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Laying Out the Future of Cryogenics

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Laying Out the Future in Cryogenics:

Thermal Insulation Systems Technology

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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 ***energy-efficient*** cryogenics on Earth and in space.

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

The ***Cryogenics Test Laboratory, NASA Kennedy Space Center***, is a one-of-a kind capability for research, development, and application of cross-cutting technologies to meet the needs of industry, government, and research institutions. We provide cryogenic expertise, prototype construction, experimental testing, engineering evaluation, and practical problem-solving for technology development with NASA, government, and commercial partners.

Technology focus areas include: *thermal insulation systems, cryogenic components, propellant process systems, and low-temperature applications.*

Our overall objective is to develop materials, produce new technology, and promote engineering for ***energy-efficient*** storage, transfer, and use of cryogens and cryogenic propellants on Earth and in space.

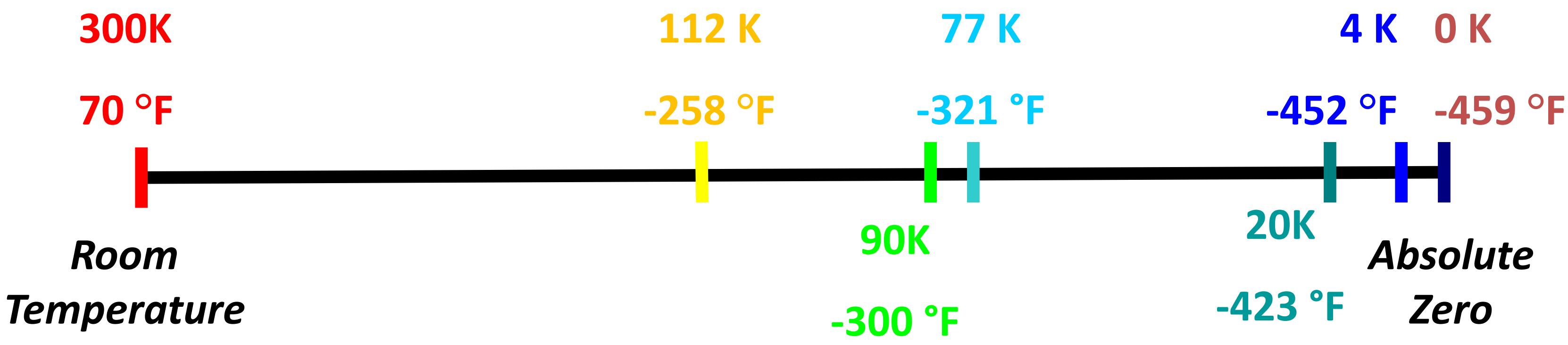

Cryostat 100

Outline

I. Cryogenics & Energy
II. Cryogenic Technology Development
III. Thermal Insulation Systems Technology

Temperature Ranges

1. Ambient or room temperature and up to about 423 K (300 °F)
2. Refrigeration, below ambient and down to about 200 K (-100 °F)
3. Cryogenic, below 123 K (-238 °F) and down to 0 K (-460 °F)



Side Note: With much of cryogenic engineering, it’s not the low temperature that is the problem, it’s the high temperature!

What is Temperature?

- What is temperature?
  - Hotness or coldness.
- What is hotness or coldness?
  - Temperature.
- OK. Thanks.

- Temperature is measured in kelvin (K), Celsius (°C), and Fahrenheit (°F)
- Extremes:
  - Absolute zero (O K) is very special and unique in the universe (the foundation)
  - There is no absolute high temperature (there is no ceiling)







What is Energy?

- No one really knows, but whatever it is, it is conserved. Greek words:
  - ἐνέργεια - energeia (activity, operation)
  - ἐνεργός - energos (active, working)
- Energy is *described* as the ability to do work.
- No one has ever seen a joule, but up until the 1800's scientists were still looking for one as the "caloric" was thought to be a substance.
- Einstein came along and gave us a simple equation for it:

$$E = mc^2$$

Cryogenics and Energy

- Cryogenics is all about energy*
  - Conserving it
  - Controlling it
  - Energy = $$$

- Thermal insulation systems minimize and/or control the energy flow (heat leakage rate)

*Thermal (Heat) Energy

Four Things to Get Straight

0th Law: "If two systems are each in thermal equilibrium with a third, they are also in equilibrium with each other"

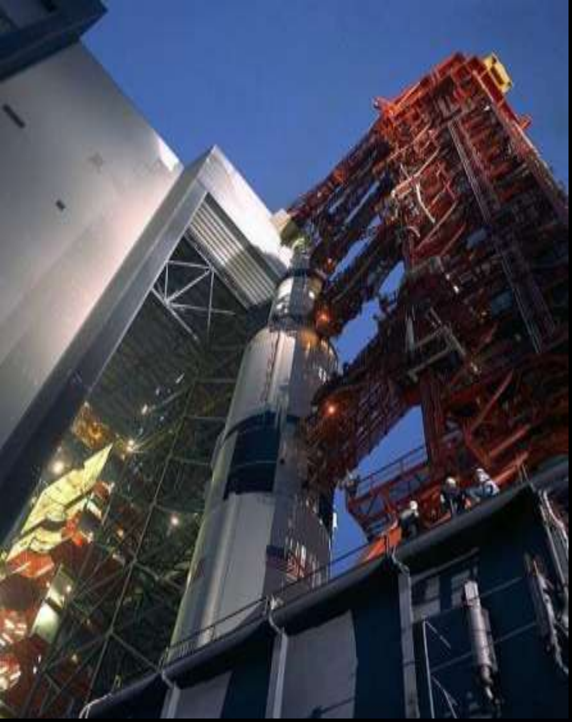
- The notion of Temperature!

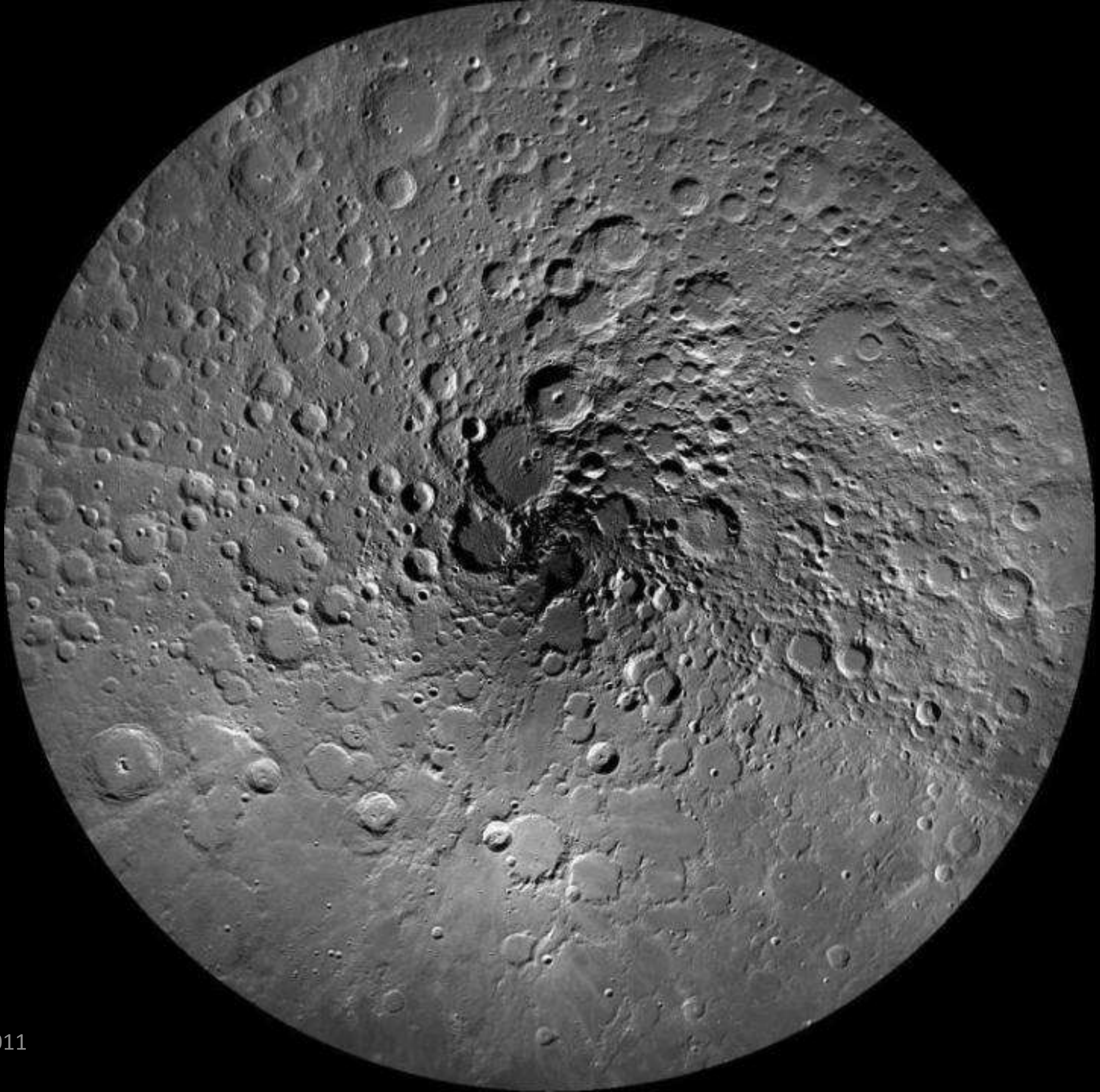
1st Law: We really don't know what energy is, but whatever it is, it is always conserved

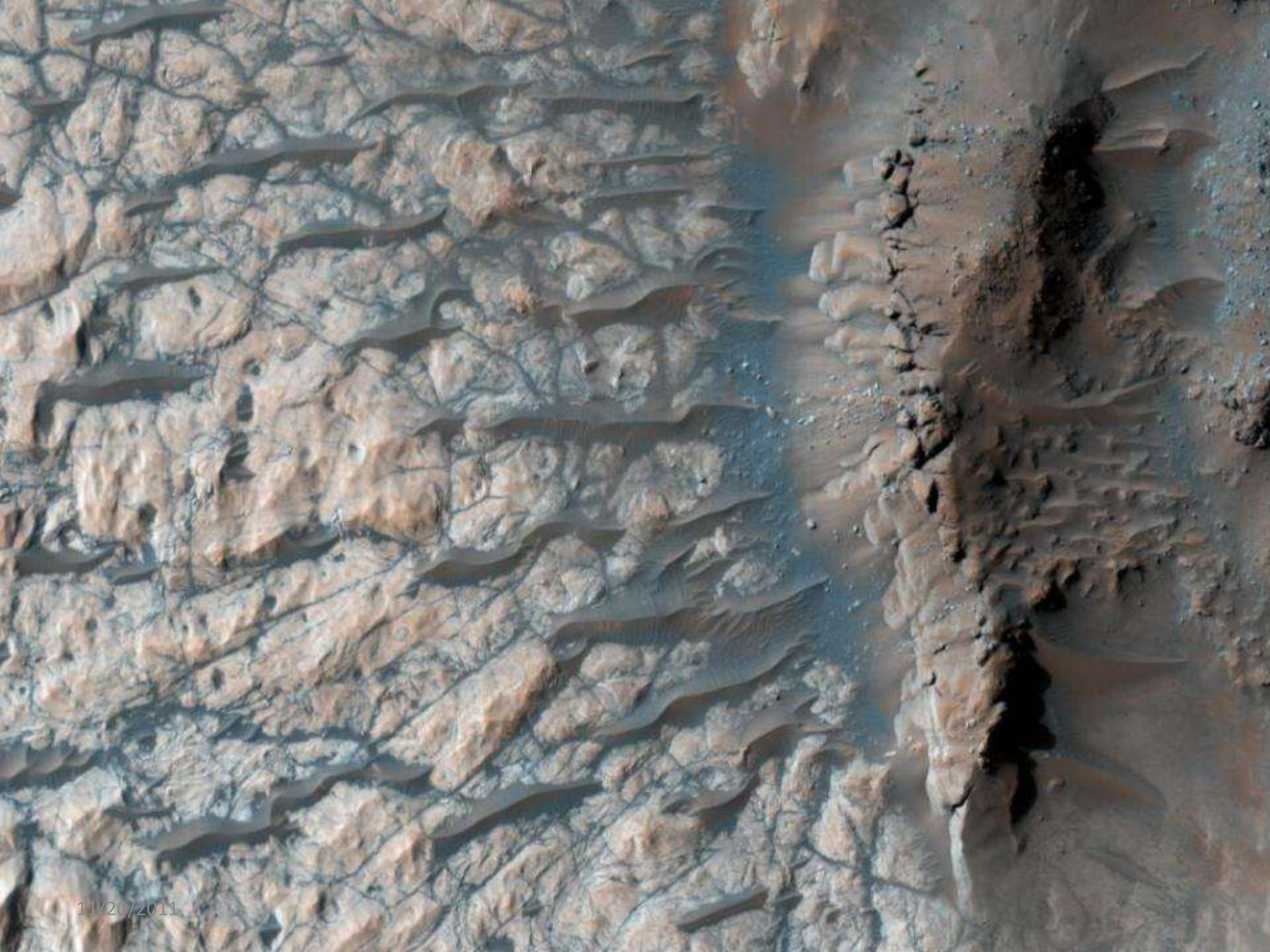
2nd Law: Heat energy always flows from the hot side to the cold side

- There is a direction to the energy flow
- Entropy (disorder) is always increasing

3rd Law: Absolute zero is a hard stop



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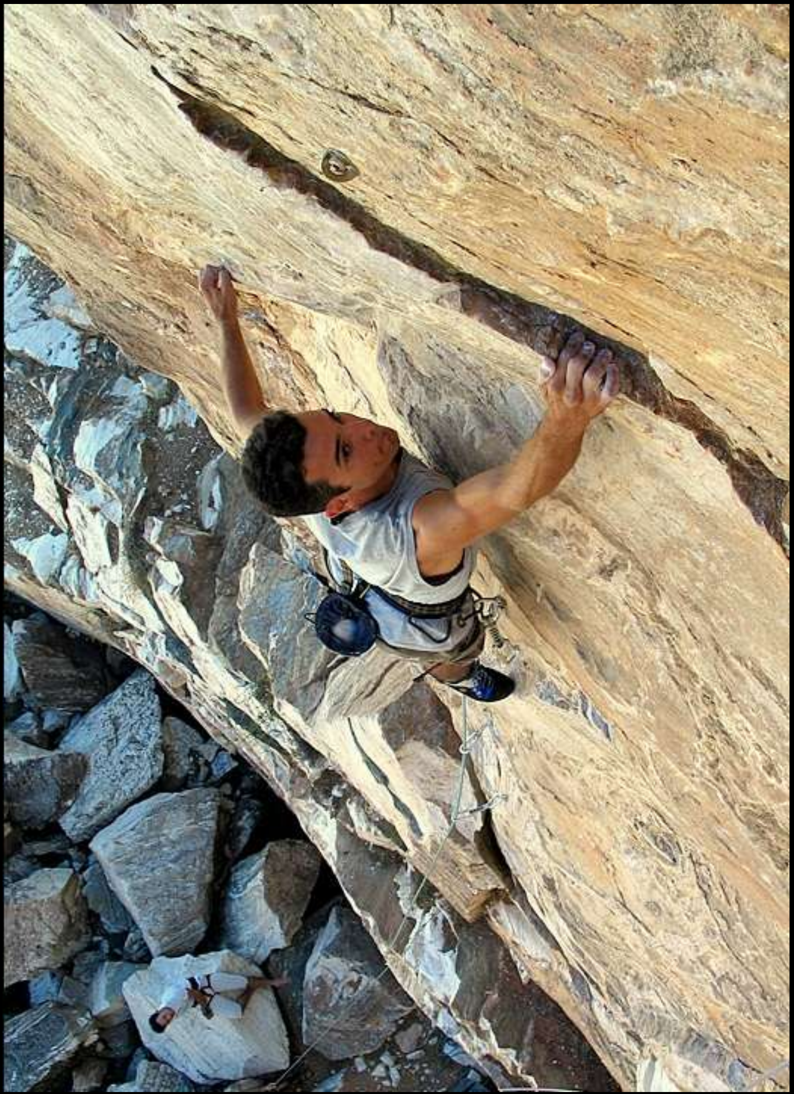
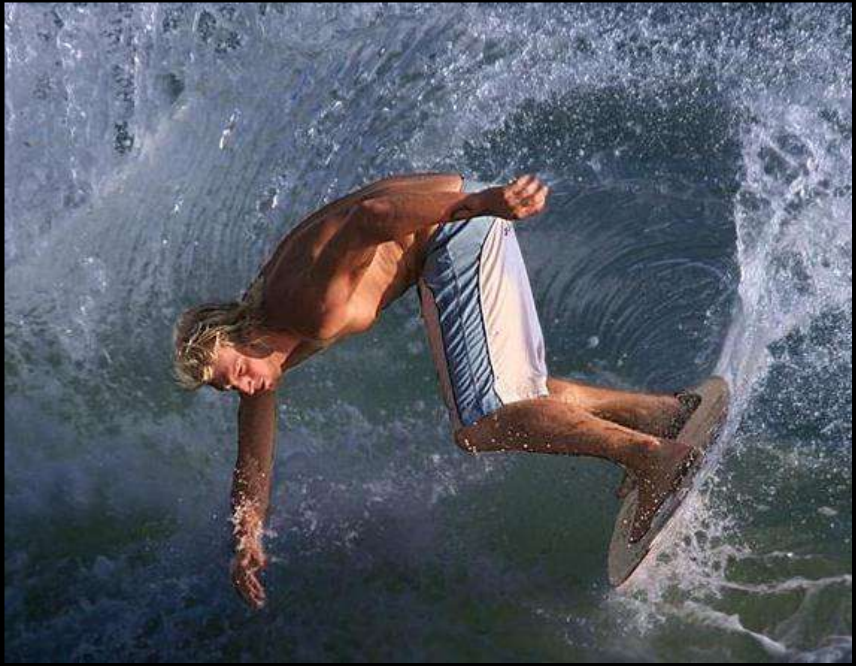




Advanced Exploration Systems

1. *Integrated Cryogenic Refrigeration*

2. *Advanced Cryogenic Propellant Loading*

3. *Efficient Storage and Transfer*

NASA Office of Chief Technologist

Cryogenics Enables:

- ✓Propulsion
- ✓Power
- ✓Life Support
- ✓Science
- ✓Manufacturing
- ✓Testing

Exploring Space Through Innovation & Technology, B. Braun, 5/25/2011
http://www.nasa.gov/offices/oct/home/index.html

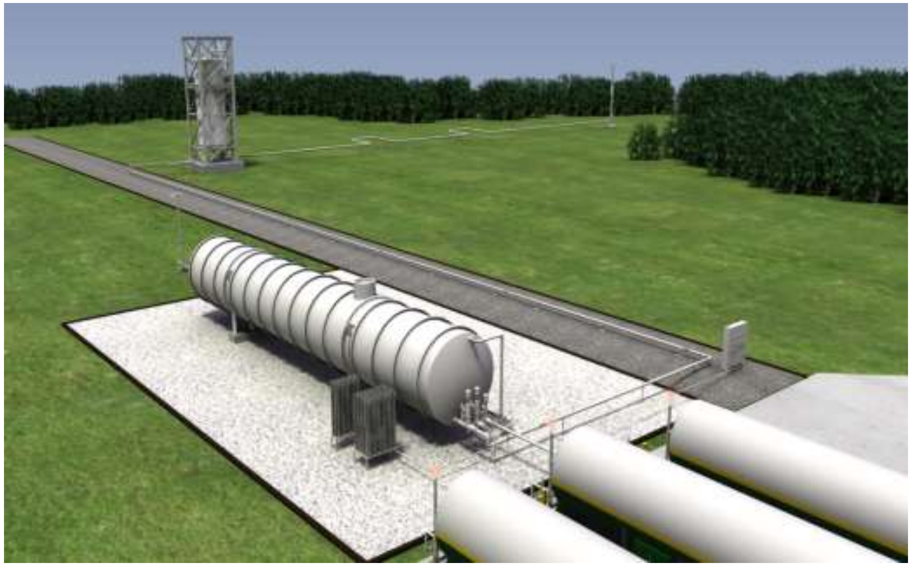
1. Integrated Cryogenic Refrigeration

- Hydrogen: potential energy backbone and future of transportation
- Hydrogen: basic to both space launch and in-space propulsion (and more)
- NASA Advanced Exploration Systems (AES) program: *Liquid Hydrogen Ground Ops Demonstration*

Liquid Hydrogen Ground Ops Demonstration

- Purpose: Validate operational concepts in a pad-like environment prior to upgrading KSC facilities
- Main Objectives:
  - Demonstrate zero loss storage and transfer of LH2 at a large scale
    - KSC loses 50% of the hydrogen purchased
  - Demonstrate hydrogen liquefaction using close cycle helium refrigeration
    - KSC currently purchases LH2 from New Orleans area (900 miles away)
  - Demonstrate hydrogen densification in storage tank and loading of flight tank
    - Increase payload mass fraction by up to 8%
- Further Objectives:
  - New densified hydrogen servicing capability
  - Demonstrate low-helium usage operations
  - Validate modern component technologies
- Partners: GRC, SSC, and ULA

New liquid hydrogen testbed facility will integrate cryogenic refrigeration inside the 33,000 gallon storage tank to control the propellant conditions



2. Advanced Cryogenic Propellant Loading

- Autonomous control and health monitoring
- End-to-end system architectures for rapid and reliable operations
- NASA Advanced Exploration Systems (AES) program: *Liquid Oxygen Ground Ops Demonstration*

Liquid Oxygen Ground Ops Demonstration

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

- Objectives:
  - Rapid propellant 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 the overall health and status of the propellant loading system.
    - Globe valve seal designs.
- 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.

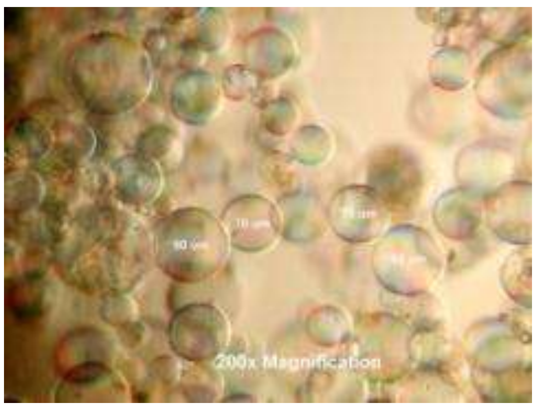
Efficient Storage and Transfer

- Energy-efficient cryogenics:
  - Mass-efficient
  - Cost-efficient
- Cryogen thermal management from ground to space environments and long-term storage
- Propellant depots in space to enable exploration of the solar system:
  - Technology development through project *Cryogenic Propellant Storage and Transfer (CPST)*

3. Mass-Efficient Storage & Transfer

- ✓ Reduced Boil-off
  - Cryocoolers Integration
  - Structural Materials
  - Thermal Insulation Systems
- ✓ Zero-gravity Control
- ✓ Multilayer Insulation Systems
  - New materials characterization
  - Test methodologies
  - Thermal modeling and analysis
  - Micro-meteoroid Orbital Debris (MMOD) Shielding
  - Launch Pad Ground Hold Considerations
  - Launch Ascent Considerations

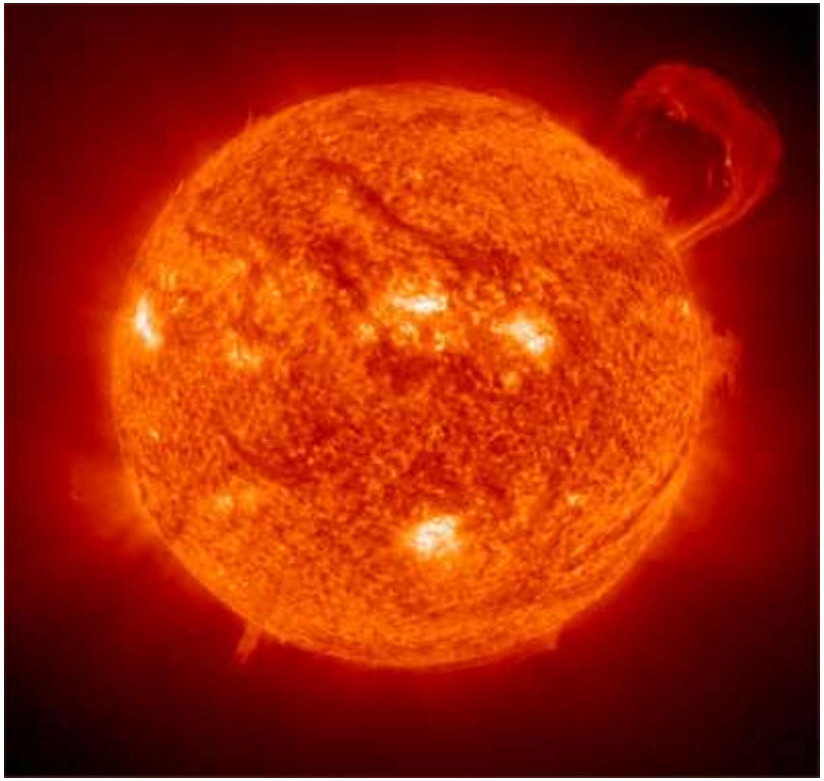
Cost-Efficient Storage & Transfer



Materials Research | **Demonstration Testing** | **System Studies**

Global positive impact for energy efficiency and cost savings.

Heat is the Enemy



Thermal Insulation Systems

The CryoTestLab team has extensive experience in the area of thermal insulation systems for low-temperature applications. With our cryogenic and vacuum test capabilities we provide specialized services including:

- *Materials characterization and analysis*
- *Thermal conductivity testing under real-world conditions*
- *Thermal performance testing of cryogenic piping systems and tanks*
- *Development of materials for engineered applications*
- *Experiment design and prototype construction*
- *Engineering thermal analysis*

Our approach to long-term research and development is through addressing today's problems. We are networked across NASA and around the world to help solve your low temperature problems.

Thermal Conductivity Testing

Thermal Conductivity Testing

- Cryostat-100: absolute, cylindrical
- Cryostat-200: comparative, cylindrical
- Cryostat-500/600: absolute, disk
- Cryostat-400: comparative, disk
- Macroflash Cup Cryostat: comparative, disk
- Netzsch Heat Flow Meter: calibrated, disk
- Anter Quick Line 10 Thermal Instrument: calibrated, disk
- Anter Quick Line 30 Thermal Analyzer: calibrated, probe

Thermal Performance Testing

- Cryogenic Moisture Uptake (CMU) Apparatus
- Spherical Cryostat (1000-liter)
- Cryogenic Pipeline Test Apparatus (CPTA)
- Sub-scale tanks and 10-liter dewar kits
- Thermal cycling, expansion & contraction, loads & vibration effects

Insulation Test Cryostats: *Basic Characteristics*

Steady-state boil-off calorimeter methods

Full temperature difference (ΔT):

- Cold boundary temperature (CBT) = 78K (to 200K)
- Warm boundary temp (WBT) = 293K (to 400K)

Full-range cold vacuum pressure (CVP):

- High vacuum (HV) <10^{-5} torr
- Soft vacuum (SV) = ~1 torr
- No vacuum (NV) = 760 torr

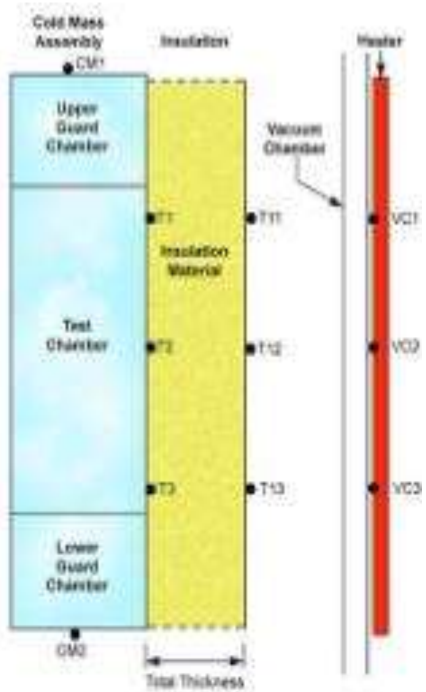
Thermal testing under actual-use conditions:

- Research of new materials
- Insulation system testing
- Heat transfer mechanisms
- Experimental methodologies
- Installation methods

Cryostat-100

- Liquid nitrogen boil-off calorimetry
- Absolute k-value [mW/m-K] and heat flux [W/m2]
- 0.01 to 60 mW/m-K and 0.1 to 500 W/m2
- Cylindrical: 6.57” diameter by 40” length cold mass
- Full delta-T, full-range cold vacuum pressure
- Foams, powders, bulk-fill, clam-shell, blankets, and MLI materials

Surface Temperature Measurement	
Sensor	Location
VC1, VC2, VC3	Vacuum Can Temperature
T11, T12, T13	Warm Boundary Temperature (WBT)
T4 – T10	Insulation Layer Temperatures
T1, T2, T3	Cold Boundary Temperature (CBT)
CM1, CM2	Cold Mass Temperature



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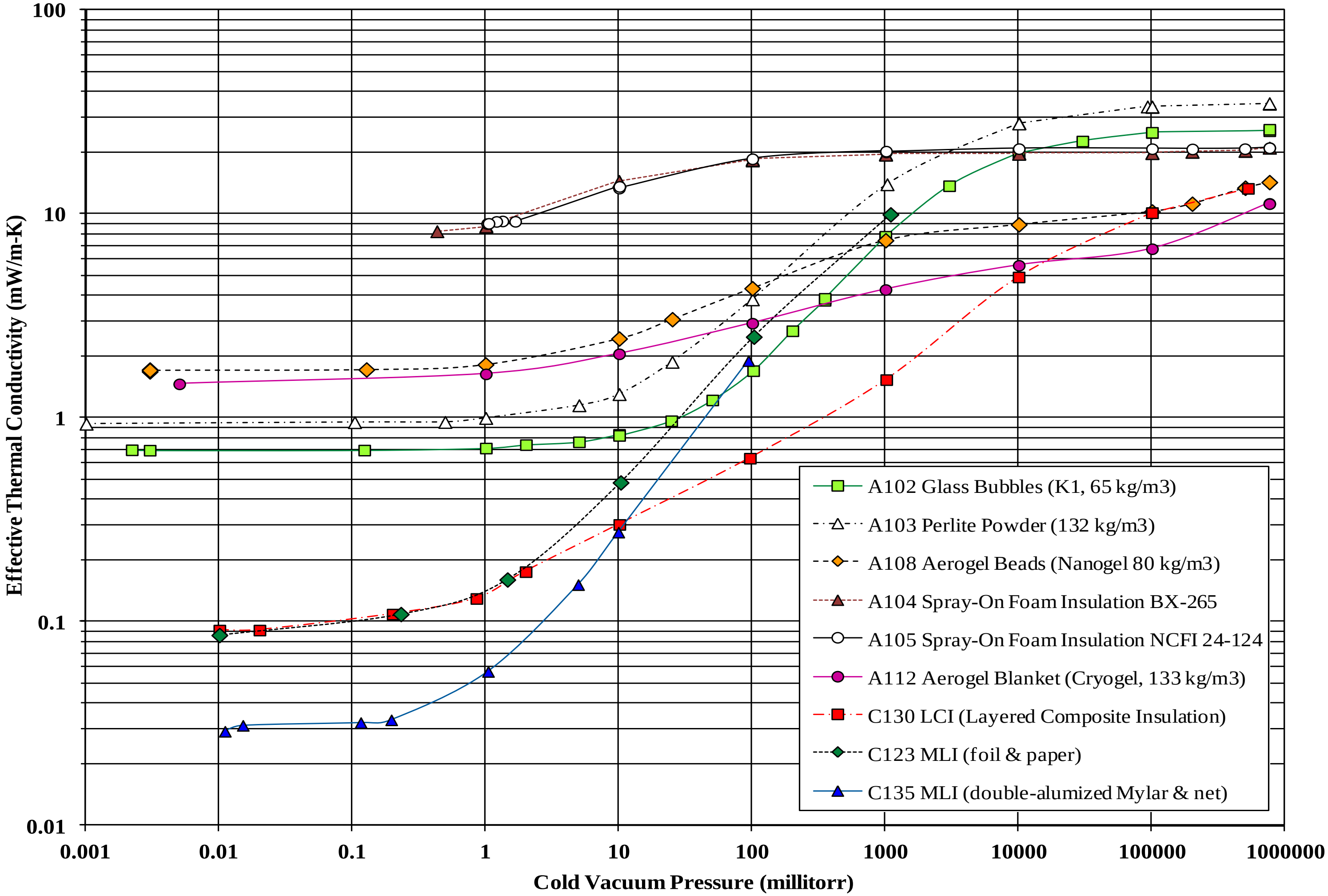
Cryostat-100

Various Cryogenic Insulation Materials

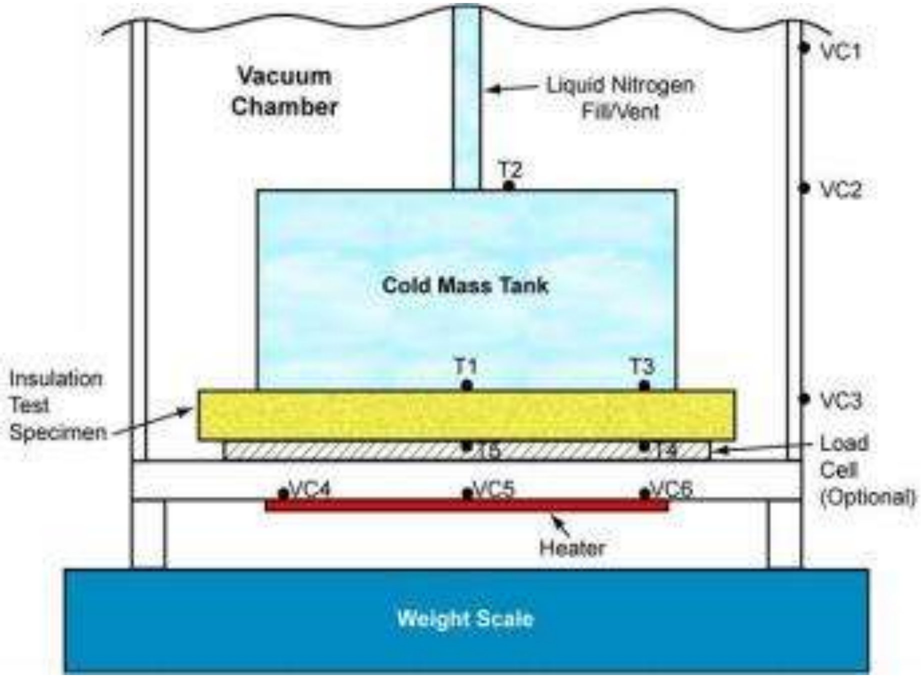


Examples of the variation of effective thermal conductivity (k_e) with cold vacuum pressure are shown for different cryogenic insulation systems. The boundary temperatures are approximately 78 K and 293 K, the residual gas is nitrogen, and the total thicknesses are typically 25-mm.[1]

[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.

Cryostat-500

- Liquid nitrogen boil-off calorimetry
- Absolute k-value [mW/m-K] and heat flux [W/m^2]
- 0.1 to 100 mW/m-K and 1 to 1000 W/m^2
- Flat plate (disk): 8” diameter by up to 1.5” thickness
- Full delta-T, full-range cold vacuum pressure
- Foams, bulk-fill, blankets, MLI, panels, and composite materials



Materials, Analysis, and Systems

Materials Test and Analysis

- Pycnometer (% open cell)
- Surface Area / Pore Size
- Cryogenic Impact
- Microscopy
- Weathering Exposure or Aging

Thermal Systems Analysis

- Thermal Desktop (SINDA/FLUINT)
- Thermal Insulation Systems Calculator (TISCALC)
- Generalized analysis tool - Multilayer Insulation Systems (MLI)

Temperature and Vacuum Range

- From 4 K to 400 K; Liquid Nitrogen (77 K) and Liquid Helium (4 K)
- From atm. pressure to high vacuum (10^{-6} torr)



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- McLean VA based engineering services company
- Prime Contractor on Engineering Services Contract at KSC supporting Engineering Directorate

Technology Access

- Engineering Services Contract at Kennedy Space Center has a WFO component
- Industry can access capabilities from the Cryogenics Testing Laboratory
- Industry can tap into NASA's expertise

Technology Transfer

- Licensed the patent for the Cryostat-200 from NASA
- Portfolio of four patents for below-ambient thermal insulation testing; additional patents pending.
- Marketing the technology to industry: materials, testing, and application; capabilities and expertise.
- Will help NASA and industry establish new international technical consensus standards
  - ASTM International, Committee C16 on Thermal Insulation
  - Below-ambient thermal insulation testing, materials thermal data, and installation practices

Conclusion

- Cryogenics is globally linked to energy generation, storage, and usage
- Thermal insulation systems research and development is an enabling part of NASA's technology goals for Space Launch and Exploration
- New thermal testing methodologies, apparatus, and standards include the licensing of the Cryostat-200 instrument

Through measurement to knowledge; through knowledge to product.

Cryogenics Test Lab

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ESC Engineering Services Contract

Partnering To Engineer the Future

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