Energy Efficient Cryogenics

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Energy Efficient Cryogenics

Overview of Technology Focus Areas and Capabilities

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The Cryogenics Test Laboratory, NASA Kennedy Space Center, works to provide ***practical solutions to low-temperature problems*** while focusing on long-term technology targets for the ***energy-efficient*** use of cryogenics on Earth and in space.

Space launch and exploration is an energy intensive endeavor; cryogenics is an energy intensive discipline.

CryogenicsTestLab
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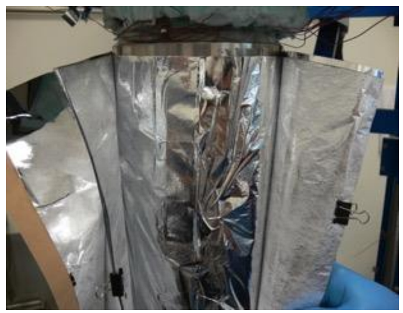
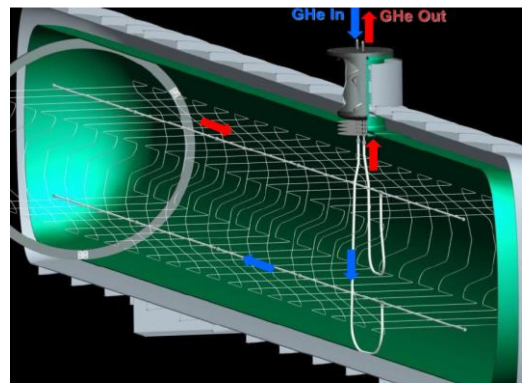
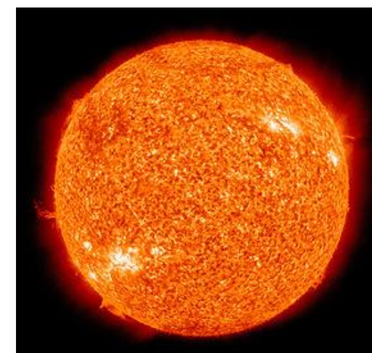
Energy Efficient Cryogenics

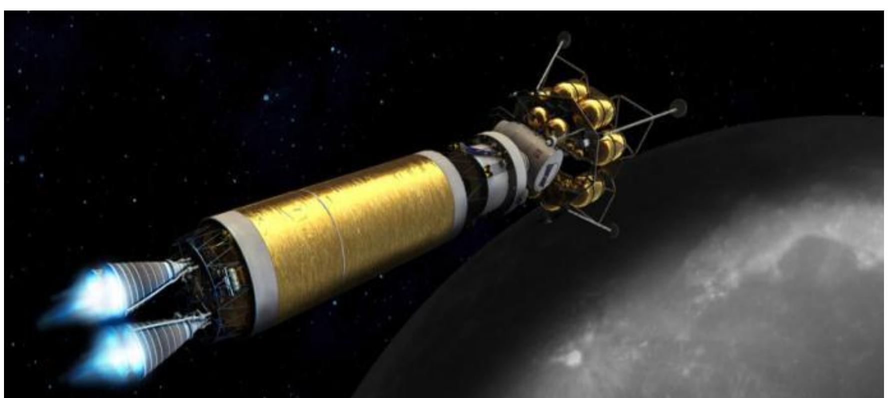
- ✓ **C**ost-Efficient Storage & Transfer on Earth
- ✓ **M**ass-Efficient Storage & Transfer in Space
- ✓ **L**ow-Temperature Materials & Novel Applications

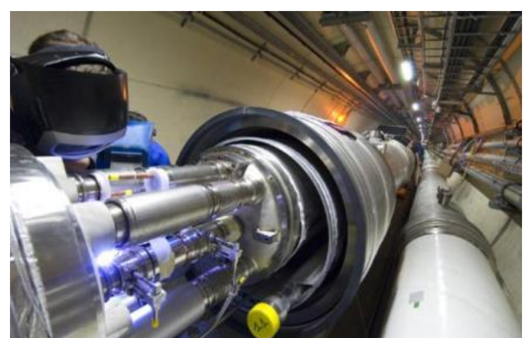
Cryogenics Enables:
✓Propulsion
✓Power
✓Life Support
✓Science
✓Manufacturing
✓Testing











The ***Cryogenics Test Laboratory, NASA Kennedy Space Center***, is a unique community for research, development, and application of cross-cutting technologies to meet the needs of industry, government, and research institutions.

Technology focus areas include:

- ✓ *Thermal insulation systems*
- ✓ *Integrated refrigeration systems*
- ✓ *Advanced propellant transfer systems*
- ✓ *Novel components and materials*
- ✓ *Low-temperature applications*

Cryogenics is about two things:

1) using low-temperatures to do something useful,

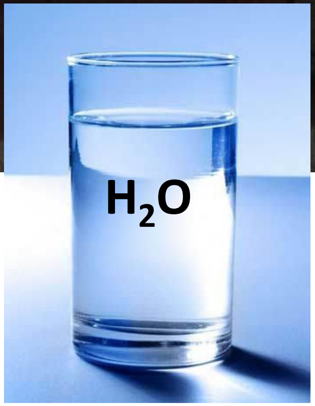
2) storing something in a small space (energy density).

Connections

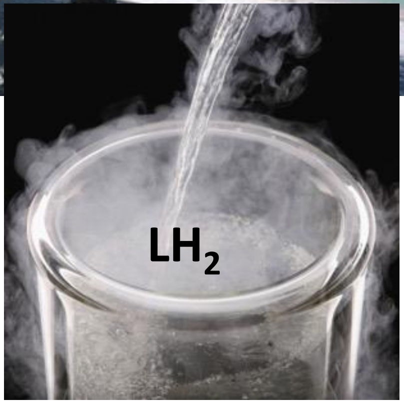
- ✓ Florida Academics: UCF, FTU, USF, UF, FSU, and ERAU
- ✓ Federal Agencies: DoD, DoE, DHS
- ✓ National Institute of Standards (NIST): Boulder and Gaithersburg
- ✓ National Laboratories: Oak Ridge, Jefferson, Fermilab, Los Alamos, Livermore
- ✓ NASA Centers: MSFC, GRC, LaRC, GSFC, JSC, SSC, ARC, JPL, WSTF
- ✓ Industry Partners: Aerospace; General Industry; High Energy Physics
- ✓ Cryogenic Society of America (CSA)
- ✓ Cryogenic Engineering Conference (CEC) and International Cryogenics Materials Conference (ICMC)
- ✓ Space Cryogenics Workshop (SCW)
- ✓ International Cryogenic Engineering Conference (ICEC)
- ✓ International Institute of Refrigeration (IIR)
- ✓ American Institute of Aeronautics and Astronautics (AIAA)
- ✓ ASTM International (ASTM)
- ✓ International Standards Organization (ISO)

Success in cryogenics has always been defined as a healthy triangle of interaction among research, industry, and training.

Preservation of the Cold



ΔT = 500 °F



ΔT = 500 °F

Technical Consensus Standards for Thermal Insulation Systems

- To help meet the today's needs and further the possibilities for future gains in *global energy efficiency*, cryogenic insulation standards are being developed.
- Under ASTM International's Committee C16 on Thermal Insulation, two new standards were published in 2014:
  - ASTM C1774 - *Standard Guide for Thermal Performance Testing of Cryogenic Insulation Systems*
  - ASTM C740 – *Standard Guide for Evacuated Reflective Insulation in Cryogenic Service*

Thermal Insulation Systems Development and Materials Research

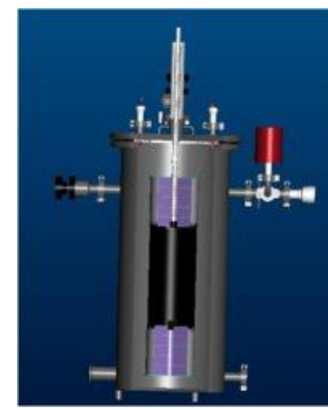
- Foams: Polystyrenes (Styrofoams), Polyimides, Polyurethanes
- Aerogels: (Space Technology Hall of Fame and R&D 100 winner)
  - Flexible blanket [Aspen Aerogels, Inc.]
  - Particles and expansion packs [Cabot Corp.]
  - Polymer cross-linked aerogels (X-aerogels) and experimental
- Bulk-Fill Powders: Glass bubbles, Perlites, Aerogels
- Multilayer insulation (MLI):
  - Aluminum foil and micro-fiberglass paper
  - Double-aluminized Mylar and polyester non-woven fabric
  - Double-aluminized Mylar and polyester netting

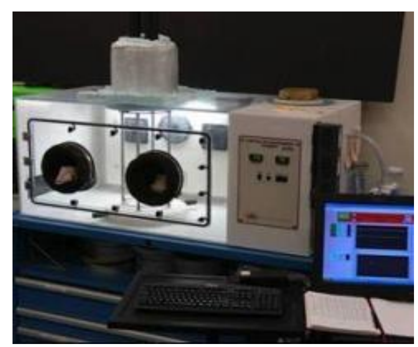
Thermal Insulation Systems Development and Materials Research (cont.)

- Layered composite insulation (LCI) systems: (patents and patents pending)
  - High vacuum or soft vacuum applications (LCI), or,
  - Non-vacuum, external environment applications (LCX)
- Vacuum insulated panels (VIP) with glass bubbles
- AeroPlastics and AeroFiber composite panels (patents and patents pending)
- AeroFoam composites for insulation, cryofuel storage, or cold batteries (patents)
- Novel smart, multifunctional composites: (patents pending)
  - Insulating – Conducting Composites (ICCs)
  - Passive-Acting Switchable Composites (PSCs)
  - Low-Temperature Shape Memory Alloy Systems for Broad-Area Thermal Management

Cryostat Insulation Test Instruments

- Cryostat-100, Cylindrical – Absolute
- Cryostat-200, Cylindrical – Comparative
- Cryostat-400, Flat Plate – Comparative
- Cryostat-500, Flat Plate – Absolute
- Macroflash (Cup Cryostat), Flat Plate - Comparative
- Cryogenic Moisture Uptake Apparatus
- Transient Thermal Tester
- 1000-liter Tank Cryostat (LH_2 or LN_2)
- Cryogenic Pipeline Test Apparatus
- Patents:
  - *Methods of Testing Thermal Insulation and Associated Test Apparatus,* US Patent 6,742,926
  - *Multi-purpose Thermal Insulation Test Apparatus,* US Patent 6,487,866
  - *Thermal Insulation Testing Method and Apparatus,* US Patent 6,824,306
  - *Insulation Test Cryostat with Lift Mechanism,* US Patent 8,628,238 B2
  - Thermal Insulation Testing Method and Apparatus, US Patent 6,824,306
  - Insulation Test Cryostat with Lift Mechanism, US Patent application, US20140079089 A1
  - Additional patents pending





Liquid Oxygen Ground Operations Demonstration Project (GODU-LO_2)

Objectives:

- Rapid propellant (cryofuel) loading concept demonstrations.
- Autonomous control and data monitoring system development.
- Testbed for development of many technologies and innovations, such as:
    - Fault tolerance of failed control valves and sensors.
    - Software to monitor overall health and status of propellant loading system.
    - Component (valves and pumps) sealing system designs.
    - Cryogenic composite tank structural/thermal monitoring.
    - Novel sensors applications and use in real world environments.

Overall view of the Simulated Propellant Loading System located at the CryoTestLab

Features:

- Up to 800 GPM flow rate and 225 PSI.
- Four cryogenic pumps are fed from a 6,000 gallon liquid nitrogen supply tank.
- Pumps have varying flow capacities from 25 up to 450 GPM.
- Complexity and component count is comparable to full scale launch pad transfer system
- Modular and re-configurable for a wide range of different vehicle or R&D requirements

ISO Work – LN_2 Vapor Work

Objective:
- Evaluate the effects of LN_2 vapor on "simulated insulation sample".

Test Hardware
- Various "nozzles"
- Data acquisition system (DAQ)
- 6,000 gallon LN_2 storage tank
- Simulated insulation sample (enclosure)

ISO Work – LN_2 Vapor Work (cont)

Test Hardware

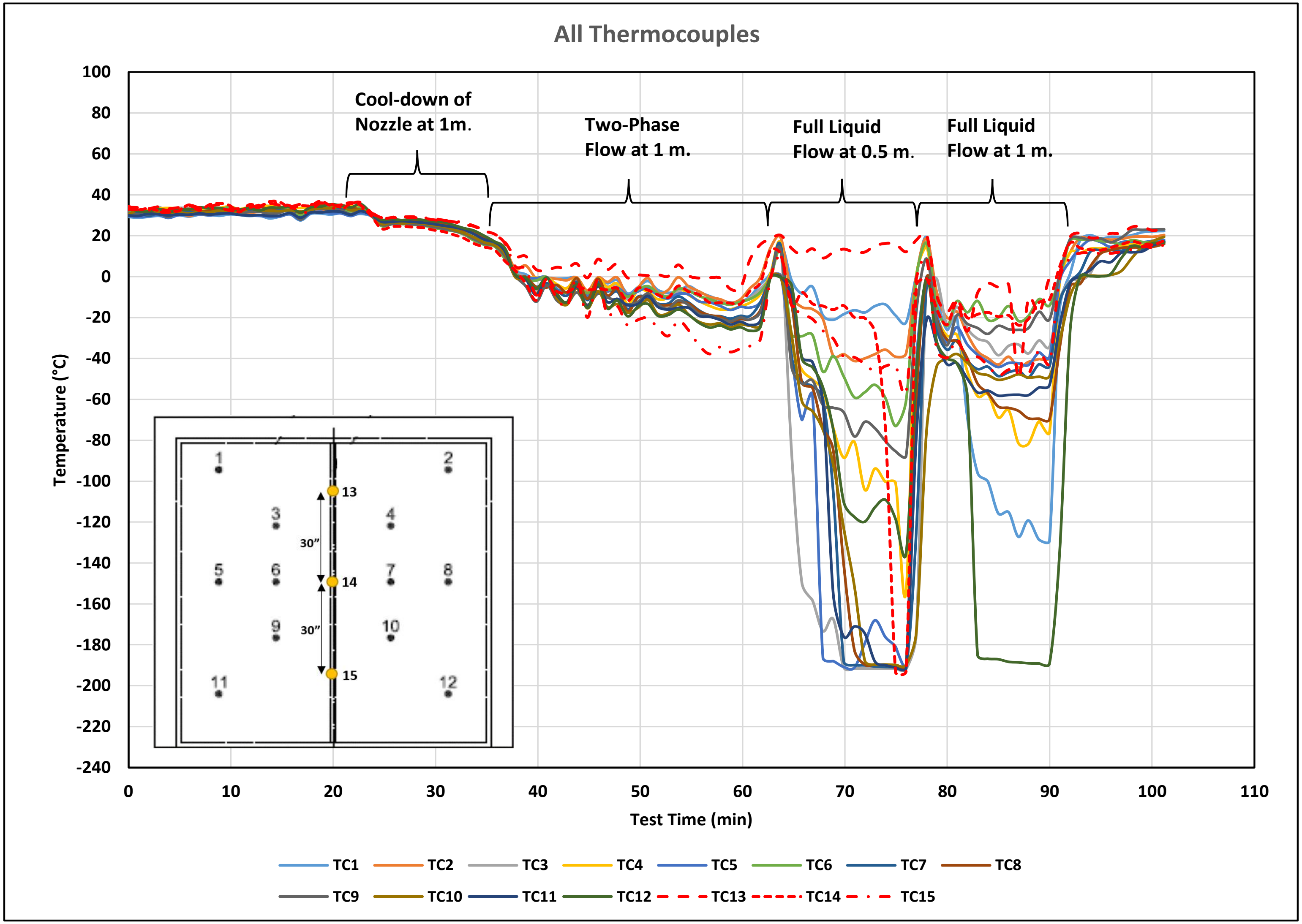
- Simulated insulation sample (enclosure)

Sample enclosure

Test run (vapor cloud)

Test run (1m distance)

ISO Work – LN_2 Vapor Work (cont)



Conclusion

- Cryogenics is globally and fundamentally linked to energy generation, storage, and usage.
- Two keys to safe and cost-efficient (on mass-efficient) storage, transfer, and application of cryogens:
  - Integrated refrigeration systems technology (active systems)
  - Thermal insulation systems technology (passive systems)
- New high efficiency designs, methodologies, and materials (active + passive) are being developed.
- Vital collaborations are with industry and academic research institutions for a wide range of applications, both commercial and government.

Through measurement to knowledge; through knowledge to product.

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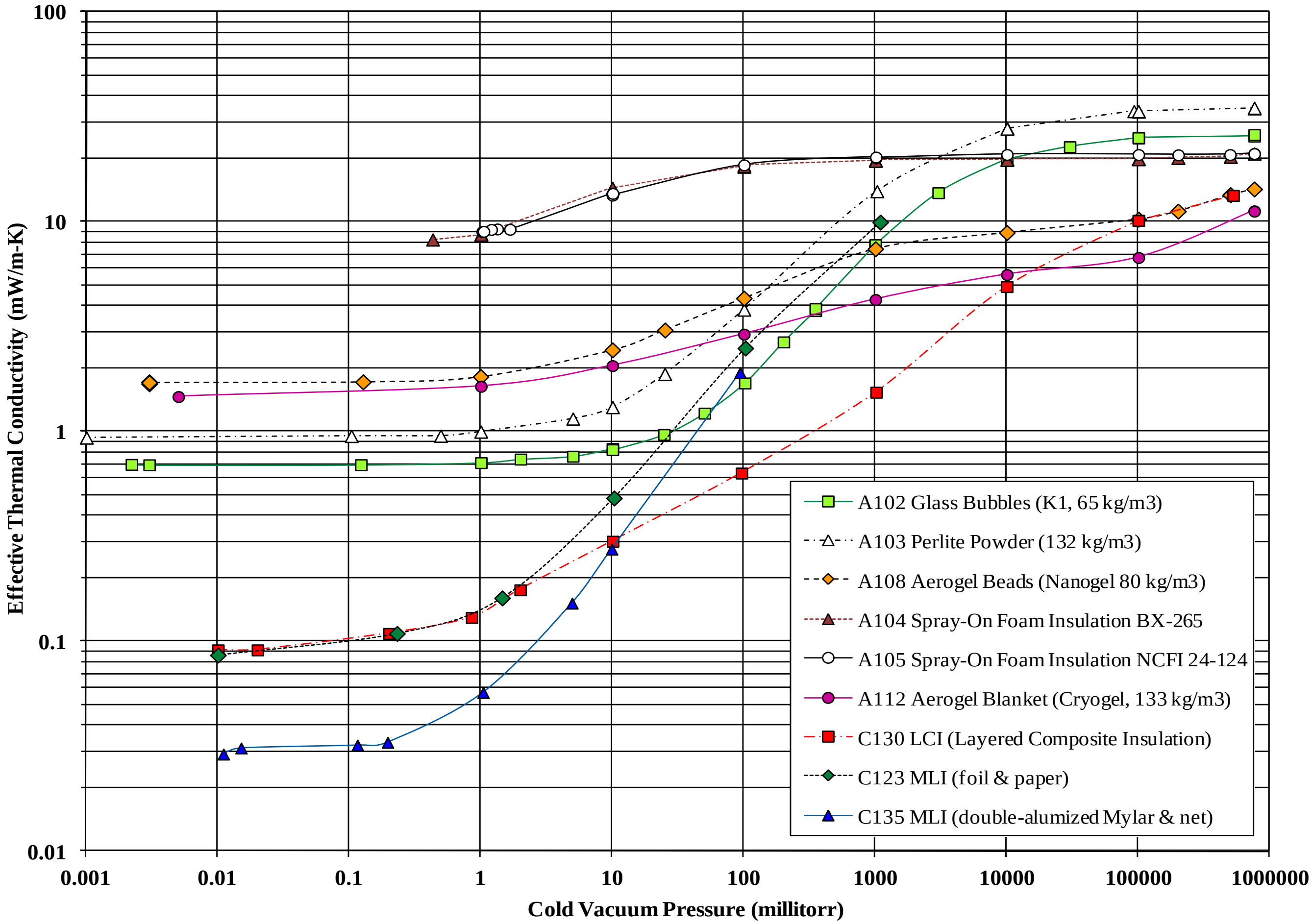
Thermal Performance of Various Cryogenic Insulation Materials



Examples of the variation of effective thermal conductivity (k_e) with cold vacuum pressure are shown for different cryogenic insulation systems. The boundary temperatures are approximately 78 K and 293 K, the residual gas is nitrogen, and the total thicknesses are typically 25-mm.[1]

[1]Fesmire, J. E., Coffman, B. E., Meneghelli, B. J., Heckle, K. W., "Spray-On Foam Insulations for Launch Vehicle Cryogenic Tanks," Cryogenics, doi:10.1016/j.cryogenics.2012.01.018.

Ground Operations Demonstration Unit for Liquid Hydrogen ($GODU-LH_2$)

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Integrated Refrigeration Objectives GODU-LH_2

- Demonstrations:
  - ✓ Zero loss storage and transfer of LH_2 on a large scale
  - ✓ Hydrogen liquefaction using close cycle helium refrigeration
  - ✓ Hydrogen densification in storage tank and loading of flight tank
- Secondary objectives:
  - ✓ Creating a densified hydrogen servicing capability
  - ✓ Maintaining critical cryogenic design and operations skills
  - ✓ Demonstrating low-helium usage operations
  - ✓ Validating modern component technologies
- Potential Advantages of IRAS LH_2 Systems:
  - ✓ Cost savings (less boiloff)
  - ✓ More autonomy in operations (less downtime)
  - ✓ Improved safety and reliability (enthalpy margin)

Integrated Refrigeration and Storage (IRAS) System for GODU-LH_2

- Vacuum-Jacketed Tank Features:
  - 125 m^3 (33,000 gal) capacity, 22 m (70 ft) length, 3 m (10 ft) diameter
  - Vacuum-jacketed with foil/paper MLI
  - Modified 600-mm diameter manway for helium and instrumentation feedthrough
  - Internal stiffening rings for sub-atmospheric pressure operation
- Heat Exchanger Features:
  - Cold helium, end-to-end flow balanced
  - Modular self-supporting system with 300 m of 6-mm diameter stainless steel tubing
  - Cold helium in-line process temperature sensors (4 silicon diodes)
  - Three temperature rakes to measure vertical and horizontal gradients (20 silicon diodes)

GODU-LH_2 Future Uses

- LH_2 Integrated Refrigeration and Storage system is fully operational at Kennedy Space Center.
- Upon completion of the GODU-LH_2 project, the system will be available for other uses:
  - Servicing on upper stages or test stands with densified hydrogen
  - Hydrogen distribution applications
  - Cryostat-900 and high efficiency transfer lines
  - Fuel cell and electrolysis research
  - Spacecraft loading ground support equipment
  - Superconductivity applications

Advanced Cryogenic Storage & Transfer

- End-to-end system architectures for rapid and reliable operations
- Composite materials development with real-world prototype combined functional testing: structural, vibration, and thermal.
- Autonomous control and system health monitoring
- Modular, semi-flexible piping systems
- Zero-loss transfer of Liquid Hydrogen
- Supporting Technology for Safe Operations (NASA-KSC Patents):
  - Color-changing tape for hydrogen gas leak detection
  - Aerogel blended polymers (AeroPlastic) for sealing components
  - Aerogel foam composites (AeroFoam) for cryogen storage
  - Aerogel fiber panel composites (AeroFiber) for structures and thermal protection systems
  - Layered composite insulation system for extreme environments (LCX)

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