NASA Chemical Propulsion
In-Space

Rocket Propulsion for the 21st Century (RP21)
Spring Meeting

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The Chemical Propulsion Sub-capability Management Forum is responsible for all chemical propulsion for the Agency, boost and in-space.

**Goals and Objectives**
- Utilize the propulsion workforce from an Agency perspective
- Increase mutual dependencies, avoid costs, create efficiencies, and align workforce to center roles

**In-Space chemical propulsion** focused on working today’s projects with a vision of the in-space chemical propulsion of tomorrow.

### Yesterday
- Storable in-space prop for science and HSF
- Slow evolution of CFM component technologies for in-space use

### Today
- Storable hypergols for in-space propulsion
- Development of SLS/Orion for beyond LEO
- Investigating Low Cost NTP with LEU fuel
- Green Propellant Systems – Advanced Dev.
- Integrating CFM technologies to demonstrate viability of in-space cryo propellant systems
- Hybrids for Ascent systems
- Long Lifetime/Extreme Env. Solid Rocket Motors

### Tomorrow
- Cryogenic In-space Prop (LOX/CH4)
- Descent/Ascent Lander engines and systems
- Use of ISRU produced propellants
- SLS Operations & Orion Operations
- NTP Engine & System Development
- Green Propellant Systems
- Advanced Chem for Science Missions
- Traditional Chem for Science Missions
Development of SLS/Orion → SLS/Orion Operations In-Space

- On-going to deliver SLS for EM-1 while proceeding with the design of SLS EUS for crewed / longer duration missions

- Orion with heritage engine hardware evolves to new engine procurement and assessment of parallel propulsion architecture

- Propulsion workforce from six NASA centers
  - MSFC, JSC/White Sands, GRC, LaRC, SSC and KSC

Investigate Low Cost NTP → NTP Engine & System Development

- STMD funded effort to assess integrated engine / reactor system and potential ground test options

- Propulsion workforce from three NASA centers
  - MSFC, GRC, SSC
CFM technologies  →  Cryogenic In-Space Systems

- STMD roadmap developed with focus on technologies needed for NTP, In-Space Methane Stage and Lander / Ascent Vehicle
  - Roadmap delineated technologies that required flight from those that benefit from large scale ground test to focus investments
    - Planned testing of Shiver (large scale ground test)

- Propulsion workforce from three NASA centers
  - MSFC, GRC, JSC

Hypergol Ascent Stage  →  Descent / Ascent / Deorbit Stages

- Many efforts on-going including SMD funded MAV and Europa Projects, HEOMD funded Lander Technologies
  - Working in solid, liquid, and hybrid propulsion

- Propulsion workforce from five NASA centers
  - MSFC, GSFC, JPL, JSC, and GRC
Green Prop Adv Development → Industry Leveraged Systems

- Chemical Propulsion Sub-capability Management forum chartered a Green Propulsion Working Group to focus the efforts for the Agency
  - Efforts were distributed and overlapping
  - Needed focus for future investments
  - Needed assessment of mission pull and strategy

- Three NASA centers involved, MSFC, GSFC and GRC
Green Propulsion Outline

• Green Propulsion Working Group
  – Purpose & Role
  – Representation & Community
  – Focus, Products, & Leadership

• NASA Green Prop Roadmap
  – Goals & Vision
  – Technology Development Areas (TDAs)
  – Strategy & Partnerships

• Missions, Projects, & Activities
  – Flight: GPIM & Lunar Flashlight
  – Ground: Aerojet Rocketdyne, Busek, Orbital ATK
  – IRAD: Propellants, Components, Tools, Range Access, Studies

What we are doing ‘Today’ to get us to the ‘Tomorrow’
• Created by NASA Chem Prop Sub-capability Management (CPSM)

• Purpose:
  – Develop & Maintain the NASA Green Propulsion Roadmap,
  – Identify Green Propulsion (GP) Technology Development Areas (TDAs),
  – Establish Strategy & Vision for address GP TDAs,
  – Track efforts to address TDAs pursued by NASA Centers, other Agencies, industry, & academia, and
  – Identify & Maintain assessment of GP test facilities & competencies related to green propulsion for NASA.

• Role:
  – Advisory group to the CPSM on In Space Green Propulsion
  – Institutional knowledge source for agency & partners
  – Advocacy for Green Propulsion Technology
  – Work across center, agency, & industry lines to achieve goals
Green Propulsion Working Group (GPWG)

• Representation:
  – Marshall Space Flight Center
  – Glenn Research Center
  – Goddard Space Flight Center
  – Ames Research Center
  – Jet Propulsion Laboratory

• Community:
  – Government:
    • Air Force Research Laboratory (AFRL)
    • Naval Air Warfare Center (NAWC)
    • Missile Defense Agency (MDA)
    • Sandia National Laboratory (SNL)
  – Academia:
    • Kent State University
    • MIT
    • Purdue University
  – Industry:
    • Aerojet Rocketdyne
    • AMA
    • Busek Company
    • ECAPS
    • Orbital ATK
    • Plasma Processes
    • VACCO Industries
Green Propulsion Working Group (GPWG)

- **Focus:**
  - Ionic liquid propellants & related technologies seen as direct or near-direct replacements for hydrazine monoprop or hypergolic bi-props

- **Products:**
  - NASA Green Propulsion Roadmap

- **Leadership:**
  - Pulling Teams together for Studies
    - AF-M315E Surface Tension Study
    - LMP-103S ADN Desolvation & Resolvation Rates
    - Green Propellant Use on ISS (NASA NESC - JAXA)
  - Engaging Agencies, Industry, & Academia
    - Green Prop Payload & Flight Opportunities TIM
    - ACO, SBIR, CAN, IA, SAA
  - Growing influence & participation in GPWG
Goals & Vision:

Goal 1: Establish Agency Vision for Green Propulsion

- Focuses upon a step-wise plan to systematically advance the state-of-the-art with each step contributing to the next while simultaneously providing for the greatest return on investment.

Goal 2: Provide Guidance to Focus Energies & Resources

- Identify NASA capabilities & provide recommendations to the best utilization of those capabilities.
- Advise on new capabilities
- Work to provide guidance to MDs, POs, Centers, projects, & NASA investments to best utilize the resources available

Goal 3: Knowledge Archiving, Distribution, and Utilization

- Ensure that the largest audience permissible has access to the wealth of knowledge, & minimizing duplicative efforts, poor performance, and/or wasted resources
Technology Development Areas (TDAs):

- TDA 1.1: Improve Propellant Throughput
- TDA 1.2: Reduce Ignition Power Requirements
- TDA 1.3: Supporting Hardware
- TDA 1.4: Manufacturing Techniques & Cost
- TDA 2.1: Plume Models
- TDA 2.2: Catalytic Decomposition Chemistry
- TDA 2.3: Transient Thermal Analysis
- TDA 2.4: Propellant Performance Modeling
- TDA 3.1: System Material Compatibility Database
- TDA 3.2: Green Propulsion ‘MAPTIS’ Database
- TDA 3.3: Radiation Flux Impacts
- TDA 4.1: Propellant Supply Base
- TDA 4.2: Propellant Properties
- TDA 4.3: New Propellant Formulations
- TDA 4.4: Alternative Applications
• TDA-1: Thruster Hardware Development:
  – TDA-1.1: Improve Propellant Throughput (near-term)
  – TDA-1.2: Reduce Ignition Power Requirements (near-term)
  – TDA-1.3: Supporting Hardware (near to mid-term)
  – TDA-1.4: Manufacturing Techniques & Cost (mid-term)

• TDA-02: Modelling & Tools Development
  – TDA-2.1: Plume Models (near-term)
  – TDA-2.2: Catalytics & Decomposition Chemistry (near-term)
  – TDA-2.3: Transient Thermal Analysis (near-term)
  – TDA-2.4: Propellant performance modeling (mid to long-term)
• TDA-03: Materials Properties & Compatibility:
  – **TDA-3.1:** Identify and increase system material compatibility database, including compatible soft-goods (e.g. seals, bladders, etc.) (near to mid-term)
  – **TDA-3.2:** Generate a green propulsion database, such as inclusion of data into NASA’s Materials And Processes Technical Information System (MAPTIS) database (mid-term)
  – **TDA-3.3:** Identify impacts of high radiation flux onto system components (long-term)

• TDA-04: Propellant Development:
  – **TDA-4.1:** Propellant Supply Base (near-term)
  – **TDA-4.2:** Propellant Properties (near to mid-term)
  – **TDA-4.3:** New Propellant Formulas (mid to long-term)
  – **TDA-4.4:** Alternate Applications (long-term)
Strategy:

- Near-Term
- Mid-Term
- Long-Term
**NASA Green Prop Roadmap**

- **Strategy:**

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<th>Near-Term</th>
<th>Mid-Term</th>
<th>Long-Term</th>
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<td>Timeframe</td>
<td>Next 5 Years</td>
<td>5 - 10 Years</td>
<td>10 - 15 Years</td>
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<td>Thrust Class Target</td>
<td>Up to 22N</td>
<td>Up to 110N</td>
<td>Up to 440N &amp; Alt. Applications</td>
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<td>Technology Development Areas (TDAs)</td>
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• **Strategy:**
  
  – **Similar Development Effort for GP Technology:**
    
    • GPWG recommends similar development efforts for the widest variety of system solutions and propellants be pursued to meet NASA mission needs.
    
    • This will give mission planners the greatest range of technologies available & thus lead to the greatest opportunity for infusion.
    
  – **SmallSats:**
    
    • GPWG sees SmallSats (≤180 kg & including CubeSats) to have tremendous promise as flight platform to address TDAs, build heritage, support industrial growth, & enable some small science mission such as Lunar Flashlight.
    
    • Budget environments makes larger demonstration missions cost-prohibitive.
    
    • Flagship missions risk-averse to new (non-heritage) propulsion systems.
• Strategy:
  – Public–Private Partnership:
    • Private commercial entities are increasingly interested in green propulsion
      – Tending to focus more on developing a sellable product
      – Can leave gaps in the knowledge base where technical issues are avoided or ignored
      – Greatest value achieved through partnering & teaming
  
  • Public-private partnerships best served through intra & inter-agency coordination:
    – Broad Agency Announcements (BAA)
    – Announcements of Collaborative Opportunities (ACO)
    – Space Act Agreements (SAA)
    – Collaborative Agreement Notices (CAN)
    – Small Business Innovative Research (SBIR)
    – Small Business Technology Transfer (STTR)
    – NASA Space Technology Research Fellowships (NSTRF)

• Universities & national labs can be capable & cost effective partners to NASA
  – Help dive deep into specific technical issues
  – Develop the industry’s future subject matter experts
Missions, Projects, & Activities

- GPIM [TDM, GRC, GSFC, KSC, MSFC]
  - AF-M315E Demonstration Mission
  - Five 1N Thrusters
  - Complete & awaiting launch
  - Ball BCP-100; Aerojet GPPS

- Lunar Flashlight [JPL, MSFC]
  - Launch on SLS EM-1
  - Lunar Polar Orbiter
  - LMP-103S Propulsion System
    - Four 100mN thrusters
    - > 200 m/s ΔV
  - Thruster Qual in May 2018
  - Delivery to MSFC in August 2018
Missions, Projects, & Activities

• **Ground Development (ACO & TP):**
  - Busek Co. [GRC, MSFC]: **COMPLETED**
    - Maturation of Busek’s 5N Green Monopropellant Thruster
      - Testing of a 5N AF-M315E thruster
  - Orbital ATK [MSFC]:
    - Green Propellant Thruster Technology Maturation
      - Testing of a 440N LMP-103S Thruster
  - Aerojet Rocketdyne, Inc. [GRC, GSFC]:
    - “2nd generation” 1-N Green Propellant Infusion Mission (GPIM) GR-1 Thruster
      - Testing of a 1N AF-M315E Thruster
    - MPS-130
      - Green propulsion system for Small Satellites
• IRAD:
  – Propellants:
    • AF-M315E Surface Tension [MSFC, GRC]
    • LMP-103S ADN Desolvation & Resolvation Rate [MSFC, GSFC]
    • AF-M315E Radiation Exposure [MSFC]
  – Components & Systems:
    • 22N LMP-103S Thruster Qualification [ECAPS, GSFC]
    • Green Prop Thrusters, Components, & Systems [MSFC]
    • Dual Mode AF-M315 System Demo [MSFC]
    • Propellant Tank Fracture Mechanics [GSFC]
    • BGT-X5 (0.5N) Thruster Improvements [MSFC]
    • Electrodeposition of PGMs from Low Temp Molten Salts [MSFC]
  – Range Access:
    • Green Propellant Loading Demo [GSFC, WFF]
    • Small Satellite Green Propellant Loading System [MSFC]
  – Other Studies:
    • Green Propellants on ISS [NASA-JAXA]
QUESTIONS
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