Dual Mode Green Propulsion for Revolutionary Performance Gains with Minimal Recurring Investments. J. W. Dankanich[1] and P. C. Lozano[2], [1]NASA Marshall Space Flight Center, ZP30, MSFC, AL, 35812, john.dankanich@nasa.gov [2]Massachusetts Institute of Technology, 77 Massachusetts Avenue, Room 37-401, Cambridge, MA, 02139, plozano@mit.edu.

Introduction: The aerospace propulsion community has been making significant investments in both green propulsion combustion engine technology and micro electrospray propulsion (MEP). Combustion thruster technology will be matured to TRL 9 and demonstrated in flight on the NASA Green Propellant Infusion Mission (GPIM) [1]. The propellant selected for the green propellant infusion mission is The Air Force Research Laboratory (AFRL) developed AF-M315E, an ionic liquid based propellant. This propellant can also be used as propellant for scalable electrospray propulsion systems with high performance and efficiency. If scalability and lifetimes are achieved, a new architecture for spacecraft propulsion is possible, enabling significant mission performance increases with minimal recurring investments. By 2050, there is reasonable expectation that both green propulsion systems and electrospray propulsion system will be flight proven scalable options.

State of the Art: The state of the art (SOA) propulsion systems include a wide range of options such as monopropellant and bipropellant combustion engines, cold gas thrusters, Hall thrusters, gridded ion thrusters, pulsed plasma thrusters, arcjets, resistojets, etc. Chemical systems are typically hydrazine based, a toxic but reliable solution with established processes and procedures. Electric propulsion systems are typically xenon based or hydrazine based. The high performance electric propulsion systems are typically xenon, but rely on disparate propulsion systems for high thruster and therefore increased system complexity if high accelerations are required.

The propellant tank is the highest volume element of a propulsion system. Spacecraft have significant benefits of high thrust during orbit transfer to high value orbits and orbit insertion, while higher performance propulsion is desired during station keeping, formation flying and/or drag make-up. The existing options for bimodal systems have significant challenges. However, even those systems have received significant investments in recent years due to the exceptional need for this capability. The alternatives to the proposed concept include two independent propulsion systems or a lower performance integrated option.

Independent Systems: The state of the art option for two independent systems is commonly found on a number of large spacecraft. Larger spacecraft have sufficient volume to allow for independent propellant tanks. For these spacecraft, the high thrust propulsion capability is provided by hydrazine based propulsion. The hydrazine based systems, whether mono-prop or bi-prop, have limitations and costs associated with complex propellant system and hazardous propellant handling. The low thrust propulsion capability is often provided by a xenon based electric propulsion option (Hall thrusters or gridded-ion thrusters). The complexity of two independent propulsion systems increases total mission risk and increases cost. This is evidenced by the recent failure of the AEHF spacecraft where the chemical thruster failed and the xenon system was required to perform orbit insertion over months instead of hours and by the transition by Boeing to an all low-thrust option using only xenon. The all-electric option has a market due to the overall lower cost, but does not have full market capture due to the lost revenue and functionality without the possibility for high accelerations.

Low Performance Integrated Options: A single propellant tank option does exist for hydrazine as well. Unfortunately, the hydrazine options are limited for higher performance (i.e. higher specific impulse operation). Propulsion systems have been fielded that operate off a common hydrazine propellant reservoir for the combustion engine and to feed an electrothermal (e.g. arcjet) thruster. The limitation of this option is the significant performance ceiling for electrothermal thrusters versus electrostatic alternatives. As example, the MR-510 Aerojet arcjet has an average specific impulse < 600s at 45% efficiency. While this is 3x the combustion thruster I_{SP}, this is far less than the 2000 – 3000s performance and 70% efficiency goals of the MEP electrostatic option. However, the hydrazine option existence gives market proof of a dual mode propulsion expectation to supplant the SOA if the promise of AF-M315E comes to fruition.

Green Propulsion Alone: Significant investments have been made and continue for green propulsion solutions because of its merit over SOA. AF-M315E has 50% great density specific impulse, comparable combustion efficiency and offers a low-toxicity alternative with anticipated cost and safety advantages.

MEP Alone: It should be noted that a fully scalable electrospray propulsion option is enabling on its own merit. Any mission that would otherwise benefit from any SOA electric propulsion system, would likely be outperformed by a scaled electrospray system. The electrospray system produces ions without the ionization cost and therefore will always yield a higher system performance [2]. Only is rare cases of areal thrust densities would an alternative propulsion system have an advantage.

Propulsion End-Game: It is unlikely to achieve higher performance (system level efficiencies at specific impulses of interest) than electrospray systems. While there are significant technical challenges to achieve these high efficiencies, with long life reliability, and at power levels of interest, no fundamental limitations have been identified. When proven, scalable MEP will likely supplant all SOA electric propulsion alternatives. This would include xenon, krypton, bismuth, iodine, etc. Hall and gridded ion systems with a single device using a single propellant. Rather than investments of Hall thrusters at 200W, 600W, 1.5kW, 4.5kW, 12.5kW, 20kW, etc. as done today, and a different thruster if xenon or bismuth or iodine, and gridded ion thrusters and 4.5kW and 7kW, etc., a single thruster array with a single propellant outperforms all alternatives.

Also, that same propellant can be used for a high thrust combustion engine that can be packaged efficiently and leverage the same propellant tank without a priori limitations on the ratio of high thrust to low thrust application; therefore common to a wide range of missions. A dual mode green propulsion solution could save $100M in propulsion technology developments of disparate systems, each with a niche application.

Mission Performance Analyses: Preliminary mission analyses indicates potential for doubling science payloads for electric propulsion missions such as Dawn, increasing the number of targets for a Trojan asteroid tour, and potentially enabling missions such as Ceres Sample Return and Kuiper Belt Object rendezvous. Mission results and system level advantages are to be presented.

References:

[1] Masse, R., Spores, R. A., Kimbrel, S., Allen, M., Lorimor, E., Myers, P., and McLean, C., “GPIM AF-M315E Propulsion System,” AIAA 2015-3753, 51st JPC, Orlando, FL, July, 2015.

[2] Krejci, D., Mier Hicks, F., Fucetola, C., Lozano, P., Hsu Schouten, A., Martel, F., "Design and Characterization of a Scalable ion Electrospray Propulsion System," IEPC-2015-149, 34th International Electric Propulsion Conference, Hyogo-Kobe, Japan, July 4-10, 2015.