National Aeronautics and Space Administration

EXPLORE SPACE TECH

Technology, Innovation & Engineering Committee Report
NASA Advisory Council

Mr. Michael Johns | November 1, 2019

TI&E Committee Scope

"The scope of the Committee includes all NASA programs focused on technology research and innovation."

–NASA Advisory Council Technology & Innovation Committee Terms of Reference, signed 6/28/12

TI&E Committee Meeting Attendees: Oct. 29, 2019

- Mr. Jim Free, Peerless Technologies
- Dr. Kathleen C. Howell, Purdue University
- Mr. Michael Johns, Southern Research Institute
- Dr. Mary Ellen Weber, Stellar Strategies, LLC

TI&E Committee Meeting Presentations: Oct. 29 , 2019

- Welcome to Kennedy Space Center
  - Robert Cabana, Director, Kennedy Space Center
- Space Technology Mission Directorate (STMD) Update & Discussion
  - Jim Reuter, Associate Administrator, STMD
- Lunar Surface Innovation Initiative (LSII) Update
  - Niki Werkheiser, LSII Lead
- Office of the Chief Technologist Update
  - Al Conde, OCT Strategic Integration Office Lead
  - David Miranda, Senior Technologist, Kennedy Space Center
- Synthetic Biology/The Center for the Utilization of Biological Engineering in Space Update
  - John Hogan, Program Manager, Ames Research Center
- Nuclear Thermal Propulsion Update
  - Rick Ballard, NASA Marshall Space Flight Center
- Early Career Initiative Overview
  - Ricky Howard, Program Executive, STMD

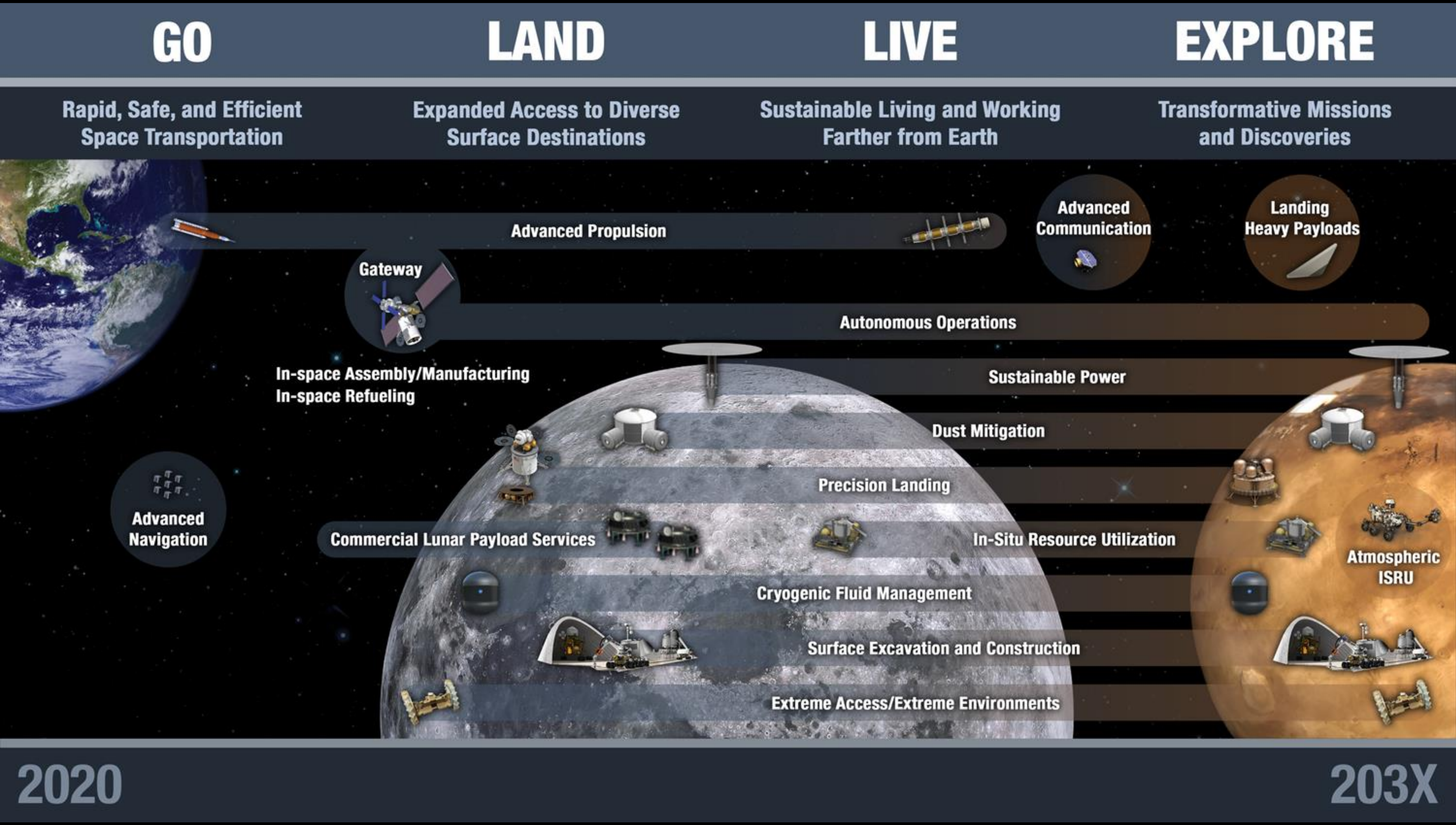
National Aeronautics and
Space Administration

EXPLORESPACE TECH

NASA Advisory Council
Technology, Innovation & Engineering Committee Meeting

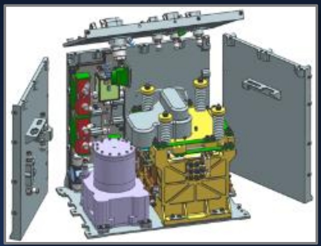
Mr. James Reuter, Associate Administrator for NASA STMD | October 29, 2019

Technology Drives Exploration

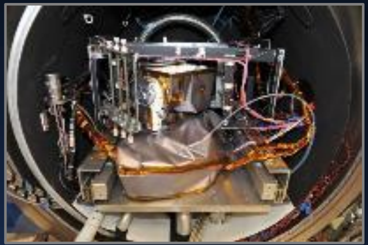


FY 2019-2020 Activities

MOXIE
March 2019 delivery to Mars 2020 for
July 2020 Launch



Terrain Relative Navigation November 2018
Delivery for integration on Mars 2020

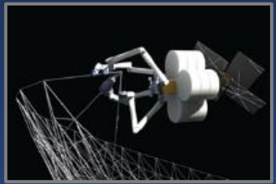


Laser Comm Relay Demo
October 2019
Payload delivery for bus integration

Deep Space Optical Comm
June 2019 KDP-C for the flight terminal

MEDLI2
November 2019
Hardware Delivery for integration on Mars 2020 entry system

Astrobee
August 2019
Three free-fliers onboard ISS for demonstration

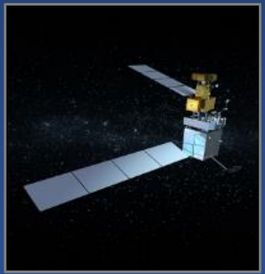


In Space Robotic Manufacturing and Assembly project
July 2019 Awarded Made in Space Archinaut mission to manufacture and assemble spacecraft components in LEO. Maxar award likely in Sept.

High Performance Spaceflight Computing (HPSC)
FY 2020
Completion of critical design

SPLICE
October 2019
Complete NDL environmental testing; 2020 flight test

Refabricator Delivery and Installation aboard ISS February 2019
The first integrated recycler and 3D printer was successfully installed

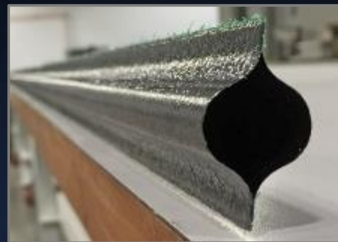


Restore-L
April 2019
Spacecraft critical design review
February 2020
Mission CDR

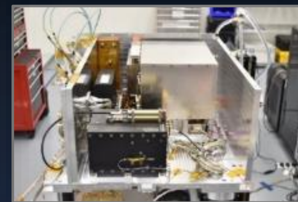
Flight Opportunities Campaigns

FY 2019-2020 Activities

eCryo
April 2020
SHIVER Testing Complete



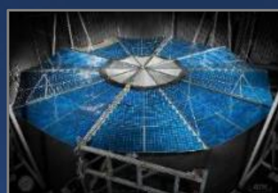
Deployable Composite Boom
November 2019
Manufactured boom and deployment system will be demonstrated early 2020



DSAC & GPIM
June 2019
Launched Aboard STP-2

LOFTID
June 2019
KDP-C
April 2020
CDR

Nuclear Thermal Propulsion
October 2019
Feasibility and risk assessment study of nuclear thermal propulsion



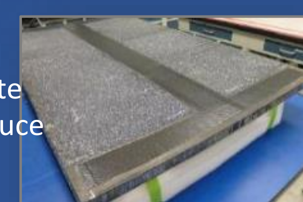
Extreme Environment Solar Power
July 2019
Developing solar cell concentrator technology for low-intensity, low-temperature space power applications. Hardware will be demonstrated for subsequent technology demonstration on SMD's future mission DART

New Space Technology Research Institutes
To advance space habitat designs using resilient and autonomous systems, NASA selected Habitats Optimized for Missions of Exploration (HOME)-Univ of Calif; and Resilient ExtraTerrestrial Habitats institute (RETHi)-Purdue Univ

SpaceCraft Oxygen Recovery (SCOR)
June 2020
Performance test results of two advanced oxygen recovery systems will be available in June 2020 for baseline comparison of capability

Solar Electric Propulsion
June 2019 KDP-C
FY19: Develop and test EDU/ETU/qualification hardware
FY20: Complete Critical Design Review, build qualification units and begin testing

Composite Technology for Exploration
September 2019
Complete testing of composite joint technology that will reduce launch dry mass



TI&E Committee Meeting 10/29 Observations

- Administrator Bridenstine should be commended for making the decision to keep STMD a standalone organization in the spring of 2019.
- STMD has achieved many successes during the past six months, including this summer's launch and deployment of the Green Propellant Infusion Mission and Deep Space Atomic Clock; MOXIE, MEDLI2, and Terrain Relative Navigation (TRN) were delivered to Mars2020; and 33 new Tipping Point and ACOs were awarded.
  - There is an increasing demand for STMD-developed technologies (e.g. TRN and precision landing by CLPS/potentially HLS providers).
  - When investment is made and sustained (e.g. SEP/high-power Solar Arrays) more NASA missions are enabled.
- The Committee believes that sustained technology funding is important for future missions so that NASA is ready to meet aggressive Artemis goals (e.g. cryo fluid management needed in the short-term for lunar & Mars exploration)
- Proven STMD technologies are positioned to be used in other NASA missions and infusion path should be better defined (e.g. TMCO approval). For instance, what is the infusion path for GPIM and DSAC into future science missions?

TI&E Committee Meeting 10/29 Observations (cont.)

- STMD has done a good job of aligning (Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) investments with Agency priorities.
  - The TI&E Committee supports NASA legislative proposals: direct to Phase II awards and increasing the Civilian Commercialization Readiness Pilot Program (CCRPP) award limit to $10M.

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EXPLORE SPACE TECH

Lunar Surface Innovation Initiative (LSII) Overview

NAC Technology, Innovation, and Engineering Committee Meeting

Niki Werkheiser, NASA STMD, LSII Lead | October 29, 2019

The Lunar Surface Innovation Initiative (LSII)

In Situ Resource Utilization

Collection, processing, storing and use of material found or manufactured on other astronomical objects

Surface Excavation/Construction

Enable affordable, autonomous manufacturing or construction

Sustainable Power

Enable continuous power throughout lunar day and night

Lunar Dust Mitigation

Mitigate lunar dust hazards

Extreme Access

Access, navigate, and explore surface/subsurface areas

Extreme Environments

Enable systems to operate through out the full range of lunar surface conditions

- STMD develops and performs demonstrations that allow the primary technology hurdles to be retired for a given capability at a relevant scale. While there may be additional engineering development required for additional scale-up, there should be none required for the foundational technologies.

- LSII will accelerate technology readiness for key lunar infrastructure capabilities enabling early technology demonstrations for early un-crewed commercial missions, as well as informing development of crewed flight systems.

Lunar ISRU Development and Demonstration Timeline

Reconnaissance, Prospecting, Sampling	Resource Acquisition & Processing	Pilot Consumable Production
Sub-system Demonstrations: Investigate, sample, and analyze the environment for mining and utilization.	*Follow The Natural Resources: Demonstrations of systems for extraction and processing of raw materials for future mission consumables production and storage.*	*Sustainable Exploration: Scalable Pilot Systems demonstrating production of consumables from in-situ resources in order to better support sustained human presence.*

Oxygen from Regolith (Lunar Simulant) Ground Demos

High-fidelity Lunar Simulant Production

CLPS Drill Down-Select

Polar Resources Ice Mining Experiment (PRIME-1) on CLPS

ISRU Subsystem Consumables Extraction Demos

Scalable Pilot-ISRU Systems for Consumable Production

2019

Synthetic Biology/CUBES Update

NAC Technology, Innovation and Engineering Committee Meeting
October 29, 2019

NASA Kennedy Space Center

John A. Hogan, Ph.D.

NASA Ames Research Center

Future Missions Need a Different Approach

- Short crew duration
- Frequent resupply of food, water, O_2, medical supplies, replacement parts
- Emergency return to Earth
- No ET planetary protection requirements

- Extended crew durations
- Infrequent or no resupply of food, water, O_2, medical supplies, replacement parts
- No emergency return to Earth
- Possibly strict planetary protection requirements

- NASA needs *In situ* manufacturing, *In situ* resource utilization and life support
- Biological systems offer tremendous potential

Sustaining Future Missions

Capabilities

- ***In situ* Resource Utilization (ISRU)** generates supplies from local resources.
- **In Space Manufacturing (ISM)** provides capability to make needed chemicals, fuels, building materials, pharmaceuticals, etc. on-site and on-demand.
- **Closed-loop life support systems** treat and recover valuable resources via regenerative air, wastewater and solid waste processing systems.
- **Food production** will be required to supply nutritional needs not met by current food provisioning systems. Eventually all food may be produced *in situ*.
- **Space medicine** systems will require the ability to monitor and maintain the health of the crew under very adverse conditions.
- These systems require increased **reliability and self-sustainability,** and decreased mass, power, volume and consumable use.

Potential of Biology – Possible Biological Products:

- Food – plants and microbial products
- Vitamins, nutraceuticals
- Enzymes, flavors, preservatives
- Therapeutics/pharmaceuticals
- Polymers – plastics for parts, habitat construction, radiation protection
- Fuels – hydrocarbons, nitrogen-based
- Primary chemicals for various product synthesis
- Adhesives/biocement - construction
- Specialized function biomolecules:
  - e.g., Carbonic anhydrase for CO_2 management

Vision Statement

The Center for the Utilization of Biological Engineering in Space (CUBES) is leveraging partnerships between NASA, other federal agencies, industry, and academia to:

- Support biomanufacturing for deep space exploration;
- Create an integrated, multi-function, multi-organism biomanufacturing system for a Mars mission; and
- Demonstrate continuous and semiautonomous biomanufacture of materials, pharmaceuticals, and food in Mars-like conditions.

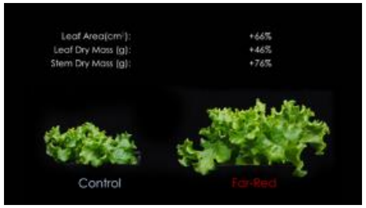
https://cubes.space

- ✓ 2.5 Years Complete
- ✓ 4 Divisions
- ✓ 5 Universities
- ✓ 15 Professors; 2 Research Scientists
- ✓ 12 Postdocs
- ✓ 21 Graduate Students

Berkeley UNIVERSITY OF CALIFORNIA — Stanford University — UtahState University — UCDAVIS — UF UNIVERSITY of FLORIDA

FPSD Division Status

Food and Pharmaceutical Synthesis Division Accomplishments



Optimizing plant production

- Demonstrated substantial increases in growth rates in lettuce with far-red wavelength addition
- Engineering rice to increase photosynthesis efficiency
- Developing microbiome management methods for increasing plant health/growth
- Developing optical fiber system for enhanced plant lighting

Plant-based production of biopharmaceuticals

- Engineered lettuce to produce a bone-regenerating therapeutic (PTH-Fc fusion protein) for crew bone health.
- Validating drug activity using cell-based assays
- Demonstrated Viral Immunosorbent Nanoparticles (VINs) for protein purification in plants to reduce needed purification resources

Pharmaceutical production in cyanobacteria

- Novel engineering of *Spirulina* for production of acetaminophen – potential breakthrough as a scalable photosynthetic drug production platform

TI&E Committee Meeting 10/29 Observations (cont.)

- STMD’s use of Space Technology Research Institutes (STRIs) has been positive as both are making great progress.
- Synthetic Bio/CUBES have defined challenges well, they are aligning to those challenges, and Karen McDonald of UC Davis was recently selected for a Translational Research Institute for Space Health (TRISH) award for a plant-based platform for "just in time" medications.

National Aeronautics and
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Space Technology Mission Directorate

Nuclear Thermal Propulsion Update

Richard Ballard
NTP Project Manager (Acting)
Marshall Space Flight Center
October 29, 2019

Nuclear Thermal Propulsion (NTP) Project Overview

Key Benefits

Provide NASA with a robust in-space transportation architecture that enables faster transit and round trip times, reduced SLS launches, and increased mission flexibility

Current Strategy and Investments

Risk Reduction: Determine the feasibility of an low enriched uranium (LEU)-based NTP engine with solid cost and schedule confidence.

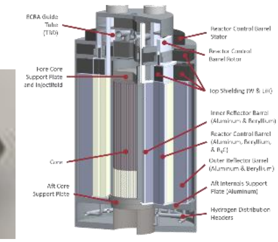
Flight Demo Study: Evaluate NTP concepts to execute a flight demonstration mission to include potential users and missions and additional fuel forms. This study is inviting industry participation

Partnerships and Collaborations

NASA and Department of Energy (DoE) (Idaho National Lab, Los Alamos National Lab, and Oak Ridge National Lab) are collaborating on fuel element and reactor design and fabrication for LEU-based NTP feasibility. DoE provides indemnity to industry.

NASA, DoE and Department of Defense (DoD)/Strategic Capabilities Office (SCO) are working to develop a common fuel source for special purpose reactors including NTP and "Pele". Shared investments will address key challenges of the TRIstructural ISOtropic (TRISO) fuel form that will inform both the NTP risk reduction and flight demo formulation.

DoD, DoE, and NASA are formulating a collaborative effort that utilizes and benefits each organization. Specific areas include: Indemnification, mission requirements, design, analysis, facilities and testing.



Fuel Element Development Status

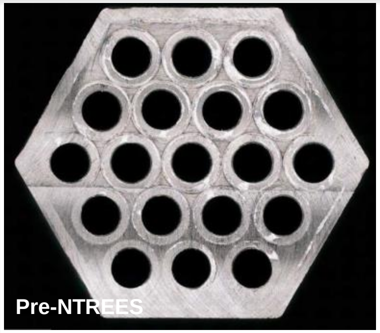
- **Packed Powder Cartridge (PPC) Fuel Element Development**
  - Results: Mo-dUN “cold end” FE testing in the NTREES Test Facility on 6/27/19 (API Milestone)
    - During a planned hold at 1850K the NTREES facility experienced a power system fault resulting in in an unintended cool down rate
    - FE separated into two pieces along a butt weld; no dUN was released in the chamber
    - The resulting rate of cooling (≈ 80-90 K/sec) was not greater than predicted for an actual nuclear fuel element in service
    - Determined that the cooling rate did not initiate nor was it sufficient to induce breakage of a properly designed FE

Fit Check

SS 304 Development Article

N19C-A1 Surrogate Test Article (S1)

N19C-A2 dUN Test Article (Cold End)



Flow tube to end cap welds show centerline cracking for outer portion of outer tube row for test N19C-A1

Above Images from here – N19C-A1

Separation at in-coil butt welds due to thermal stresses

Design Independent Review Team (DIRT) Established Following 2nd NTREES PPC FE Failure

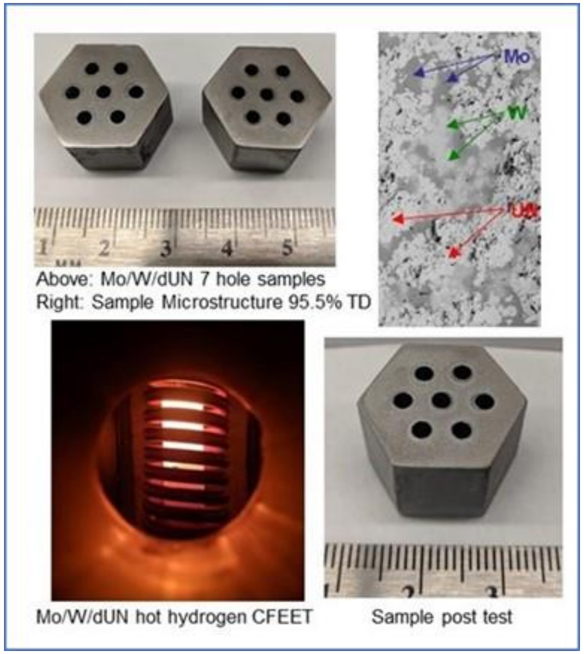
Fuel Element Development Status, (cont.)

- **Fuel Development Design Independent Review Team (DIRT)**
  - Provide an assessment of the ability and confidence of NTP design approach to meet the intended purpose and survive the environments
    - ❖ Identify strengths and challenges of the design approach
    - ❖ Suggest if design concept should be altered and/or continued
    - ❖ Assess design development priorities needed to assure survivability to environments and associated technical/programmatic risks
  - The Board made the following recommendations
    1. Discontinue packed powder cartridge fuel development at the end of FY19.
    2. Focus resources on alternate Spark Plasma Sintering (SPS) reactor design development for the remainder of the project baseline
    3. Pursue a fuel form that advances the near-term design, fabrication, and testing needs of a SPS reactor design and is extensible to the Isp needs of NASA.
    4. Project should submit written rationale detailing technical reasons why graphite composite should not be pursued.
    5. Assess potential for establishing a fuel testing capability analogous to that provided by the Nuclear Furnace facility developed during NERVA.
    6. Assess benefits vs. liabilities associated with pursuing a HEU-based NTP.

Fuel Element Development Status, (cont.)

- **SPS Cermet FE Development at MSFC**
  - Process rapidly (~5 min.) consolidates powder material into solid components (no free powder)
  - Allows for built in cooling channels that optimize heat transfer
  - Met integrity and density (>95%)
- **Successfully fabricated 2 hex Mo-W-dUN fuel wafers for testing in the CFEET system**
  - Tested in CFEET at 2250K for 20 minutes under hot hydrogen with no noticeable dissociation of UN
  - Migration at Mo-UN interface confirms hydrogen is detrimental and cladding needed to mitigate attack

A NASA developed SPS Process SPS

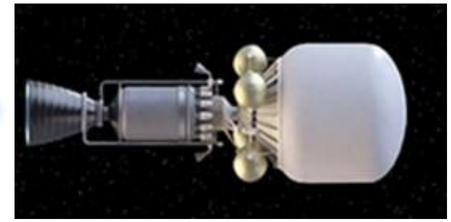


- **Current Development**
  - Will deliver a 16-inch surrogate test article for NTREES testing in November 2019
  - Fabrication and NTREES test Mo-W-dUN diffusion bonded article scheduled for March, 2020

Pursuing multiple manufacturing options for fuel element development
Spark Plasma Sintered (SPS)

NTP Flight Demo Options

NTP Flight Demo Development



- **Flight Demo (FD) Options to be Considered**
  - FD1 - Nearest Term, Traceable, High TRL (Target Soonest Flight Hardware Delivery)
    - Emphasis on schedule over performance
  - FD2 - Near Term, Enabling Capability (TBD availability Date)
    - Emphasis on extensible performance over schedule
- **Internal (NASA-led) and Industry-led Studies using similar GR&A**
- **Customer Utilization Studies**
  - Science Mission Directorate
  - DoD (via DARPA)
- **Outbrief to STMD will provide “MCR-like” products**
  - Including acquisition strategy, draft project plan, certification strategy, etc.

TI&E Nuclear Thermal Propulsion (NTP) Finding

- The Committee brought a Finding to the NAC in April 2019. The Committee still believes an NTP system could reduce crew transit time to Mars and increase mission flexibility which would enable a human exploration campaign.
- The STMD NTP project is making good progress in addressing the key challenges related to determining the technical feasibility and affordability of an LEU-based NTP engine.
  - However, STMD's NTP project and its risk reduction activities recently experienced a technical issue with the fuel development.
  - Recovery from this issue is central to moving forward with NTP development and a future flight demonstration.
- Ongoing internal and external NTP flight demonstration studies need to be completed and an integrated solution set developed for Agency leadership to make decisions on the future course of NTP development.
  - For instance, for a projected human-Mars mission in ~2035, the STMD NTP demonstration flight would have to occur in the mid-to-late 2020s.
  - Therefore, STMD would have to set a path for the NTP flight demonstration soon.
  - Planning for such a demonstration flight would have to occur in the upcoming budget cycle.

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The Early Career Initiative

Presented to the NASA Advisory Council

October 29, 2019

Ricky Howard
Program Executive – Center Innovation Fund

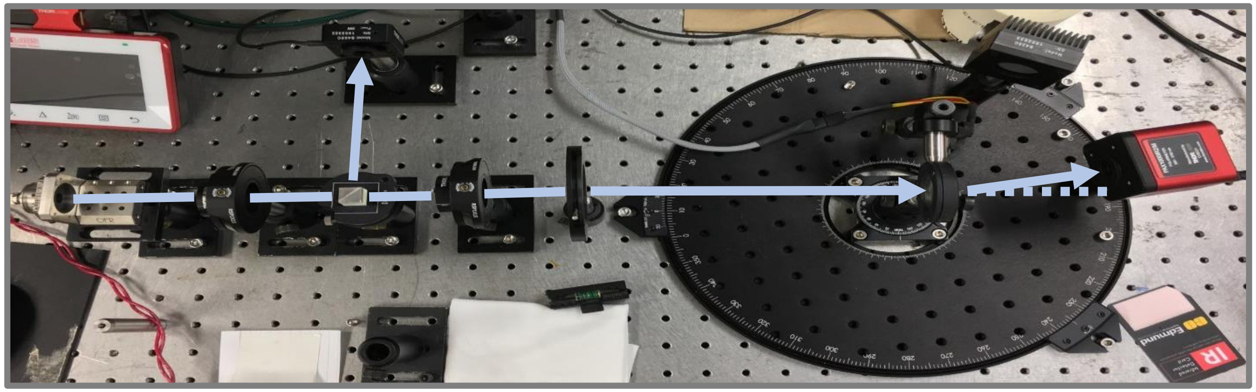
ECI Goal and Funding

Initiative Goal

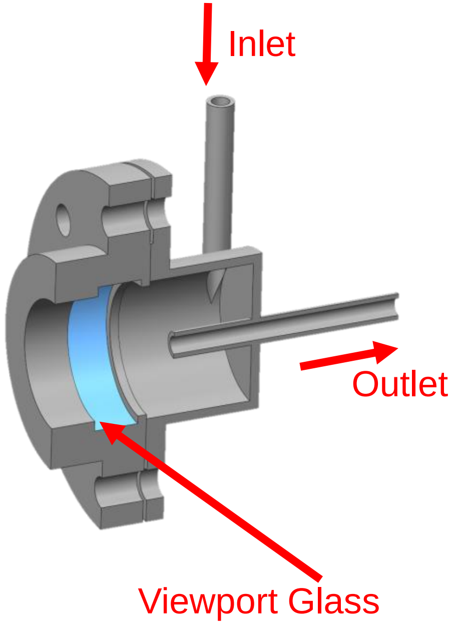
Invigorate NASA's technological base and best practices by partnering early career NASA leaders with world class external innovators.

ECI Projects by year:

FY15 $5M – 4 projects initiated; completed in FY17
FY18 $2.5M – 2 Projects initiated; completing in FY20
FY19 $6.5M – 3 Projects initiated
FY20 $13M – 7 Projects initiated



Electro-Optical Technology Development In Liquid Crystal Beam Steering

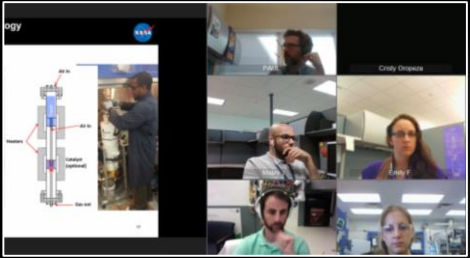


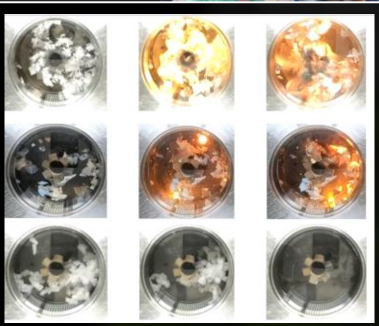
OSCAR

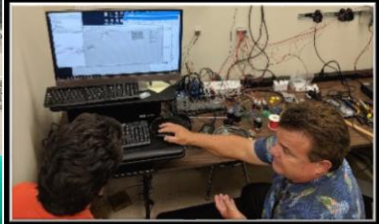
TI&E Committee Meeting 10/29 Observations (cont.)

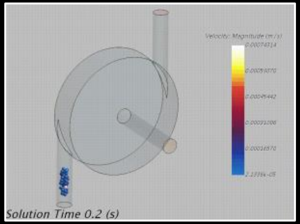
The TI&E Committee commends STMD’s Early Career Initiative (ECI) which invigorates NASA’s technological base and best practices by partnering early career NASA leaders with world class external innovators.

- Development of:
  - Science and Technology
  - Engineering processes
  - Budget, Travel, Schedule
  - People: (scientists, engineers, emotional beings)
- Fast Paced Testing and Hands on work
- Multi-Center and Commercial Collaboration









- Collaborative Tools, Teambuilding, Networking
- Hybrid Project Management: agile/lean/waterfall
  - Collaborative Workspace & Tools
- Mentoring, Outreach, Authorship
- Community, Teamwork, Teambuilding

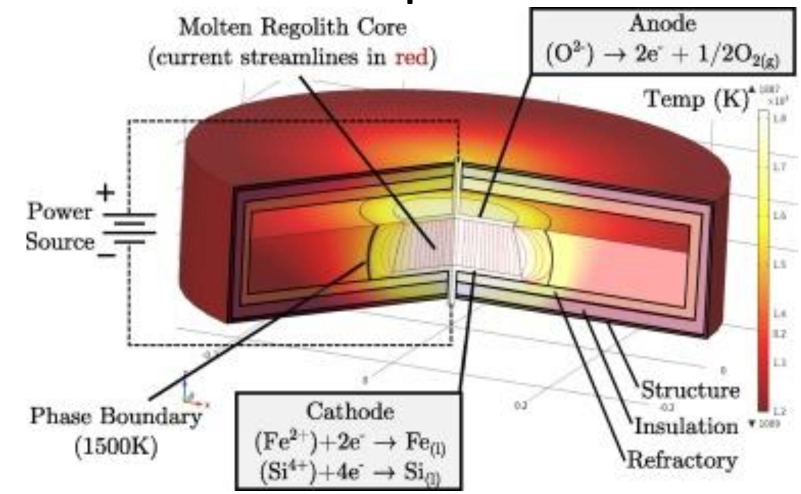
Molten Regolith Electrolysis- Starter Device [KSC]

Goal: Enable lunar oxygen production via electrolysis of molten regolith

- **Problem:** Melting an entire bed of regolith is extremely harmful to the reactor walls and unnecessary when only the volume between electrodes needs to be melted.

Strategy: Develop localized melting technologies to enable minimal viable melting pools of regolith, and demonstrate end-to-end oxygen production from lunar regolith.

Cold-Wall Reactor Concept



Samuel S.Schreiner (2016)

Team Overview

- Dr. Kevin Grossman. (EC) – PI, Materials Engineering
- Elspeth Petersen (EC) – Oxygen Production and analysis
- Jerry Wang (EC) – Simulation and Analysis
- Evan Bell (EC) – Mechanical Engineering
- Jaime Toro Medina – Mechanical Engineering
- Mark Lewis – Systems Engineering
- Dr. Laurent Sibille – Molten Regolith Electrolysis subject Matter Expert
- Dr. Luke Roberson – Project Mentor
- Dr. Anne Meier – Project Mentor

External Partner – Honeybee Robotics , Engineering, rapid prototyping mentors

Project Management Approach

Modified Agile focused on short, interative hardware development cycles in parallel

- 3-month short-term plans

Enables rapid iteration, technical evolution, and team adaptation.


NASA
EXPLORE SPACE TECH
TECHNOLOGY DRIVES EXPLORATION