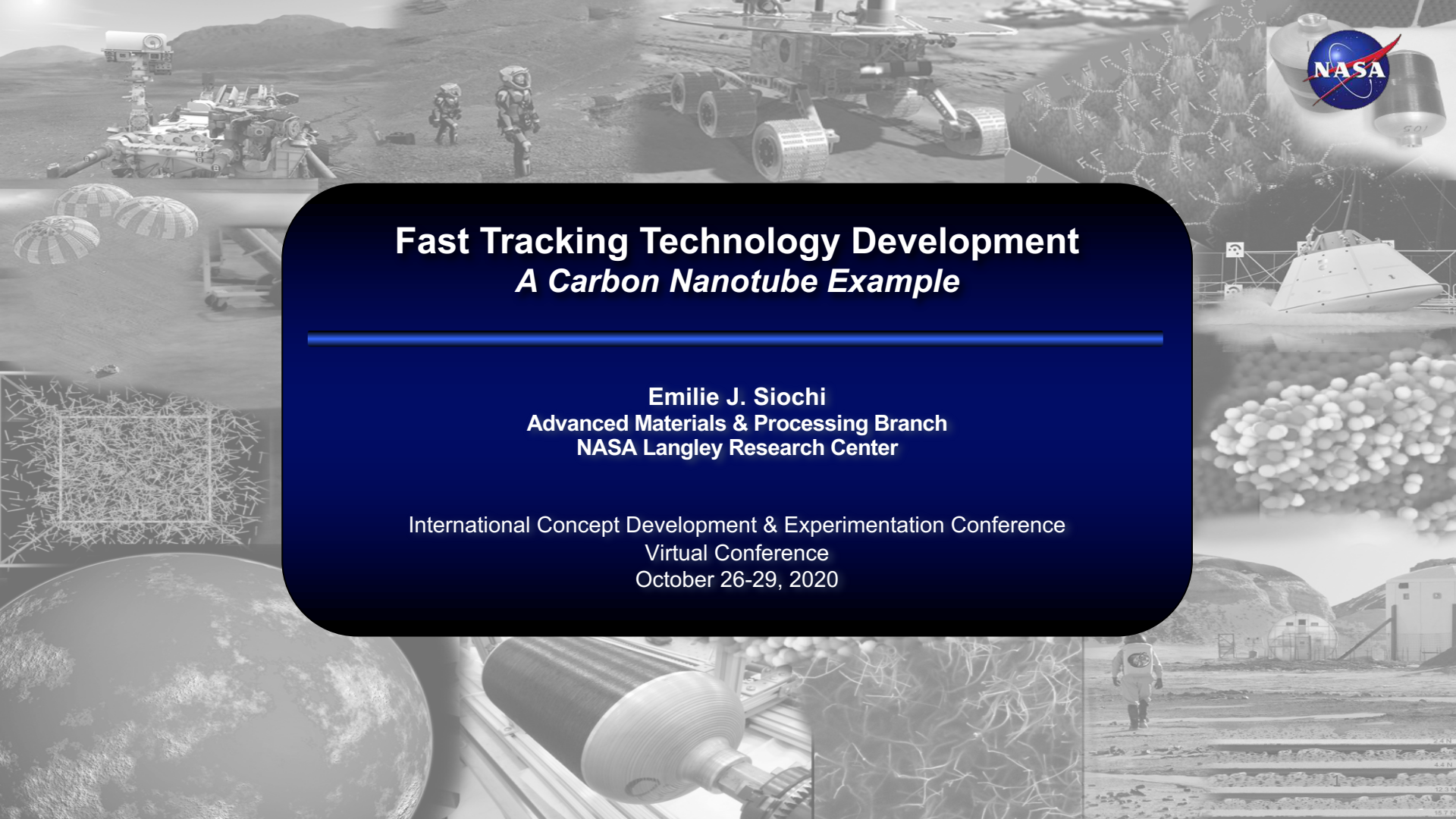




Fast Tracking Technology Development

A Carbon Nanotube Example

Emilie J. Siochi
Advanced Materials & Processing Branch
NASA Langley Research Center

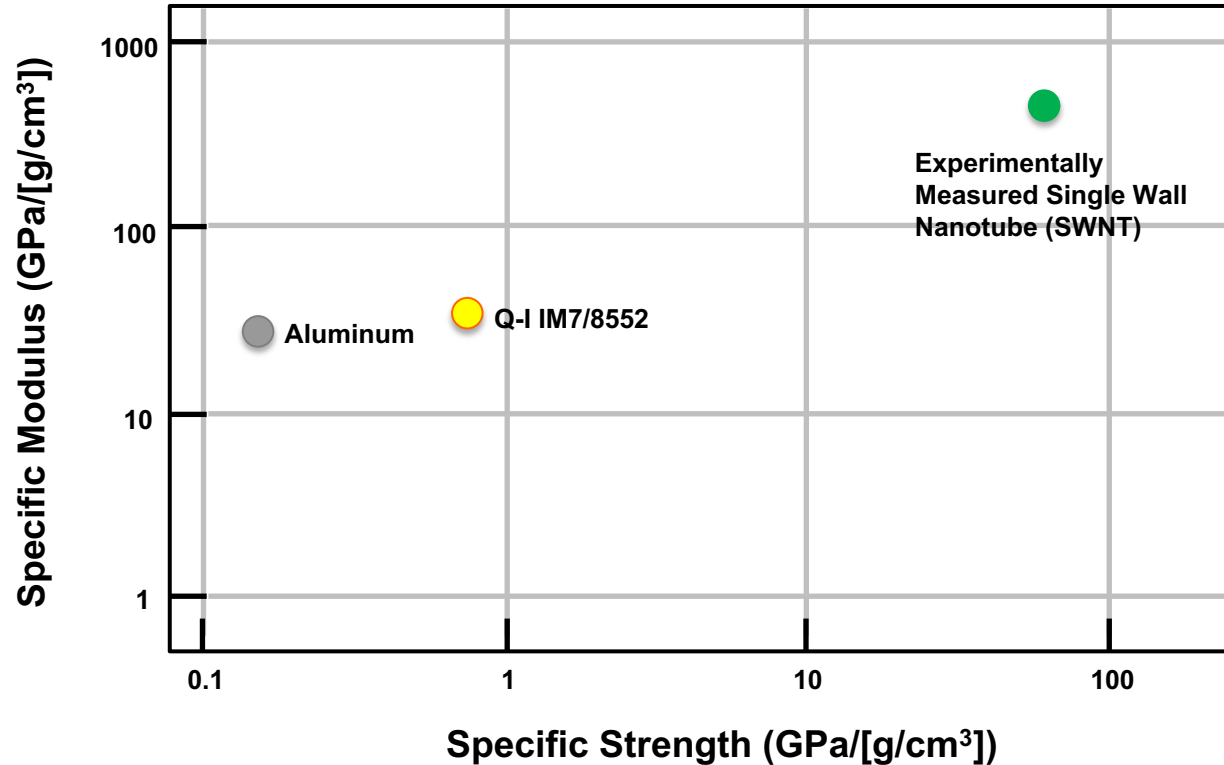
International Concept Development & Experimentation Conference
Virtual Conference
October 26-29, 2020

Summary of the Problem

- Cost increases in proportion to the mass ratio
- Mass ratio increases linearly with the dry mass and exponentially with Δv
- Reducing structural mass reduces mission cost at constant payload or increases mission capability at constant cost.

	Mass Ratio*	Cost per pound*
Low Earth Orbit	20	\$4,000
Earth to Moon	200	\$40,000
To Moon, Return to Earth	500	\$100,000
Earth to Mars	500	\$100,000
To Mars, Return to Earth	5000	\$1,000,000

Motivation



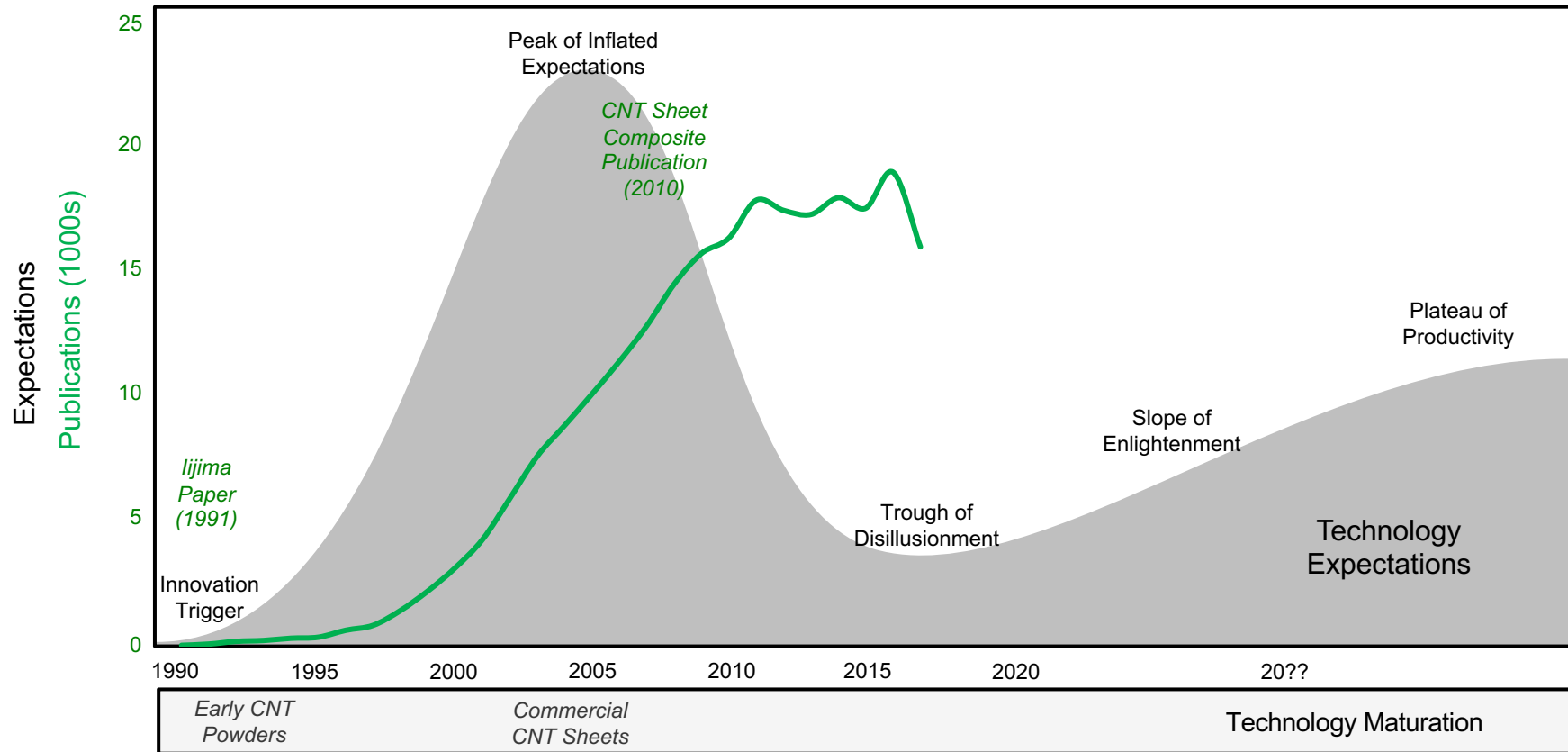
Technology Development Approaches

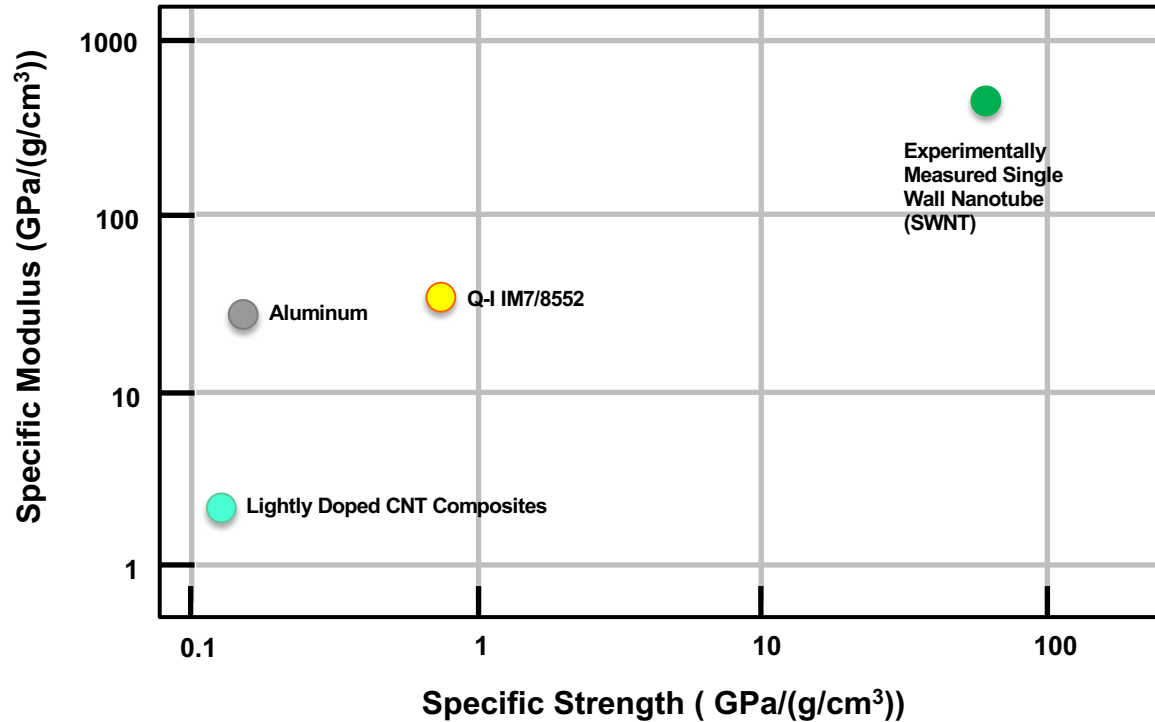


- **Technology Push**
- **Technology Pull**
- **Technology Pull Guided Technology Push**

- New/Different
- Immature
- Hyped
- Potentially disruptive
- Can spur significant basic research investments

Carbon Nanotube (CNT) Gartner Hype Cycle





Lessons Learned

- Analogous to very short chopped fiber composites
- Limited by material supply and quality
- Very low volume fraction (<5%)
- Limited improvement over matrix mechanical properties
- Payoffs noted in electrical/multifunctional properties
- Output: Papers, presentations, patents
- Structural applications envisioned did not materialize

Technology Development Approaches



- Technology Push
- **Technology Pull**
- Technology Pull Guided Technology Push



- Performance needs identified
- Schedule driven
- Solution space defined by what is ready for insertion
- Typically risk averse

Carbon Nanotubes on Juno Spacecraft



Composites and carbon nanotubes were implemented in four components on the Juno spacecraft: the rocket engine tubes, the engine cover and the outside and inside face sheets.

Lessons Learned

- Emerging technology can be implemented if it meets a performance requirement for which there is no other existing solution.
- Technology must be evaluated for the required function.
- Technology must be ready to insert on schedule.
- Structural performance objective still not realized, but technology is flown due to other performance benefits.

Technology Development Approaches



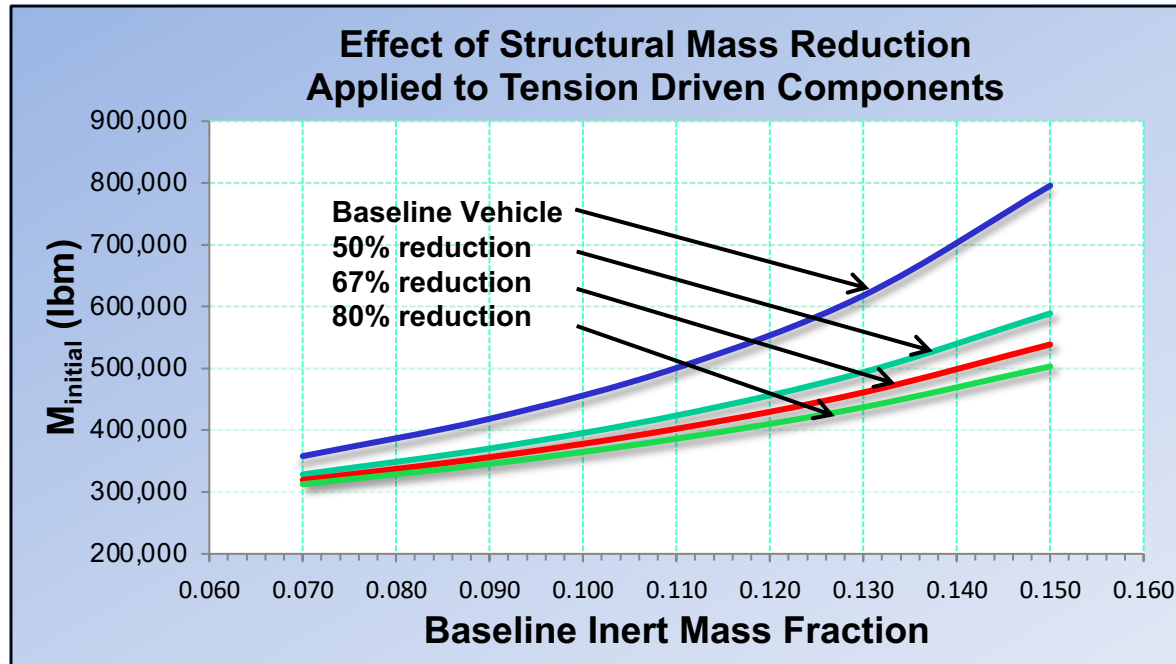
- Technology Push
- Technology Pull
- **Technology Pull Guided Technology Push**

Technology Pull Guided Technology Push



- Use-driven fundamental research
- Considers systems level benefits
- From lab to demonstration

Setting Goals using Systems Analysis

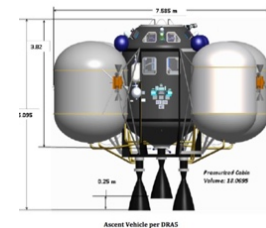
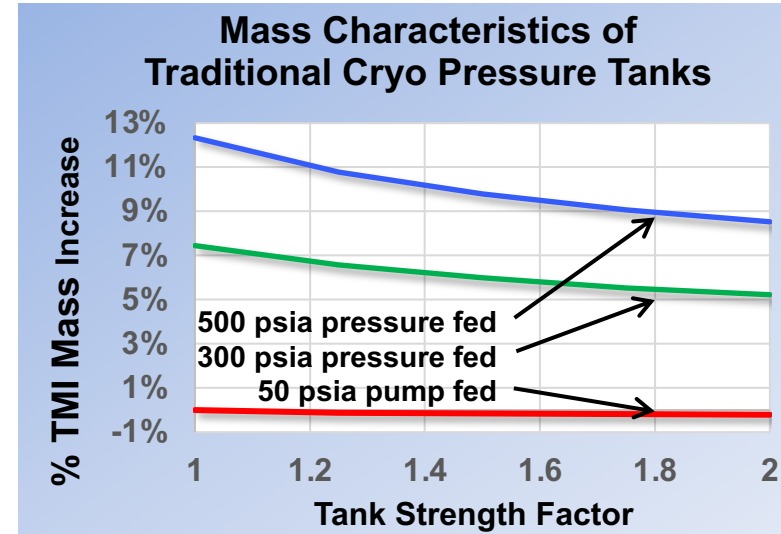
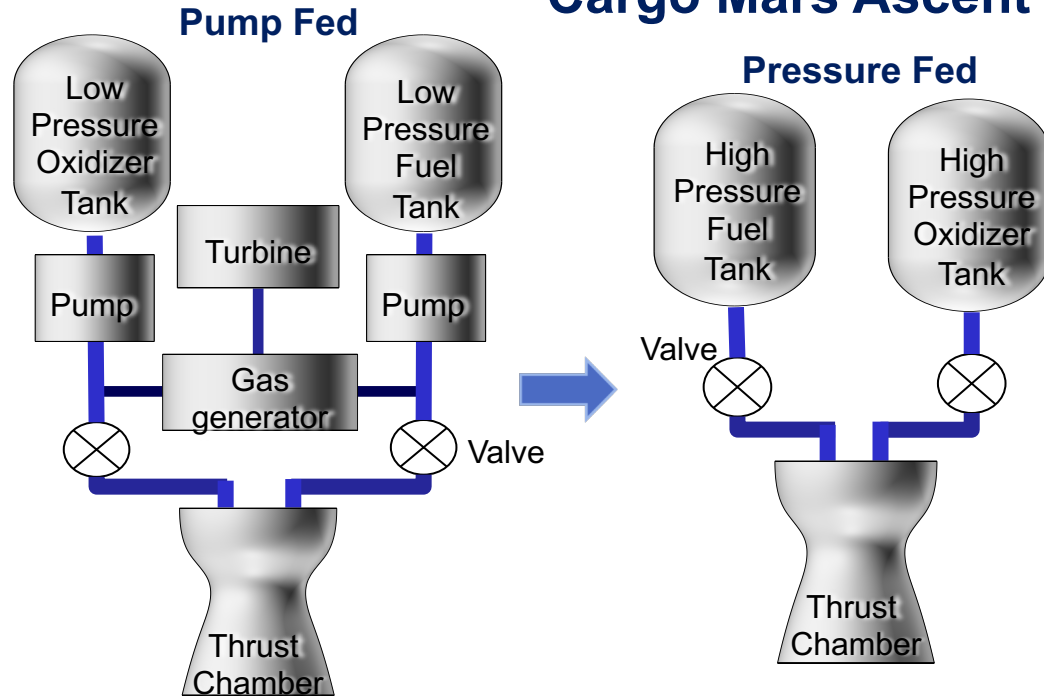


- A 2-3x improvement in specific mechanical properties will permit substantial mass reduction in structural and non-structural components

Setting Goals using Systems Analysis



Cargo Mars Ascent Vehicle (MAV)

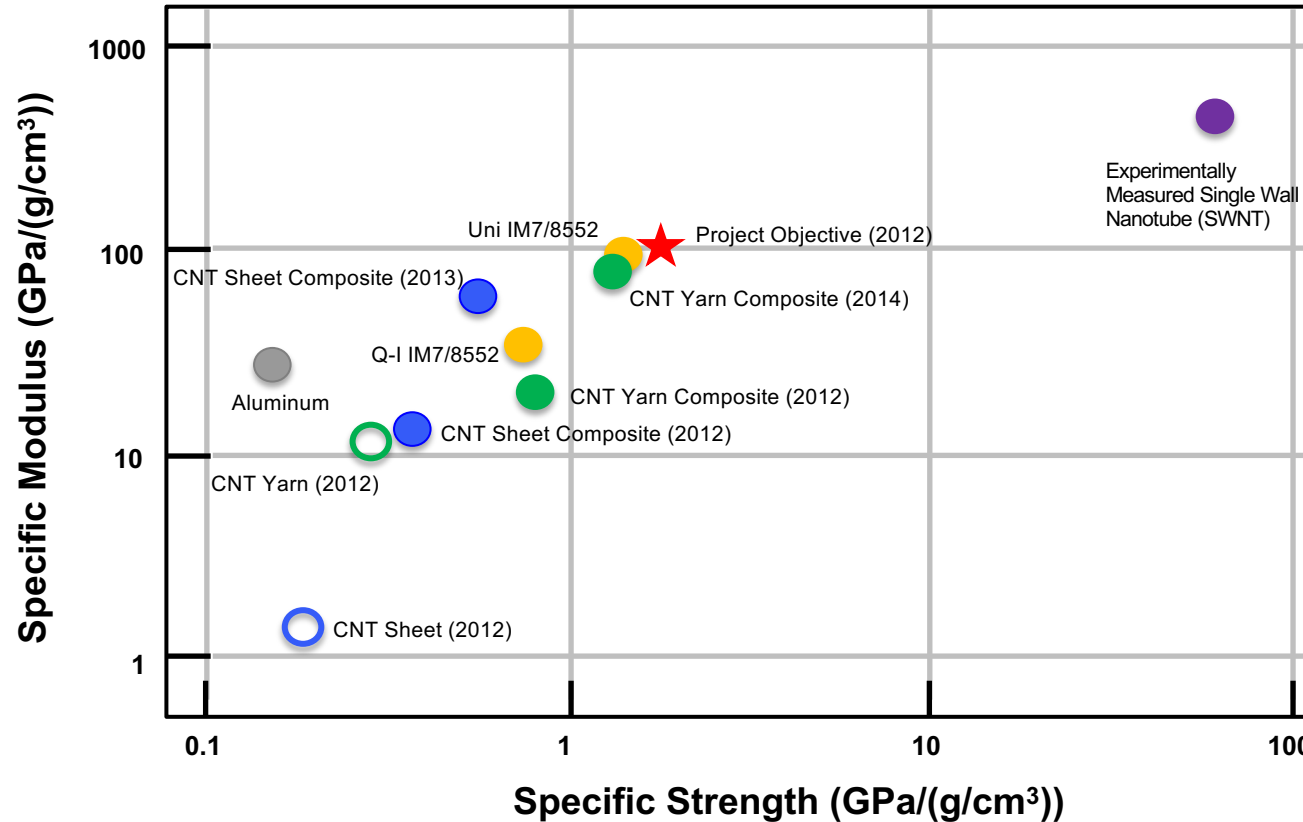


➤ Mass savings are potentially large enough to change propulsion system design concept.

State of the Art Lightweight Structural Material



Nano to Macro Challenge



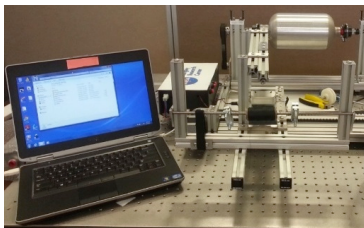
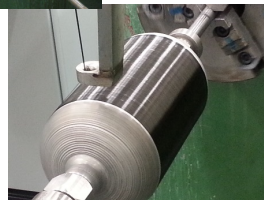
Prototyping to Support Materials Development



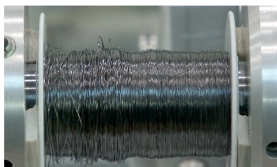
Commercial Scale CNT Composite Winding



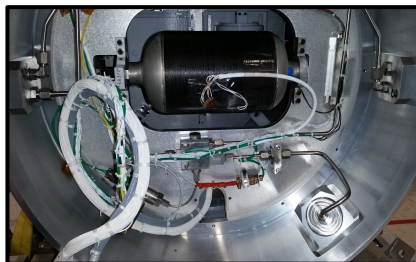
CNT Composite Overwrapped Ring



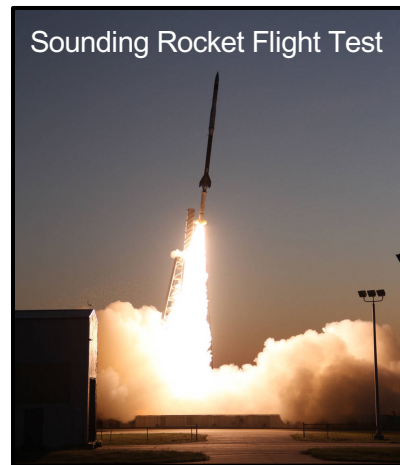
Composite Process Prototyping



High Strength CNT Yarn



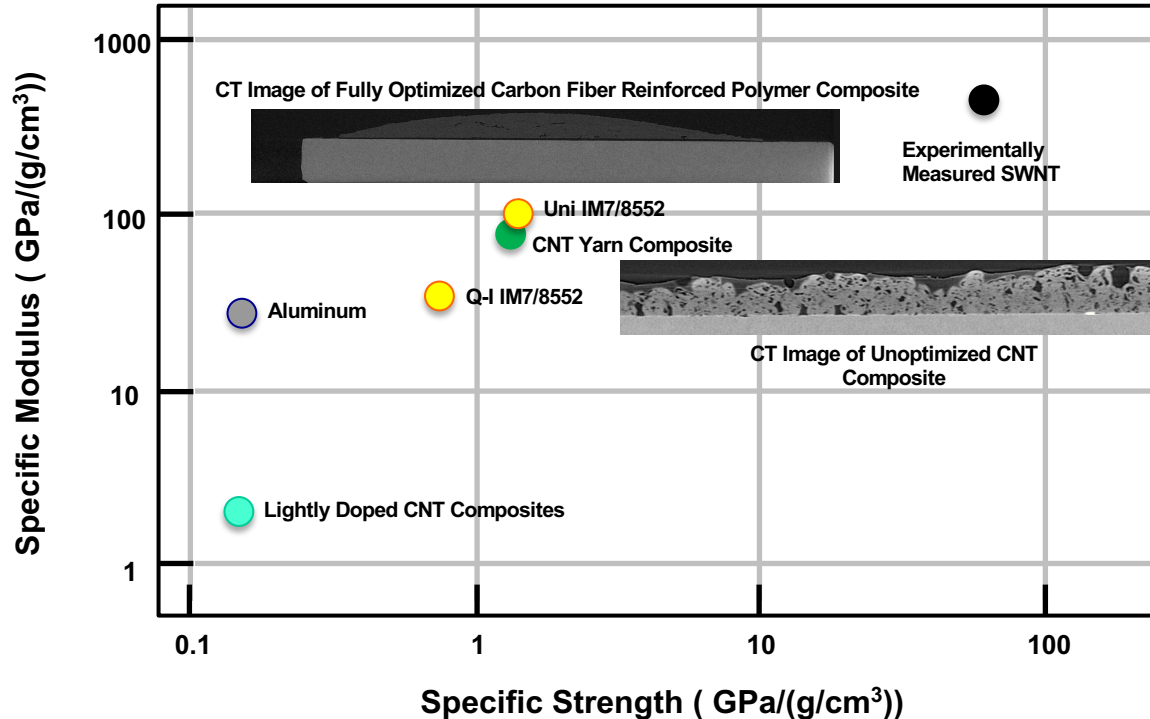
CNT Composite Overwrapped Pressure Vessel Cold Gas Thruster



Sounding Rocket Flight Test



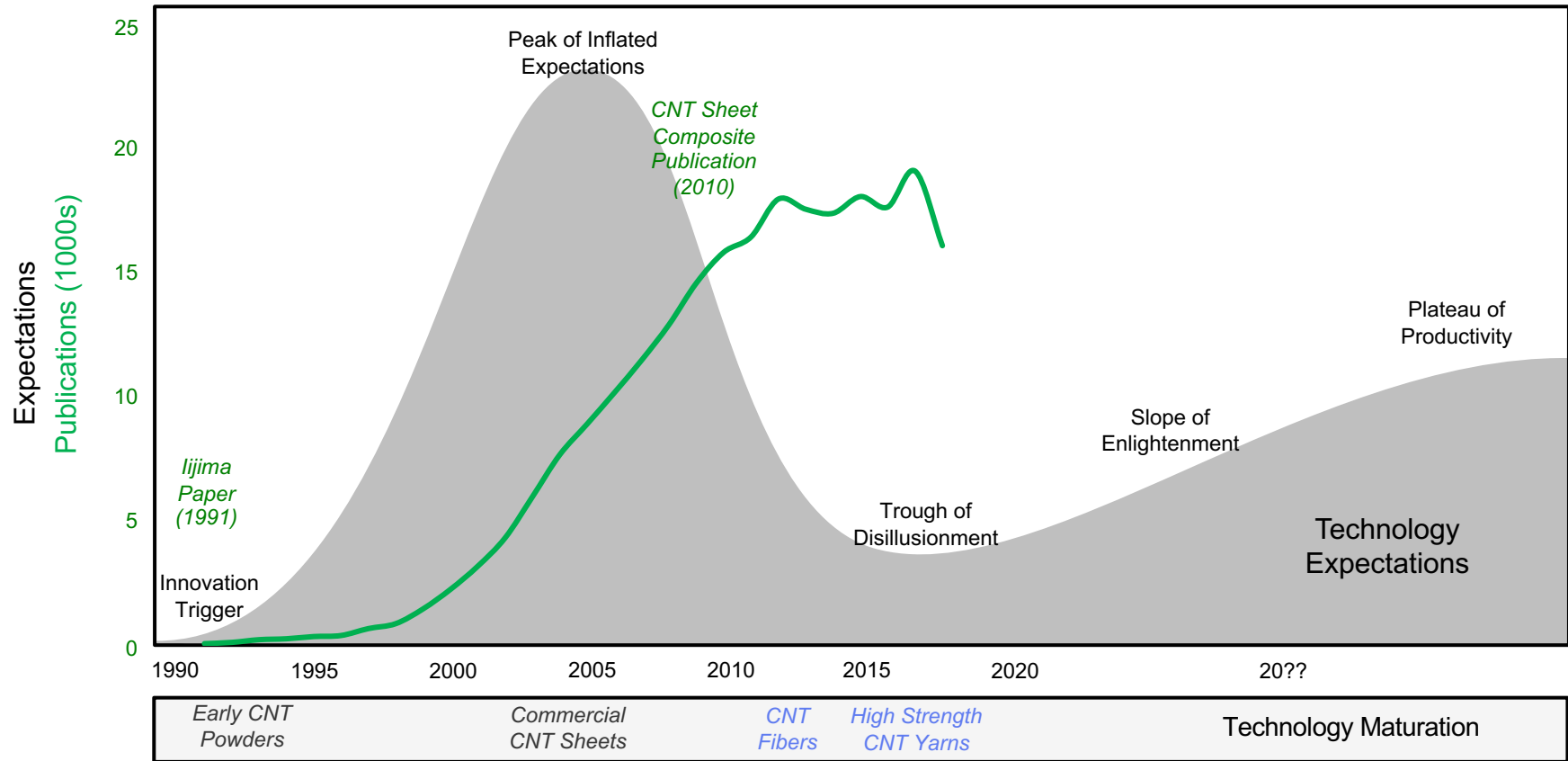
Sounding Rocket Integration



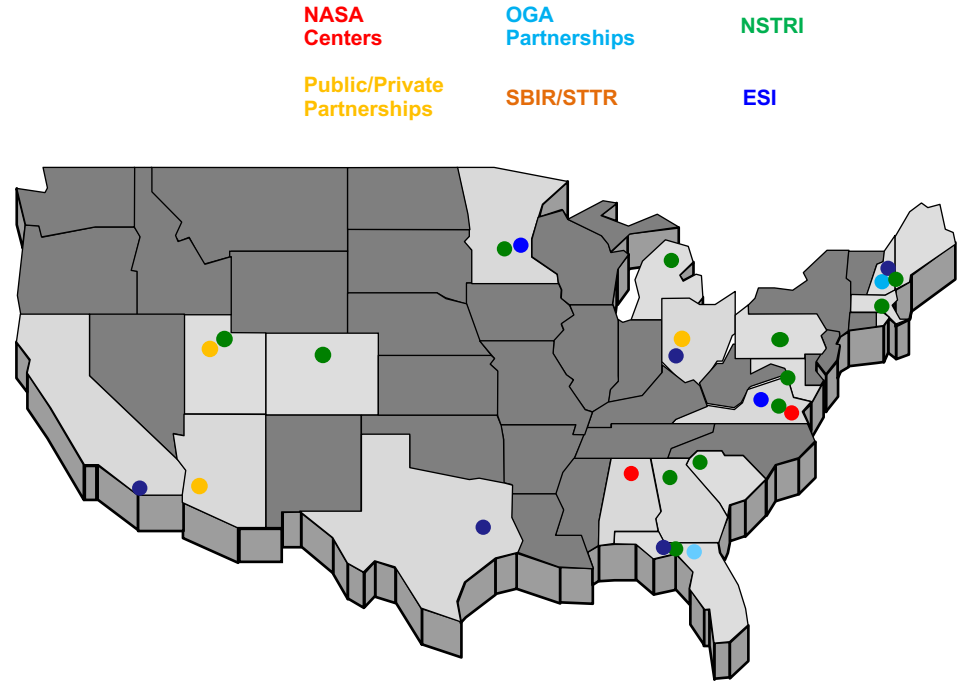
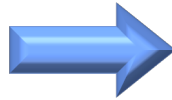
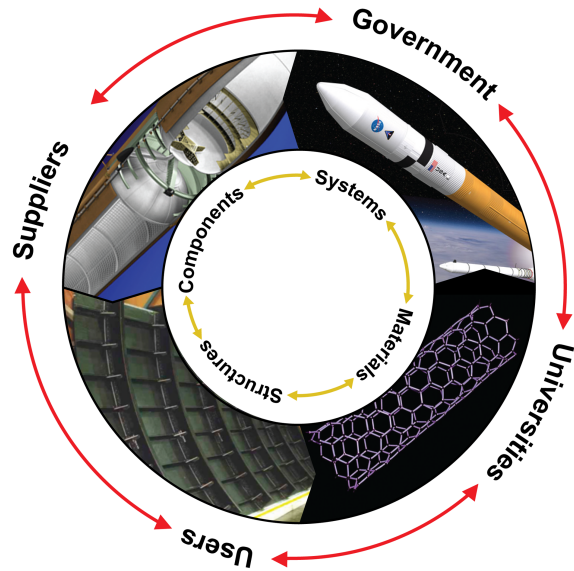
Measurable Advancements

- Improvement in mechanical properties
 - Systems level guided, goal focused research.
 - Project objective provided basis for objective decisions.
- Increase in MRL
 - Volume – material available in spool lengths of hundreds of meters
 - Consistency – materials met A-basis allowable of at least 20 N breaking force

Use Driven Technology Maturation



Systems Defined Goal Provides Common Objective



Collaborative multidisciplinary partnerships to leverage fiscal resources, ideas, knowledge & expertise



Technology pull can guide accelerated maturation of emerging technologies.