State-of-the-Art for Small Satellite Propulsion Systems

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Agenda

- State-of-the-Art Overview
- Obstacles to System Development
- SmallSat Propulsion System Performance
- Conclusion

State-of-the-Art Overview

- **SmallSats enable low-cost access to space.**
- **Their uses and capabilities are growing to the point where a propulsion system is required.**
- **Current state-of-the-art for SmallSat propulsion systems is rapidly evolving. However, their technology readiness level (TRL) is still relatively low.**
- **Desired SmallSat propulsion system SoA:**
  - Lowest cost possible
  - High performing
  - High reliability
  - Simplest design feasible
- **Current SmallSat propulsion system SoA:**
  - Low-cost, unreliable, and low performing, or
  - High-cost, reliable, and high performing

Obstacles to System Development

- **Reliability**
  - Low quality standards
  - Components not tested in harsh environments (radiation, thermal, vibration)
- **Maturity**
- **Safety**
  - Academia and hobbyists have low quality standards compared to government agencies and large private organizations.
  - Primary payloads and NASA/Johnson Space Center (NASA/JSC) (for ISS) will not allow additional hazards to be flown, e.g., high pressure systems (>100 psia) or hazardous propellants.
- **Cost**
  - Power Processing Unit (PPU) development is hindered by availability of space-flight qualified components (e.g., radiation hardened) at a low cost
  - Exceeding or well-documenting U.S. Range Safety compliance demonstrating that the system will not create undesirable risk.

SmallSat Propulsion Systems

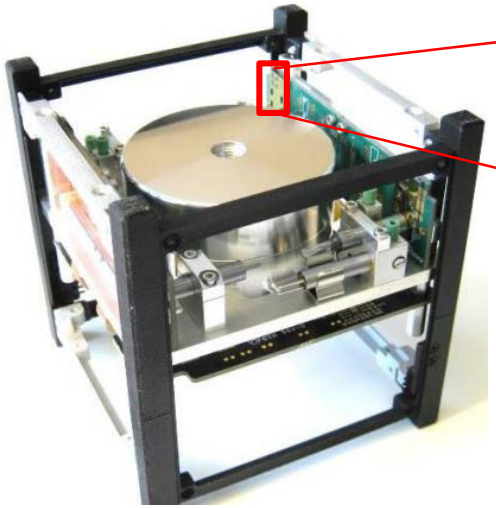
- **Chemical Propulsion Systems**
  - Cold gas propulsion system propellants use primarily saturated liquids:
    - Refrigerants
      - R134a – used in air conditioning systems
      - R236fa – used in fire extinguishers
    - Sulfur Dioxide
    - Isobutane
  - High energy propulsion system development has primarily focused on green propellants (AF-M315E, LMP-103S). However, there are some hydrazine systems in development.
- **Electric propulsion system**
  - Electrospray (ionic liquids)
  - RF Ion (iodine or noble gases (xenon, krypton, etc.))
  - Electrothermal (refrigerants, ammonia, sulfur dioxide, isobutene)
  - Field Emission Electric Propulsion (liquid metal)

Performance & Development Metrics

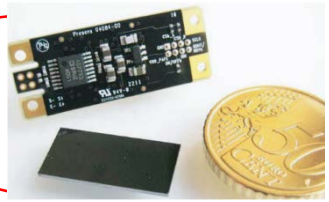
- **The following are the performance metrics used to evaluate SmallSat propulsion system capability:**
  - Change in Velocity, Δv (m/s)
  - Specific Impulse, I_{sp} (sec)
    - System's fuel efficiency
  - Thrust, F (N or lbf)
  - Power, P (W)
  - Total Impulse, I_t (N-sec)
    - Total momentum applied to a body
  - Volumetric Impulse, I_t / V ((N-sec)/U)
    - The amount of total impulse a system can impart to a body per unit volume
    - Volume in this case is based on a 1U CubeSat
    - An efficiency parameter (i.e., amount of performance per U)
- **Technology Readiness Level, TRL, is a fundamental development metric used to evaluate technology maturation.**

Examples of SmallSat Propulsion Systems

SmallSat Cold Gas Propulsion

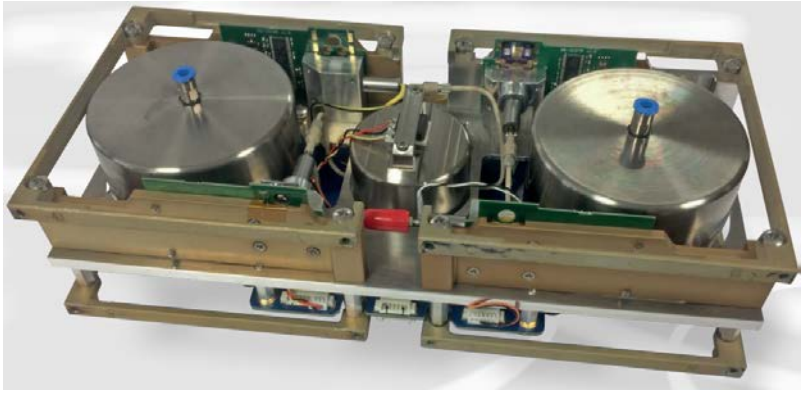


NanoProp for 3U S/C



NanoProp MEMS Thruster Chip

NanoProp Electronics Board



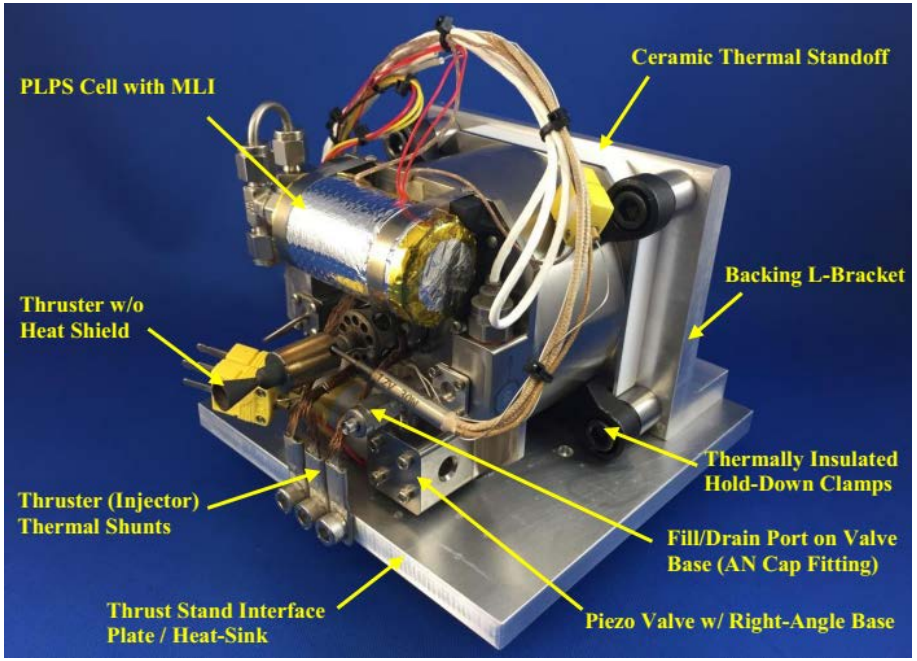
NanoProp for 6U S/C

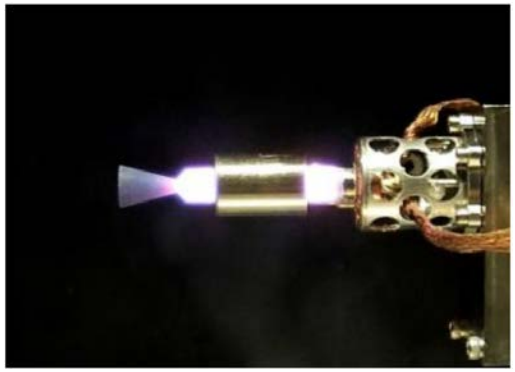
NanoProp 3U/6U

(NanoSpace AB - Sweden)

- System Type: Cold Gas
- Propellant: Butane
- Volume:
  - 3U: 1U (10 x 10 x 5 cm)
  - 6U: 2U (20 x 10 x 5 cm)
- Wet Mass:
  - 3U: 0.35 kg (Prop: 0.05 kg)
  - 6U: 0.90 kg (Prop: 0.13 kg)
- Performance:
  - Thrust: 0.01 to 1 mN (per thruster)
  - Specific Impulse: 110 sec
  - Vol. Imp.: 133.3 Ns/U
  - MEOP: 29 – 72.5 psi
- Power Req: < 2.5 W
- Input Voltage: 12 Vdc
- TRL: 6
- Digital Comm: CAN, I2C
- Salient Features:
  - MEMS thruster chips contain flow components
  - Closed loop control

SmallSat Green Propulsion



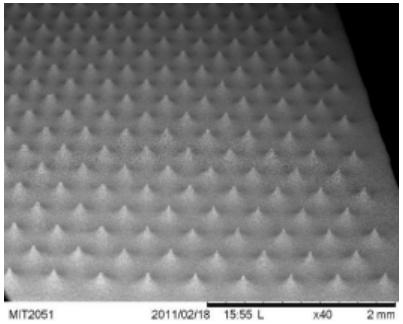


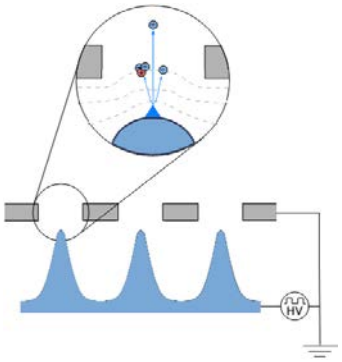
***AMAC**: Advanced Monoprop Application for CubeSats*

(Busek)

- System Type: Green Prop
- Volume: 10 x 10 x 10 cm
- Propellant: AF-M315E
- Wet Mass: 1.5 kg (Prop: 0.27 kg)
- Performance:
  - Thrust: 425 mN
  - Specific Impulse: 225 sec
  - Vol. Imp.: 565.0 Ns/U
- Power Req: 20 W
- Input Voltage: 12 Vdc
- Digital Comm: RS422
- TRL: 5
- Salient Features:
  - Developed 500 mN thruster & catalyst
  - Post-launch Pressurization System (PLPS)

SmallSat Electric Propulsion



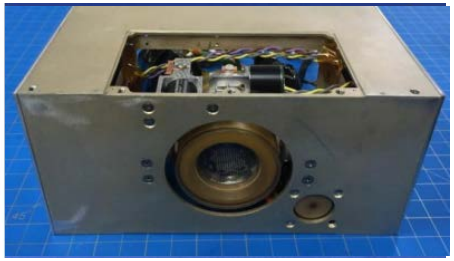


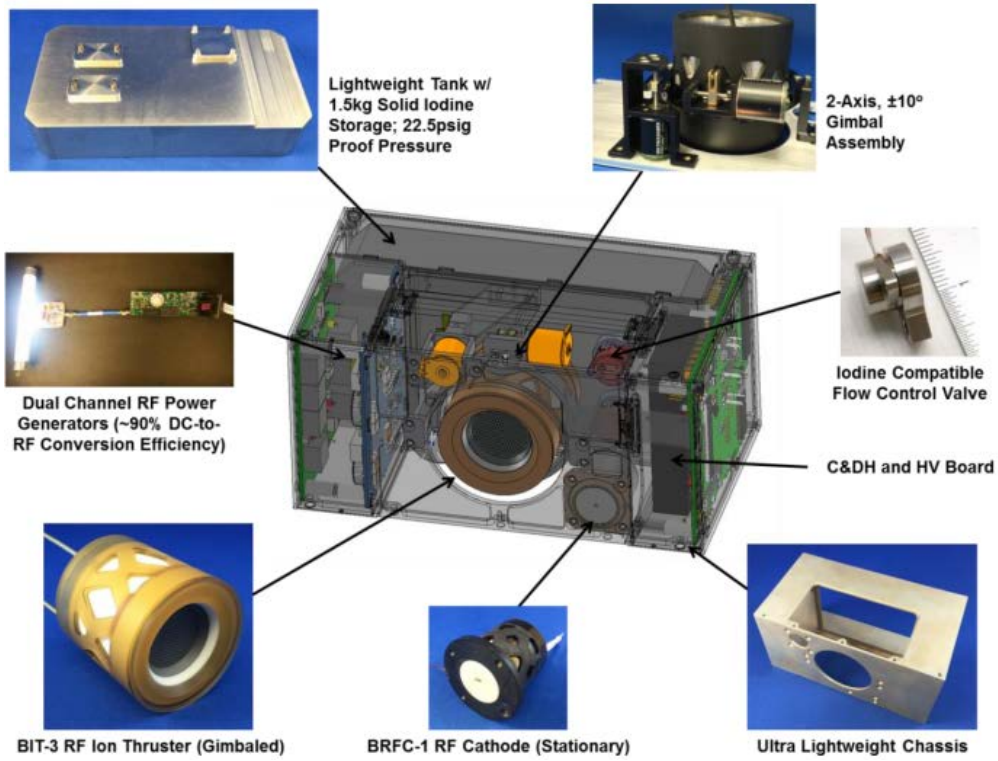
TILE-V1

(Accion Systems)

- System Type: Electrospray
- Volume: 10 x 10 x 12.5 cm
- Propellant: Ionic Liquid
- Wet Mass: 1.7 kg (Prop: 0.3 kg)
- Performance:
  - Thrust: 1.5 mN
  - Specific Impulse: 1500 sec
  - Vol. Imp.: 260.6 Ns/U
- Power Req:
  - Standby: 1.5 W
  - Nom. Thrust 25W
- Input Voltage: 12V
- Digital Comm: RS485, SPI
- TRL: 5
- Salient Features:
  - Low power usage
  - Useful for fine maneuvering (Min I-bit < 15 µN-s)

SmallSat Electric Propulsion





BIT-3

(Busek)

- System Type: RF Ion
- Volume: 1.6U (18 x 8.8 x 10.2 cm)
- Propellant: Iodine
- Wet Mass: 3 kg (Prop: 1.5 kg)
- Performance:
  - Thrust: 1.24 mN
  - Specific Impulse: 2640 sec
  - Vol. Imp.: 19,424 Ns/U
- Power Req: 80W
- Input Voltage: 12 Vdc
- TRL: 6
- Salient Features:
  - First system that will use iodine in flight
  - Better performance than benchmark Xenon

SmallSat Electric Propulsion

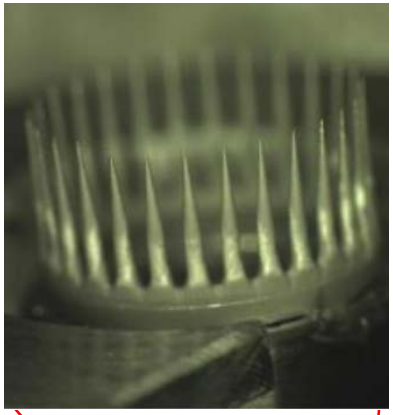
***PUC**: Propulsion Unit for CubeSats (CU Aerospace/VACCO/AFRL)*

- System Type: Electrothermal
- Propellant: R-134a, R-236fa, SO_2
- Wet Mass: 0.72 kg (Prop: 0.27 kg)
- Performance (R-236fa/Warm Gas):
  - Thrust: 5.4 mN
  - Specific Impulse: 72 sec
  - Vol. Imp.: 514.5 Ns/U
- Power Req: 15 W
- TRL: 6
- Salient Features:
  - Compact

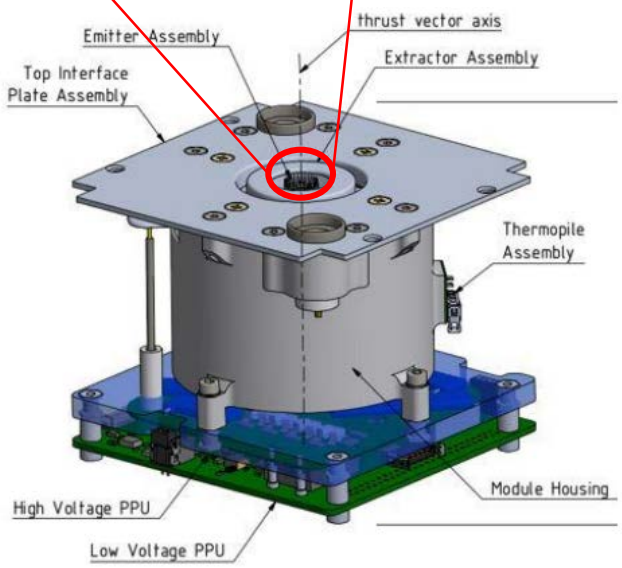
***CHIPS**: CubeSat High Impulse Propulsion System (CU Aerospace/VACCO/AFRL)*

- System Type: Electrothermal
- Propellant: R-134a, R-236fa, SO_2
- Wet Mass: 1.2 kg (Prop: 0.7 kg)
- Performance (R-236fa/Warm Gas):
  - Thrust: 30 mN
  - Specific Impulse: 82 sec
  - Vol. Imp.: 526.2 Ns/U
- Power Req: 30 W
- TRL: 5
- Salient Features:
  - Integrated battery pack
  - Cold Gas ACS thrusters

SmallSat Electric Propulsion



IFM Nano firing during test

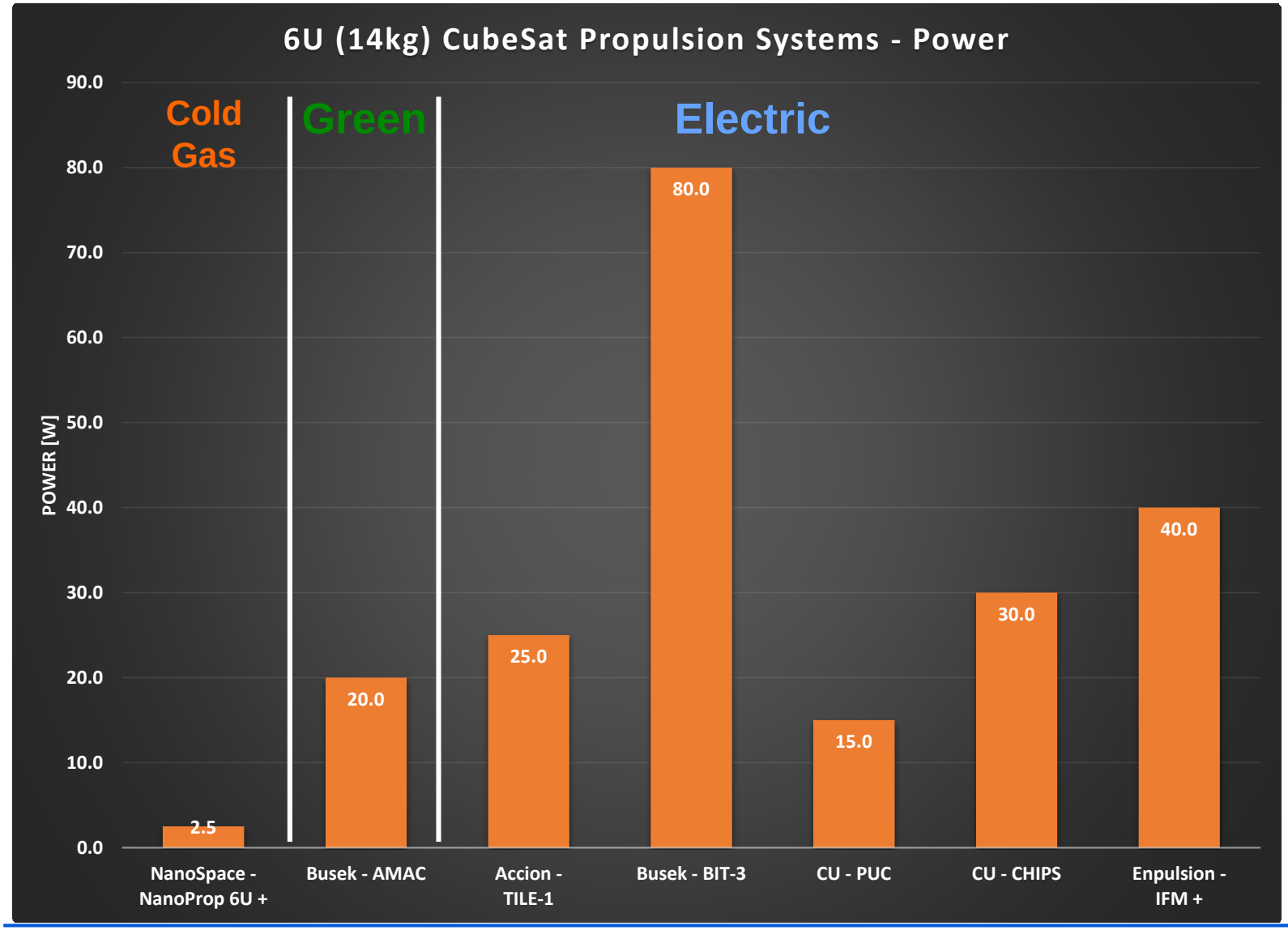


IFM-350 Nano Thruster

(Enpulsion GmbH - Austria)

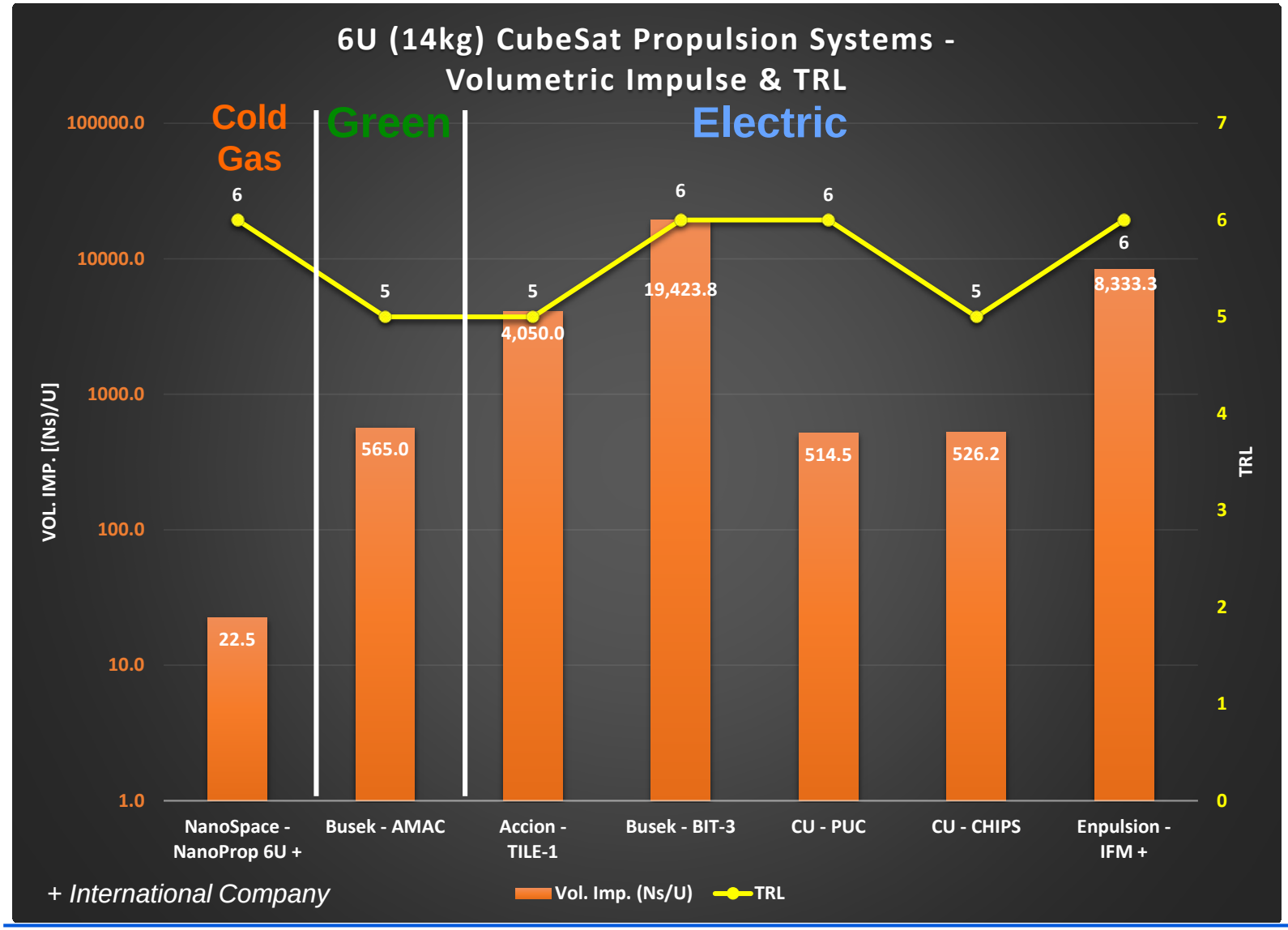
- System Type: Field Emission Electric Propulsion (FEEP)
- Volume: 1U (9.4 x 9.0 x 7.8 cm)
- Propellant: Liquid Indium
- Wet Mass: 0.87 kg (Prop: 0.25 kg)
- Performance (Nominal):
  - Thrust: 0.35 mN
  - Specific Impulse: 4000 sec
  - Vol. Imp.: 8333 Ns/U
- Power Req: 40 W
- Input Voltage: 12 Vdc
- TRL: 5
- Salient Features:
  - Solid propellant upon deployment
  - Throttleable
  - Modular

SmallSat Propulsion System Performance

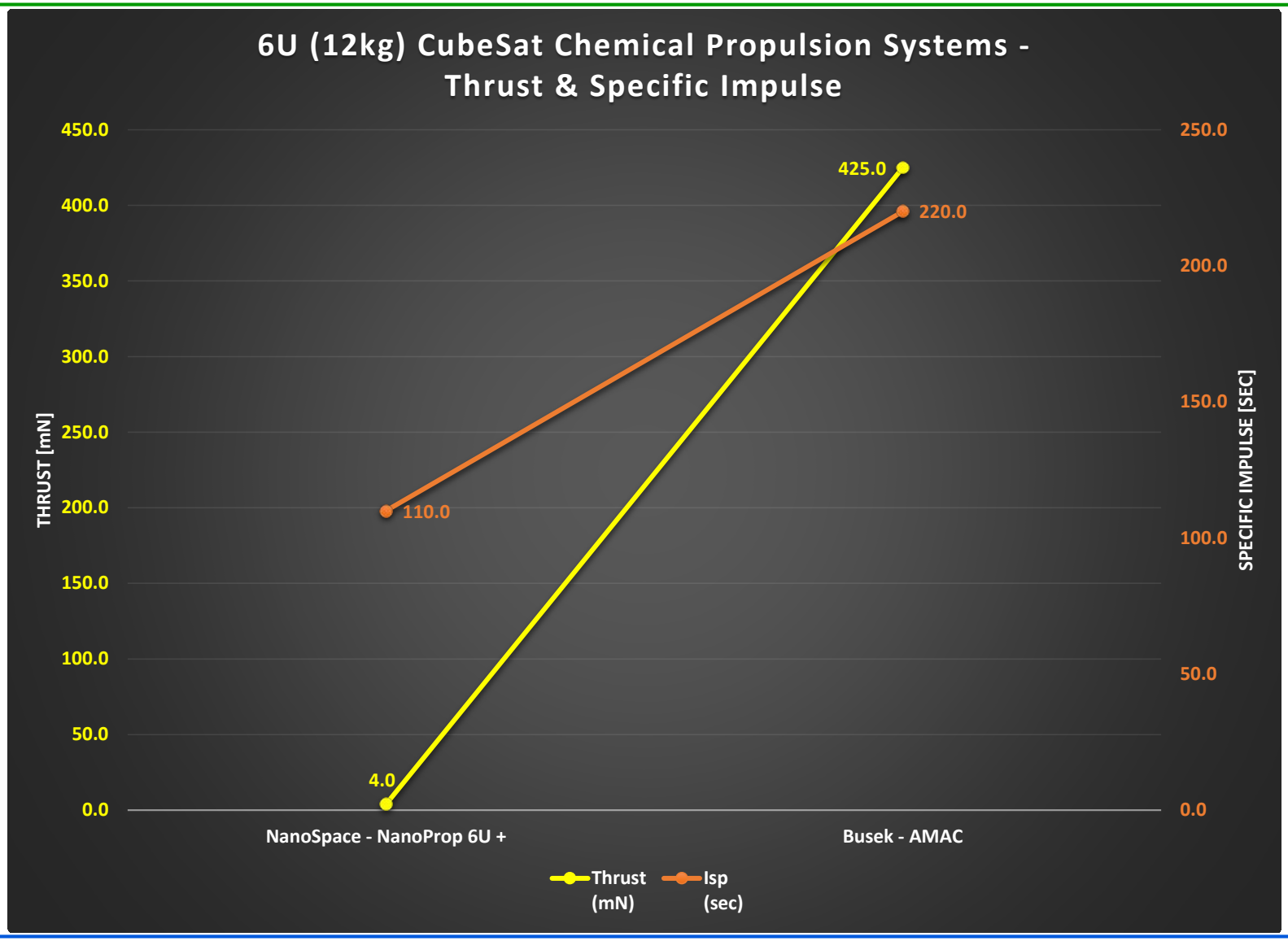


+ International Company

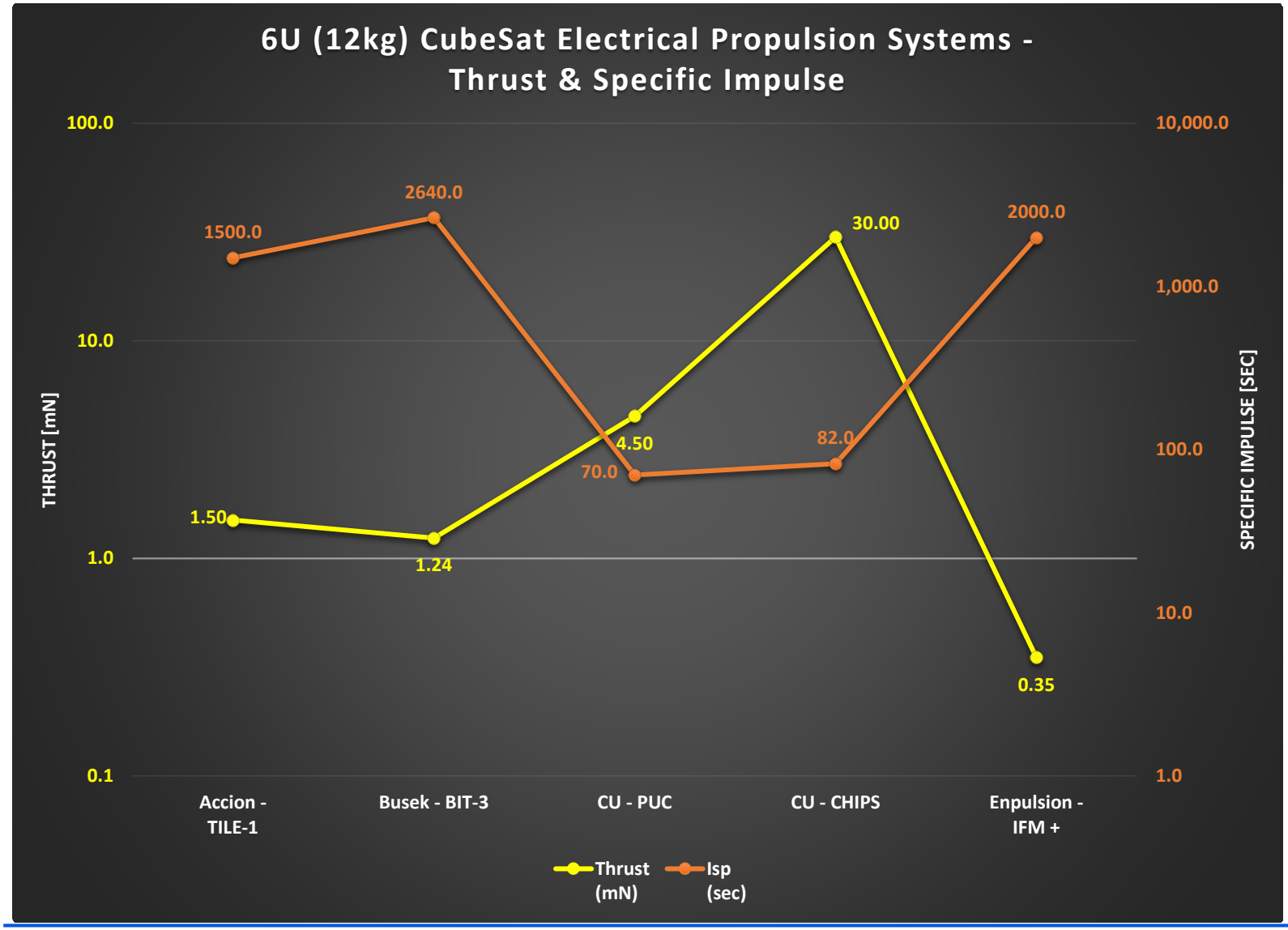
SmallSat Propulsion System Performance



SmallSat Propulsion System Performance



SmallSat Propulsion System Performance



Conclusion

- **SmallSats are a low cost access to space with an increasing need for propulsion systems.**
- **NASA, and other organizations, will be using SmallSats that require propulsion systems to**
  - Conduct high quality near and far reaching on-orbit research
  - Perform technology demonstrations
- **Increasing call for high reliability and high performing for SmallSat components**
- **Many SmallSat propulsion technologies are currently under development**
  - Systems at various levels of maturity
  - Wide variety of systems for many mission applications