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Propulsion

LAUNCH, IN-SPACE & RELATED GROUND TECHNOLOGIES

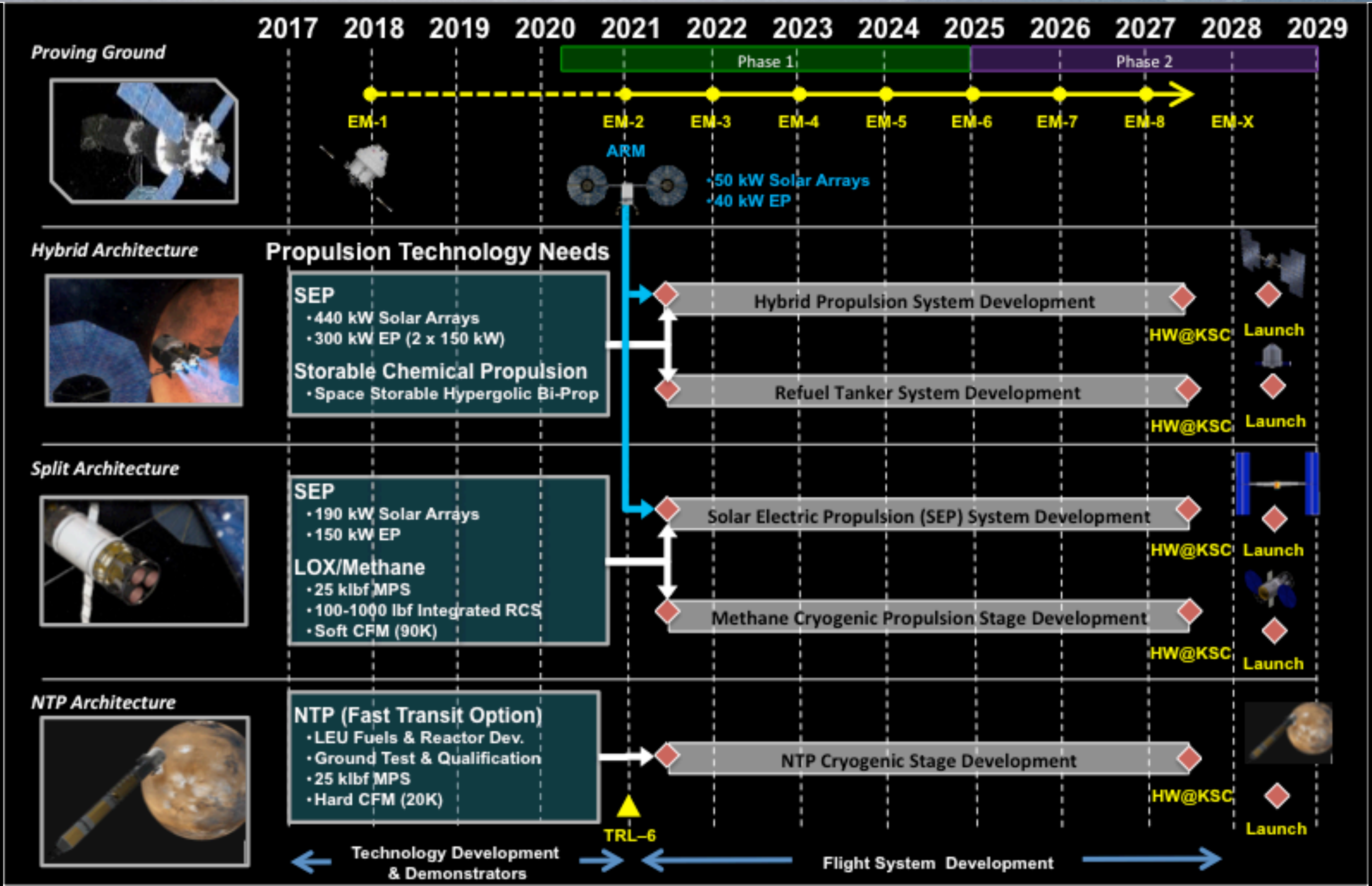
Ronald J. Litchford, PhD, PE
Principal Technologist for Propulsion
NASA/STMD | HQ

Overview

- **NASA Propulsion Innovation & Technology Priorities**
  - Agency Mission Drivers: EMC | Science | Commercial
  - Alignment with STMD Quantifiable Capability Development Objectives
- **Perspective on the Role of Small Businesses & Universities**
  - Strategic Cross-Program Integration
  - Agile Spiral Development
- **Elaboration on SBIR/STTR Propulsion Subtopics**
  - Z10.01 – Cryogenic Fluids Management
  - Z10.02 – Methane In-Space Propulsion
  - Z10.03 – Nuclear Thermal Propulsion
  - Z09.01 – Small Launch Vehicle Technologies
  - T01.01 – Affordable Nano/Micro Launch Propulsion Stages
  - T01.02 – Detailed Multiphysics Propulsion Modeling & Simulation
  - T02.01 – Advanced Nuclear Propulsion

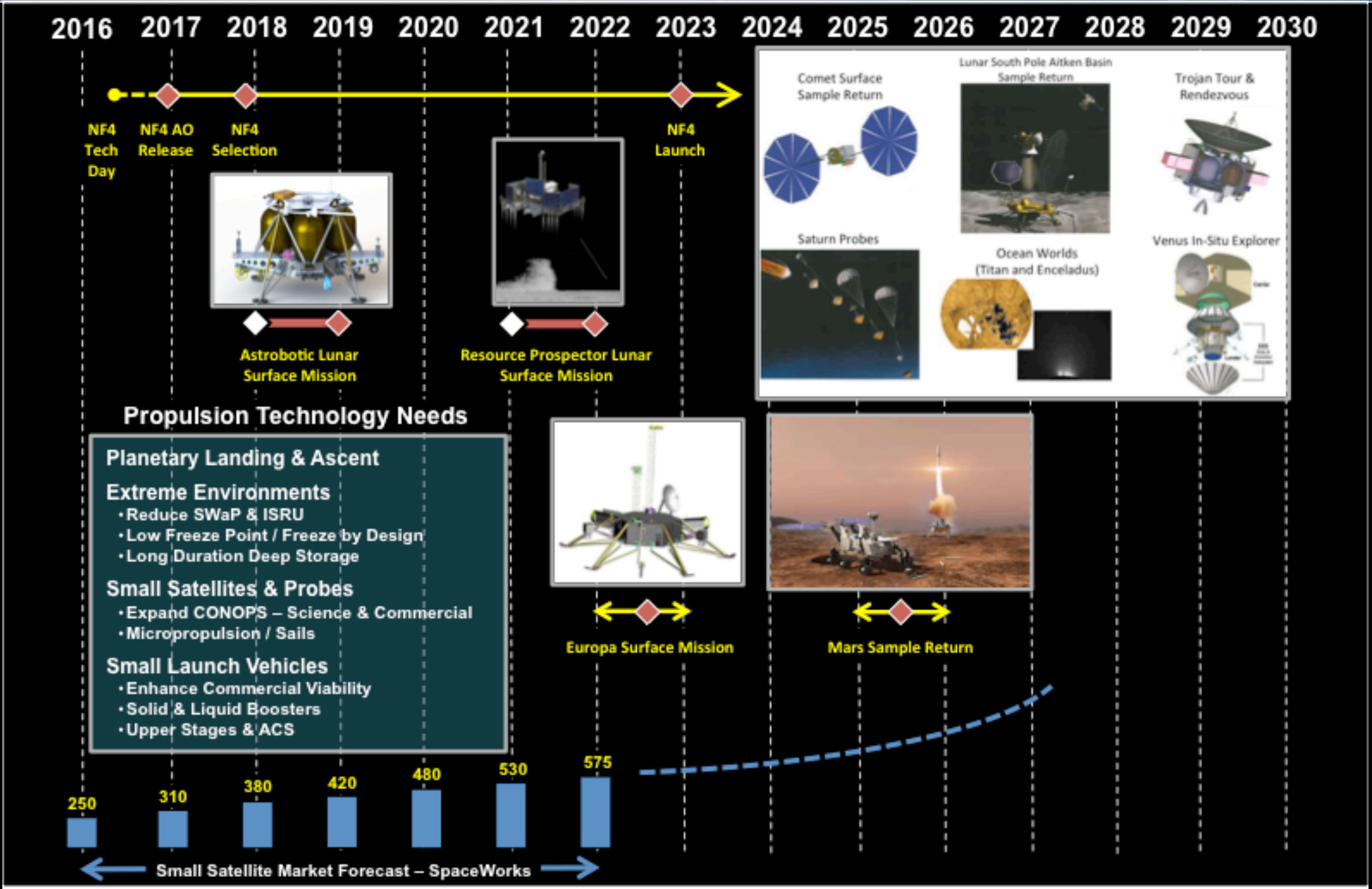
Propulsion Technology Mission Drivers

Evolvable Mars Campaign



Propulsion Technology Mission Drivers

Science & Commercial

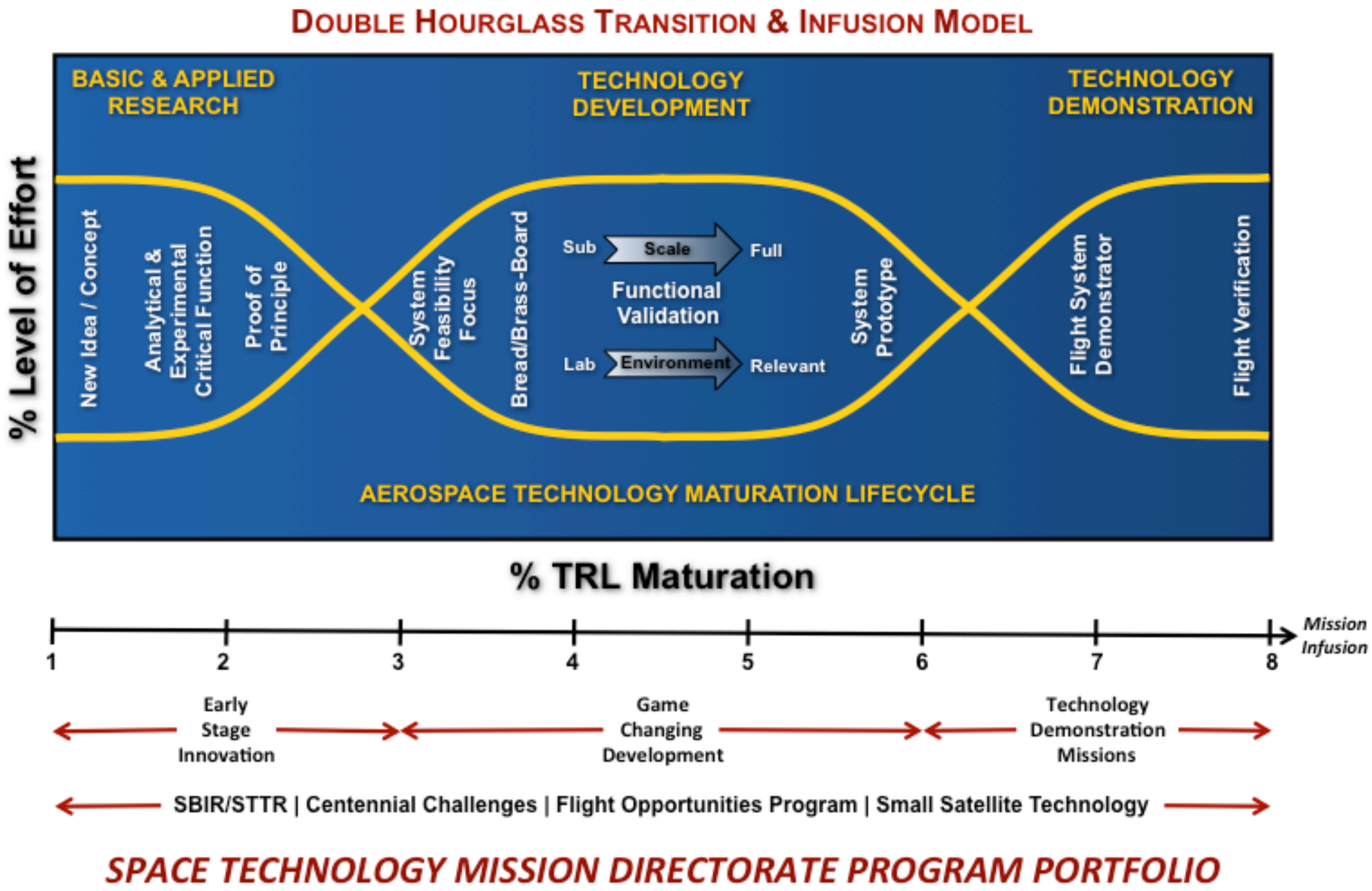


Alignment with STMD Capability Development Objectives

Capability Objective	Quantifiable Metrics	SBIR/STTR
EMC NTP Propulsion Architecture	• Thrust ≥ 25klbf @ Thrust/Weight ≥ 4 • High Temperature Fuel Element Temp ≥ 2850 K @ Isp ≥ 900 sec • Δv ≥ 10 km/s – Enable Opposition & Conjunction EMC Mission Options • Fission Product Leakage << NERVA/ROVER Milestone • Run Duration ≥ 2 hrs @ rated temperature • Engine Restarts ≥ 10 • Hydrogen CFM - Zero Boil Off & Liquefaction at Low Power (kW's @ 20k) • NTP Engine System Development LCC ≈ Comparable Scale LRE LCC ($1-2B)	Z10.03 – Nuclear Thermal Propulsion Z10.01 – Cryogenic Fluid Management
EMC LOX/Methane Propulsion Architecture	• MPS Thrust ≥ 23 klbf with 5:1 Throttling Capability • RCS Thrust ≥ 100 lbf with Integrated Feed Systems • Isp > 360 sec • Lifetime > 300 hours • LOX/Methane CFM - Zero Boil Off and Liquefaction at Low Power (100's Watts @ 90K)	Z10.02 – Methane In-Space Propulsion Z10.01 – Cryogenic Fluid Management
Mission Enhancing In-Space Storable Propulsion	• 100-lbf Class MON-25/MMH Bipropellant Engine (Flight Qualified within 2 years) • Reduce Propellant Freezing Point < -40 °C • Reduce Propulsion System Mass ≥ 80% • Reduce Propulsion System Volume ≥ 50% • Reduce Propulsion System Cost ≥ 60% • EMC Class Scale-Up: RCS Thrust = 100-1000 lbf, MPS Thrust = 25,000 lbf	T01.02 – Detailed Multiphysics Propulsion Modeling & Simulation
Mission Enhancing In-Space Green Propulsion	• 22-N Scale Green Monopropellant Thruster (Flight Qualified within 3-5 years) • Increase Density-Isp ≥ 25% • Reduce Propellant Freezing Point < -40 °C • Reduce Thruster Power Consumption ≥ 50% • Increase Propellant Throughput/Lifetime ≥ 125 kg • Reduce Ground Operation Costs ≥ 50% (Reduce or Eliminate SCAPE Suit Ops) • Scale-Up: 110-N Thruster (5-7 years), 440-N Thruster (7-10 years)	T01.02 – Detailed Multiphysics Propulsion Modeling & Simulation
Fast Transit Deep Space Transportation	• Exploration Class Propulsion System Specific Mass: α ≤ 5kg/kW	T02.01 – Advanced Nuclear Propulsion
Affordable Small-Scale Launch Services	• 5-180 kg payload delivery capacity to 350-700 km altitude @ 28-98.3 degrees inclination (CONUS & Sun Synchronous Ops) • Launch Costs < $60,000/kg (Threshold Objective) • Launch Costs < $20,000/kg (Stretch Goal) • Reliability ≥ 90%	Z09.01 – Small Launch Vehicle Technologies T01.01 – Affordable Nano/Micro-Launcher Stages

Strategic Cross-Program Integration

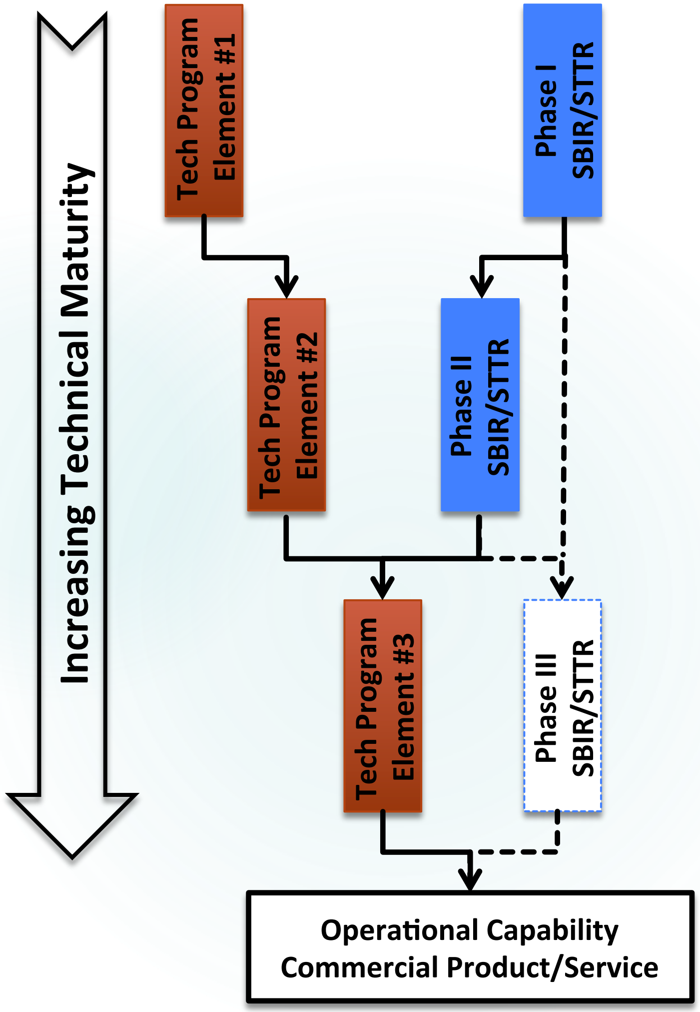
Technology Lifecycle



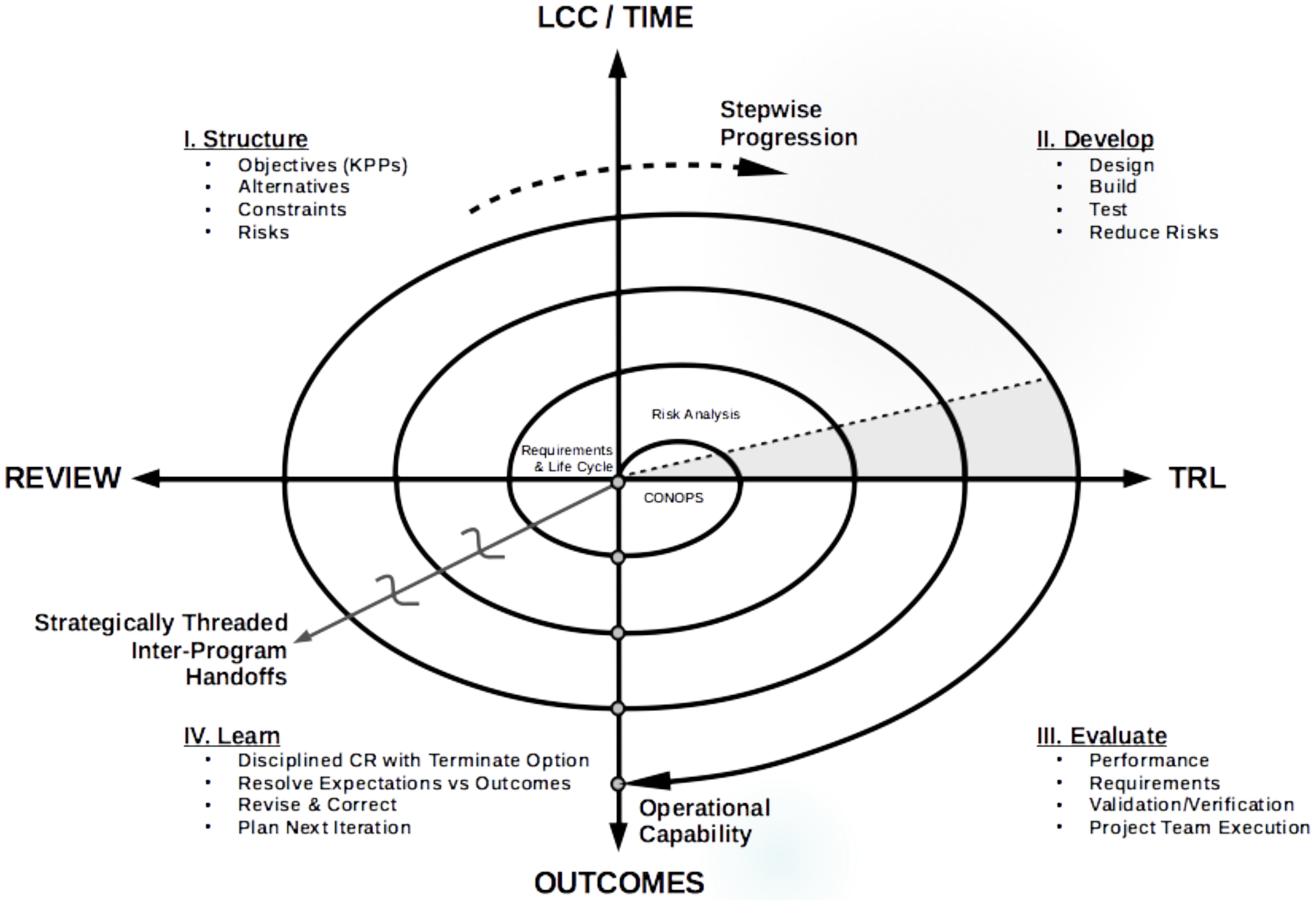
Capability Development Partition

Adoption of Agile Spiral Development Practices

NASA PROGRAM ELEMENTS



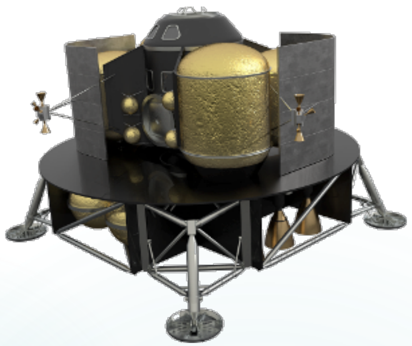
CAPABILITY DEVELOPMENT COMMITMENT PARTITION



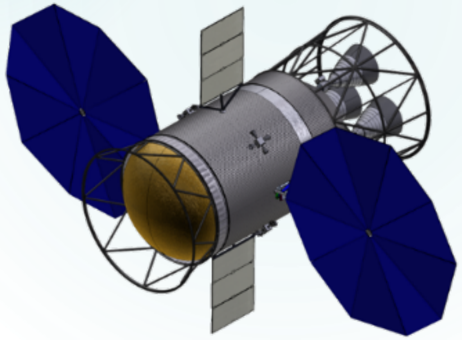
EMC Methane Propulsion Architecture

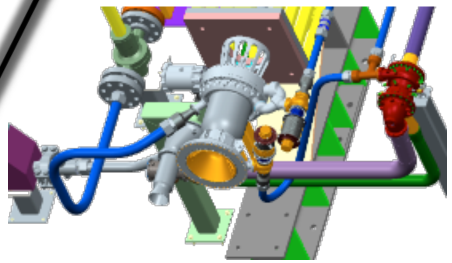
Technology Gaps & Needs

EMC Mars Descent Vehicle

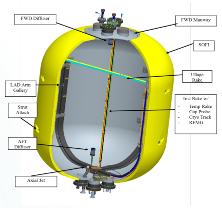


EMC Methane Propulsion Stage





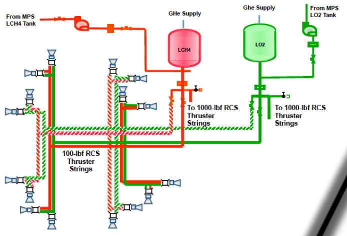
Main Propulsion System (MPS)
- Combustion Chamber
- Deep Throttling Injectors
- Ignitors
- Main Valves
- Turbopumps

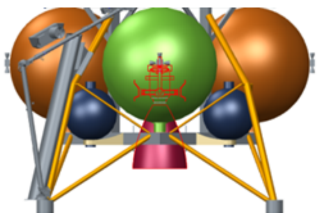


Cryo-Fluid Management (CFM)
- Passive CFM (Cryocooler/BAC)
- Active CFM (TVS/MLI/Foam)
- Low Leak Valves
- Helium Storage
- Thermal Conditioning

METHANE IN-SPACE PROPULSION TECHNOLOGY DEVELOPMENT NEEDS (TRL 4-6)

Reaction Control System (RCS)
- Thrusters (100-lbf & 1000-lbf)
- Electric Pumps
- Feed Systems
- Fast Acting Valves
- Components





Integrated Ground Demonstration

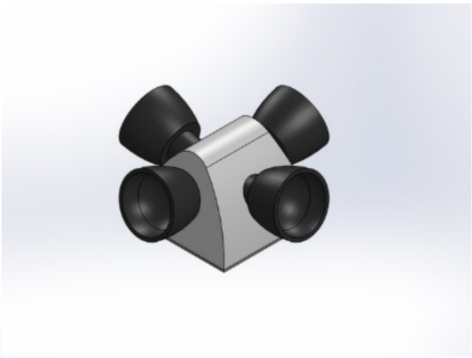
Risk Reduction

EMC Mars Ascent Vehicle

2nd stage

1st stage

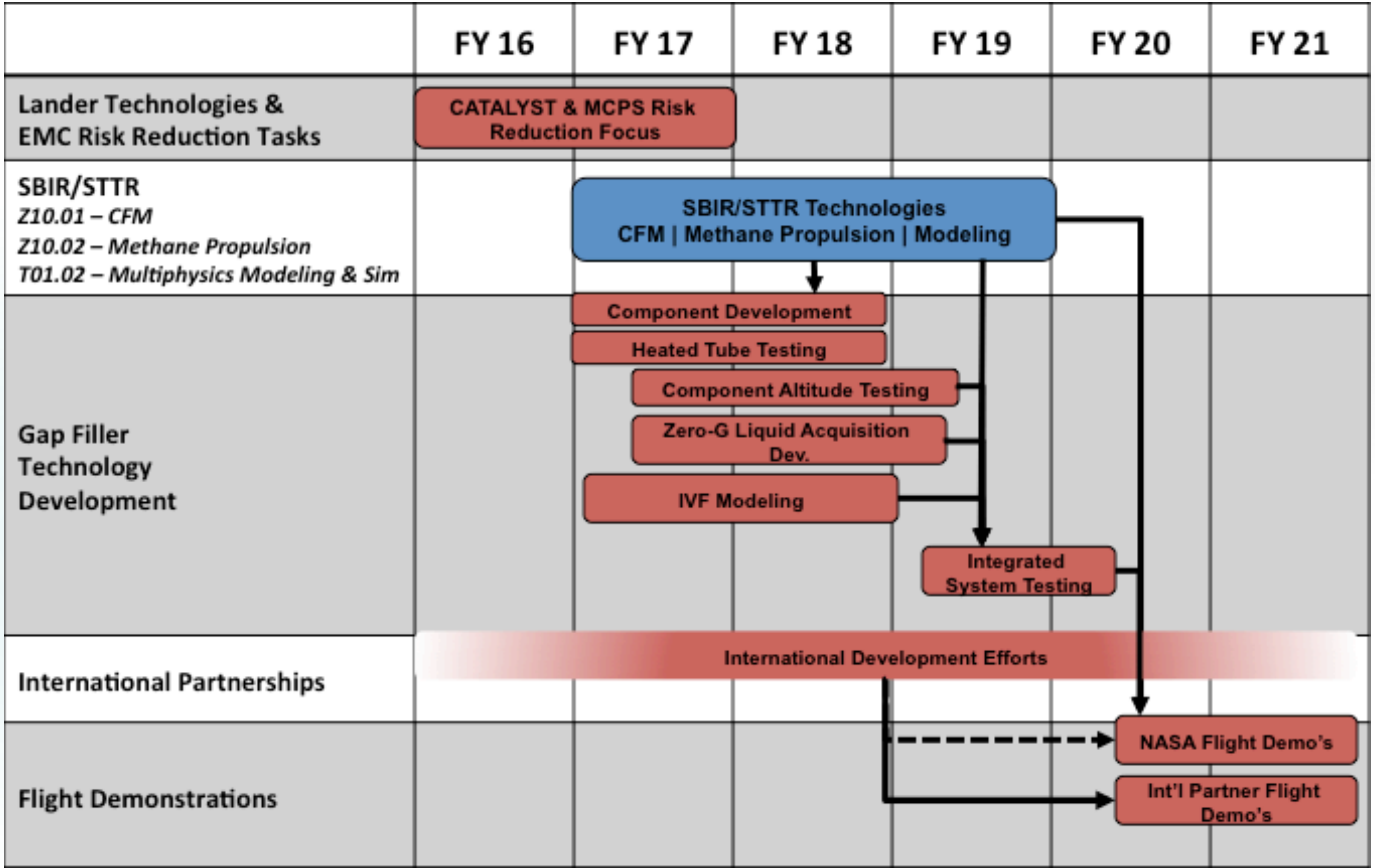
Mars Descent Module (MDM)



EMC Class Reaction Control System

EMC Methane Propulsion Technology

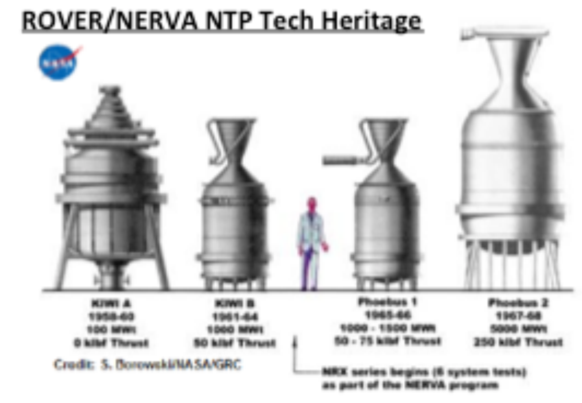
Notional Capability Development Plan

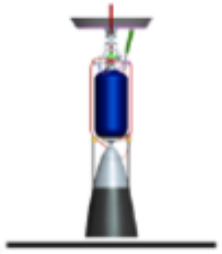


EMC NTP Architecture

Objectives & Capability Development Strategy

- **Capability Need – "In-Space Nuclear Propulsion for Sustainable Mars Exploration"**
  - **High Thrust, High Isp Performance –** *"Fast Transits & Reduced Crew Hazards"*
  - **Low Architectural Mass & Reduced Mission Launch Count** – *"Improved Mission Affordability"*
  - **Affordability** – *"Reduce Nuclear System Life Cycle Costs"*



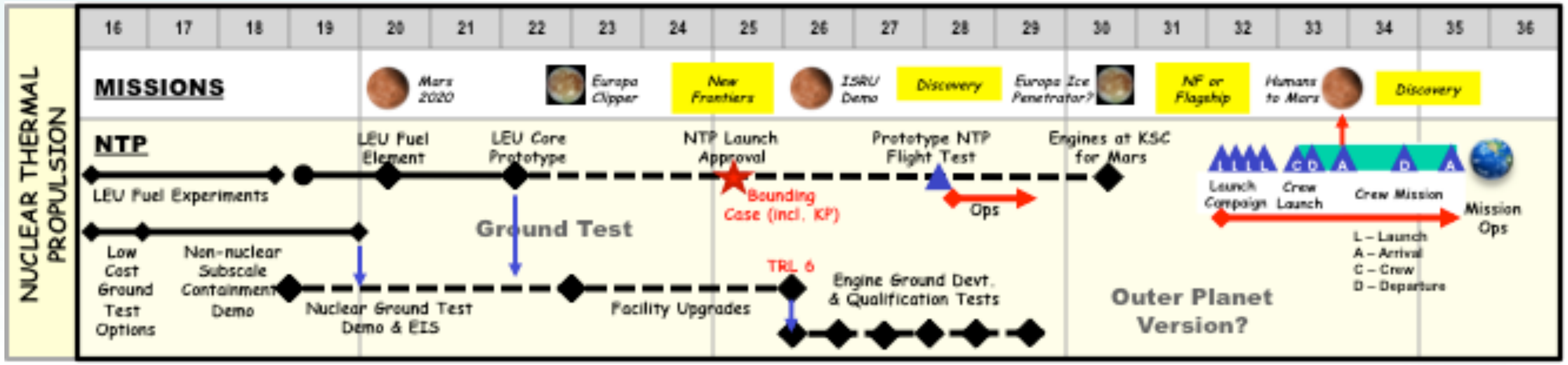


Affordable Lower Thrust NTP Concepts Using Low Enrichment Fuel

CAPABILITY GOAL

Enable NTP Option for FY20/21 EMC Architecture Downselect

Develop the foundational technology for affordable NTP and establish viability & feasibility, with good cost & schedule confidence, prior a decision to proceed with full-scale engine system development

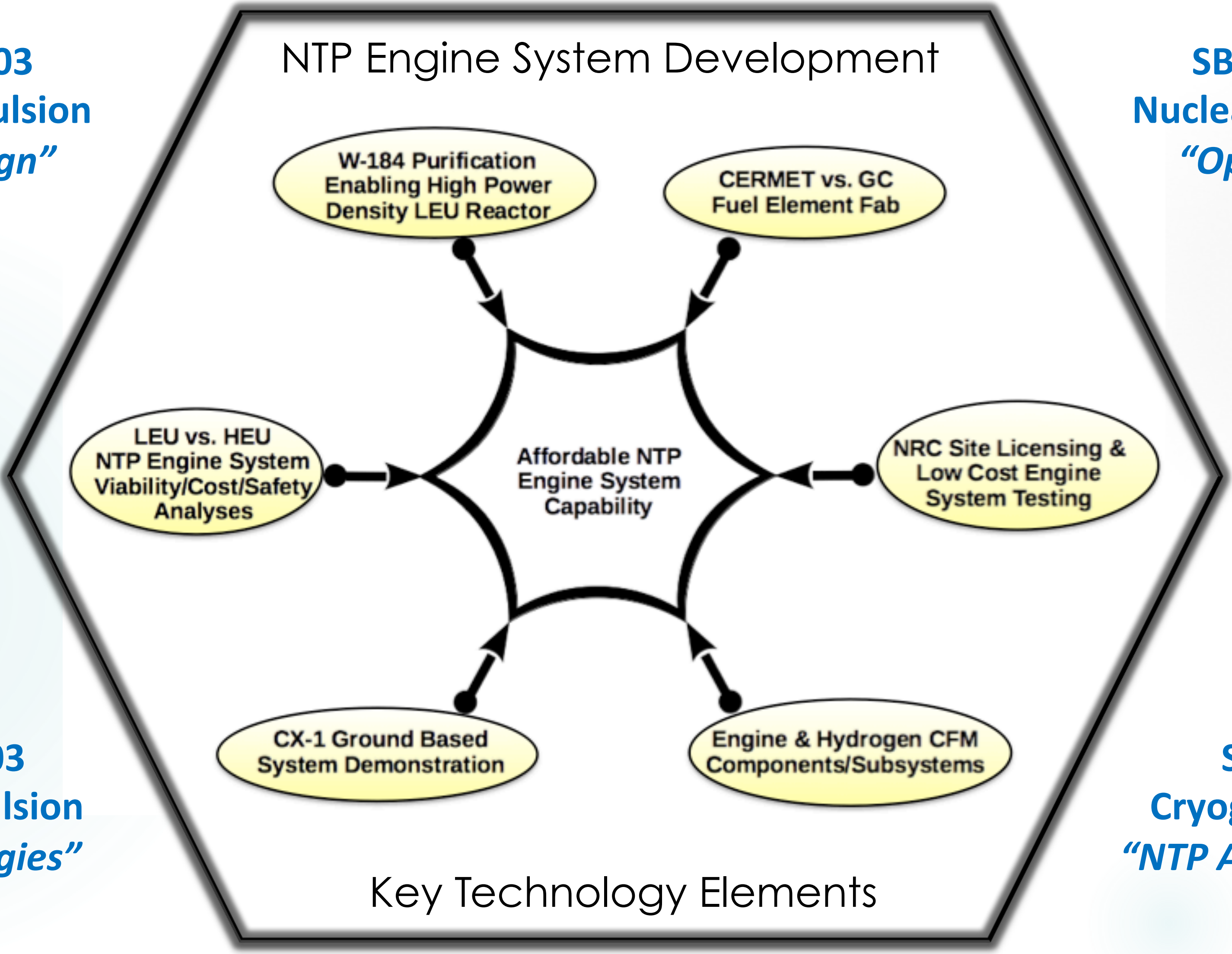


EMC NTP Technology

Technical Challenges & Needs

SBIR Subtopic Z10.03
Nuclear Thermal Propulsion
"Engine System Design"

SBIR Subtopic Z10.03
Nuclear Thermal Propulsion
"Operations & Safety"

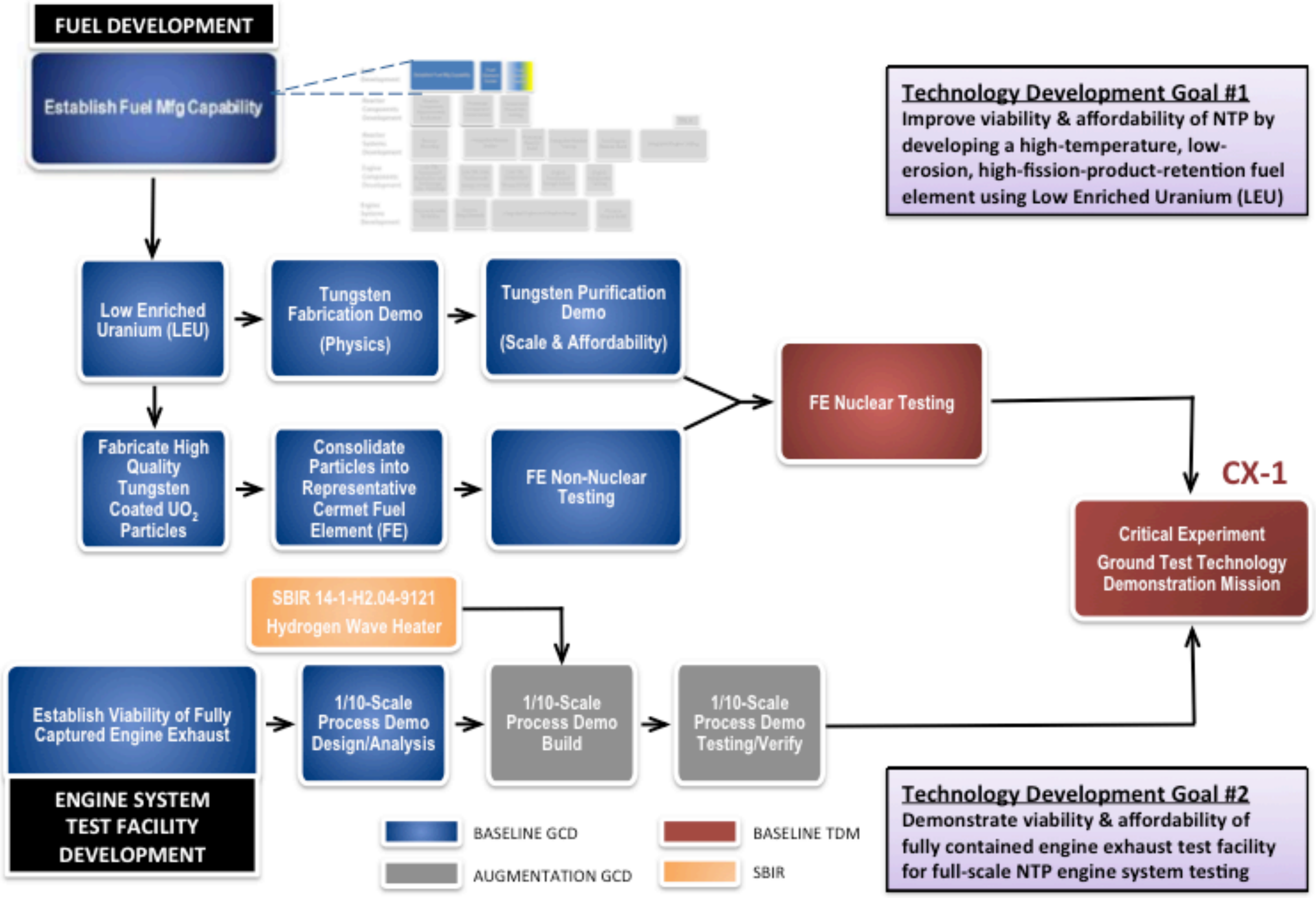


SBIR Subtopic Z10.03
Nuclear Thermal Propulsion
"Ground Test Technologies"

SBIR Subtopic Z10.01
Cryogenic Fluid Management
"NTP Architecture Technologies"

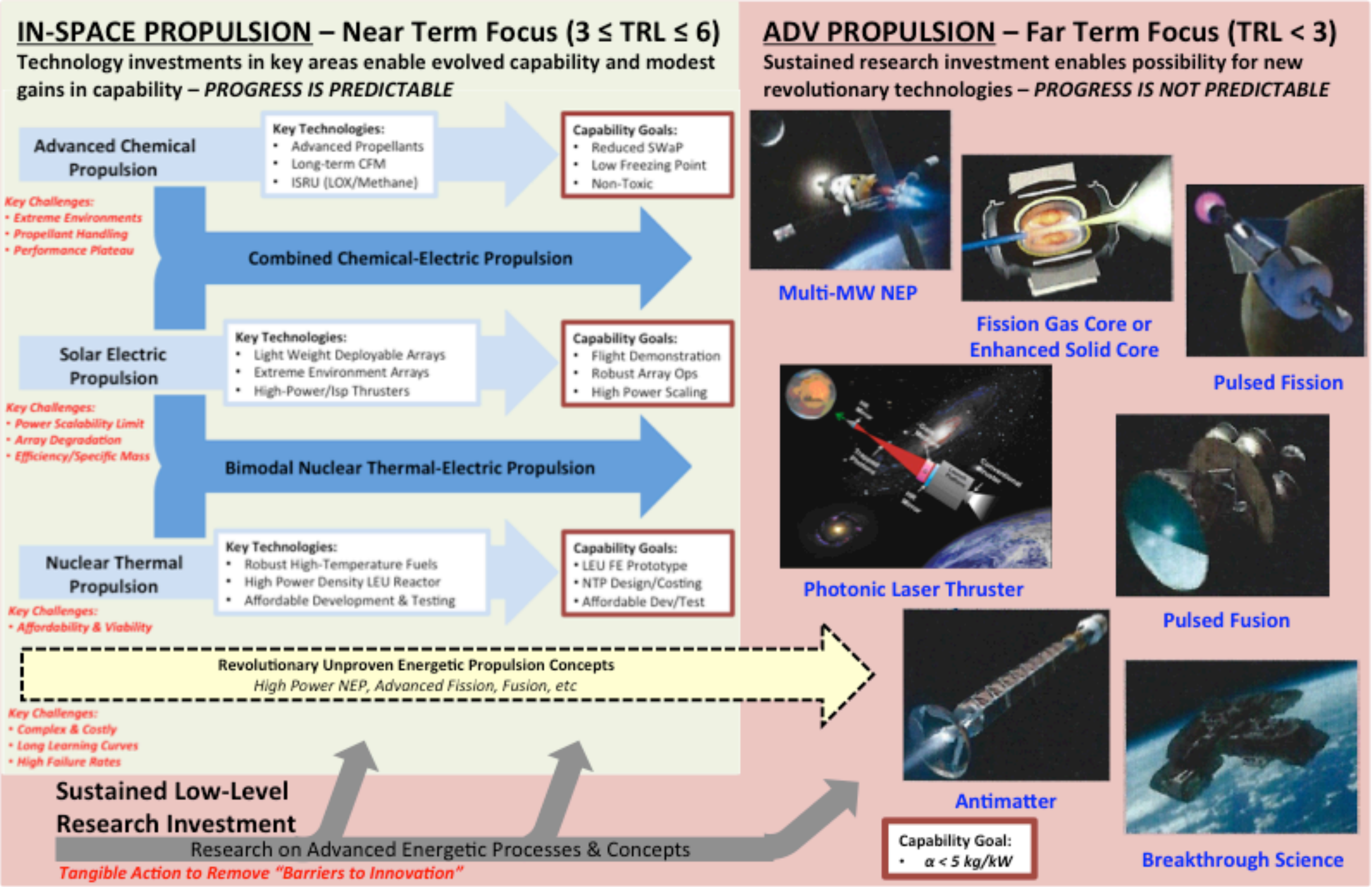
EMC NTP Technology

Successful SBIR Infusion Example



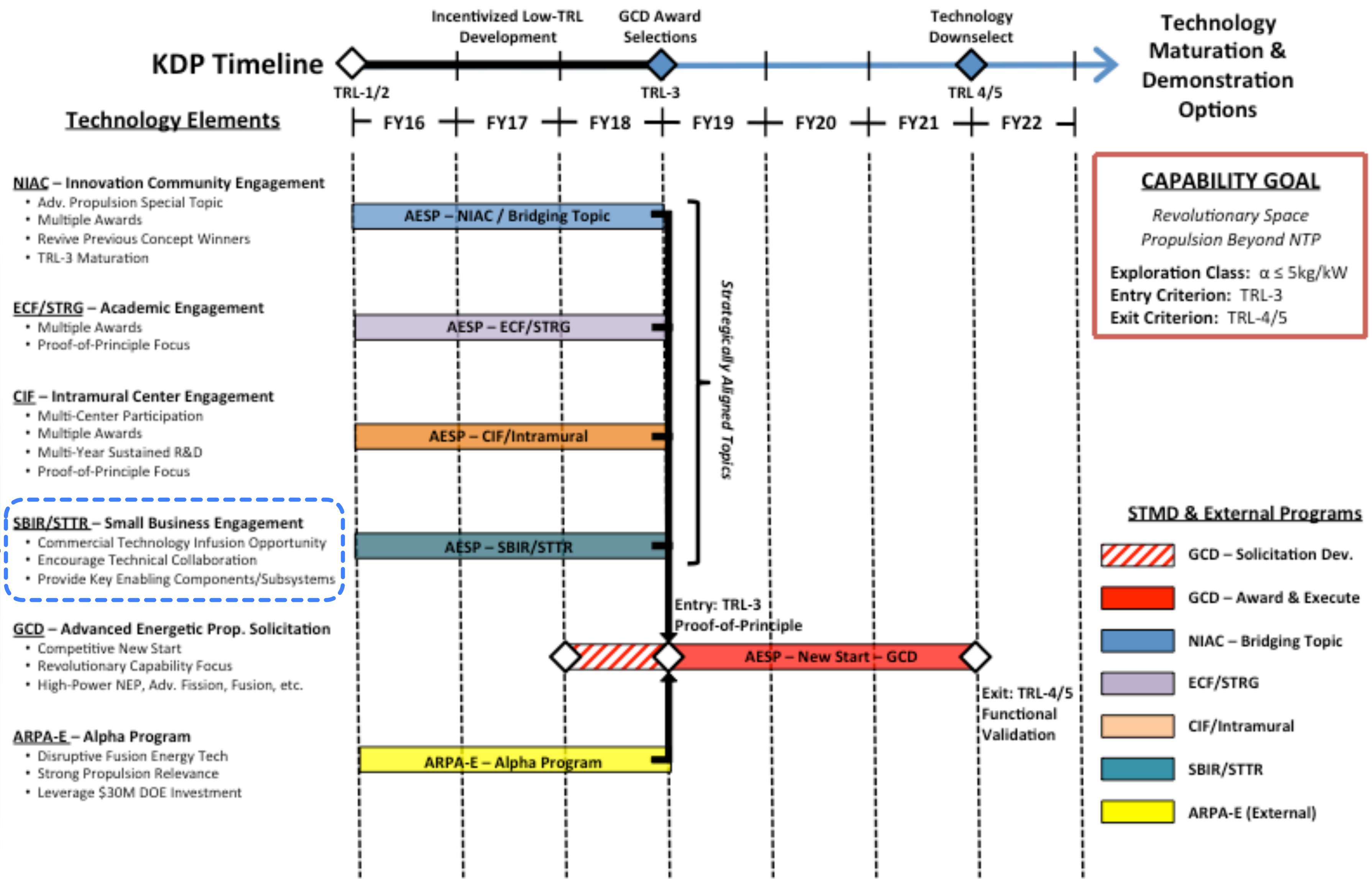
Advanced Nuclear Propulsion

A Diversified R&T Vision



Advanced Nuclear Propulsion
Notional Capability Development Plan

STTR Subtopic T02.01
"Advanced Nuclear Propulsion"



Affordable Small-Scale Launch Services

Perspectives & Strategy

- **Capability Need – "Economically Viable Small-Scale Launch Services"**
  - Conventional Spacecraft/Launch Affordability Poses Severe Threats to Future Mission Cadence
  - Rapid Miniaturization is Revolutionizing Small Spacecraft Platform & Mission Capabilities
  - Economically Viable Small-Scale Launch Systems Needed to Support Small Spacecraft Missions
  - NASA is Fully Committed to Commercial "Launch Service Provider" Acquisition Model
- **Dynamic & Competitive Private Sector Environment Currently Exists**
  - All Face Significant Investment & Expertise Shortfalls
  - Continuing Need for NASA to make Technology & Incentive Investments with respect to Capability Development

SBIR Subtopic Z09.01

"Small Launch Vehicle Technologies"

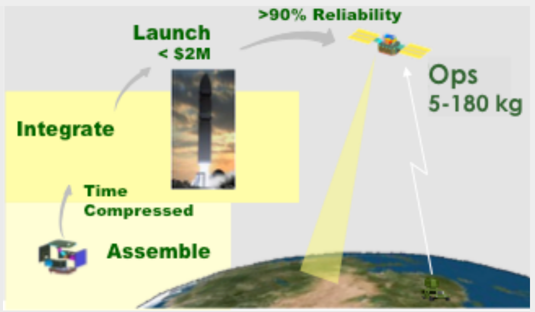
- **Innovative Propulsion Technologies**
- **Affordable Guidance, Navigation & Control**
- **Manufacturing & Structure Innovations**

NASA LSP Venture Class Awards

- **Firefly Space Systems**
- **Rocket Lab**
- **Virgin Galactic**

Demonstrate 3 Test Flights by April 2018

Dedicated Small-Scale Launch System Capability



- 5-180 kg payload delivery to 350-750 km altitude
- 28.5° to 98.3° inclination
- Launch Costs < $60,000/kg (Threshold Objective)
- Launch Costs < $20,000/kg (Stretch Goal)
- ≥ 90% reliability

STTR Subtopic T01.01

"Affordable Nano/Micro Launch Stages"

- **Stage Level System Technologies**
- **Plug-and-Play Architecture**
- **Propulsive Flight Test in Phase II**

NASA STMD ACO/Tipping Point Initiatives

- **ACO Reusable Launch System Development Awards**
  - **Up Aerospace: "Spyder"**
  - **Virgin Galactic: "LauncherOne"**
  - **Generation Orbit: "GOLauncher"**
- **ACO Small, Affordable LRE Development Awards**
- **Tipping Point Technology Solicitation (open)**

NASA