OPERATIONAL HISTORY OF LIQUID HYDROGEN TANK WITH GLASS BUBBLES INSULATION

Cryogenic Engineering Conference
Tucson

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Timeline History

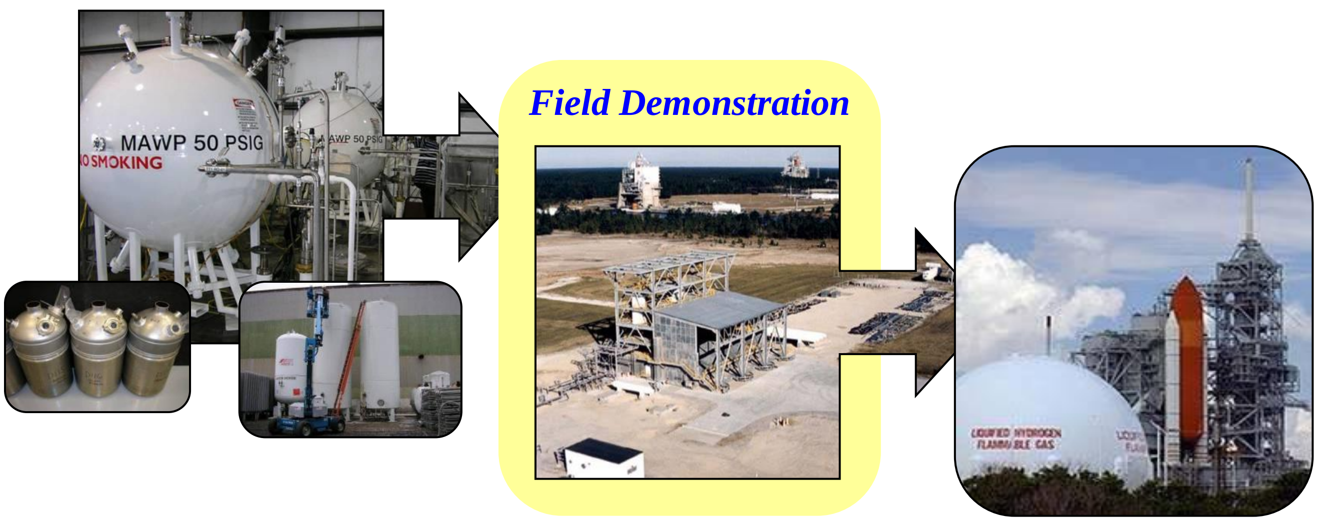
- **1972 Accidental production of first glass bubbles at 3M plant in Guin, AL.**
- **1975 Cryogenic research testing by G.R. Cunnington and C.L. Tien.**
- **2003 Proposal to Rocket Propulsion Technology Development Board, Stennis Space Center**
- **2003 OSF NASA IR&D solicitation, November 2003 and Proposal, New Materials & Technologies for Cost-Efficient Cryogenic Storage & Transfer**
- **2003 SBIR Phase I, Cryogenic Propellant Insulation Project, Technology Applications Inc.**
- **2004 Cost-Efficient Storage and Transfer (CESAT) proposal accepted in April, start of project.**
- **2004 SBIR Phase II, Cryogenic Propellant Insulation Project, Technology Applications Inc.**
- **2005 Field demonstration of 6000 gallon LN2 tank insulation at Acme Cryogenics in Allentown, PA (TAI, SBIR).**
- **2007 Completion of CESAT project and presentation of six papers at the Cryogenic Engineering Conference in Chattanooga, TN for publication in *Advances in Cryogenic Engineering.***
- **2008 Field demonstration of 50,000 gallon LH2 tank insulation at Stennis in September**
- **2009 Paper presented at Cryogenic Engineering Conference, Tucson, AZ on the field demonstration at SSC and the one year boiloff performance results.**
- **2011 Vibration/mechanical impact testing and experimentation with bulk fill materials.**
- **2013 Paper presented at Cryogenic Engineering Conference, Spokane on the vibration test results for glass bubbles in comparison with perlite powder and aerogel beads.**

Overview

To bridge the gap between lab scale testing and massive storage tanks, a full-scale field application of glass bubbles insulation was executed using a 218,000 L liquid hydrogen storage tank at Stennis Space Center, MS

NASA/Industry shared costs under NASA HQ Innovative Partnership Project

- **NASA**
  - Kennedy Space Center
  - Stennis Space Center
- **Industry**
  - 3M Energy and Advanced Materials Division
  - Technology Applications, Inc.



Outline

- **Introduction**
- **The Cryogenic Tank**
  - Perlite Removal
  - Vacuum Manifold
- **Installation of Glass Bubbles**
  - Bulk Delivery and Installation
  - Dust Collection System
  - Evacuation of Tank Annulus
- **Performance Test (2 cryo cycles)**
- **Conclusions**

Introduction

LARGE CRYOGENIC STORAGE TANKS

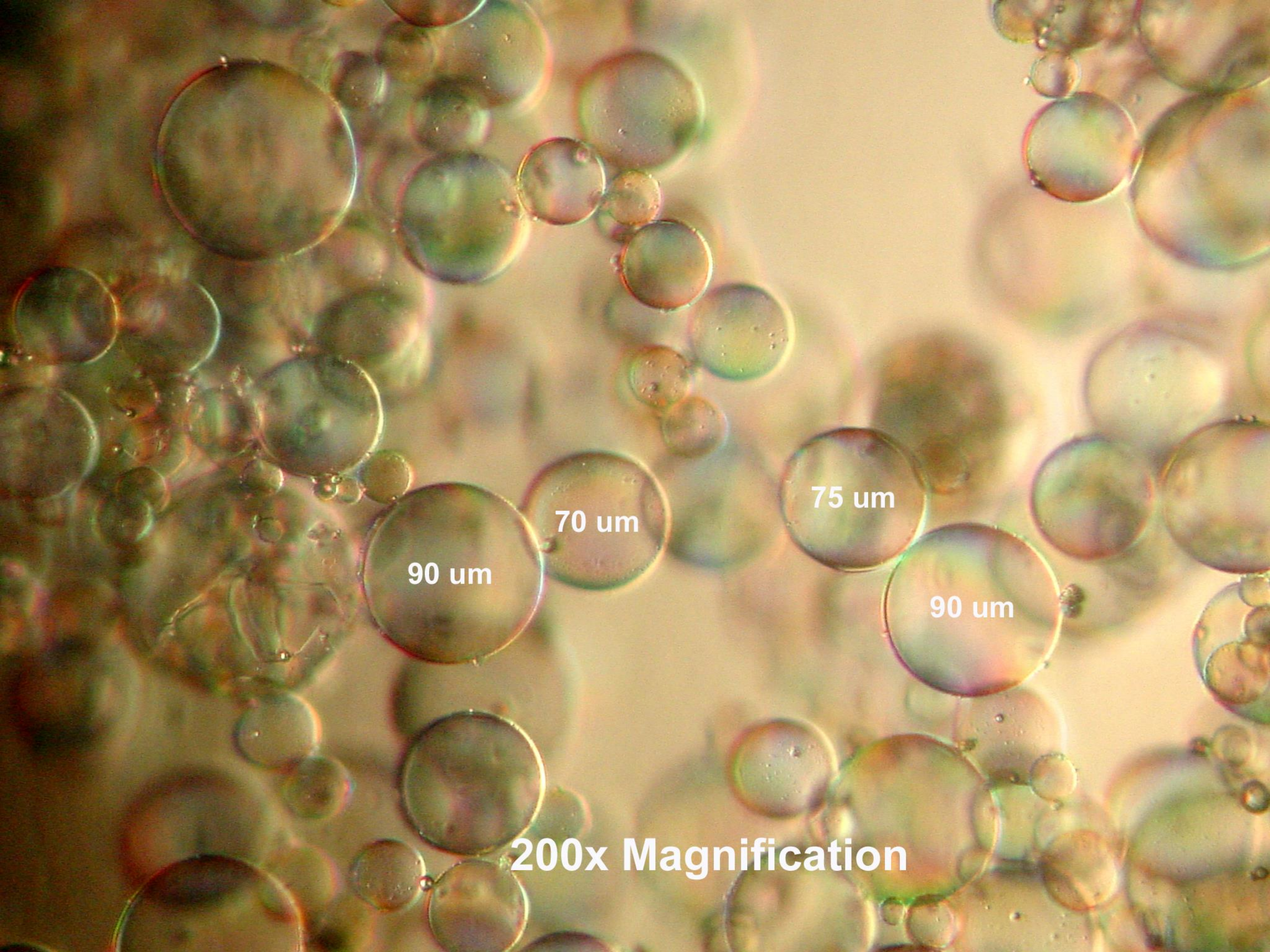
- **~200,000 liters and up**

TRADITIONAL INSULATION SYSTEM

- **Double-wall tank with perlite powder insulation filling the annular space**
- **For LH2 tanks, annular space evacuated to a high vacuum level**

INSULATION SYSTEM ALTERNATIVE

- **Glass bubbles**
- **Mechanical characterization**
- **System studies**
- **1000 L tank demonstration testing**
  - Reduced liquid hydrogen boiloff by 34%
  - 46% reduction for degraded vacuum (100 millitorr)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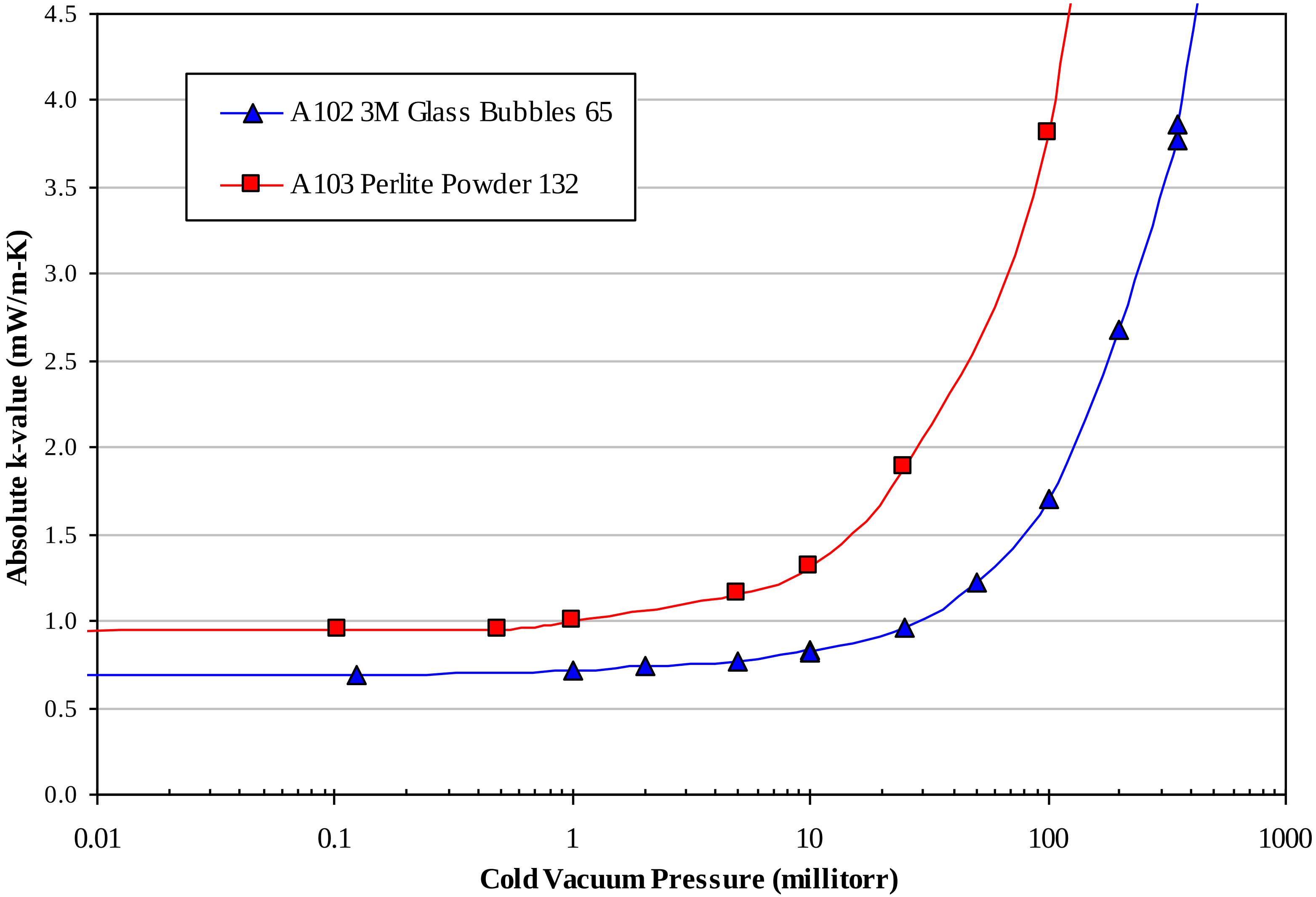
Why Glass Bubbles?



Better Thermal Performance

The Cryogenic Tank

- Constructed in early 1960's
- Spherical double wall tank
- Evacuated perlite annulus
- Internal sphere supported by rods near the equator
- Outside sphere = 9.3 m ∅
- Inner sphere is 7.3 m ∅
- Insulation thickness = 0.90 m
- Internal volume = 218,000 L
- Annulus volume = 200 m^3

Perlite Removal and Inspections

- **Original 45 year old perlite insulation was in pristine condition**
  - No signs of deterioration or compaction
  - Free-flowing
  - Majority of it was easily removed from the tank using vacuum trucks connect to ports on the bottom of the tank
  - Technicians entered annulus to suction out small amounts of residual perlite that was left on top of the inner sphere and in structural catch points

- **Annular space was fully inspected and found to be in excellent condition**
  - Internal tank support structure
  - Internal piping
  - Vacuum manifold

Installation of Glass Bubbles

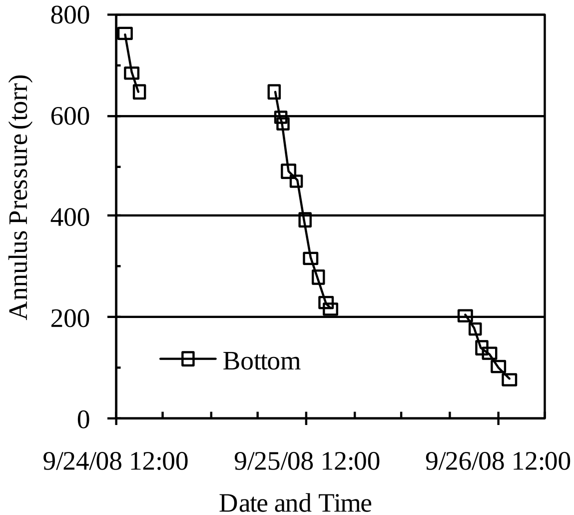
4 Trailers offloaded

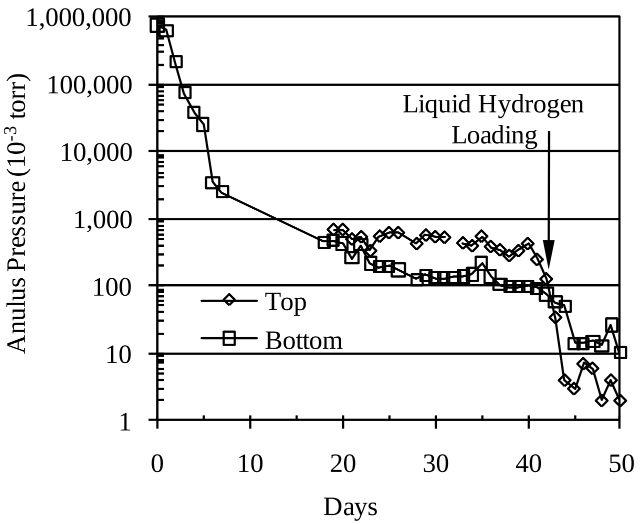
Each offloaded in about 1 to 1.5 hours

Could be a continuous operation until nearly full

Evacuation of Tank Annulus

- **Vacuum pump down operation lasted about two months**
  - 12 hours of pumping time over first three days to reach 13 kPa (100 torr)
  - After 1 month, vacuum levels were 27-67 Pa (200-500 millitorr)
  - After 2 months, vacuum levels were 13-40 Pa (100-300 millitorr)
- **Significant amounts of moisture were removed during the process**
  - Between 13 – 0.13 kPa (100 – 1 torr)
  - Necessitated regular pump oil changes over the course of about 1 month
  - Not uncommon, no equipment damage, however used a lot of pump oil





2009 Performance Test

- Tank filled with liquid hydrogen to 80% full
- After nearly six months, the liquid level was at 66% full

- Boiloff reduced by 44% compared to baseline perlite data
- Stable vacuum at 1.3 Pa (10 millitorr)

	Baseline Perlite	Glass Bubbles	
Normal Evaporation Rate (NER)	0.18 %/day	0.10 %/day	44 % Reduction
Boiloff Rate	386 L/day	216 L/day	
Vacuum Pressure	4.5 Pa (34 millitorr)	1.3 Pa (10 millitorr)	

2008 – 2011 and 2013 – 2015 Performance Tests

- **Starting tank level for 2nd cryo cycle higher than 1st cryo cycle**
- **Boiloff data within 2 gallons per day difference**
- **Both cycles vacuum stable**
- **Data collected using controls system (stores data up to 14 days)**
  - Each data file 501 samples
  - Data file for second cryo cycle consistent at 4.5 days files

	1st Cryo Cycle	2nd Cryo Cycle
Normal Evaporation Rate (NER)	0.10 %/day	0.10 %/day
Boiloff Rate	208 L/day	201 L/day

Conclusions

- **Full-scale glass bubbles field application completed**
  - Logistical aspects on this scale were straightforward to execute
  - No special facility requirements necessary
- **The boiloff rate was reduced by 44% compared to perlite**
- **Glass bubbles are an excellent high performance insulation choice for future large storage tanks and for perlite retrofits**
- **Glass bubbles insulation is ready to be adopted in spherical tanks**
- **Further demonstration tests are suggested to answer questions for more demanding tank geometries such as horizontal cylindrical tanks**

Potential Applications

- KSC Launch Complex 39   850,000 gallon Storage Spheres
- SSC LH2 barges and maybe LOX barges
- Glass bubbles research for the ultimate in VJ bulk-fill insulation systems (beating out MLI in some cases).
- Glass bubbles insulation systems deployment in the world's first LH2 tanker ship (two 240,000 gal tanks) by Kawasaki in Japan.

Acknowledgements

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- We also wish to thank all of the engineers and technicians at the E-1 Test Complex for their dedication to making this project a success

Questions?