

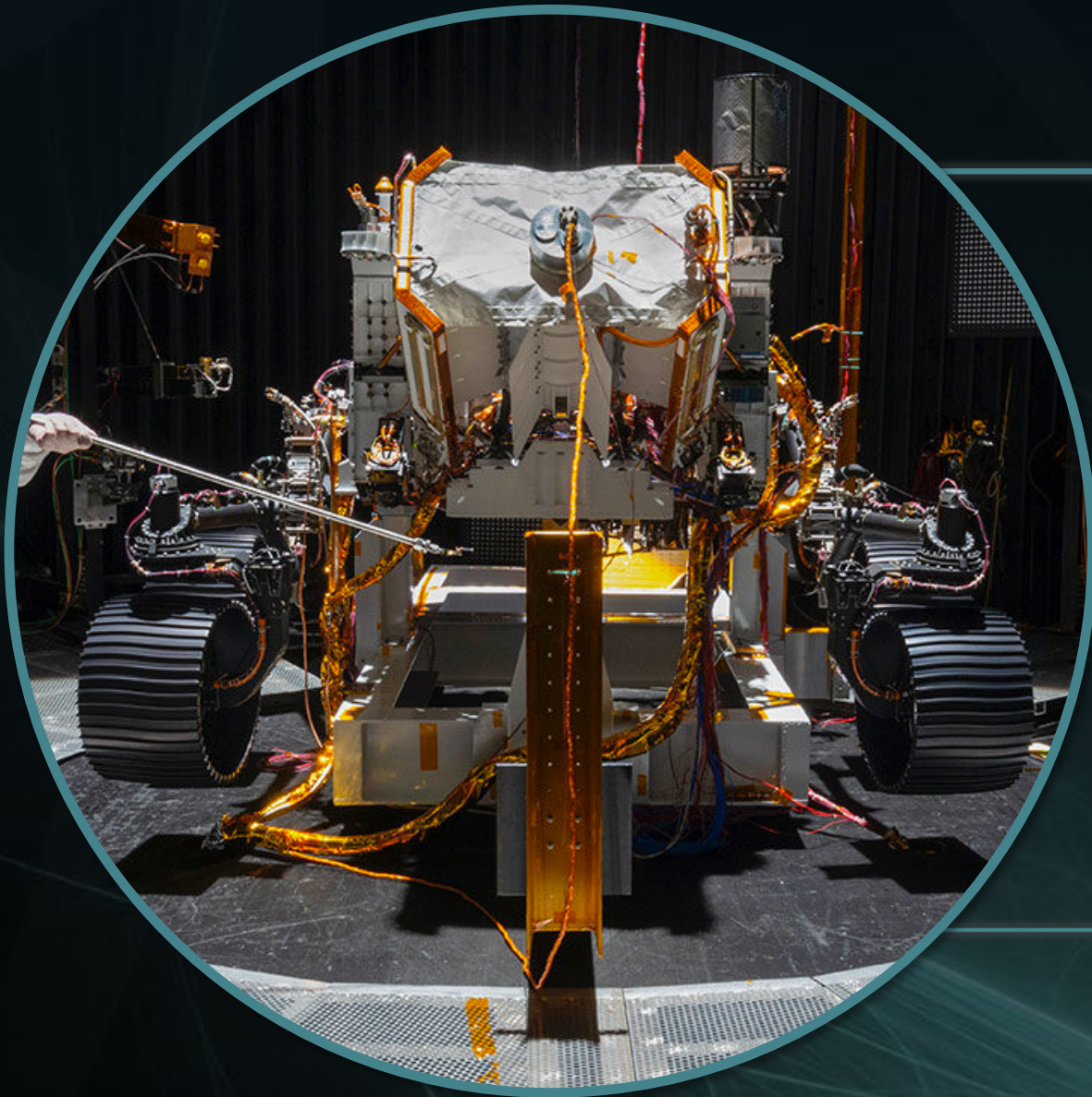
RADIOISOTOPE POWER SYSTEMS PROGRAM

Ocean Worlds and Dwarf Planets Panel of the
2023-2032 Planetary Science and Astrobiology Decadal Survey

RPS Program Technology Updates **March 5, 2021**

June Zakrajsek
RPS Program Manager

Power to...



EXPLORE



DISCOVER



UNDERSTAND

PEOPLE



POWER



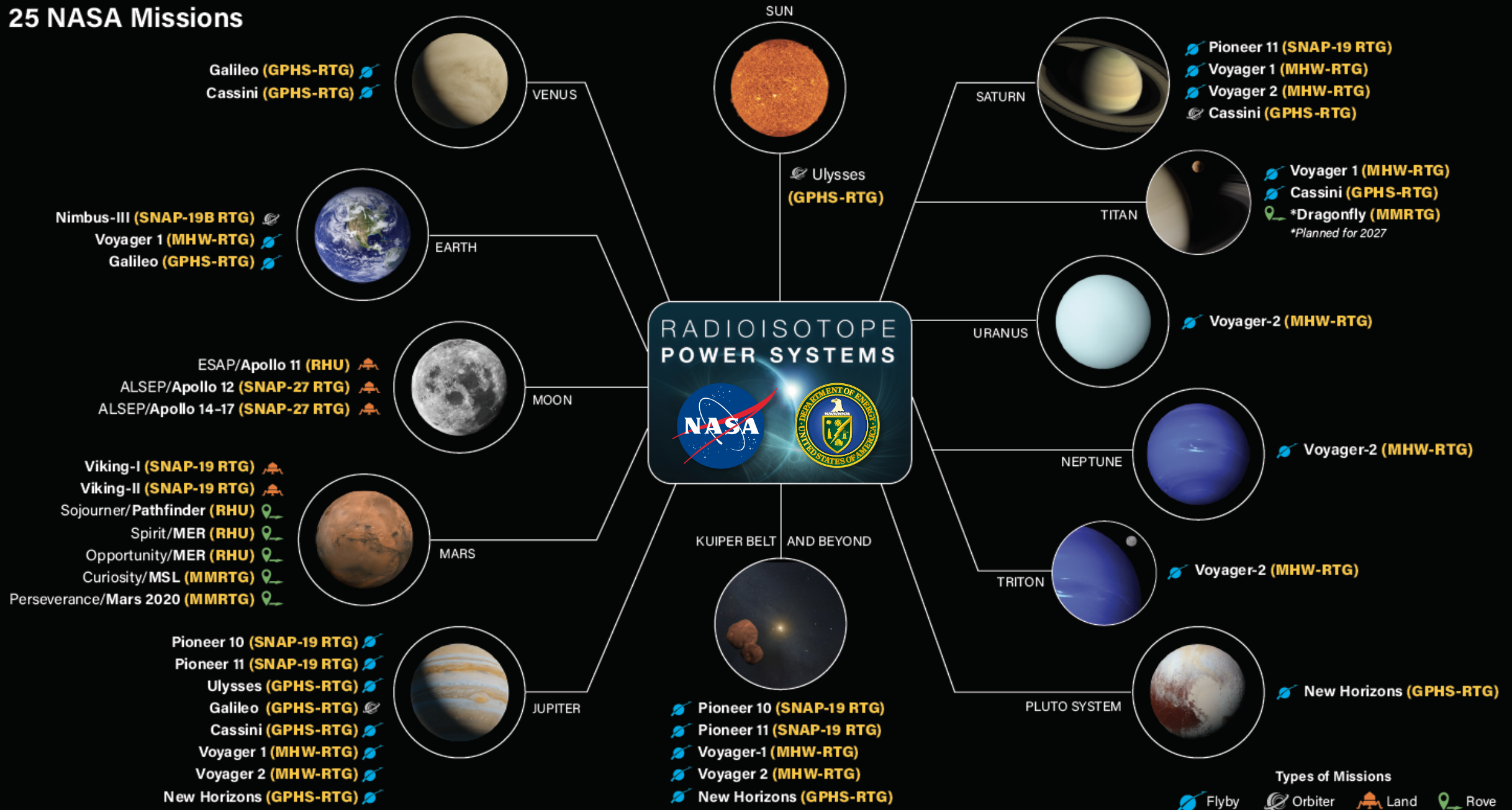
PRODUCTION



PROGRESS



25 NASA Missions



Addressing Community Impressions

- *Potential mission pull exceeds production capability*
 - *Fuel production*

Balanced Trade: investment in fuel production vs. investment in missions

DOE has capacity in fuel production above current production rates

- *System production*

Balanced Trade: investment in system production vs. investment in missions

Next Gen reestablishes system production line

- *Next Gen performance changed since the initial ground rules for mission concept studies in support of Planetary Decadal Survey*

Pragmatic approach delivers systems earlier than 2028

- *RPS lifetime requirement may be shorter than mission duration*

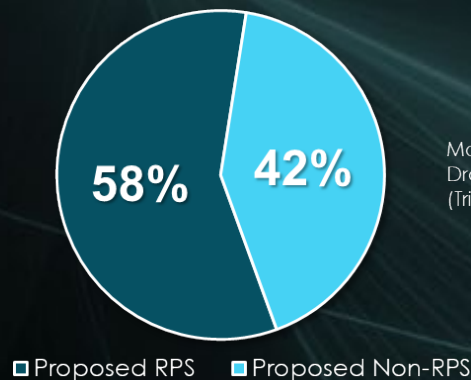
Proven track record with RPS missions lasting over 40 years

NASA and DOE Balancing Supply and Demand

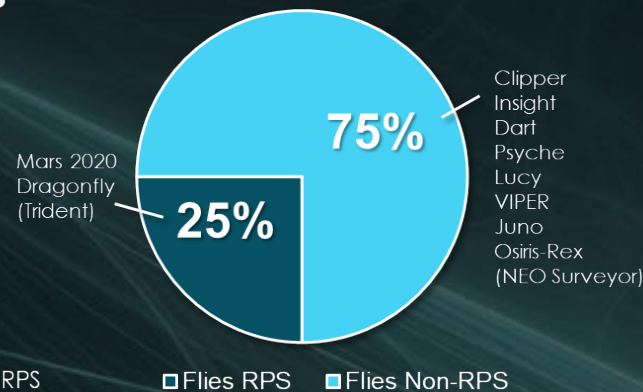
WHAT

- Constant Rate Production
 - Plutonium-238 heat source production
 - Fueled clad production
 - Maintaining essential infrastructure
- Power system production

**Vision and Voyages
Interest in RPS Missions**



Actual Mission Needs



WHY

- Sized to meet identified NASA missions needs
- Maximize products usability
 - Balancing production rates and the on the shelf time
 - Clads can “age-out”
- Stewardship
 - Maximize mission opportunities requires fiscal responsibility
 - Increasing production reduces funding available to missions



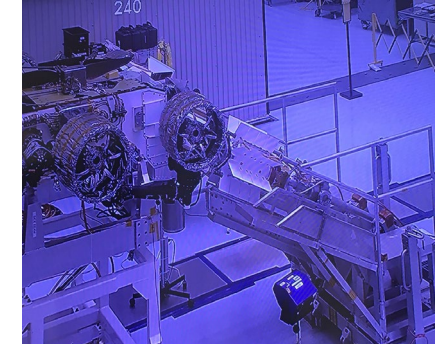
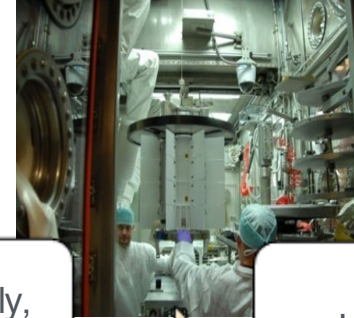
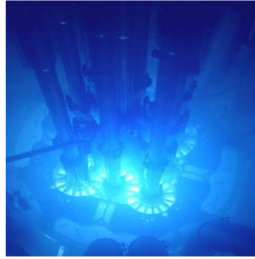
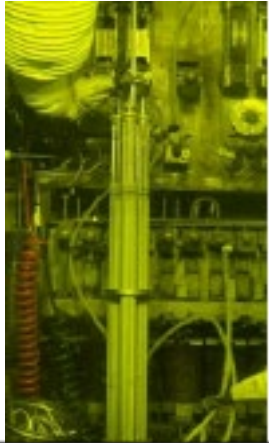
Constant Rate Production



- In early 2017, DOE and NASA agreed to transition the delivery of radioisotope power systems from a mission-driven approach to a constant-rate production strategy
- Constant Rate Production establishes clear deliverables, as defined by annual average production rates, across the DOE radioisotope power system supply chain
 - 1.5 kg/yr heat-source plutonium oxide
 - 10-15 fueled clads
- Benefits of applying a constant-rate production strategy include:
 - improved reliability and predictability to deliver systems
 - flexibility to align resources to
 - optimize plutonium production
 - identify, evaluate, and implement improvements

Constant Rate Production maximizes NASA investments by ensuring fuel inventory is available and ready for NASA mission use, reducing schedule risk and costs

Radioisotope Power System Production



Pu-238 Isotope
Production

- Oak Ridge National Laboratory
- Idaho National Laboratory

Fuel Clad Component
Manufacturing and
Encapsulation

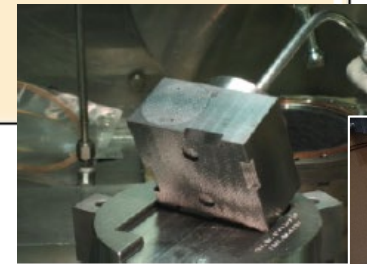
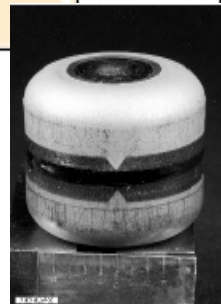
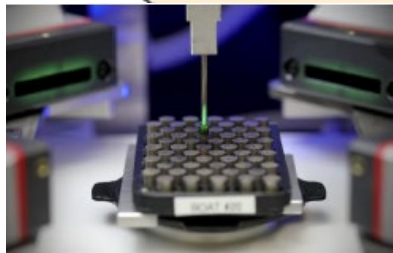
- Oak Ridge National Laboratory
- Los Alamos National Laboratory

Heat Source Assembly,
RTG Fueling and
Testing

- Idaho National Laboratory

Launch Support

- Idaho National Laboratory
- Kennedy Space Center



Constant Rate Production – Major Accomplishments



- Heat Source Plutonium Oxide Production
 - Increased capability of producing up to 700 grams of heat source plutonium oxide each year
 - Produced 1 kg of heat source plutonium oxide cumulative since 2015
 - Production campaign efficiency has increased several times and continues to optimize
- Heat Source Production
 - Manufactured 22 fueled clads in one year for the Mars 2020 mission, surpassing the production goal of 10-15 fueled clads/year
 - Material Inventory model provides management of material inventories in real time analysis between defense side and NASA
 - Leverages the heat source mission of the National Nuclear Security Agency (NNSA) for Defense-Programs extending NASA resources farther

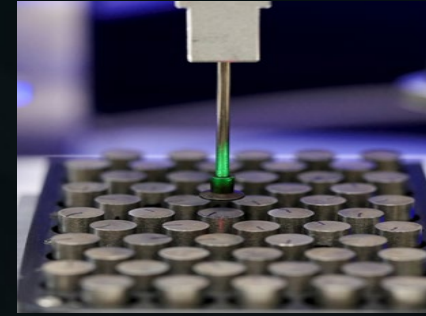
Constant Rate Production – Major Accomplishments



- Infrastructure Modernization, Maintenance and Replacements
 - Multiple Single Point failures addressed
 - Continuing to address equipment/infrastructure needs
- NASA mission benefits achieved through Constant Rate Production
 - Cost savings on Mars 2020 in part attributed to CRP of ~\$11M
 - 50% fuel production for the Dragonfly Mission (2027) has been manufactured

NASA and DOE Missions Needs Yearly Evaluation Cycle

- Increasing heat source production
 - Reduced campaign cycle time by 27% in FY20
 - Additional 20% goal for FY 21
- Sized to meet PSD mission needs, reevaluated on a yearly basis with a 10-year sliding window
 - 2020 mission set included:
 - 2 MMRTGs for Discovery in 2025
 - 1 MMRTG for Dragonfly in 2026
 - 1 DRPS (2-GPHS modules) in 2025
 - 1 Next Gen RTG (16-GPHS modules) in 2030
 - 2021 mission set in progress



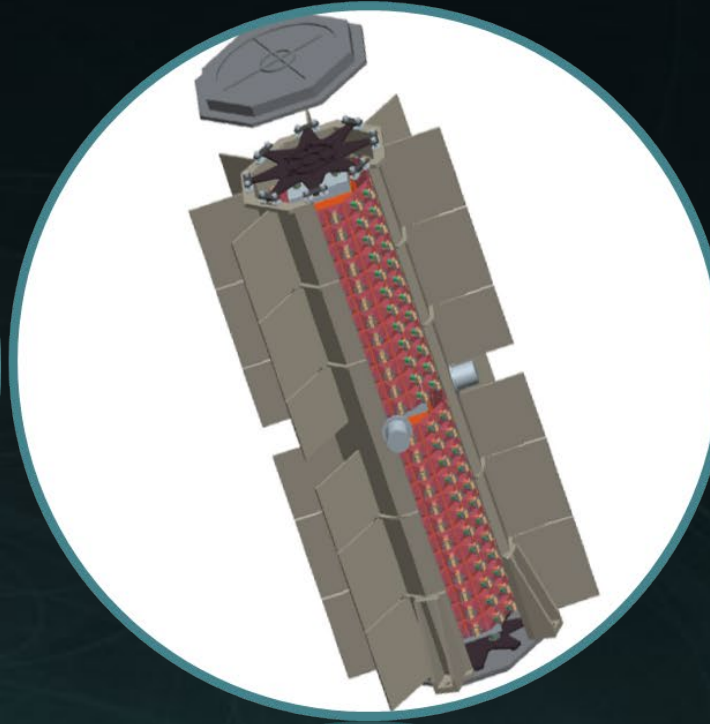
SCAN ME

Technology Investments to Enable Innovative Science Missions



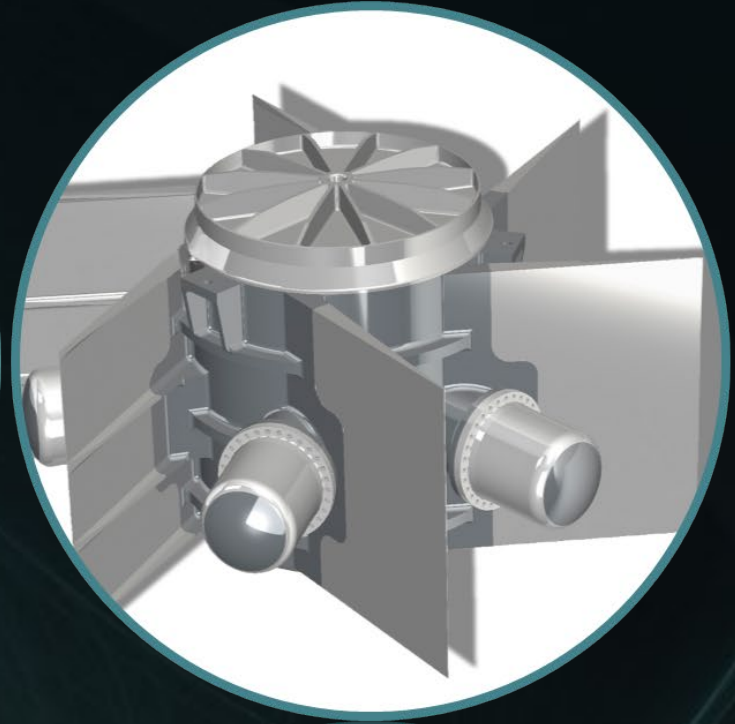
MMRTG

Multi-Mission
Radioisotope Power
System



Next Gen RTG

Vacuum Rated
Radioisotope Power
System



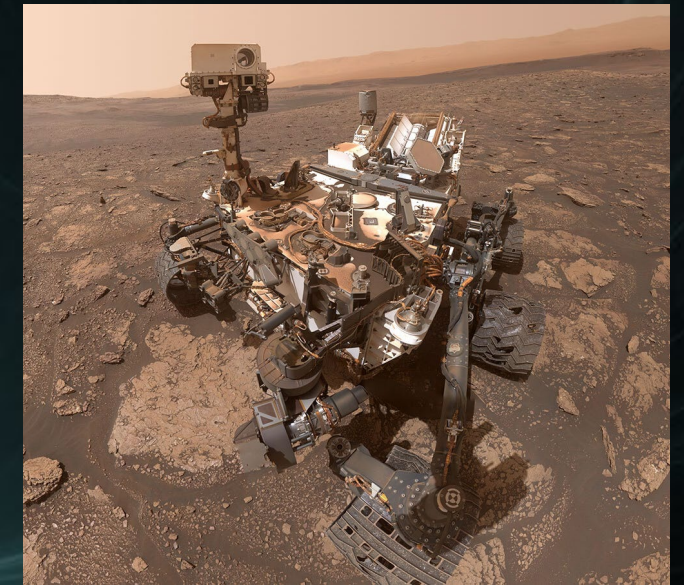
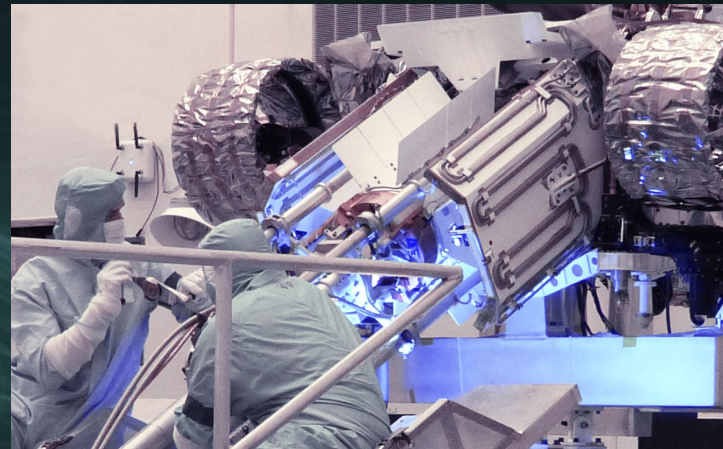
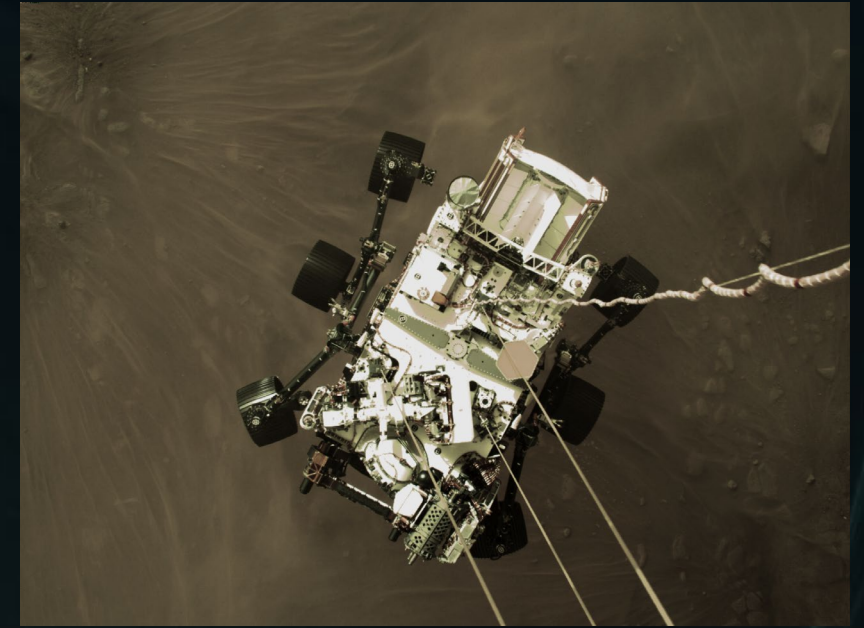
DRPS

Multi-Mission
Dynamic Radioisotope
Power System

Multi-Mission systems can be used in both vacuum and environments

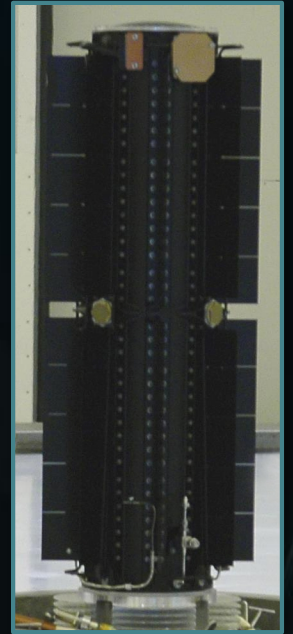
Multi-Mission Radioisotope Thermoelectric Generator (MMRTG)

- **F1** on Mars on Curiosity
 - Current Power 83.8 W_e
- **F2** on Mars on Perseverance
 - Current Power 112.6 W_e - 117.6 W_e W_e
- **F3** at INL ready for a mission
 - Completed 1-MMRTG 48-couple module
- **F4** under contract
- **F5** contract decision late FY21



Next Gen RTG Background

- Two Contractors
 - Aerojet Rocketdyne
 - Lockheed Martin
- Phase 1 design efforts complete
 - Both contractors chose silicon germanium (SiGe) conversion technology instead of advanced thermoelectrics
 - Integration of the new technology is a high-risk on-ramp
 - Additionally, contractors' input indicated an additional cost threat
 - Both contractors proposed a Mod 2 technology upgrade post 2028
- Phase 1 outcomes
 - 2028 Next Gen RTG performance only slightly better than GPHS-RTG performance
 - ~10 % gain in power, for approximately 2x the funding*
- Phase 2 Next Gen RTG Request for Proposal (RFP) released and the “Blackout Period” in effect



* Based on DOE/NASA cost estimates

Next Gen RTG Benefits

- Next Gen RTG fills a gap identified by the Program and SMD and confirmed through the 2015 Nuclear Power Assessment Study (NPAS)
- Vacuum rated system will provide
 - Early capability, higher power, long life, low degradation
- Reestablish GPHS-RTG production capability
 - Use of proven heritage design
 - More cost effective
 - Less risk
- Delivers two systems earlier than the original 2028 date
- Maintains opportunity for enhancements providing increased performance and greater efficiency
- Sustains capabilities
 - Industry
 - Government



LES 8*
Mar. 14, 1976–2004
MHW RTG: 158 W_e BOL



LES 9*
Mar. 14, 1976–2020
MHW RTG: 158 W_e BOL



Voyager 1
Sept. 5, 1977–Present
MHW RTG: 158 W_e BOL

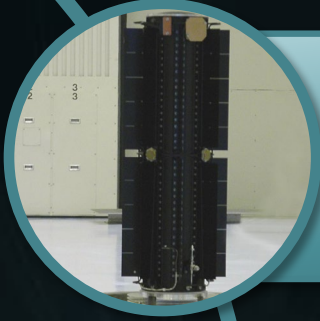


Voyager 2
Aug. 20, 1977–Present
MHW RTG: 158 W_e BOL

New Horizons
Jan. 19, 2006–Present
GPHS RTG: 245 W_e BOL

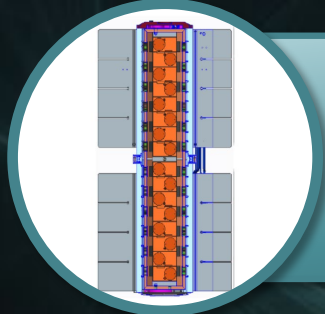
Cassini
Oct. 15, 1997–2017?
GPHS RTG: 292 W_e BOL

Power Progression: Deep Space Exploration



MOD 0

Utilize proven GPHS-RTG design, QU at INL refurbished, re-qualified; same couples as the multi-hundred watts used on Voyager; EODL $\sim 210 W_e$



MOD 1

90% heritage design, but lower heat; lower power; 2 trades going on to consider change to stretch the housing; more efficiency of the couples; EODL $\sim 177-210 W_e$

*Mod 1 reestablishes the "GPHS-RTG" production line



MOD 2

"New" Next Gen RTG; which should have a EODL $\sim 290 W_e$

*Mod 2 production requires funding post 2027

Path Forward

1

Original plan, per PSD commitment, produces at **least 1** system for a mission for 2030

2

Revised plan to deliver a **Next Gen RTG Mod 0** (GPHS-RTG) by 2022

3

Re-establish a deep space RPS production line and deliver a **Next Gen RTG Mod 1** by 2026

4

2 flight systems will be ready to be fueled by 2026 for 2030 missions

5

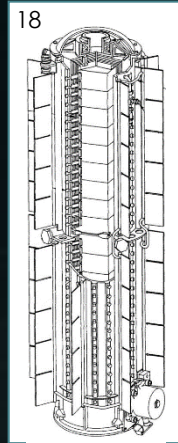
This approach delivers 2 flight systems in **80%** of the time, at **half the cost, less risk**, while meeting the original Next Gen RTG performance objective

6

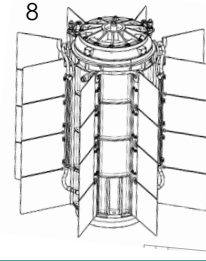
This approach **ensures** continued investment in thermoelectric energy conversion technology that will **increase performance** and deliver a **Next Gen RTG Mod 2**

Performance Comparison

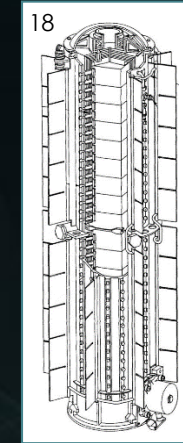
GPFS RTG:
Cassini, Galileo,
Ulysses,
New Horizons



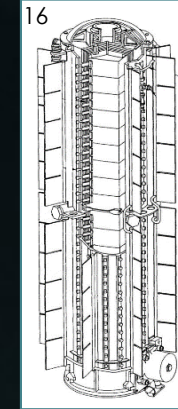
MMRTG:
Curiosity, M2020,
Dragonfly



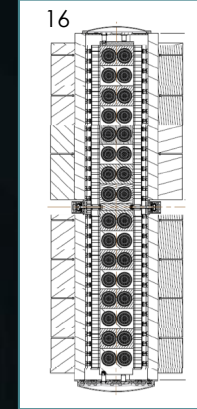
GPFS RTG:
Cassini, Galileo,
Ulysses,
New Horizons



Next Gen RTG
Mod 1



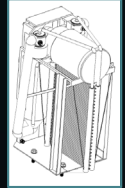
Next Gen RTG
Mod 2



AMSC/FISC



Creare/TBC

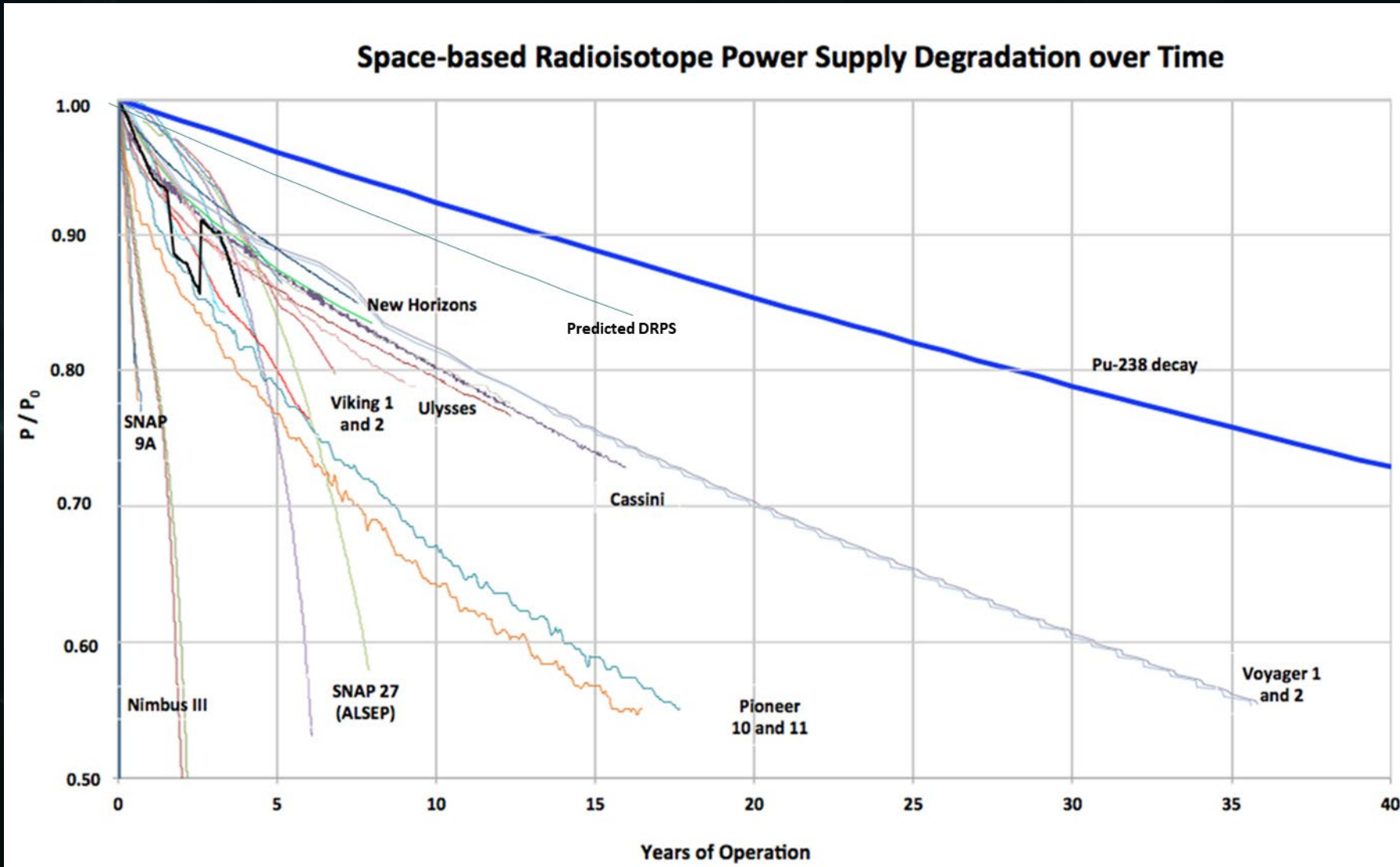


Sunpower/SRSC



Parameter	GPFS-RTG	MMRTG	Next Gen Mod 0	Next Gen Mod 1	Next Gen Mod 2	DRPS
$P_{BOL} (W_e)$	291	110	293	245	400	300 to 400
Mass (kg)	58	44	56	56	56	100 to 200
$Q_{BOL} (W_{th})$	4410	2000	4500	4000	4000	1500
$P_{EODL}, P=P_0 \cdot e^{-rt} (W_e)$	N/A	63	208	177	290	241 to 321
Maximum Average Annual Power Degradation, r (%/yr)	1.54	3.8	1.9	1.9	1.9	1.3
Fueled Storage Life, t (yrs)	2	3	3	3	3	3
Flight Design Life, t (yrs)	16	14	16	14	14	14
Design Life, t (yrs)	18	17	18	17	17	17
Allowable Flight Voltage Envelope (V)	22-34	22-34	22-34	22-36	22-36	22 to 36
Planetary Atmospheres (Y/N)	N	Y	N	N	N	Y
Estimated Launch Date Availability	N/A	Now	2026	2029	2034	2030

Power Degradation Chart



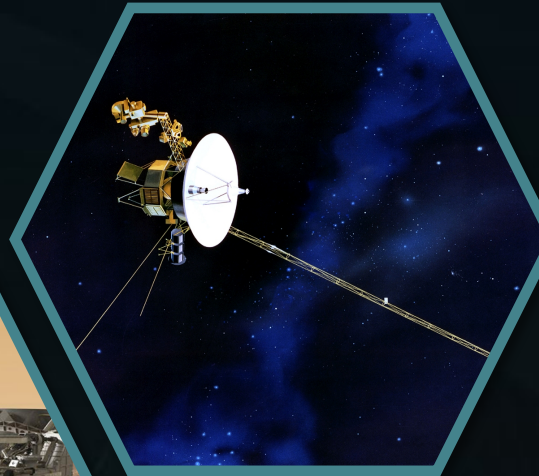
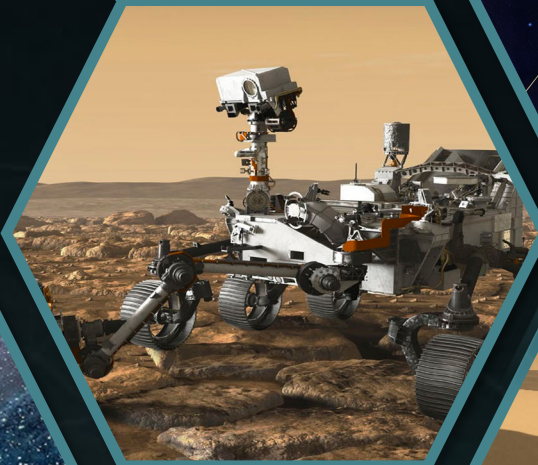
- EODL of 17 years allows for equal comparison of systems
- MHW RTG and GPHS-RTG (SiGe couples) degrade gracefully and do not fail
- Lifetimes 40+ years demonstrated and life prediction models indicate power at 50 years $\sim 100 W_e$

RPS Program Provides

- Strong partnership with DOE
 - DOE can make fuel now, where 10 years ago they could not
 - DOE is scaling up
 - There is capacity in the system
 - Additional capacity requires additional funding and infrastructure changes
- Power systems availability and mission support
 - MMRTG available, producing additional units
 - Next Gen Mod 0 on shelf in 2022; Mod 1 in 2026
 - Next Gen RTG production starting in 2026
 - DRPS investments
 - Proven track record with RPS missions lasting over 40 years
- Balanced approach to supporting missions and reducing risks
- Corporate memory provides opportunities to maximize positive impacts for mission community

The RPS Program's priority is mission success!

PERSEVERANCE



Voyager 1 & 2

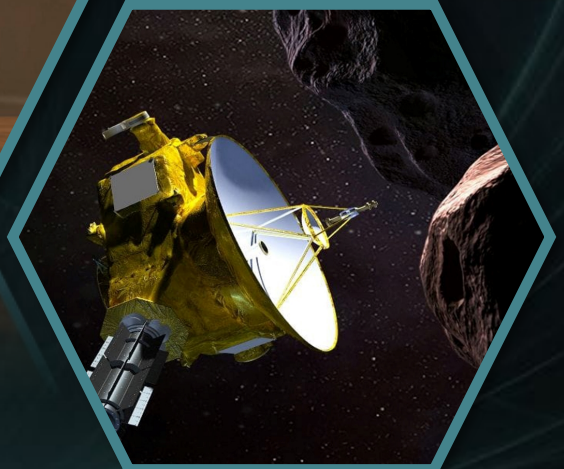
UNKNOWN
POSSIBILITIES



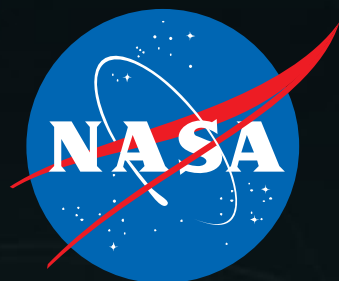
DRAGONFLY



(PROPOSED)
TRIDENT



New Horizons



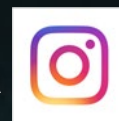
NASA



NASA



@NASA



NASA

POWER TO EXPLORE

<https://rps.nasa.gov>

nasa-rps@mail.nasa.gov

BACKUP SLIDES

PMCS Studies – Summer 2020

Compatibility with a 400 W_e Next Gen RTG Mod 2 available for launch 2034



Study		# of Next Gen RTGs	Launch Year	Flight Time
Mercury Lander	G	1 Next Gen RTG	2035	11 years
Lunar INTREPID*	G	1 Next Gen RTG, 300 W _e	–	4 years (7 years if solar)
Enceladus Orbilander	G	2 Next Gen RTG	2038	15-18 years
Neptune Triton	Y	3 Next Gen RTG	2033, backup 2049	20 years
Pluto Orbiter & KBO	R	5 Next Gen RTG	2031	31-39 years

From Final Reports by APL to the RPS Program and NASA HQ

* Mark Robinson [*Intrepid: Unraveling Four Billion Years of Lunar Magmatism*](#), LPI Workshop, May 26, 2020

RPS Guidance updated to reflect data in this briefing at start of current 2021 PMCS Studies