National Aeronautics and Space Administration

SP2014_2969495 GREEN MONO PROPULSION ACTIVITIES AT MSFC

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marshall

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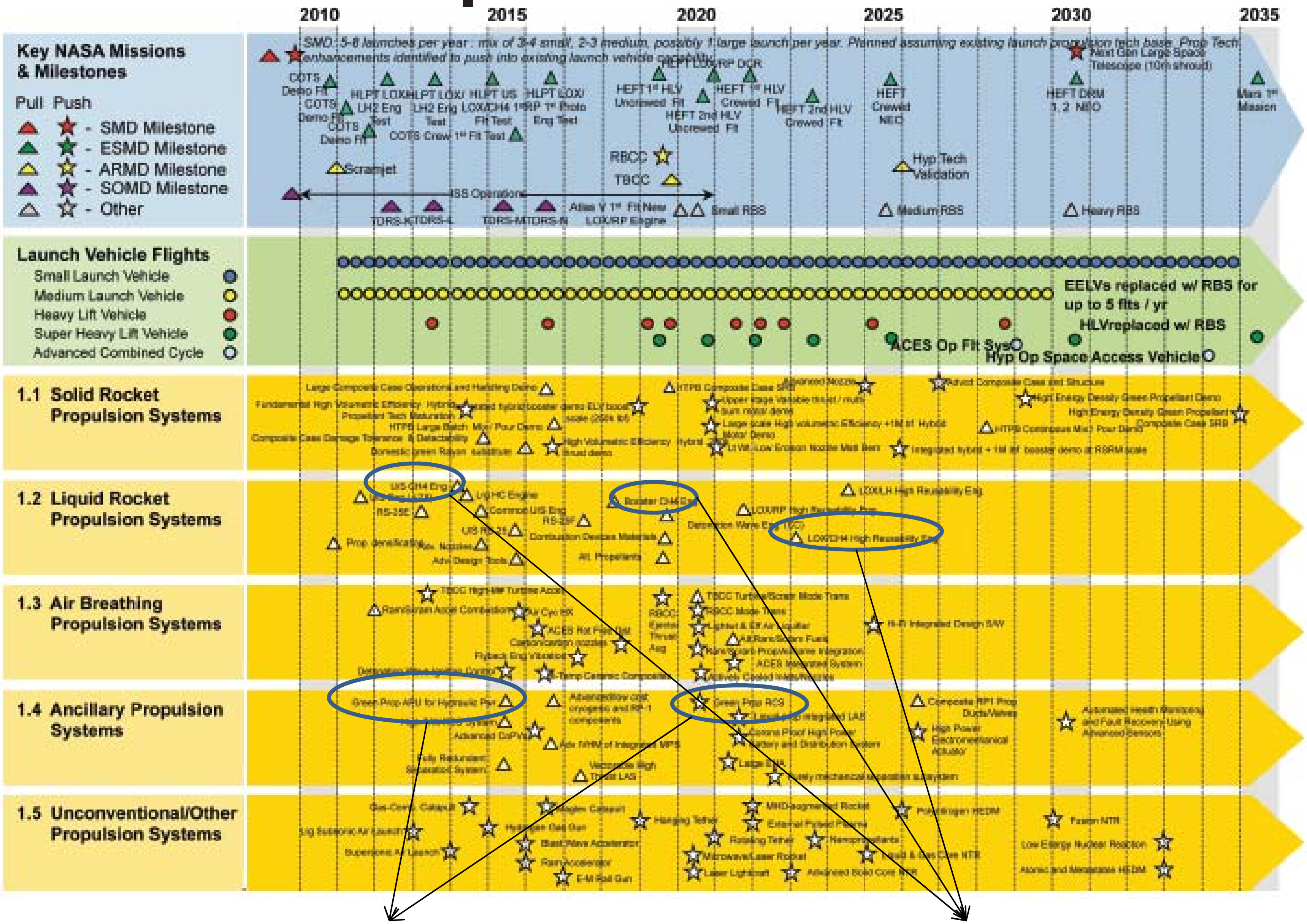
Outline

1. Discussion of TA-01 and TA-02 Roadmap
2. MSFC History
3. In-House Efforts
4. MSFC Roadmap
5. Future Applications
6. Conclusion

- Companion paper to SP2014_2925788
  - Green Propulsion Auxiliary Power Unit Demonstration at MSFC

TA-01 Roadmap

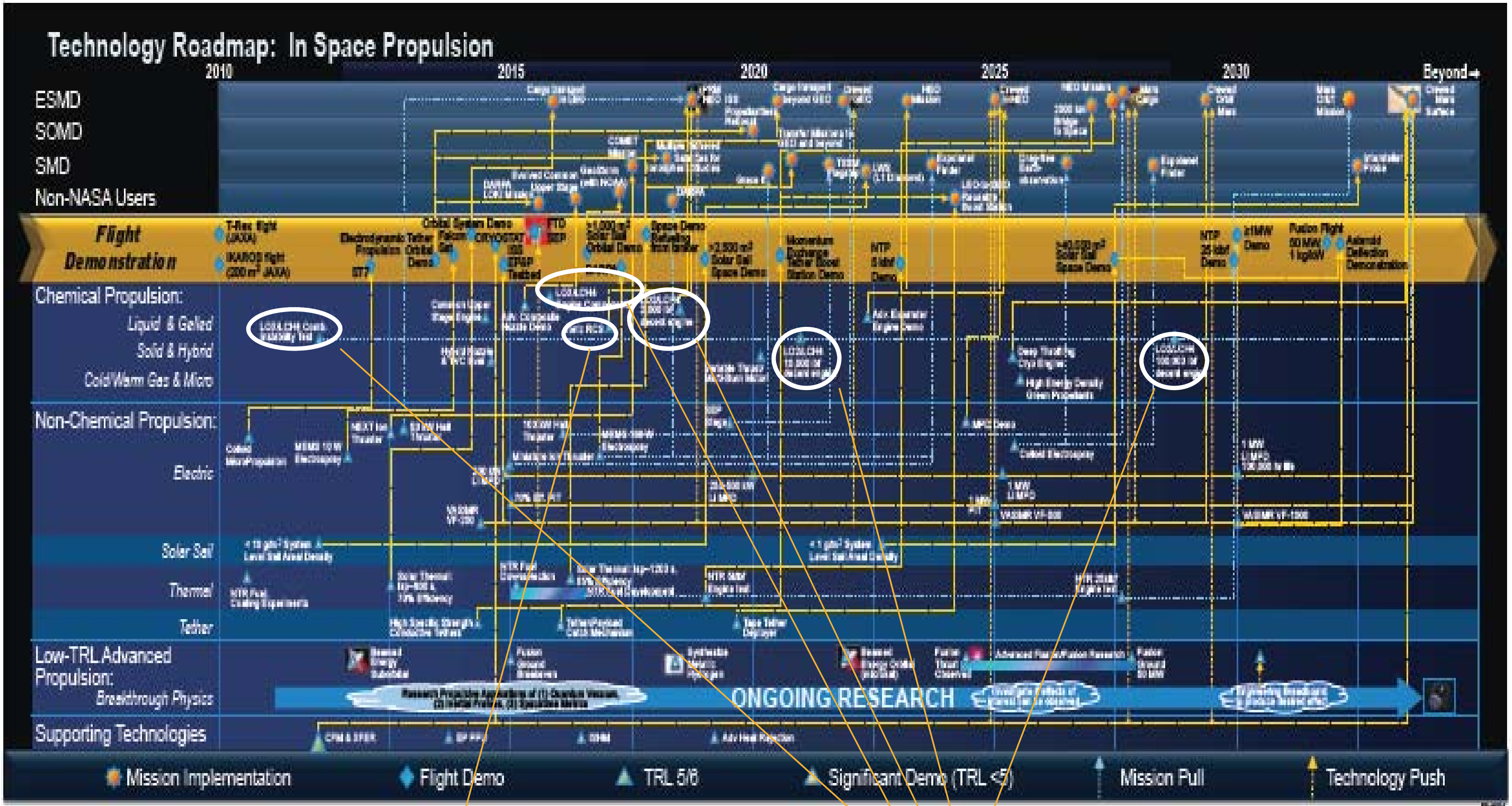


Green Prop APU, RCS

Focus on LO2/CH4 Green Propulsion

TA-02 Roadmap

Figure 2: In Space Propulsion Technology Area Strategic Roadmap (TASR)



Ionic Liquid RCS

Focus on LO2/CH4 Green Propulsion

MSFC In-Space Propulsion Experience

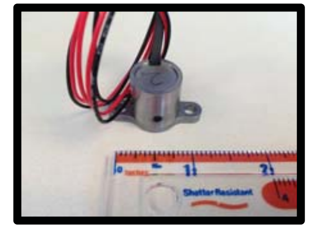
Spacecraft or System Name	Most Recent Activity*	Human Rated	Biprop (MMH/NTO)	Mono-prop (N2H4)	Oxygen/ Methane	Hydrogen Peroxide, JP-8	Dual Mode	Cold Gas	Non-Toxic	Cryogenic
Robotic Lunar Lander	Ongoing	No	• (MMH/MON-25)							
Orion Service Module Propellant Tanks	Ongoing	Yes	•							
Chandra	Flying	No	•	•			•			
Ares I Upper Stage ReCS	Ongoing	Yes		•						
Ares I First Stage RoCS	2010	Yes		•						
Ares I-X First Stage RoCS	2009	No	•							
PCAD LO2/LCH4 Engine	2008	No			•					
Demonstration of Automated Rendezvous Technology (DART)	2005	No		•				•		
NGLT LO2-Ethanol thruster	2005	No							•	•
In-House 25-lbf O2/CH4 Thruster	2005	No			•				•	•
Orbital Space Plane	2004	Yes	•	•						
X-37 Orbital Vehicle (2nd version)	2003	No	•							
X-38 Deorbit Propulsion	2002	No		•						
NGLT LO2-LH2 Thruster	2002	No							•	•
X-37 (Original version)	2001	No				•	•		•	
US Prop Module (for International Space Station (ISS))	2000	Yes	•							
X-33 Reaction Control System (gaseous O_2/CH_4)	2000	No			•				•	
Interim Control Module (ICM) for ISS	1998	Yes	•							
Aeroassist Flight Experiment	1994	No		•						
Combined Radiation and Release Effects Satellite	1991	No		•						
Orbital Maneuvering Vehicle (OMV)	1990	No	•	•						
Inertial Upper Stage RCS; Transfer Orbit Stage RCS	1990	No		•						
HEAO (3 spacecraft)	1981	No		•						
Skylab	1977	Yes						•		
Saturn S-IVB Auxiliary Propulsion System	1973	Yes	•							

MSFC has similar, long history with solid propellants:

- Orion LAM & ACM
- Ares-I motors (USM, BDM, FSTM, BSM)
- STAR motors
- Inertial Upper Stage
- Sounding Rockets

In-House Efforts

- **Cubesat Propulsion [MSFC IRAD]**
  - Low-cost Nitrous Oxide based system
  - Targets low-cost propulsion for small satellite market
  - Uses automotive racing nitrous pack as the backbone of a propulsion system



Pulsed Thruster Valve

- **DMLS Catalyst for Green Monopropellants [MSFC IRAD]**
  - Tri-gas (Tridyne ™) catalyst optimization – monolithic substrate for catalyst
  - Additive Manufacturing (Direct Metal Laser Sintering or DMLS) of the catalyst substrate
  - Targets small satellite market with cold-gas alternative

- **AF-M315E Microthruster [MSFC IRAD]**
  - Partnership with Plasma Processes, Inc. via SBIR Phase 3
  - Leverage existing PPI SBIR investments to further develop 1N thruster.
  - Future work will probably target lower thrust applications

22 N ECAPS LMP-103S Thruster

Piston Propellant Tank Body

- **22N ADN Thruster Testing [MSFC IRAD, 2012]**
  - Purchase and test 22N ADN thruster at MSFC
  - Further advance the TRL of ADN-based thrusters
  - Provide hands-on experience at MSFC with green monopropellants.
  - Testing Planned for 4Q, FY14 at MSFC

- **SRB for Green Propellant Infusion Mission (GPIM) [OCT TDM Award]**
  - Ball Aerospace is contractor
  - MSFC provides chair and propulsion membership on the GPIM SRB

MSFC Green Propulsion Roadmap

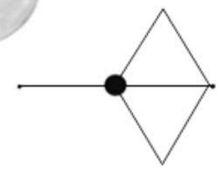
International

ISS

WE ARE HERE!

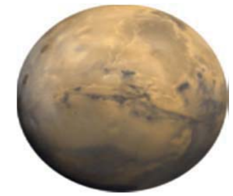
Lunar

Lagrange Point



Asteroid

Mars



Pre-2012

- *The Swedes have worked over the past decade with propellant blends, material compatibility and resultant space mission with PRISMA.*
- *The USAF investigates their propellant blend.*

2014

Current actvities:

- *TDM investment in GPIM.*
- *MSFC is testing 0.2 lbf (1 N) AF-M315E and 5 lbf (22N) LMP-103S thrusters*
- *MSFC utilizing discretionary funds to test green prop in power units.*

2016

Pilot test projects leading to scale up

- Use of green prop in F-16 EPU's.
- Materials compatibility and stability testing.
- Flight results of GPIM.
- Use of advanced manufacturing to reduce costs and schedule.

2018

Future implementation

- Scale up thruster technology to 100 lbf (440N class).
- Integrate thrusters into cubesat and LEO sat missions.
- Focus on duty cycles for HEOMD thrusters and sustained thrust for landers.
- Demonstrate in APU hardware.

2020-25

Lunar, Lagrange

2025

Asteroids

2030 - 40

Mars

Future implementation

- APU application → SLS
- Landers → Asteroid/Mars
- HEOMD thrusters → Replace bi-prop up to 200 lbf (880N) class
- SMD missions →

MSFC leadership in green propulsion will enable replacement of hydrazine monopropellant over a large range of applications.

HEOMD Applications

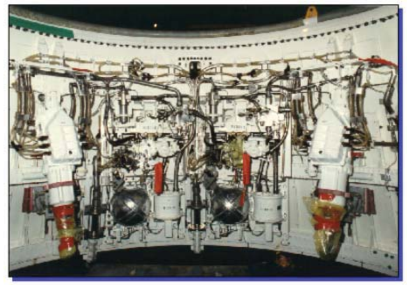
- Hydrazine fueled APU's for SLS booster nozzle gimballing

- Hydrazine roll control thrusters for launch vehicles

- Twelve 160 lbf thrusters in the Orion crew module.

- Sixteen 25 lbf and the eight 100 lbf thrusters in the Orion service module.

- Hydrazine thrusters on the HTV (four 490N, twenty-eight 110N), ATV (four 490N, twenty-eight 200N) and Commercial Cargo resupply missions.



ATV

SMD Applications

- Looking at the last 5 years of SMD missions, the majority of those have required hydrazine propulsion for either apogee and/or RCS functions.
- Examples include:
  - IBEX
  - Chandrayaan (one 440N biprop, eight 22N)
  - Kepler/Planck
  - SDO (one 440N biprop, 12 hydrazine)
  - Grail (single 22N)
  - Suomi NPP (eight hydrazine)
  - NuStar
  - Van Allen Probes (eight 0.2 lbf)
- Recurring missions that could aid the infusion to green prop include the GOES and Landsat spacecraft as well as adoption by spacecraft vendors (ie OSC Leo Star-3 bus).

Conclusions

- MSFC has embarked on use of green propellant replacement of hydrazine for a variety of applications.
- MSFC has a history of taking lower TRL assets and maturing them to eventual flight systems.
- MSFC is interested in partnership with the international community to address the infusion of green propellant into greater use.