Composites Australia Conference
Composite Cryotank Project
Structures for Launch Vehicles

John Vickers
NASA Marshall Space Flight Center
March 5, 2013
Marshall supports three of the NASA Mission Areas
Vision of the National Network for Manufacturing Innovation

NASA Game Changing Development Program

Composite Cryotank Project

June 2011

Report to the President on Ensuring American Leadership in Advanced Manufacturing

Executive Office of the President
President’s Council of Advisors on Science and Technology

February 2012

A National Strategic Plan for Advanced Manufacturing

Executive Office of the President
National Science and Technology Council

July 2012

Report to the President on Capturing Domestic Competitive Advantage in Advanced Manufacturing

Executive Office of the President
President’s Council of Advisors on Science and Technology

January 2013

National Network for Manufacturing Innovation: A Preliminary Design

Executive Office of the President
National Science and Technology Council
Advanced Manufacturing National Program Office
• **Enabling Our Future in Space:** By investing in **high-payoff, disruptive technologies** that industry cannot tackle today, Space Technology matures the technology required for NASA’s future missions in science and exploration while proving the capabilities and lowering the cost for other government agencies and commercial space activities.

• **NASA at the Cutting Edge:** **Pushing the boundaries** of aerospace technology and seizing opportunities, Space Technology allows NASA and our nation to remain at the cutting edge.
Space Technology Programs

NASA Game Changing Development Program

Composite Cryotank Project

Game Changing Development Program
Technology Demonstration Missions Program
Small Spacecraft Technologies Program

Space Technology Research Grant Program
NASA Innovative Advanced Concepts (NIAC) Program
Center Innovation Fund Program

Centennial Challenges Prize Program
Small Business Innovation Research & Small Business Technology Transfer (SBIR/STTR) Program
Flight Opportunities Program

Develop Technology Breakthroughs
New Concepts
New Markets
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
Composites Manufacturing Supports Agency and National Needs

NASA Game Changing Development Program

Composite Cryotank Project

- Supports all Mission Directorates: Aeronautics Research, Science, Human Exploration and Operations, Space Technology
- Supports Advanced Manufacturing National Initiative, and National Network for Manufacturing Innovation
- Other Government Agencies: DOD, DARPA, DOE
- Identified in NASA’s Space Technology roadmap TA12 (light weight materials and structures among the highest priorities identified by NRC)
- Spans multiple Centers and disciplines
- Industry and Research community
Develop New Resins and Fibers

Pre-Pregging of Composite Tows

Develop Advanced Manufacturing and NDE Processes

Manufacture of Flight Vehicle Structures

Testing and Analyses of Composite Structures

Post-Cure, In-Situ NDE of Composite Structures

Design and Manufacture of Composite Structures

TRL 1-3

TRL 4-6

TRL 7+
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

John Vickers Level III, PM
John.h.vickers@nasa.gov

March, 2013
Composite Cryotank Capability Need

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.)


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 (GH2) infiltration
    - Cryopumping of the exterior nitrogen (N2) purge gas
    - Reduced bondline strength and toughness
    - Manufacturing flaws and defects
    - Infiltration of GH2 into the core, which produced higher than expected core pressures
The Problem

- Agency’s need for an affordable lightweight heavy lift vehicle - Greater payload capability is required to enable future exploration missions
- No composites experience at this scale
- Cryo – LH$_2$ presents severe environment
- OoA technologies are untested
- Many materials, design and manufacturing challenges
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**

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

**Capability Needs**

- Heavy Lift Vehicle
- Fuel Depot
- Departure/Service Stages
- Habitations

**Mission**

- Mars
- Near Earth
- Lunar

**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

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**Operational System**

**Flight Demonstration**

**Subsystem / Component Demonstration**

**Technology Maturation**
Composite Cryotank Concept

- 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

NASA Game Changing Development Program

Composite Cryotank Project

• 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
• Structures discipline is actively leveraging the explosion in computational capabilities and advances in simulation, -- to rethink/revise standard practices, – to rethink/revise testing requirements… NESC
• 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)
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

<table>
<thead>
<tr>
<th>Year</th>
<th>Rocket</th>
<th>Diameter</th>
<th>Upper Stage</th>
<th>Common Booster Core</th>
<th>Weight Savings</th>
<th>Dollar Value of Weight Savings PER LAUNCH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>DC-XA</td>
<td>2.5 meter</td>
<td>Aluminum (unless otherwise specified)</td>
<td>N/A (experimental vehicle)</td>
<td>33%</td>
<td>N/A</td>
</tr>
<tr>
<td>2004</td>
<td>Delta IV</td>
<td>5 meter</td>
<td>Composite (both tanks)</td>
<td>43% &amp; 26%</td>
<td>$4.3M - $9.3M</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Upper Stage (both tanks)</td>
<td>35%</td>
<td>$12.6M - $27.8M</td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td>NASA 10 meter</td>
<td>10 meter</td>
<td>Al-Li Upper stage LH$_2$ tank only</td>
<td>39%</td>
<td>$17M - $37M</td>
<td></td>
</tr>
</tbody>
</table>

Estimated unit production cost savings: $7M
Aviation Week & Space Technology
By Frank Morring 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”

NASA Game Changing Development Program
Composite Cryotank Project

Boeing Selected by NASA for Composite Cryogenic Propellant Tank Tests

The Engineer
www.theengineer.co.uk
Boeing set to develop new technologies for NASA

Lighter
Continued from page 8

NASA eyes a lighter heavy-lift

By Lee Roop
www.nasa.gov

America’s next deep-space rocket may carry its composite cryotanks 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 tank sets made of composite materials for future space craft. It’s an effort to modify the greatest source of weight on a spacecraft, so 40 percent of the total mass in a launch vehicle can be saved.

“We’re all pretty excited about this” says Marshall Director Robert Lightfoot, listing some of the new tank’s potential uses.

Boeing will build two demonstration tanks in Seattle for testing at Marshall, NASA said. For Boeing, the contract is worth $164 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 goal of the test, Vickers said, is to save 25 percent on cost.

“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 in Florida is handling operations and support, and Vickers said NASA may fly the composite tanks after they pass ground tests.

NASA PICKS BOEING FOR COMPETITIVE CRYOTANK DEMONSTRATION EFFORTS
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 the 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 crew's 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 spacecraft.

“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 set us up well beyond the state-of-the-art.”

Boeing 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 Changer 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 Technology and Space Technology Program, visit:
http://www.nasa.gov/establishment

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NASA & Industry Team

NASA Game Changing Development Program

Composite Cryotank Project

Partnerships: Government Agencies, industry, academia, international

J. Vickers - Project Manager
J. Fikes - Deputy Project Manager
J. Jackson - Project Engineer
MSFC

Composites for Exploration (CExE)
M. Stuart
ESMD/LaRC

1.0
Project Management
MSFC

2.0
Materials
J. Sutter / GRC

3.0
Manufacturing
J. Jackson / MSFC

4.0
Structural Analysis
T. Johnson / LaRC

5.0
Testing & Evaluation
M. White / MSFC

Phase I Contracts
"Industry"

Phase II Contract

Boeing, Seattle
Manufacturing

Boeing, Seal Beach
PM & Design

Boeing, Huntington Beach
Coupon & Joint Tests

Janicki Industries
Tooling Packages

Cytec Industries
OoA Material (S320-1/IM7)

NASA JSC
Transportation

Southern Research Institute
Permeation Coupon Testing

NASA GRC

NASA LaRC

NASA MSFC

NASA KSC

Boeing, Huntsville
Integrated Testing
Al-Li Tank Design Overview

Orthogrid Stiffened 33 Foot tank Design

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

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

**Design Information:**

- Diameter: 33 ft (~10 m)
- Height: 34.8 ft (10.6 m)
- Volume: 22,396 ft³ (634 m³) → 167,533 Gallons
- Operating Pressure: 42 psi (290 kPa)
- Empty Weight: 6,696 lbs (3,037 kg)
- LH2 Weight @ .00256 lb/in³: 99,072 lbs (44,938 kg)
- Full Tank Weight: 105,768 lbs (47,976 kg)

("Anthroman" is 5' 8.5" tall)
Building Block Approach

Proof Test
Flight Units

Full-Scale Qualification Test
Development Tests
Life-cycle tests with damage

Coupon Tests: B-Basis Level of Data
Flat Coupon Testing: OHC, CAI, Sandwich Flexure, Repairs, etc…

Proof tests to demonstrate no growth of damage accepted pre-proof and no initiation of damage during proof

Building Block Tests For Damage Tolerance Verification

Substantial materials database already exists for candidate materials

NASA design and certification standards are not an impediment, but they must be applied differently for composite structures:

- More emphasis on allowables at structural scales rather than material scales.
- Collaborative approach to tailoring with U.S. industry to leverage the experience already applied to commercial aircraft, military aircraft, and EELV.
Building Block Program supports 5.5m

NASA Game Changing Development Program

Composite Cryotank Project

2.4 meter Precursor Tank

Manufacturing Demonstration Units

5.5 meter Tank

Joint Testing

Coupon Testing

Available to Support 5.5m Tank

Coupon, Joint, and MDUs are Complete
Baseline Master Schedule - Overview

**NASA Game Changing Development Program**

**Composite Cryotank Project**

**Saves 13 months Compared to More Typical Serial Development**
Technologies Matured by CCTD

NASA Game Changing Development Program

Composite Cryotank Project

Large Scale, OoA (5320-1/IM7) Design & Manufacturing

Lightweight, All-Composite Tank Shell

Cryogenic Composite Joint

Vetable & Purgeable Sandwich Structures

Automated Fiber Placed, including Thin-Tape

Structural Health Monitoring to support Damage Tolerance

Thin-plies for Permeation Barrier

Matured & Demonstrated in Building Block Program
SHM Enables Higher Strength Allowable

Impact damage is both SHM and thermography detectable.

**Acoustic Energy Detection**
- 38 sensors
- Sensors on Dome
- Sensors on Skirt

**Thermography Detection**
- 1 ft-lb

**Bar Graph**
- B Basis: Ultimate Strain Allowable, Limit Strain (1.5 factor)
- 50% Higher

**Legend**
- Ultimate Strain Allowable
- Limit Strain (1.5 factor)

**Notes**
- Impact damage is both SHM and thermography detectable.

**Technical Details**
- MSFC-RQMT-3479
- SHM Enables Higher Strength Allowable
Composites Damage Tolerance Approach

- Assess possible accidental and fabrication induced damage threats
  - For payload fairing blunt impact damage is the most likely type of accidental damage
- Investigate effect of damage size with respect to structural scale
  - Boundary conditions can affect the impact energy level necessary to produce a given size of damage.
- Repair all detectable damage
- Demonstrate through element and sub-component testing that under simulated flight loads the structure is insensitive to undetectable size damage
  - Ten meter diameter curved composite sandwich panels (3ft by 5ft) representing fairing acreage were impacted at 5.5 ft-lb to produce barely visible damage (golf ball size shallow indentation) and loaded to buckling at Room and Elevated Temperatures.

Test specimens were found to be insensitive to barely visible damage.
Fluted Core Composites

Thin laminate angled web members with structural radius fillers evenly spaced between laminate face sheets

- Web
  - Thickness
  - Orientation
  - Material Form (Tape/Fabric)
  - Fiber Modulus

- Face sheets
  - Material Form (Tape/Fabric)

- Flute height & width

- 10’ H x 13.1’ D (4m)
- Delivered to NASA/LaRC COLTS
- Test planned for August

- Web Orientation Provides Efficient Compressive Load Capability
- Integral Web to Facesheet Construction Improves Damage Tolerance
2.4m Precursor Status / Accomplishments

Thin & Thick Ply AFP – July 17

OoA Cure – July 20

NDI
2.4m Precursor Status / Accomplishments

Sept 1, 2012  Initial Skirt Plies
2.4m Precursor Status / Accomplishments

Segmented Tool Extraction
2.4m Precursor Status / Accomplishments

At NASA/MSFC: http://www.nasa.gov/topics/technology/features/cryotank.html
2.4m Precursor Status / Accomplishments

Dec 12, 2012

Dec 18, 2012

NASA-MSFC West Test Area
Successful Design and Fabrication. Test Site Prep In Work.
• **Accomplishments**
  – 1<sup>st</sup> successful large AFP test article using 5320-1/IM7
  – 1<sup>st</sup> successful 70gsm fiber placed cryotank (hybrid laminate)
  – 1<sup>st</sup> successful spherical segmented tool use
  – 1<sup>st</sup> successful all composite bolted sump/fwd cover joint

• **Next Steps**
  – Tank Leak Check Complete
  – Test Site with Tank Leak Check Complete
  – Facility Test Readiness Review 2/19/13
  – Ambient Proof Test (190psi) 2/26/13
  – Cryogenic Proof Test (190psi) 3/5/13
  – Test Report Delivered 4/2/13
5.5m Tank Overall Dimensions

• Pressure wall mid-surface diameter = 216.54 in
• Pressure vessel cylinder height = 69.6 in
• Skirt end-to-end length = 131.88 in
• Dome to dome length = 229.70 in
• Volume = 3785 cu. ft.
• Two (2) 30-in dia access openings at fwd and aft dome
Test Site & Test Hardware Overview

Test Stand 4699, NASA MSFC
Test Site & Test Hardware Overview

- Existing MSFC load spiders
- CCTD load ring
- Load adapter finger-ring
- 5.5 m CCTD tank
- Load adapter finger-ring
- Load struts
5.5m Cryotank Status / Accomplishments

5m Segmented Tool Mandrel Fabrication
5.5m Cryotank Status / Accomplishments

5m Spindle Fabrication
5.5m Cryotank Status / Accomplishments

5m Segmented Tool Assembly
5.5m Cryotank Status / Accomplishments
5.5m Robotic AFP Cell Install

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Composite Cryotank Project
5.5m Cryotank Status Overview

CDR Held. 5.5m Tank Shell Mandrel Arrived Jan 27th.
5.5m Design, Fab, and Test Next Steps

- Approval to proceed with Component Fab  
  - Started

- Approval to proceed with Tank Shell Fab  
  - Late March
    - At completion of Delta CDR/MRR

- 5m Pressure and Integrated Load Testing  
  - 1Q2014
Summary

• Permeation
  – Mechanism is understood
  – Solutions validated by coupon tests
  – System demo in relevant environment planned within CCTD

• CCTD aims to mature & demonstrate several technologies
  – 8.4m subscale designs (*increased stress at lower OoA allowables*)
  – Ventable and purgeable structures eliminates trapped gas risks
  – AFP of large structure using thin ply
  – Segmented breakdown tool use and extraction for lightweight design
Transition Potential

**NASA Game Changing Development Program**

- 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 Project**

- 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)
Conclusions

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.“
NASA Game Changing Development Program

Composite Cryotank

5.5 M Tank
Materials Modeling and Simulation

NASA Game Changing Development Program

Composite Cryotank Project

Figure 3: Initiative overview
NASA Game Changing Development Program

Composite Cryotank Project

Manufacturing Modeling and Simulation

Agenda
- FetchMilestones and Data
- The Missing Middle Challenge - NMM/Redundancy
- NMM Design Process
- Institute Dignition Diagram
- NMM Characteristics
- Investment Plan and Selective career
- Workshop Mission Today