



**JANNAF Liquid Propulsion  
Subcommittee Meeting  
Materials Session**

**Composite Cryotank Technologies and  
Demonstration Project**

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**John Fikes, Deputy Project Manager**

**John Vickers, Project Manager**

**NASA MSFC**

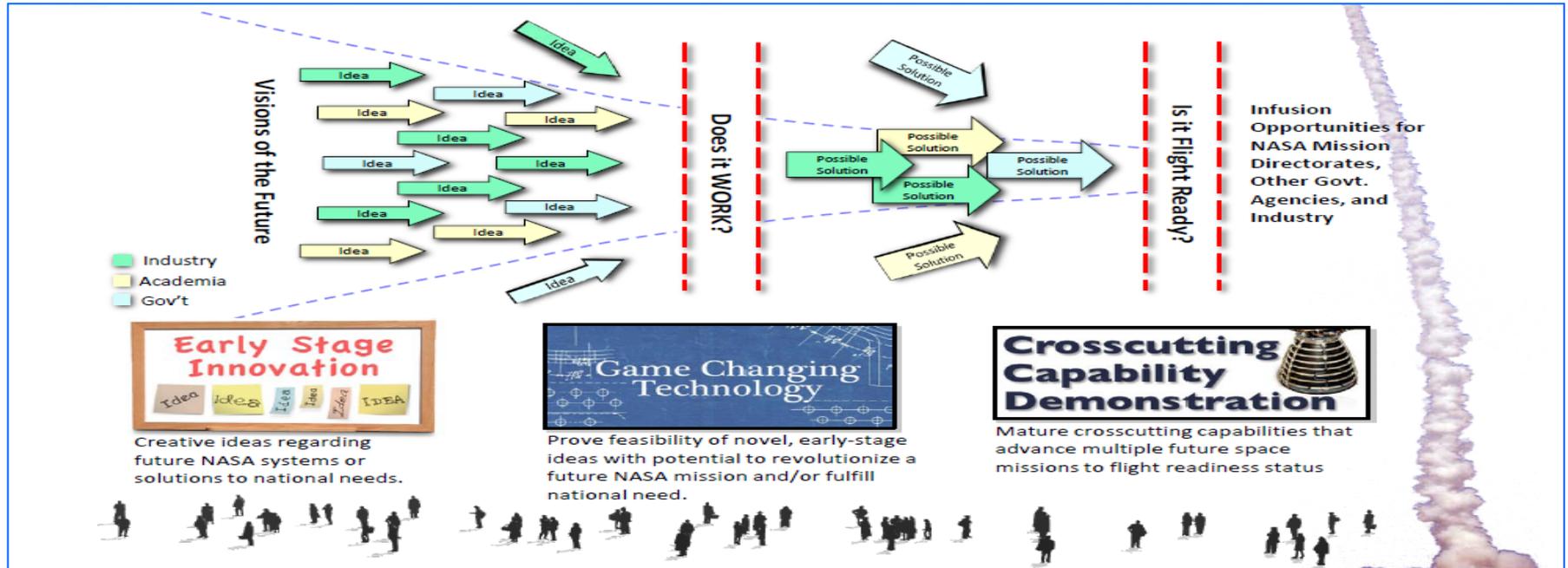
**December 7, 2011**



# Space Technology Program Approach

NASA Game Changing Development Program

Composite Cryotank Project



Cornell Professor Mason Peck, who takes over NASA's Office of the Chief Technologist in **January 2012**.

“It's key to recognize that innovation drives economic success. It inspires people, it provides new directions for new businesses, and that's always been the case. We're lucky that Congress agrees with the president that NASA needs this kind of technology program. It provides innovation that creates jobs, stimulates the economy -- and for NASA particularly, provides a path for NASA's future.”



# The Game Changing Program

NASA Game Changing Development Program

Composite Cryotank Project

## The Game Changing Mission

*To focus on transformative space technologies that will lead to advances in space and terrestrial capabilities, serve as a stimulus to the US economy while providing inspiration and opportunity to our nation's youth*

### Goals

- Develop Game Changing technologies that produce dramatic impacts for NASA's Space Exploration and Science Missions
- Capitalize on opportunities to leverage funding and cost-share from external organizations in technology area mutually benefiting NASA and the other organizations
- Formulate and implement technology projects that deliver the required performance to stakeholders on schedule and within cost
- Deliver technology knowledge that is used internally for NASA missions as well as externally throughout the aerospace community



# Composite Cryotank Technologies and Demonstration

NASA Game Changing Development Program

Composite Cryotank Project



- Objective:** Advance technologies for lightweight cryotanks for heavy lift vehicles + spin-off capabilities for multiple stakeholders - NASA, DOD, and Industry
- Concept:** Develop and demonstrate composite tank critical technologies – Materials, Manufacturing, and Structures; Autoclave and/or Out-of-Autoclave
- Approach:** Focus on achieving affordability, technical performance, through agreement between experiment and analysis
- Goal:** Produce a major advancement in a demonstrated readiness; successfully test 5-meter diameter composite hydrogen fuel tank, achieve 30% weight savings and 25% cost savings compared to state-of- the-art

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December, 2011

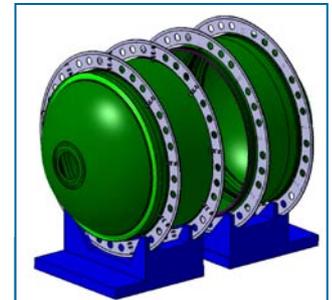


# Composite Cryotank Capability Need

NASA Game Changing Development Program

Composite Cryotank Project

- NASA and industry continuously strive to reduce the weight and cost of the launch vehicles
  - Ares Upper Stage incorporated an extremely difficult common bulkhead configuration to save weight, approx. 1400 lbs (#1 project risk)
  - Shuttle External Tank - Standard weight tank 77,000 lb, light weight tank 66,000 lb, super light weight tank 58,500 lb
- "Of all the technologies that may reduce the mass fraction composite materials for the primary structures and for the liquid hydrogen tanks is projected to have the greatest potential" (Harris, Starnes, and Shuart, Journal of Aircraft, July-August 2002.)
- Tank Materials - Composites offer the potential for the greatest mass reduction of all of the materials (Committee on Materials Needs and R&D Strategy for Future Military Aerospace Propulsion Systems; National Research Council, May 2011)
- HEFT Affordability – Develop architecture scenario options that have potential to increase affordability & HLV current designs may not be affordable, based on existing cost models, historical data, and traditional acquisition approaches
- Projected budgets for the U.S. Air Force's Evolved Expendable Launch Vehicle (EELV) program will rise by more than 50 percent over the next few years as the cost of materials has increased sharply. (Space News, Fri, 14 January, 2011)
- Headline New Delhi "Boeing has offered to partner with India on manned space missions, including on the very significant "composite cryogenic tanks" for launch and propulsion control." (India Strategic, February 2011)





# Why Composite Cryotanks

- NASA chief technologist Robert Braun: “We intend to take considerable risks” to innovate
- Dr. Pete Rustan, retired Deputy, NRO,: “U.S. technological leadership was not achieved by people who were afraid of failure.”
- DARPA chief Regina Dugan: “Failure is okay for us”
- Gene Austin, X-33 program manager, "X-vehicle programs are about taking risks and pushing the envelope. That is how we break through barriers that previously held us back. While composite technologies are a promising part of future space transportation, they require further research. “
- Final Report of the X-33 Liquid Hydrogen Tank Test Investigation Team (May 2000)
  - The tank design is highly innovative, pushing the limits of technology and combining many unproven technology elements. The interaction and integration of these elements created a highly complex system...
  - The most probable cause of the failure was determined to be a combination of the following phenomena:
    - Microcracking of the inner facesheet with gaseous hydrogen (GH<sub>2</sub>) infiltration
    - Cryopumping of the exterior nitrogen (N<sub>2</sub>) purge gas
    - Reduced bondline strength and toughness
    - Manufacturing flaws and defects
    - Infiltration of GH<sub>2</sub> into the core, which produced higher than expected core pressures

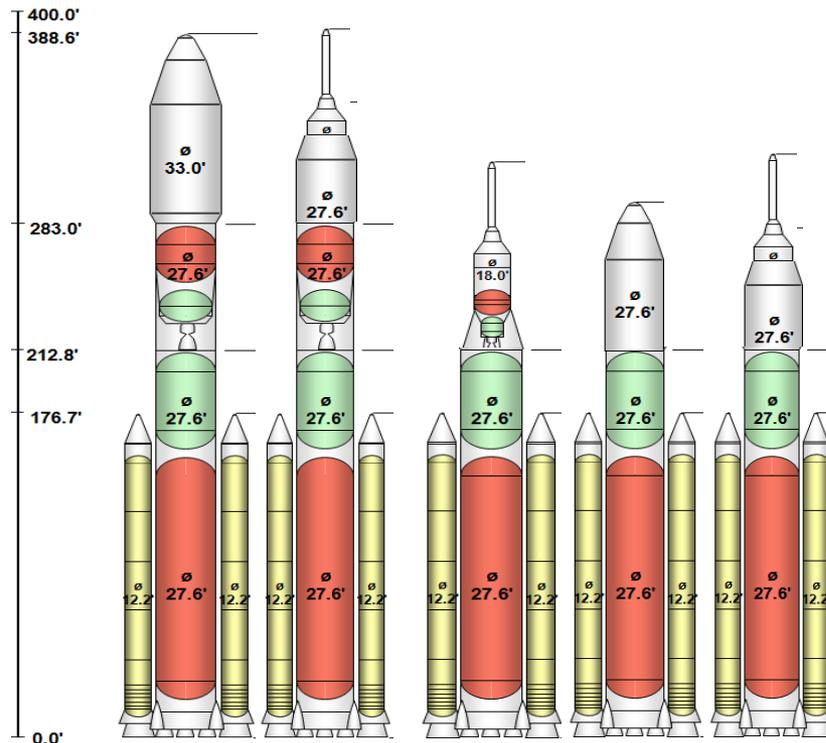


# Composite Cryotank Capability Need

NASA Game Changing Development Program

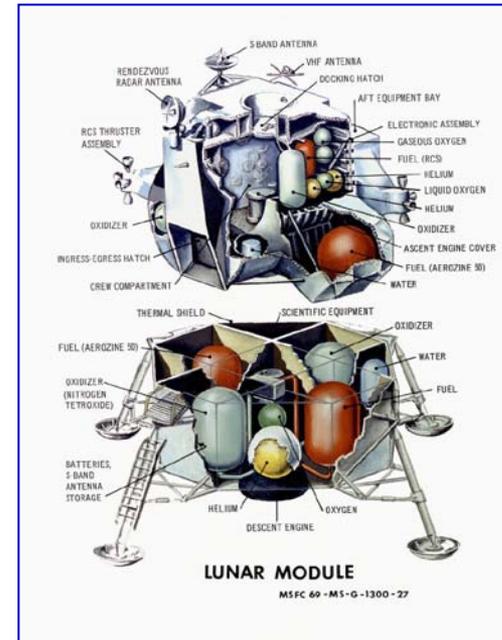
Composite Cryotank Project

Space Launch System (SLS)  
70 tonnes(t) evolvable to 130t



## SLS Affordability Tenets

- ✓ Evolvable Development Approach
- ✓ Manage Within Constrained Budgets
- ✓ Leverage Existing National Capabilities
- ✓ Infuse New Design Solutions for Affordability



**Approximately 60% of the dry mass of a launch vehicle is the fuel and oxidizer tanks. A composite material can produce a cryotank structure that weighs 30% less than aluminum**



# Composite Cryotank Concept

NASA Game Changing Development Program

Composite Cryotank Project

- ✓ Utilize 10 meter diameter reference design
- ✓ Build 5 meter diameter demonstrator
- ☑ Out-of-Autoclave

## Capability Needs

### Mission

Mars  
Near Earth  
Lunar

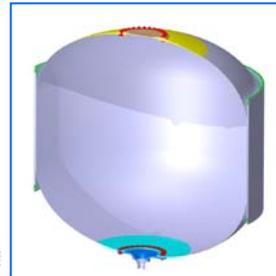
Heavy Lift Vehicle

Fuel Depot

Departure/Service Stages

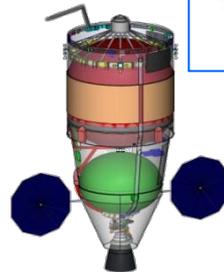
Habitats

Composite Cryotank



## Enabling Technology Needs

- ✓ **Concept Trade Studies**
- ✓ **Technology trade studies**
- ✓ **Structural Design**
- ✓ **Materials**
- ✓ **Manufacturing**
- ✓ **Long duration permeability demos**
- ✓ **Composite resins/chemistry**
- ✓ **Joints**
- ✓ **Damage tolerance**
- ✓ **Test Capability**
  
- ✓ **Non Destructive Evaluation (NDE)**
- ✓ **Structural Health Monitoring**
- ✓ **TPS**
- ✓ **Repair processes**
- ✓ **Leak detection**
  
- ✓ **Subsystems and interfaces**
- ✓ **System level trade studies and analysis**
- ✓ **Thermal attachments and penetrations**
- ✓ **MMOD design and analysis**
- ✓ **Space and Launch Environments**
- ✓ **Propellant management (vents/slosh)**
- ✓ **Certification**



Operational  
System

Flight  
Demonstration

Subsystem / Component  
Demonstration

Technology  
Maturation

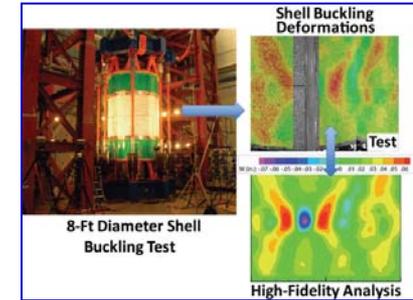
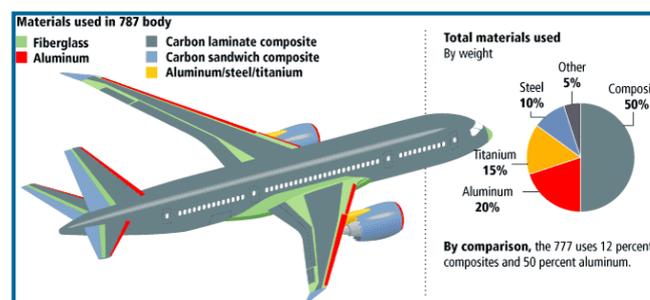
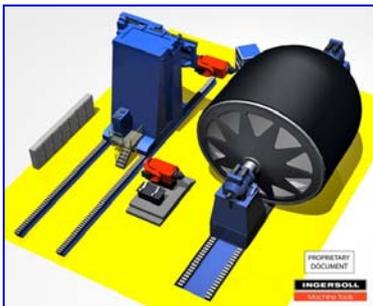


# Composite Cryotank Concept

NASA Game Changing Development Program

Composite Cryotank Project

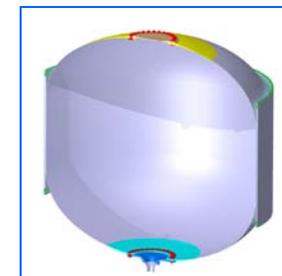
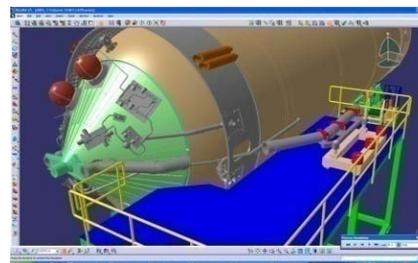
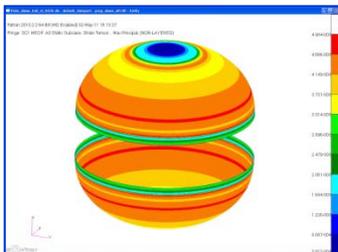
- **Development demonstration activity: Design, Build, Test (accelerated building block), 5 meter diameter test articles in a relevant environment (autoclave and/or OOA)**
- **Tackle Critical Technologies**
  - **Materials -- out of autoclave (mechanical properties/porosity/out time - e.g. 25% improvement), processing, microcracking density/permeability level (quantitative measurement of permeation at defined temperatures and strain levels)**
  - **Structures -- conservative design/analysis/allowables criteria (geometries, loads/environments, factors of safety/knockdowns) philosophy of incorporating 10M tank features (thickness/pressure), accelerated building block approach**
  - **Manufacturing -- large scale, automated systems, design for manufacturing/affordability (facilities, equipment, lay down rates, producibility/tooling issues)**
  - **Test -- full scale element test articles, precursor/subscale ~ 2 meter test, structural/cryo test of 5 meter diameter cryotank (key performance parameters)**
- **Multiple competing approaches, requirements, conceptual designs, modeling, cost, risk, TRL/MRL analysis, R&D equivalency testing (permeability, OOA materials)**
- **Increase the composite tank value enough to trigger a switch from existing solutions (Innovation!)**





# Why Now ?

- **Critical technologies are converging**
  - **Advances in out-of-autoclave processing**
    - **Key technology developments in resin formulation, DoD investment in OOA ~\$20 million**
  - **Materials and manufacturing technologies enable reduced manufacturing costs as well as diameters in excess current autoclave dimensions -- Airbus SAMPE 2011 “The Challenges for the future are Cost and Rate !”**
  - **Substantial growth in aerospace composites markets projected in next decade (NASA and China don’t use composites)**
  - **Structures discipline is actively leveraging the explosion in computational capabilities and advances in simulation, -- to rethink/revise standard practices, – to rethink/revise testing requirements... NESG**
- **The Mission -- aligned with SLS, HEFT, HAT, and NASA Space Technology Roadmaps**
  - **Push technology for future architectures time is now**
  - **Affordability is top figure of merit - Innovative new processes, techniques, or best practices to improve the safety, cost, schedule, or performance**
  - **Required - Lightweight Structures and Materials (HLLV), Lightweight Structures and Materials (In-Space Elements)**





# Composite Cryotank Project History

## April 5, 2010 Plan

- Engage industry to develop a technology development roadmap that leverages their recent and on-going IRAD activities
- NASA evaluates the roadmaps and selects one of them to design, analyze, and test a composite cryotank by May 1, 2012

## May 3, 2010

- Industry Technology Interchange Meeting at MSFC
- Industry is eager to work composite cryotanks - a shared sense of urgency
- General consensus on 20% - 30% weight savings achievable
- Concepts using autoclave materials are more mature than those using out-of-autoclave (OOA) materials; OOA materials offer the best potential for a 1-piece cryotanks but need more technology development

## September 2010

Phase I - \$6.5M FY10 (ETDP, \*ARRA funds), LARC SMAAART industry contracts (ATK, Boeing, Lockheed Martin, Northrop Grumman)

1-yr development activity with discrete deliverables; multiple competing approaches; requirements, conceptual designs, modeling, cost, risk, TRL/MRL analysis, R&D equivalency testing

## September 2011

- NASA Picks Boeing for Composite Cryogenic Propellant Tank Tests

✓Decisions: Autoclave vs OOA 5-meter diameter

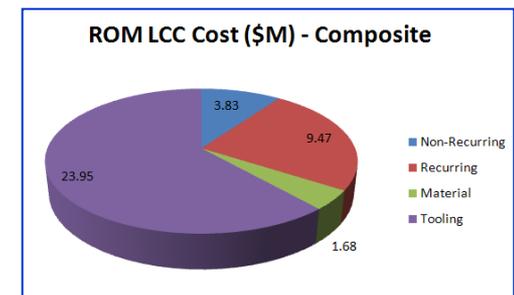
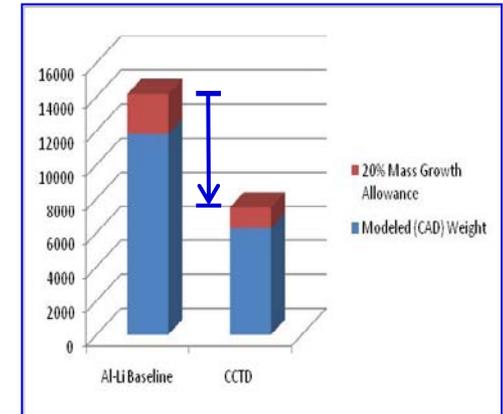


# Composite Cryotank Phase I

NASA Game Changing Development Program

Composite Cryotank Project

- Phase I Project significant milestone – 10-meter diameter Composite Cryotank final design reviews with Lockheed Martin, Boeing and Northrop Grumman
- Background: NASA provided a reference design for an aluminum-lithium cryotank design that was a point of departure for developing a 10-meter diameter composite cryotank design
- Targets for weight and cost savings were 25-30% and 20-25%, respectively.
- Summary & Conclusions:
- Drastic weight savings were consistently predicted over the Al-Li baseline, 43% to 47%! (~12,000lbs vs 7000 lbs)
- Moderately good life-cycle cost reduction predictions ranged from 15% to more than 30%
- Evidence was presented that permeation rates due to microcracking can be controlled or eliminated with thin ply composite material

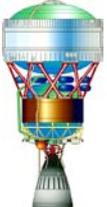




# Projected Composite Cryotank Benefits

NASA Game Changing Development Program

Composite Cryotank Project

	<b>Aluminum</b> <small>(unless otherwise specified)</small>	<b>Composite</b>	<b>Weight Savings</b>	<b>Dollar Value of Weight Savings <i>PER LAUNCH</i></b>
1996 DC-XA 2.5 meter			<b>33%</b>	<b>N/A (experimental vehicle)</b>
2004 Delta IV 5 meter	 	Upper Stage (both tanks)	<b>43% &amp; 26%</b>	<b>\$4.3M - \$9.3M</b>
		Common Booster Core (both tanks)	<b>35%</b>	<b>\$12.6M - \$27.8M</b>
2011 NASA 10 meter	<b>Al-Li</b>  <b>Upper stage LH<sub>2</sub> tank only</b>		<b>39%</b>	<b>\$17M - \$37M</b>

**Estimated unit production cost savings: \$7M**



# “CCTD in the News”

NASA Game Changing Development Program

Composite Cryotank Project

## Aviation Week & Space Technology

By Frank Moring Jr.

(Sep 21, 2011) “Boeing Will Test Composite Cryotanks For NASA”

(October 7, 2011) “Jumping-Off Point - New Space Economy”

(November 12, 2011) “Technology Readiness”



Boeing Selected by NASA for Composite Cryogenic Propellant Tank Tests

## The Engineer

[www.theengineer.co.uk](http://www.theengineer.co.uk)

Boeing set to develop new technologies for NASA

## NASA eyes a lighter heavy-lift

Marshall seeking new composite materials for future fuel tanks

By Lee Roop  
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America's next deep-space rocket may carry its fuel in composite tanks light enough to save millions in costs and make room for thousands of pounds of extra fuel and supplies.

NASA announced Tuesday that Huntsville's Marshall Space Flight Center will lead a new project to develop fuel tanks made of composite materials for future spacecraft. It's an effort to modify the greatest source of weight on a spacecraft, as 60 percent of a typical rocket's mass is in its propellant tank.

“Probably applicable to

heavy-lift, propellant depots, advanced in-space transportation and any future landing systems,” Marshall Director Robert Lightfoot said, listing some of the new tanks' potential uses.

Boeing will build two demonstration tanks in Seattle for testing at Marshall, NASA said. For Boeing, the contract is worth \$24 million.

“NASA and industry are constantly striving to reduce the weight and cost of launch vehicles,” Marshall's John Vickers told a Tuesday teleconference. Vickers is project manager of what is formally called the Composite Cryotank Technologies Demonstration effort at Marshall.

The goals of the test, Vickers said, are a 25 percent cost

See **LIGHTER** on B4

## Lighter

Continued from page B1

savings and tanks weighing 30 percent less than current aluminum and aluminum/lithium models.

Boeing's two test tanks will be five meters and two meters in diameter. They will be filled with liquid hydrogen and tested in “a realistic environment,” Vickers said. Testing will begin at Marshall in late 2013.

“There's lots of opportunity here for us to really push the envelope on what we're trying to do,” Lightfoot said.

Among the challenges facing composite tanks are micro-cracks that could lead to leakage. Characteristics of the Boeing design to stop micro-cracks include a “fluted core sandwich wall geometry” for the tank cylinder, Vickers said.

Vickers noted that other NASA centers are also working on the demonstration project. It takes cooperation, he said, to do this kind of cutting-edge technological development.

Marshall will manage the project and lead the overall technical effort.

The Glenn Research Center in Ohio will lead the materials work, and the Langley Research Center in Virginia will lead design and structure research.

The Kennedy Space Center Florida is handling operations and repair, and Vickers said NASA may flight-test the composite tanks after they pass ground tests.

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Sept. 20, 2011

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RELEASE: 11-305

### NASA PICKS BOEING FOR COMPOSITE CRYOGENIC PROPELLANT TANK TESTS

WASHINGTON – NASA has selected The Boeing Company of Huntington Beach, Calif., for the Composite Cryotank Technologies Demonstration effort. Under the contract, Boeing will design, manufacture and test two lightweight composite cryogenic propellant tanks. The demonstration effort will use advanced composite materials to develop new technologies that could be applied to multiple future NASA missions, including human space exploration beyond low Earth orbit.

Boeing will receive approximately \$24 million over the project lifecycle from NASA's Space Technology Program for the work which starts this month. The tanks will be manufactured at a Boeing facility in Seattle. Testing will start in late 2013 at NASA's Marshall Space Flight Center in Huntsville, Ala.

“The goal of this particular technology demonstration effort is to achieve a 30 percent weight savings and a 25 percent cost savings from traditional metallic tanks,” said the Director of NASA's Space Technology Program, Michael Gazarik at NASA Headquarters in Washington. “Weight savings alone would allow us to increase our upmass capability, which is important when considering payload size and cost. This state-of-the-art technology has applications for multiple stakeholders in the rocket propulsion community.”

By investing in high payoff, disruptive technology that industry does not have today, NASA matures the technologies required for future missions, while proving the capabilities and lowering the cost of government and commercial space activities.

Continuing the advancement of technologies required for NASA's missions in deep space exploration, science and space operations, the composite cryotank demonstration effort will advance the areas of materials, manufacturing and structures.

The tanks incorporate design features and new manufacturing processes applicable to designs up to 10 meters in diameter. Tanks could be used on future heavy-lift vehicles, in-space propellant depots and other Earth-departure exploration architectures.

“This technology demonstration effort is different in the fact that we're focused on affordability concurrently with performance,” said John Vickers, NASA project manager for the Composite Cryotank Technologies Demonstration effort at Marshall. “This technology has excellent transition potential for NASA and commercial product lines. Critical technology advances such as out-of-autoclave composites are being matured, and when demonstrated in an operational environment will let us go well beyond the state-of-the-art.”

Marshall will lead the project with support from NASA's Glenn Research Center in Cleveland; NASA's Langley Research Center in Hampton, Va.; and NASA's Kennedy Space Center in Florida. The composite cryogenic tank effort is part of the Space Technology Game Changing Development Program, managed by the Office of the Chief Technologist.

For more information about NASA's Marshall Space Flight Center, visit:

<http://www.nasa.gov/marshall>

For information about NASA's Office of the Chief Technologist and Space Technology Program, visit:

<http://www.nasa.gov/ocet>

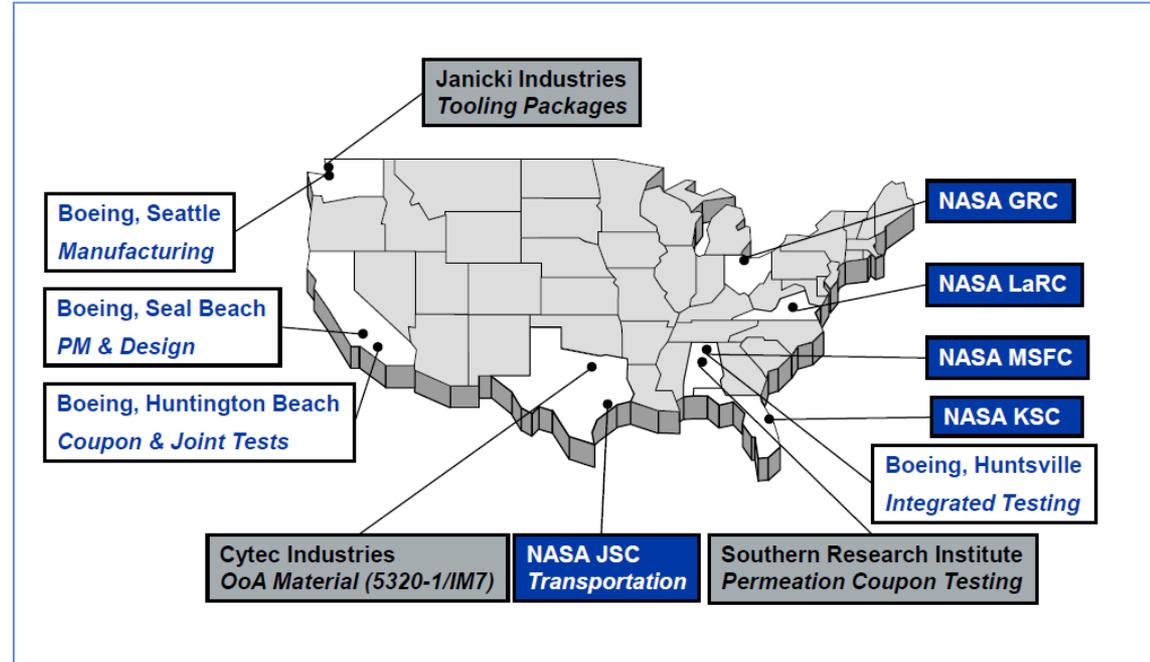
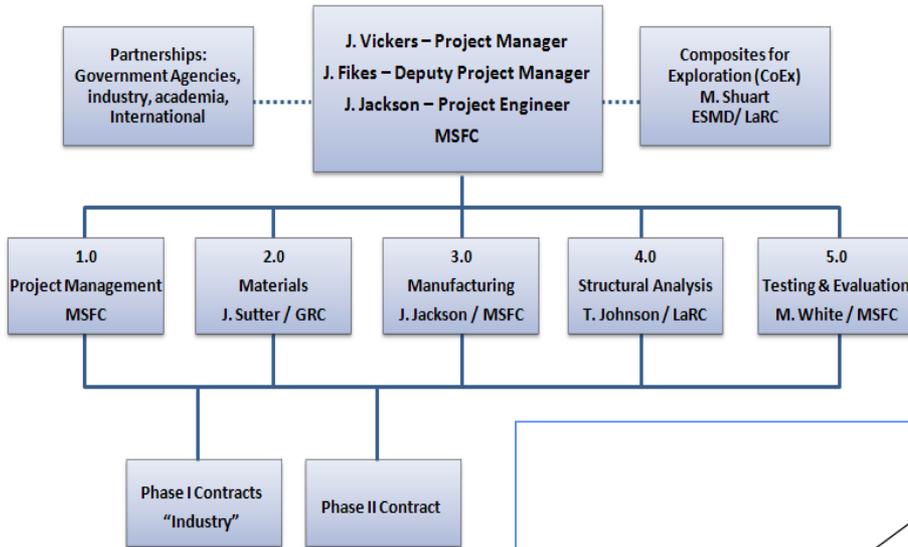
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# NASA & Industry Team

NASA Game Changing Development Program

Composite Cryotank Project





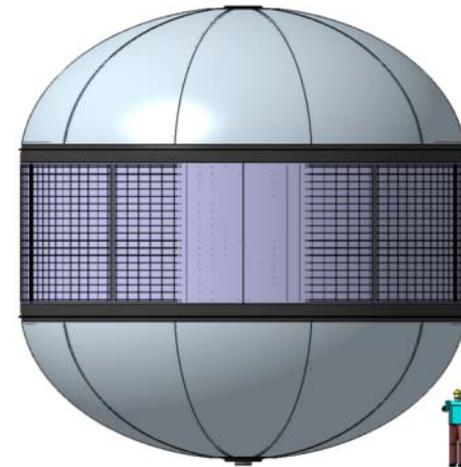
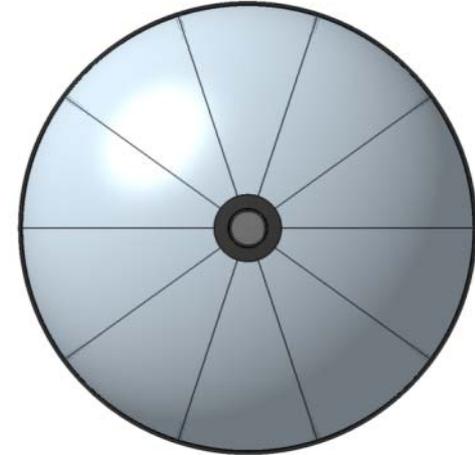
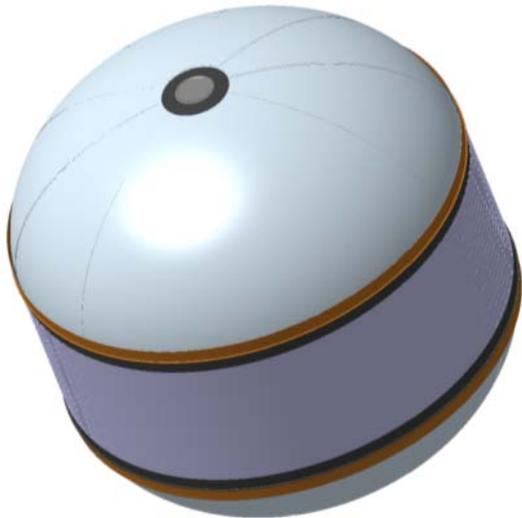
# Al-Li Tank Design Overview

NASA Game Changing Development Program

Composite Cryotank Project

## Orthogrid Stiffened 33 Foot tank Design

- 33 Foot Inner Diameter
- .707 Elliptical dome
- Tank Volume =  $38.7 \text{ E } 6 \text{ in } ^3$
- Weight  $\approx 10,925 \text{ lbs}$
- Length  $\approx 413 \text{ in}$
- Design is based on TRL 9+ materials and manufacturing techniques.

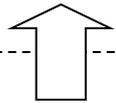




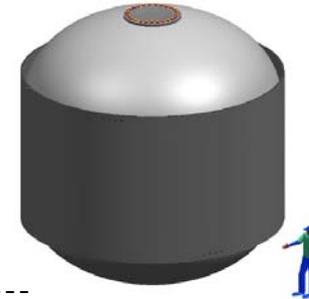
# Building Block Approach

NASA Game Changing Development Program

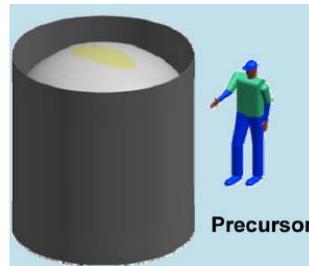
Composite Cryotank Project



Results Available to Support 5.5m Tank CDR

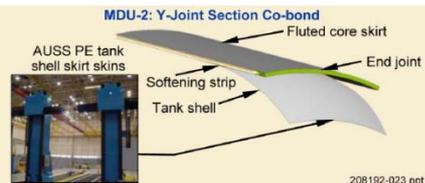


5.5 meter Tank

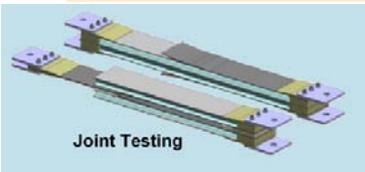


Precursor

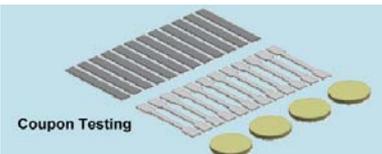
2.4 meter Precursor Tank



Manufacturing Demonstration Units



Joint Testing



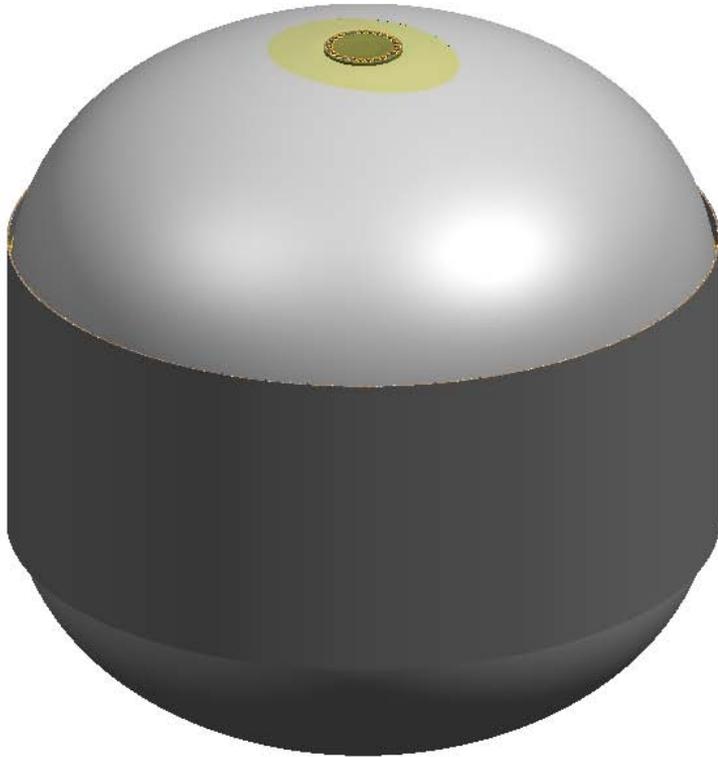
Coupon Testing



# CCTD Tank Designs

NASA Game Changing Development Program

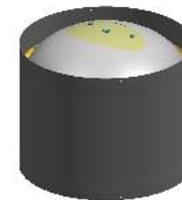
Composite Cryotank Project



**Phase I Ten Meter Diameter Reference Tank**



**Phase II 5.5 Meter Diameter Test Tank**



**Phase II 2.4 Meter Diameter Precursor Tank**



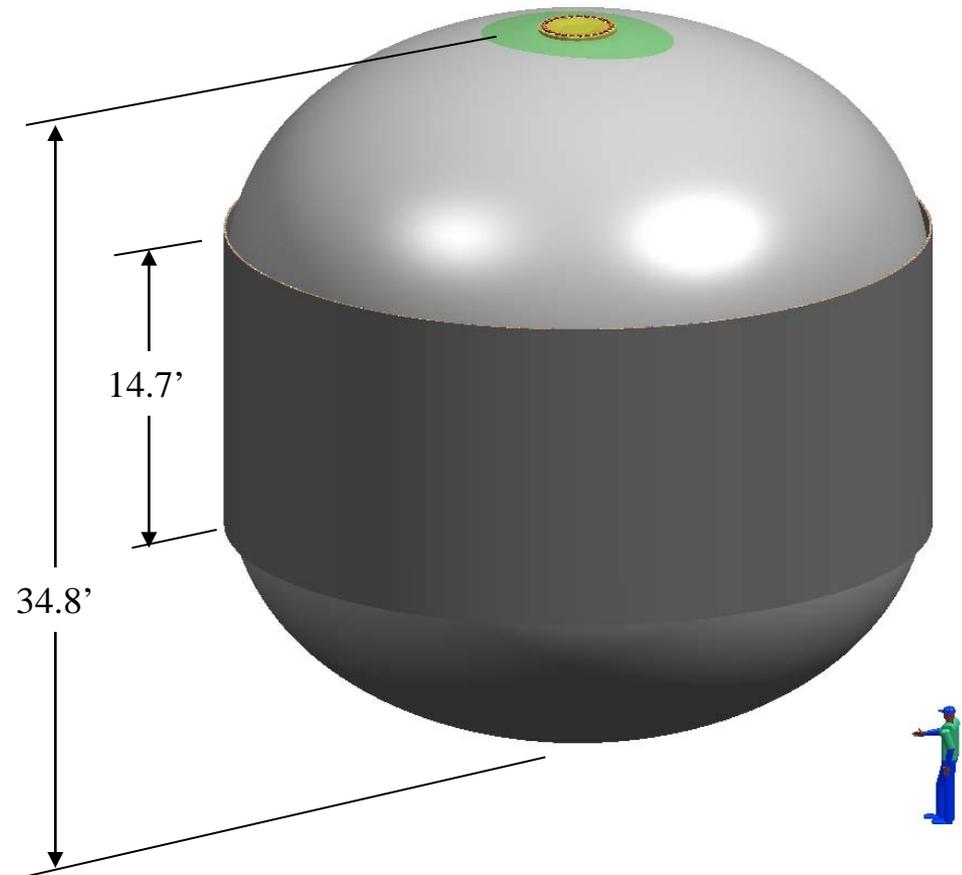
# "10-Meter" Composite Cryotank

NASA Game Changing Development Program

Composite Cryotank Project

## Design Information:

- Diameter: 33 ft (~10 m)
- Height: 34.8 ft (10.6 m)
- Volume: 22,396 ft<sup>3</sup> (634 m<sup>3</sup>)
- ➔ 167,533 Gallons
- Operating Pressure: 42 psi (290 kPa)
- Empty Weight: 6,696 lbs (3,037 kg)
- LH2 Weight @ .00256 lb/in<sup>3</sup>:  
99,072 lbs (44,938 kg)
- Full Tank Weight: 105,768 lbs  
(47,976 kg)



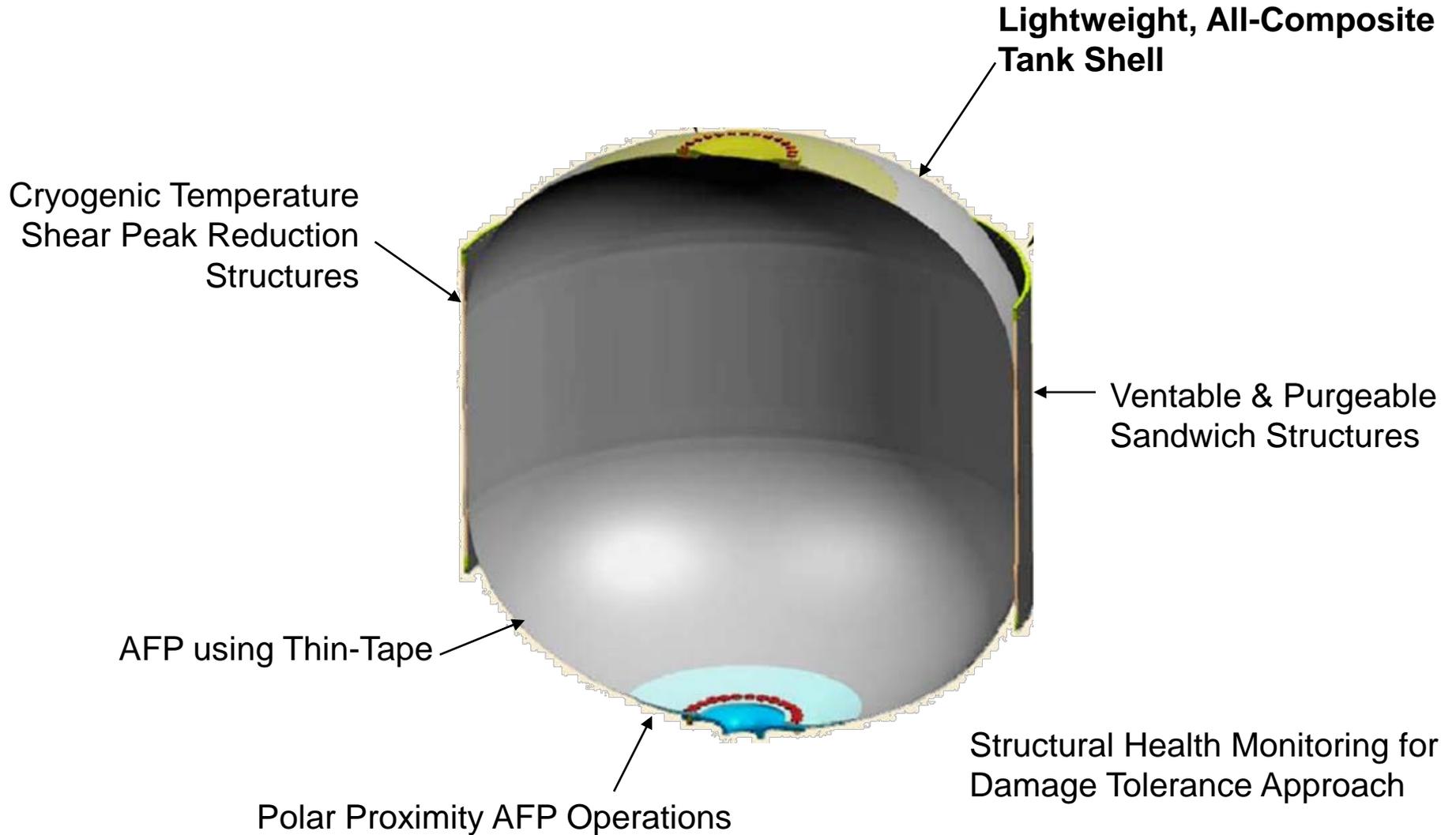
*("Anthroman" is 5' 8.5" tall)*



# CCTD Tank Design

NASA Game Changing Development Program

Composite Cryotank Project

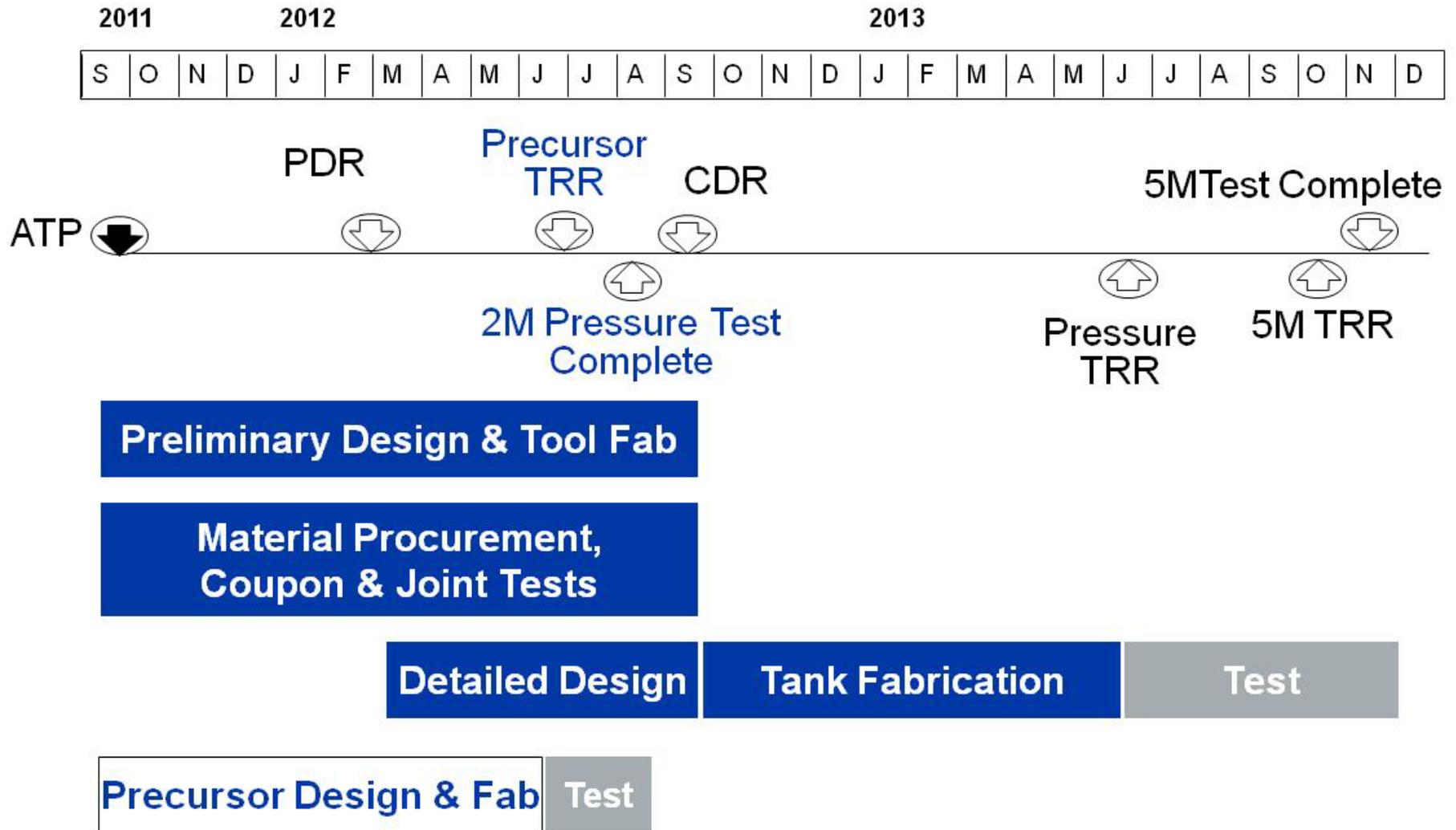




# Master Schedule - Overview

NASA Game Changing Development Program

Composite Cryotank Project



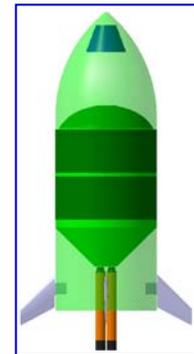
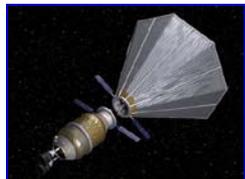
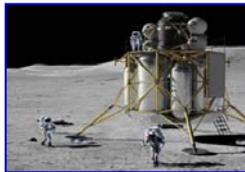
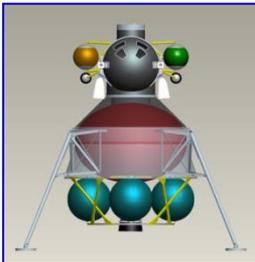


# Transition Potential

NASA Game Changing Development Program

Composite Cryotank Project

- Communicate with stakeholders and customers
  - (Lockheed Martin, Boeing, Northrop Grumman, Space X, MSFC, LARC, NESC, JSC, KSC, and DOD)
  - Synergy with HLV study concepts
- Composite cryotank technologies for HLV (8.4m-10.0m) architectures + spin-off capabilities to meet multiple customer needs
  - NASA, DoD, and Commercial customers + in-space propulsion, propellant depot, and LOX or RP tank capabilities
- In-Space Cryogenic Propellant Depots and Landers are needed in New Exploration Architecture (The In-Space Cryogenic Propellant Storage and Transfer Demonstration Mission Concept Studies BAA )
- Multiple flight opportunity identified in phase I (benefits commercial flight)





# Summary

- **The Composite Cryotank Technologies and Demonstration Project will make significant advancement to achieve 30% weight and 25% cost savings over SOA cryotanks at the 10-meter diameter scale**
- **Critical Technologies**
  - **Materials**
  - **Structures**
  - **Manufacturing**
  - **Testing -- 5-meter diameter composite hydrogen tank**
- **Technology provides important benefits to NASA and Commercial needs plus diverse sectors of the economy/enhances global competitiveness -- Composites are important materials for the future of aerospace strategic leadership -- Leapfrogging the SOA puts NASA in a leadership position**

"The goal of this particular technology demonstration effort is to achieve a 30 percent weight savings and a 25 percent cost savings from traditional metallic tanks," said the Director of NASA's Space Technology Program, Michael Gazarik at NASA Headquarters in Washington. "Weight savings alone would allow us to increase our upmass capability, which is important when considering payload size and cost. This state-of-the-art technology has applications for multiple stakeholders in the rocket propulsion community."