The Thermal Protection System (TPS) protects a spacecraft from the severe heating encountered during hypersonic flight through a planetary atmosphere. In general, there are two classes of TPS - reusable and ablative. Typically, reusable TPS applications are limited to relatively mild entry environments like that of Space Shuttle. No change in the mass or properties of the TPS material results from entry with a significant amount of energy being re-radiated from the heated surface and the remainder conducted into the TPS material. Typically, a surface coating with high emissivity (to maximize the amount of energy re-radiated) and with low surface catalycity (to minimize convective heating by suppressing surface recombination of dissociated boundary layer species) is employed. The primary insulation has low thermal conductivity to minimize the mass of material required to insulate the primary structure. Ablative TPS materials, in contrast, accommodate high heating rates and heat loads through phase change and mass loss. All NASA planetary entry probes to date have used ablative TPS. Most ablative TPS materials are reinforced composites employing organic resins as binders. When heated, the resin pyrolyzes producing gaseous products that are heated as they percolate toward the surface thus transferring some energy from the solid to the gas. Additionally, the injection of the pyrolysis gases into the boundary layer alters the boundary layer properties resulting in reduced convective heating. However, the gases may undergo chemical reactions with the boundary layer gases that could return heat to the surface. Furthermore, chemical reactions between the surface material and boundary layer species can result in consumption of the surface material leading to surface recession. Those reactions can be endothermic (vaporization, sublimation) or exothermic (oxidation) and will have an important impact on net energy to the surface. Clearly, in comparison to reusable TPS materials, the interaction of ablative TPS materials with the surrounding gas environment is much more complex as there are many more mechanisms to accommodate the entry heating. NASA has successfully tackled the complexity of thermal protection systems for numerous missions to inner and outer planets in our solar system in the past; the knowledge gained has been invaluable but incomplete. Future missions will be more demanding. Better performing ablative TPS than currently available is needed to satisfy requirements of the most severe missions, e.g., Near Earth Object Earth Return with velocities exceeding 11.5 km/s and Heavy Mass Mars Landing with 8 km/s entry. In addition, new low ballistic coefficient deployable systems may require flexible ablative TPS materials that can protect systems experiencing heat fluxes ranging from 30 W/cm$^2$ to 300 W/cm$^2$, depending on their missions. Beyond the improvement needed in ablative TPS materials, more demanding future missions such as large payload missions to Mars will require novel entry system designs that consider different vehicle shapes, deployable or inflatable configurations and integrated approaches of TPS materials with the entry system sub-structure.
The technologies described below support the goal of developing higher performance ablative TPS materials for higher performance future Exploration missions. Developments are sought for ablative TPS materials and heat shield systems that exhibit maximum robustness, reliability and survivability while maintaining minimum mass requirements, and capable of enduring severe combined convective and radiative heating. In addition, in order to adequately test and design with these materials, advancements in instrumentation, inspection, and modeling of ablative TPS materials is also sought.

Areas of interest include improvements in the reinforcement materials as follows:

- Advancements in carbon felts including thickness (>1.0-in), density (>0.12 g/cm³), uniformity to use as reinforcement for high strain-to-failure ablative TPS materials.
- Advancements in thin (~0.1-in) three dimensional woven carbon materials to act as stress bearing structure for deployable aeroshells.
- Advancements in thick (>1.0-in) three dimensional woven carbon materials to use as reinforcement for high heat flux mid-to-high density ablative TPS materials.

TPS Materials advancements sought in felts or woven materials impregnated with polymers to improve ablation performance. Areas of interest include:

- One class of materials, for planetary aerocapture and entry for a rigid mid L/D (lift to drag ratio) shaped vehicle, will need to survive a dual heating exposure, with the first at heat fluxes of 400-500 W/cm² (primarily convective) and integrated heat loads of up to 55 kJ/cm², and the second at heat fluxes of 100-200 W/cm² and integrated heat loads of up to 25 kJ/cm². These materials or material systems must improve on the current state-of-the-art recession rates of 0.25 mm/s at heating rates of 200 W/cm² and pressures of 0.3 atm and improve on the state-of-the-art areal mass of 1.0 g/cm² required to maintain a bondline temperature below 250 ºC.
- The second class of materials, for planetary aerocapture and entry for a deployable aerodynamic decelerator, will need to survive a single or dual heating exposure, with the first (or single pulse) at heat fluxes of 50-150 W/cm² (primarily convective) and integrated heat loads of 10 kJ/cm² and the second at heat fluxes of 30-50 W/cm² and heat loads of 5 kJ/cm². These materials may be either flexible or deployable.
- The third class of materials, for higher velocity (>11.5km/s) Earth return, will need to survive heat fluxes of 1500-2500 W/cm², with radiation contributing up to 75% of that flux, and integrated heat loads from 75-150 kJ/cm². These materials, or material systems must improve on the current state-of-the-art recession rates of 1.00 mm/s at heating rates of 2000 W/cm² and pressures of 0.3 atm and improve on the state-of-the-art areal mass of 4.0 g/cm², required to maintain a bondline temperature below 250 ºC.

Development of in-situ heat flux sensors, surface recession diagnostics, and in-depth or interface thermal response measurement devices for use on rigid and/or flexible ablative materials. In-situ heat flux sensors and surface recession diagnostics tools are needed for flight systems to provide better traceability from the modeling and design tools to actual performance. The resultant data will lead to higher fidelity design tools, risk reduction, decreased heat shield mass and increases in direct payload. The heat flux sensors should be accurate within 20%, surface recession diagnostic sensors should be accurate within 10%, and any temperature sensors should be accurate within 5% of actual values.
Non Destructive Evaluation (NDE) tools for evaluation of bondline and in-depth integrity for light weight rigid and/or flexible ablative materials. Non Destructive Evaluation (NDE) tools are sought to verify design requirements are met during manufacturing and assembly of the heat shield, e.g., verifying that anisotropic materials have been installed in their proper orientation, that the bondline as well as the TPS materials have the proper integrity and are free of voids or defects. Void and/or defect detection requirements will depend upon the materials being inspected. Typical internal void detection requirements are on the order of 6mm, and bondline defect detection requirements are on the order of 25.4mm by 25.4mm by the thickness of the adhesive.

Advances are sought in ablation modeling, including radiation, convection, gas surface interactions, pyrolysis, coking, and charring for low and mid-density fiber based (woven or felt) ablative materials. There is a specific need for improved models for low and mid density as well as multi-layered charring ablator (with different chemical composition in each layer). Consideration of the non-equilibrium states of the pyrolysis gases and the surface thermochemistry, as well as the potential to couple the resulting models to a computational fluid dynamics solver, should be included in the modeling efforts.

Technology Readiness Levels (TRL) of 2-3 or higher are sought.

Potential NASA Customers include:

- Human Exploration and Operations Mission Directorate.
  - Multi Purpose Crewed Vehicle (MPCV) heatshield and backshell projects.
  - Asteroid Sample Return projects.
  - Future design of low Ballistic Coefficient entry vehicles using Hypersonic Inflatable Aerodynamic Decelerator (HIAD) or Adaptive Deployable Entry and Placement Technology (ADEPT) systems.

- Science Mission Directorate - Planetary Exploration Entry, Decent and Landing heatshield and backshell projects and Planetary Sample Return projects.

- NASA Commercial Orbital Transportation Services (COTS) projects.