# Sustaining Mature Entry System Technologies Crucial for Future In-Situ Venus Missions

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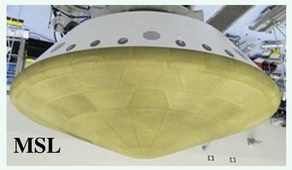
**INTRODUCTION:** Severe entry environments at Venus are a key challenge for all missions employing probes, landers, areal platforms, aerocapture and atmospheric skimming

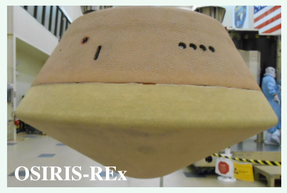
- **Three specific mature technologies, PICA**, **HEEET**, and **ADEPT**, **are enablers for Venus in-situ missions but are at risk of atrophy or loss if not maintained**
- All three technologies were NASA-developed in partnership with US industry and rely on both organizations for intellectual property
- These technologies are needed only for NASA missions and lack applicability elsewhere
- NASA has experienced the loss of prior TPS technologies due to lack of use, including Apollo's Avcoat (re-created at enormous expense for Orion) and Pioneer-Venus' heritage carbon phenolic
- Given the low flight cadence for planetary entry missions overall and the lack of non-NASA uses for these technologies, there is a real concern for the sustainment of key entry technologies

## P I C A
### Phenolic Impregnated Carbon Ablator

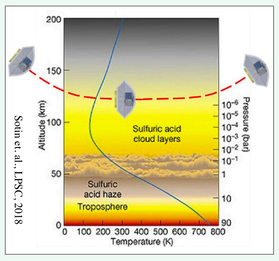



Low-density TPS, optimal for moderate heat-fluxes, with significant flight heritage (MSL @ ~100 W/cm$^2$, & Stardust @ ~ 1000 W/cm2).

Tiled PICA heatshields over 1.4 meter dia., for heat flux ~ 100 – 300 W/cm$^2$




Single piece heatshields up to 1.4 meter dia., for ~ 100 – 1800 W/cm$^2$

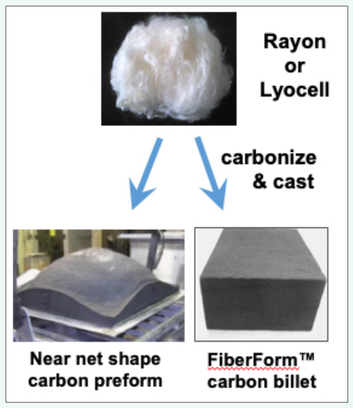



Multiple Venus mission architectures require PICA as currently planned:

- Backshell for large aeroshells
- Skimmer heatshield, nominal entry velocity (Cupid's Arrow)
- Drag modulated aerocapture primary spacecraft heatshield

**PICA-D (Domestic):**

Carbon FiberForm™, made by FMI, is derived from rayon fiber until recently when NASA & FMI replaced it with Lyocell due to better sustainability




In 2019 FMI announced that **FiberForm™ production would cease** due to market forces

NASA has worked with FMI to **maintain FiberForm™ & PICA-D production capability for NASA: Dragonfly, Mars Sample Return SRL and EEV through 2024**

**Risk Assessment:**

With no PICA production planned after 2024, a gap in PICA production would lead to diminished capability & technical skills even if equipment & documentation remain in place

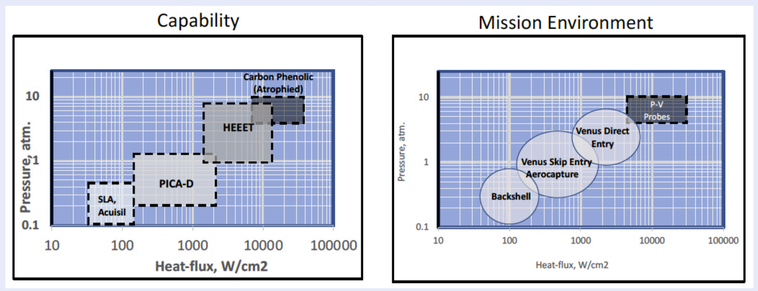
Reviving manufacturing capability takes years & is costlier

**Proposed Sustainability Risk Mitigation**

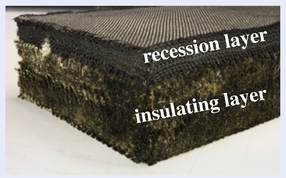
- If no new missions require PICA production by 2025, NASA should perform annual assessments of future PICA demand & starting material availability, equipment status
- Fund small production runs every few to several years to maintain capability for future Venus missions

## H E E E T
### Heatshield for Extreme Entry Environment Technology

HEEET is a mid-density 3D woven TPS developed by NASA to TRL 6 to enable Venus & outer planet direct entry missions



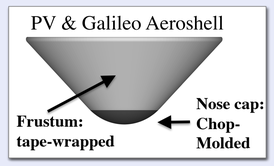

HEEET replaces forward heatshield capability once provided by Heritage Carbon Phenolics (HCP) for Pioneer-Venus (PV); HEEET's dual layer design is ~ 50% more mass efficient than HCP





HEEET is the only feasible TPS for in-situ Venus direct entry missions that use rigid aeroshell to deliver landers, probes, aerial platforms, & aerocapture to deliver orbiters

Chop-molded HCP was critical to PV but has not been produced or used in flight since the 1980s; NASA deemed restart of HCP ineffective, not sustainable

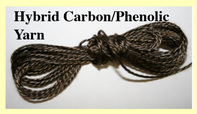



**Risk Assessment**

Current missions through 2029, do not require dual-layered, tiled HEEET & there is no foreseeable infusion pathway before ~2030


HEEET development established a unique 3D loom (BRM) & this capability is at risk if unused

The insulating layer of HEEET requires a special process to blend carbon & phenolic fibers




**In the absence of need, crucial HEEET capabilities including fabrication & integration plus technical skills & design expertise will be lost over time**

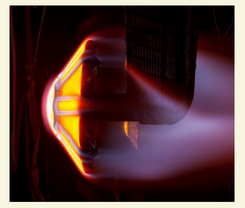
**Proposed Sustainability Risk Mitigation**

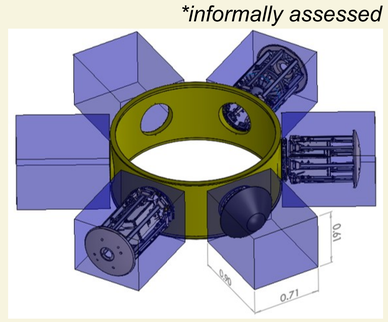
- Perform annual assessment to ensure loom, hybrid yarn & manufacturing capabilities are available when needed
- Periodically (few to several years): manufacture small yarn batches, manufacture narrow HEEET dual layer material, conduct focused testing, make a small integrated tile/seam unit

## A D E P T
### Adaptable Deployable Entry and Placement Technology

ADEPT is a deployable heatshield well suited for the demanding thermal environments of Venus atmosphere entry at TRL 4/5*

**informally assessed*

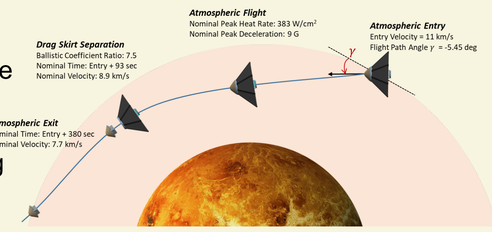




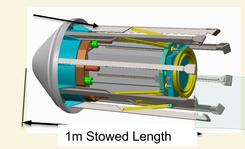

ADEPT's heatshield can be stowed at launch enabling SmallSat class missions to Venus with minimal packaging volume

ADEPT enables Drag Modulated Aerocapture (DMA)

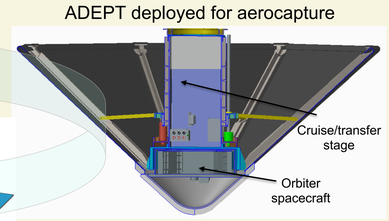
SmallSat missions can be delivered using DMA with significant mass advantages

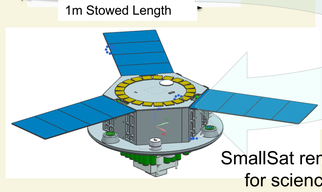



Stowed in ESPA volume for launch




ADEPT deployed for aerocapture

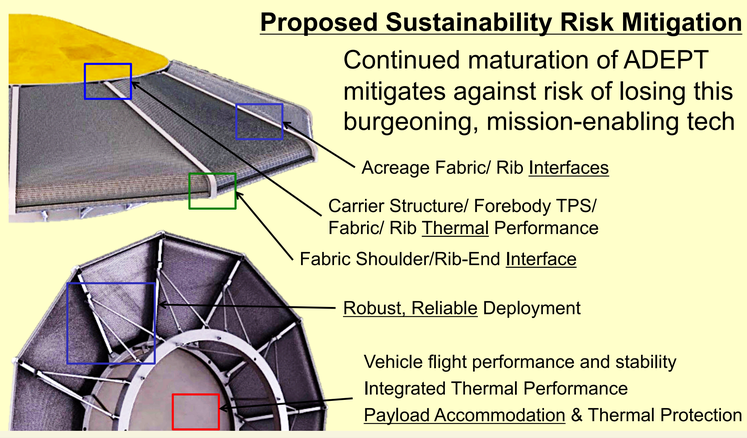


SmallSat remains in orbit for science mission

**Proposed Sustainability Risk Mitigation**

Continued maturation of ADEPT mitigates against risk of losing this burgeoning, mission-enabling tech




**SUMMARY:** The white paper summarized above describes atrophy that has plagued ablative TPS, assess scenarios for enabling technologies HEEET, PICA, and ADEPT, and makes recommendations to sustain these; a second white paper describes the maturity and readiness of available TPS materials

- In-situ Venus missions that deliver landers, probes, areal platforms or those that use atmospheric skimmers or aerocapture all need either rigid or deployable aeroshells with capable thermal protection systems
- PICA & HEEET are mature TPS for in-situ Venus mission architectures where no other systems are currently available or capable
- ADEPT offers advantages of small packaging & low-mass entry for in-situ missions at Venus
- NASA's investments in PICA, HEEET, and ADEPT for planetary science missions require maintenance since they are not used for other commercial purposes
- Actively monitoring and managing NASA's TPS investments saves significant cost and time compared with recreating technology once it is lost