This subtopic includes two major technology areas:

(1) Reusable, Reliable and Low Cost Composite Tanks
(2) Advanced Material Integration Technology Development

Proposals will be accepted for either area.

Reusable, Reliable and Low Cost Composite Propellant Tanks (RRLCCPT)

The objective of this subtopic is to help dramatically reduce the cost to low Earth orbit by advancing the technology involved in composite propellant tanks and advanced composite material development. The ability for launch vehicles to combine the significant weight savings of composite tanks with airline like operations could be possible if these tanks are also reusable, reliable, and need little to no maintenance between flights.

Purpose and Current State-of-the-Art: Composite tanks offer significant weight savings, but there are significant shortfalls in terms of reusability, especially when using cryogenic fluids. This lack of reusability severely hampers adoption of this enabling technology in future reusable vehicle. This subtopic will also address emerging composite tank technologies, specifically in the areas of testing and verification pertaining to damage tolerance, safe-life and checkout.

General Operational Needs and Requirements/ Performance Metrics:

Airline-like Operations
Government and commercial reusable launch vehicles are only economically viable if they can achieve high flight rates of dozens of flights per year or more per vehicle. These flight rates themselves are only possible if something akin to airline like operations becomes possible for spaceflight.

**Reusability and Reliability**

Reusable, reliable, and low cost composite tanks that need little to no maintenance between flights and minimal check-out are required for economic and operational sustainability. These developments can:

- Ease operability of the tank diagnostics
- Enable tank prognostics
- Enable tanks to handle high pressure cycles and loads without leaking or developing structural failure
- Promote ease of manufacture, and by more than one American company
- Promote ease of repair without returning tanks to the manufacturer's facility
- Promote rapid certification/recertification techniques to meet expected FAA commercial RLV requirements

**Data and Technology Development**

Of specific concern and interest are safe-life and damage tolerance testing. There is much scrutiny regarding the manner and degree of testing in these areas, specifically after some number of pressure cycles. Also of concern is the effect of temperature on and during cycling and material compatibility. Due to the limited amount of flight and long term performance data there is little to base future design on when the desire is heritage similarity. Thus, development in regards to these specific metrics (safe-life and damage tolerance testing) would be most beneficial to both short and long term missions.

The outcome of this portion of the SBIR is expected to be technologies and data that make possible composite propellant tanks that have improved reliability and performance that will enable a high degree of reusability. Data should show that proper material, manufacturing processes and design are used to produce a vessel that performs well under long-term use in a cryogenic condition. The vessel would minimize microcracking, should be damage tolerant and repairable, and have mounting capabilities.

For the proposed technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II hardware demonstration and testing. Delivery of a demonstration unit for NASA testing at the completion of the Phase II contract is also required.

*Phase I Deliverables (RRLCCPT): Final report containing:*
Optimal design and feasibility of concept,
Detailed path towards Phase II demonstration,
Detailed results of Phase I analysis, modeling, prototyping and development testing
Material coupon data and a prototype sub-scale tank

Desired deliverables at the end of Phase I should be at TRL 3-4

Phase II Deliverables (RRLCCPT): By the end of Phase II, working proof-of-concept technologies, including features and demonstration of long term, high cycle performance at cryogenic temperatures, demonstrated and delivered to NASA for testing and verification.

Deliverables expected at the end of Phase II should be at TRL 5-6.

Advanced Material Integration Technology Development (AMITD)

Advanced materials including ceramic composites and metallic materials, will require technologies that will allow joining of these materials, specifically the development of advanced joining and integration technologies with enhanced temperature and performance capability. Typical materials are carbon and silicon carbide based composites and super alloys. The quality of joined sub-elements should also be evaluated nondestructively to assess the integrity and quality of the joints. Material systems may be similar or dissimilar in nature (composite to metals or composite to composites).

Purpose and Current State-of-the-Art: Currently the most commonly used fabrication approaches (CMC, CVI and PIP) have severe limitations in terms of size and shape of CMC components that can be manufactured with appropriate property attributes and a reasonable cost. Therefore, current design considerations for the manufacturing of large CMC components and structures will be utilizing technologies for joining/attaching smaller-sized components with simpler geometries and dissimilar material systems.

General Operational Needs and Requirements: Ceramic joining and integration is an enabling technology for the successful implementation of CMC’s in a wide variety of high temperature applications. Among the various alternatives available to overcome the limitations of the many fabrication technologies for the manufacture of large CMC components and structures of complex shape, the joining of smaller components with simple geometry appears to be the most promising and practical. Application of simple equipments for curing and during the high temperature joining process is critical. Requirements include, but are not limited to:

- Materials to be joined are silicon carbide or carbon-based matrix fiber reinforced composites to a similar CMC or high temperature metallic alloy
- Proposed joining approach should be robust and able to produce joints with tailorable microstructures
- Thermo-mechanical properties of the joint interlayer should be tailorable and close to those of the base
• Proposed technologies are expected to be easy to apply in a manufacturing environment at high
technology readiness levels

• For CMC-CMC joining, the joint interlayer material should be able to yield ceramic interlayers with
  temperature capability similar or better than the substrate materials with low porosity

Performance Metrics: The temperature capability of the ceramic joints in joined CMC should be similar to that of the
CMC substrate materials. The chemical composition of the joints should not alter the stress rupture, creep, high
temperature mechanical strength, and stiffness of the overall system in any significant manner. The environmental
stability, time dependent mechanical properties, and performance of the joints should not be significantly different
than the substrate materials.

For the proposed technologies, research should be conducted to demonstrate technical feasibility during Phase I
and show a path toward Phase II sub-element and subcomponent development and testing. Delivery of a
subcomponent demonstration unit for NASA testing at the completion of the Phase II contract is also required.

Phase I Deliverables (AMITD): Develop and demonstrate a robust joining concept, understand common test
methods for joint testing, and assess the interfacial microstructure and mechanical properties of joints. Assess high
temperature durability of joints and effect of joint design on thermo mechanical performance.

Desired deliverables at the end of Phase I should be at TRL 3-4.

Phase II Deliverables (AMITD): Produce and test additional joint prototypes (sub-elements and subcomponents)
under representative flight conditions to include anticipated temperatures, heat fluxes, thermal gradients, and
environmental effects. Full macro-structural and micro-structural material characterization of joints before and after
testing will be required to assess life-limiting failure mechanisms and joint reliability. Provide joined CMC
subcomponents or segmented structures with a method to non-destructively evaluate the joint quality.

Deliverables expected at the end of Phase II should be at TRL 5.