TPS Technology Status on enabling New Frontiers Sample Return Missions from Moon, Asteroids and Comets, and Probe missions to Saturn and Uranus

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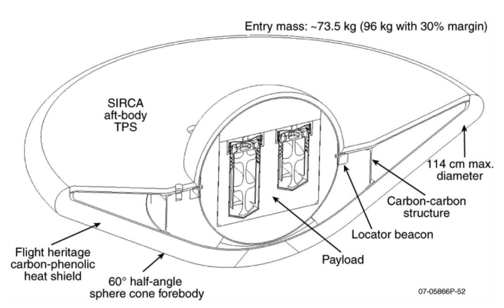
TPS Needs for New Frontiers and Uranus Orbiter Probe

Over half of the New Frontiers 5 Draft AO missions involve TPS for sample return or planetary probes. These include Comet Surface Sample Return, Lunar South Pole-Aitken Basin Sample Return, and Saturn Probe. Ceres Sample Return mission also requires TPS.

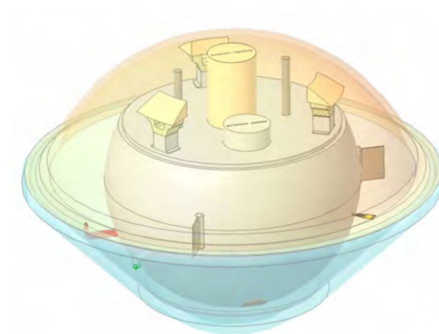
Additionally, the UOP Mission will require TPS for the probe, and if aerocapture is pursued, for the aerocapture element of the Orbiter.

Heritage single-piece PICA and Full Density Carbon Phenolic are no longer manufacturable. **We propose that NASA invest now in two materials that span all New Frontiers and future flagship UOP concepts.**

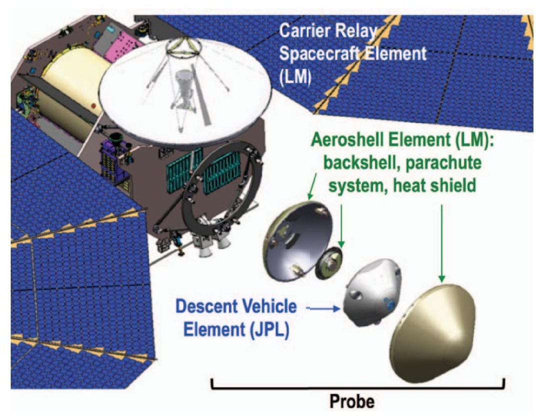
OSIRIS-REx Capsule After Landing [Image NASA]



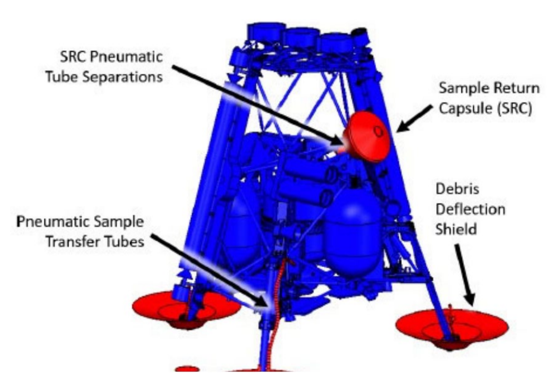
Concept for Comet Surface Sample Return [NASA CSSR Mission Concept Study]



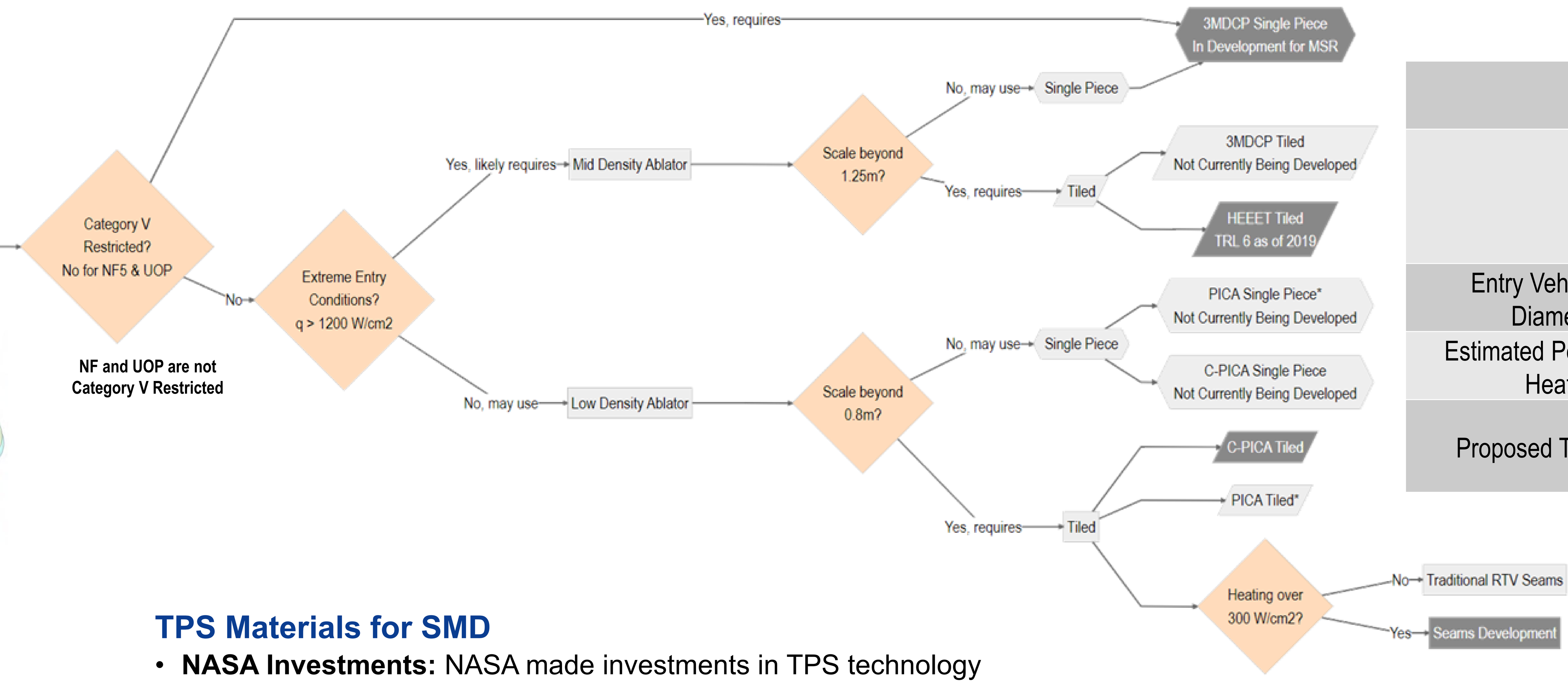
Concept for Uranus Probe [JHUAPL, NASA Mission Concept Study]



Saturn Probe Concept [JPL, NASA Saturn Probe Mission Concept Study]



Ceres Sample Return Concept Showing Capsule location [NASA Ceres Sample Return Mission Concept Study]



	Sample Return Missions	Saturn	Uranus	
	Comet Surface Sample, Lunar Sample, Ceres Sample	Probe	Orbiter	Aerocapture Element
Entry Vehicle Diameter	0.8 - 1.3m	> 1m	~1.25 m	> 4m
Estimated Peak Heating	> 1200 W/cm²	> 2500 W/cm²	< 1800 W/cm²	< 1200 W/cm²
Proposed TPS	C-PICA, HEEET	HEEET	HEEET	C-PICA

TPS Selection Drivers

Thermal Protection Systems (TPS) are essential for spacecraft entering planetary atmospheres at high speeds. TPS is a critical single point of failure, typically dissipating over 95% of the kinetic energy during entry.

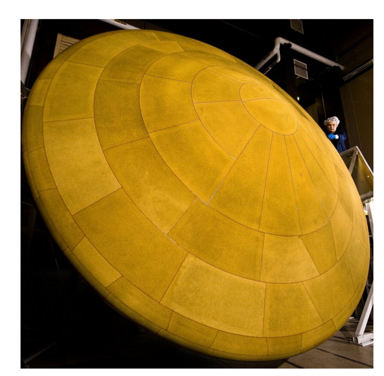
Technical Factors Driving TPS Selection:

- **Peak Entry Environments:** Maximum heating, temperatures, and pressures encountered during atmospheric entry, typically determine the type of TPS to be used. (Ex. low density vs mid density, silicone vs phenolic resins…)
- **Total Integrated Heat Load:** Typically determines how thick the TPS needs to be and can run into manufacturing constraints.
- **Vehicle Scale:** Size and shape of the spacecraft affecting material system design (single piece or tiled).

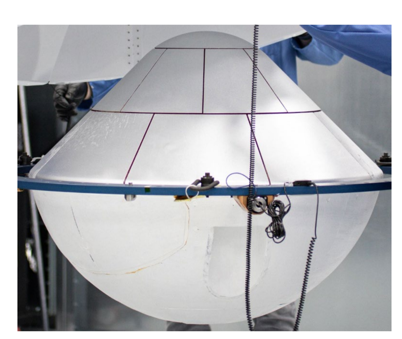
The TPS selection principle emphasizes **choosing the lowest-mass solution** for the anticipated entry environment, against any other unique mission requirements (e.g. robustness for Planetary Protection).

Sustainability Challenges for TPS

- **TPS Performance and Heritage:** Often tied to specific manufacturing procedures and suppliers.
- **Unique TPS Materials:** Many TPS materials used for NASA missions are unique to NASA and have no other applications.
- **Complex Supply Chains:** Often involve non-aerospace companies for initial components and processing.
- **Cyclical Business:** Supplying TPS for NASA is often an unpredictable part of vendor business, making it challenging for NASA to maintain relationships during lean times.
- **Early Investments:** TPS will likely require early investments to meet mission schedules due to its long lead times and fragile supply chains. NASA support (SMD and STMD) will be key to ensure capable TPS for future NF missions.
- **Capabilities Not "Shelve-able":** Require support from NASA to maintain available capability, including industrial processes (to keep viable and operational for NASA use) and individual expertise (to ensure NASA TPS-specific skills are available to NASA and industry).



MSL PICA Heatshield [Image NASA]



Winnebago W-1 with C-PICA [VARDA]

Genesis Capsule with ACC4/Fiberform [NASA]

HEEET Full Scale MDU [NASA]

3MDCP Subscale Demonstration [NASA]

TPS Materials for SMD

- **NASA Investments:** NASA made investments in TPS technology development over the past decade, to support Decadal Survey mission recommendations. The Fully Dense Carbon Phenolic used in Pioneer and Galileo missions is heavy and no longer available.
- **Candidate Heatshield Materials in 2024:**
  - **Low-Density NASA Ablators:**
    - **PICA-D:** PICA is a low-density, ablative material developed by NASA, flown on Stardust, MSL, M2020, OSIRIS-REx. The latest version, PICA-D, utilizes different raw material, and is baselined for Dragonfly and MSR SRL.
      - FiberForm preform used in PICA-D production is no longer a commercial product and is now a NASA- unique material
      - Single-piece PICA-D (akin to Stardust and OSIRIS-REx) is no longer available (techniques and tooling) due to vendor prioritization.
    - **Conformal PICA (C-PICA):** A felt-based variation of PICA developed by NASA, with lower thermal conductivity (lower mass) and improved structural properties compared to PICA-D.
      - Recently flown by VARDA on the Winnebago-1 return capsule, at LEO conditions.
      - Arc jet testing has demonstrated C-PICA capability up to OSIRIS-like entry conditions.
      - Utilizes commercial felting processes and equipment, NOT NASA-unique
      - Current manufacturing limited to a tiled solution to support an OSIRIS-scale or larger entry capsule.
    - **ACC6/Fiberform:** A structural carbon-carbon layer atop a low-density carbon insulator. Similar to the Genesis material, and the TPS for DAVINCI. Density is roughly between Low-density and High-density materials, but with lower demonstrated performance than mid-Density materials.
      - Limited performance in high heating and high shear. DAVINCI will test to extended conditions.
      - Manufacturing challenges for scale-up to larger aeroshells.
      - Likely not as mass efficient as PICA-D or C-PICA.
  - **Mid-Density NASA Ablators:**
    - **HEEET:** A 3D woven, dual layer ablator tiled system, developed by NASA for extreme entry environments. Matured to TRL 6 in 2019 and incentivized during NF4.
      - Has very long lead time due to weaving.
    - **3MDCP:** Single piece mid-density ablative TPS derived from HEEET. Baselined for the Mars Sample Return Earth Entry System, offering seamless application for missions with stringent requirements.
      - Single piece limited to ~1.25m diameter vehicle.
      - Also long lead time due to weaving.

Investing in C-PICA and HEEET for Future Missions

Based on the NF5 and UOP mission needs and current state of TPS, we recommend NASA invest in 2 TPS systems:

- C-PICA as a replacement for missions that would have formerly selected Stardust/OSIRIS-REx PICA.
- HEEET for missions with extreme entry conditions.

Reasons for SMD to Invest in C-PICA:

- **Mass Efficiency:** Lower thermal conductivity compared to PICA-D. Expect lower mass than either ACC6/FF or PICA-D solutions.
- **Scalability:** Larger tiled arrangements enable larger vehicles than ACC6/FF.
- **Thermostructural Performance:** Higher strain to failure than PICA-D addresses recent SMD mission issues.
- **Sustainability:** Mitigation for PICA-D / ACC6 Precursors Sustainability.
- **Testing:** Easier testing on the ground than ACC6/FF and PICA-D.

Reasons for SMD to Invest in HEEET:

- **Maturity:** Proven seam design and TRL 6 over a broad range of entry conditions.
- **Size Scaling:** Scalable to larger systems compared to 3MDCP.

Key Efforts for C-PICA and HEEET Investments

- **C-PICA:** Main effort should be to finalize a seam design, including aerothermal testing, structural analysis, and integration logistics. Threshold seam design for 1200 W/cm², target 1500 W/cm².
- **HEEET:** Main effort should be to pre-weave the HEEET dual-layer material for meeting future mission readiness.

Recommendations for NASA TPS Strategic Investment for SMD

- We recommend that NASA prioritize the following efforts separate from ongoing SMD missions (Dragonfly, Davinci, MSR):
  - **C-PICA Tile Development as Low-Density Ablator:** Focus on high heat capable seam design to enable widely-scalable heatshields for NF5, Aerocapture, and beyond.
  - **HEEET Sustainment as Mid-Density Ablator:** Focus effort on pre-weaving HEEET material, to shorten schedule for the longest-lead item and ensure key precursor availability. HEEET is key to missions with extreme entry conditions.

- **Long-lead issues will impact HEEET (loom set up and weaving) and C-PICA (seam development) TPS availability.**
- **50% of NF mission themes need TPS and can expect tight schedule between selection and PDR.**
- **We recommend immediate NASA investment in HEEET and C-PICA seam development for reliable and performant TPS solutions.**