (FY22)

- **Key Risk:** PPUP replan to maintain full technical content is not approved by TDM.
- ❖ PPUP is updating project plans to extend ACO period of performance into FY22.
- ❖ Testing in FY22 would seek to complete post-environmental integrated testing with commercial and NASA thrusters along with a duration functional test to assess the viability of a complete electric propulsion string utilizing the PDU PPU.

Conclusion

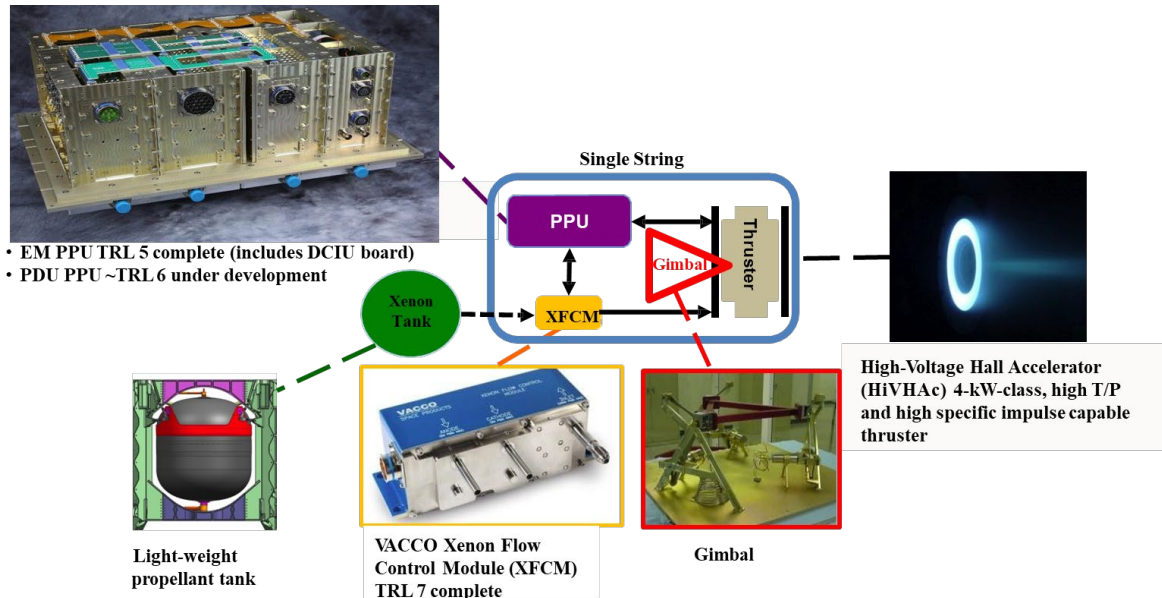
- The PPUP ACO effort is the **culmination of a decade-long NASA investment in the CPE HET PPU technology.**
- Successful formulation and execution of replanned FY21 and FY22 work are expected to yield **a highly-capable, ~TRL-6 PPU technology to support NASA and commercial 5-kW HET system needs.**

Key PPU Features

- ❖ Wide input / output ranges at high efficiency
- ❖ Modular construction with power scalability
- ❖ Rad-hard flight parts assembled with flight processes
- ❖ Autonomous system control algorithms with thruster stability monitoring and safety features
- ❖ Magnet reversal capability for roll torque cancellation
- ❖ Default compatibility with VACCO XFCM

Key Mission Benefits Anticipated

- High performance and flexible compatibility with different spacecraft buses and thrusters
- Wide operating range to accommodate deep thruster throttleability for closing more missions
- Modular, light-weight (low kg/kW) design to facilitate high-power electric propulsion systems
- Comprehensive PPU design without need for additional subsystem development





Supplemental Slides

CPE-NASA PPUP



“Key” Commercialization Documents

- Requirements document - (CPE and NASA)
- Specification document - (CPE and NASA)
- CDR package - (CPE and NASA)
- Worst Case Analysis (WCA) package - (CPE)
- Stress analysis package - (CPE)
- Thermal analysis package - (CPE)
- Radiation assessment and tolerance report - (CPE)
- Structural analysis package - (CPE and NASA)
- Bill of Materials (BOM) - (CPE)
- Qualification test package - (NASA and CPE)
 - Functional - EMI / EMC
 - TVAC - Vibe / Shock
- Integrated test package - (NASA and CPE)
 - HiVHAc+ - XR-5
 - SPT-140 - HERMeS