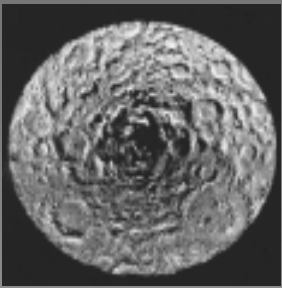
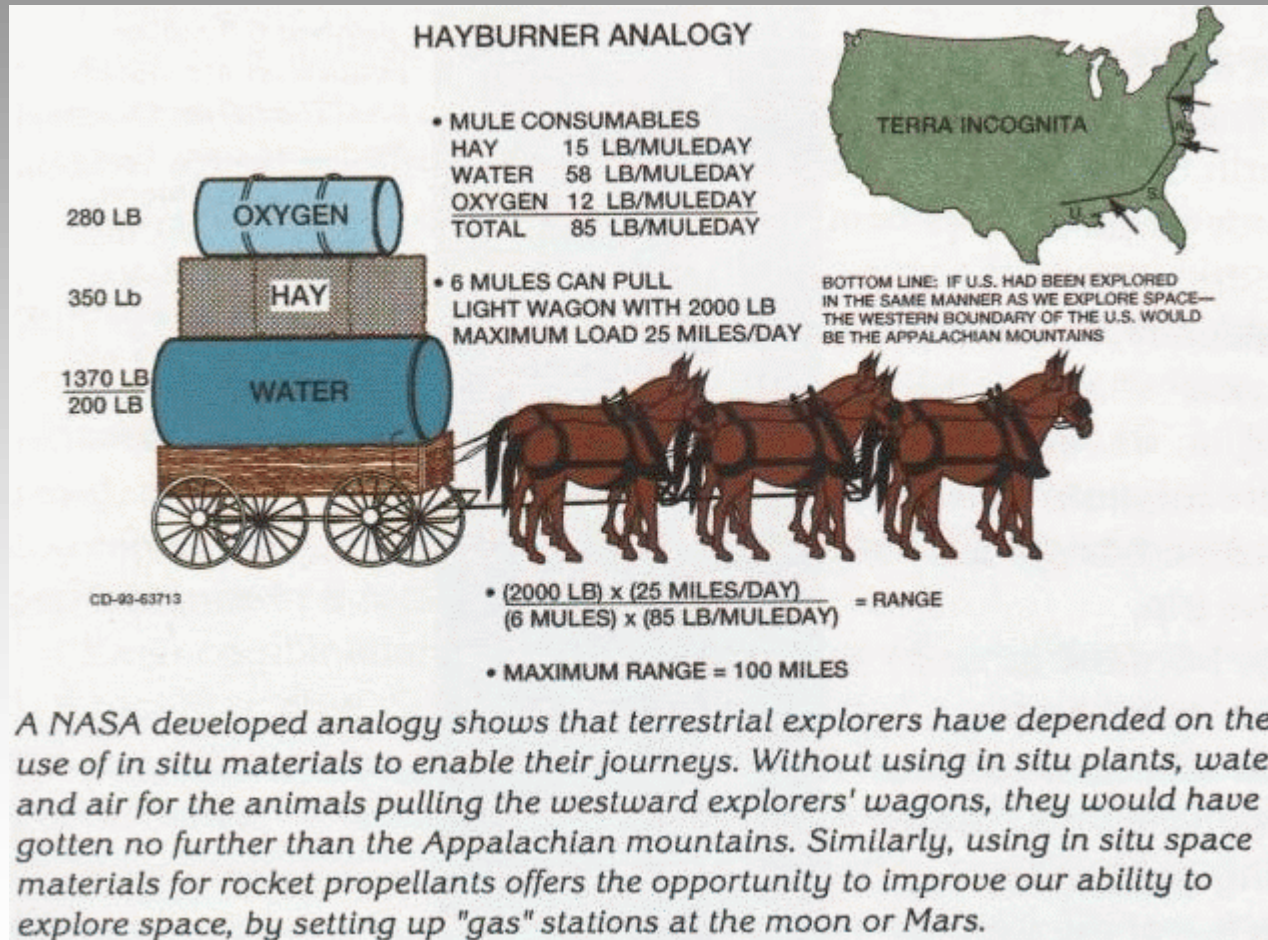


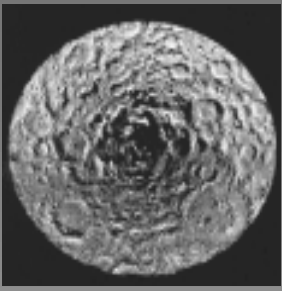
INTRODUCTION

- **Background**
- **Hydrogen vs. Water**
- **Project Objective**
- **Program Plan Status**
- **Conclusions To Date**



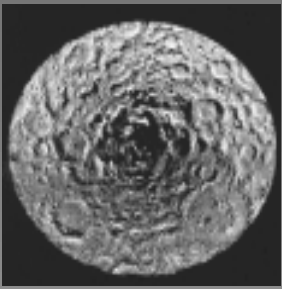
ISRU



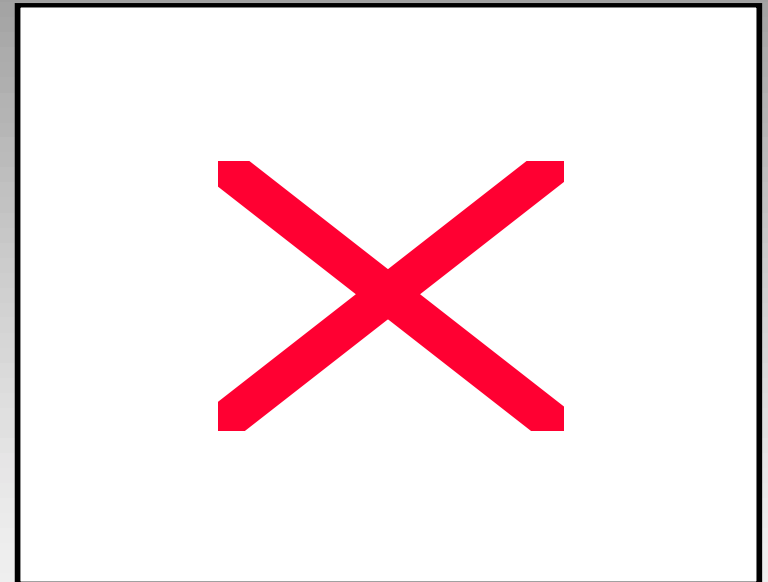
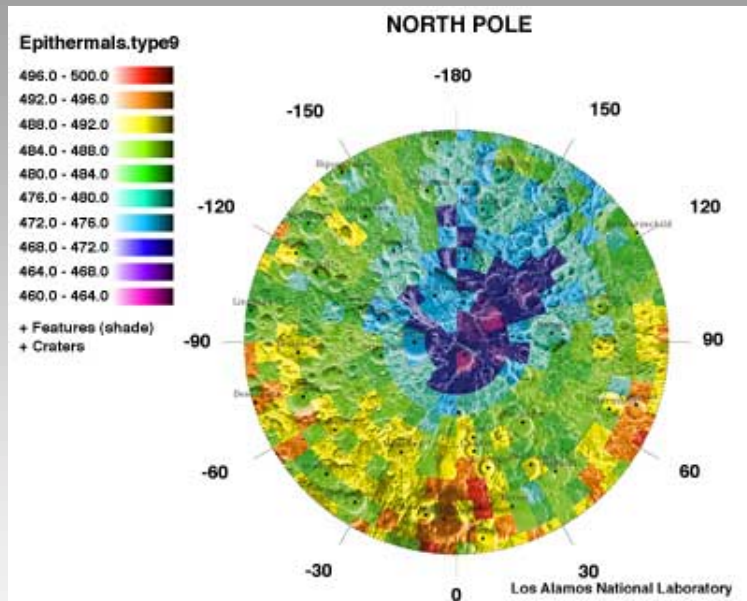


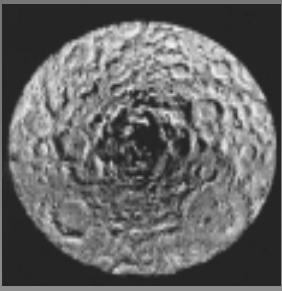
BACKGROUND

- **"ISRU" -- Insitu Space Resource Utilization**
- **The Utilization of Lunar Water Ice Near the Lunar Poles (cold traps) Is Expected to Have a Dramatic Effect on the Affordability of Future Lunar and Mars Exploration and Colonization**
- **The Latest Lunar Prospector Data Indicates up to 260 Million Tons of Water Ice is Present**
- **The Use of Water Includes: Hydrogen and Oxygen Propellants for: Space Transport Systems, Life Support, Food Production, Chemical Energy Storage, Rover Fuels/Oxidizers, Concrete Production for Infrastructure, etc.**
- **The Discovery and Use of Water Ice on the Moon is a Tremendously Important Event for Man's Exploration and Colonization of the Solar System**
- **In This Effort, We Are Developing a Detailed Program Plan that NASA May Choose to Use to "Discover, Extract and Use" Lunar Water or Lunar Hydrogen and Oxygen**



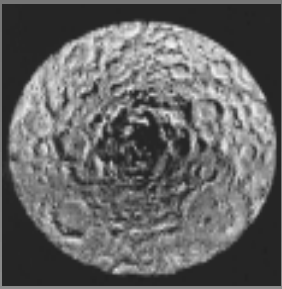
LUNAR PROSPECTOR DATA





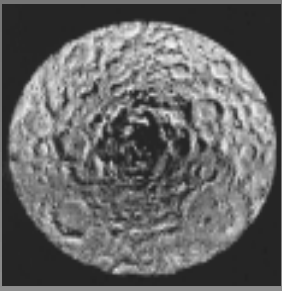
WATER VS. HYDROGEN

- **Lunar Prospector's Neutron Spectrometer (NS) is Designed to Detect the Presence of Hydrogen, which Is Believed by Many to Indicate the Presence of Water Ice**
- **Current Data Indicate up to 260 Million Metric Tons of Water Ice Have Been Predicted by the Science Team, (July 1999)**
- **Estimates Indicate 200 Million MT at the South Pole and 60 Million MT at the North Pole**
- **Ice Likely in Deposits of Pure Water Ice Buried Beneath ~5 cm of Dry Regolith in ~1.5% Concentrations**
- **Concentrations Appear Higher at the North Pole**
- **Kulcinski, Schmidt and Others Have Suggested That the Neutron Spectrometer Data Are Due to Increased Hydrogen Concentration in the Regolith, Not Water**
- **Binder Now Thinks That Perhaps Both Water and Hydrogen May Be Contributing to the NS Signal**
- **Regardless, Still Gives Strong Motivation for Exploration and Extraction Missions**
- **We Now Are Integrating the "Hydrogen Possibility" into the Study**



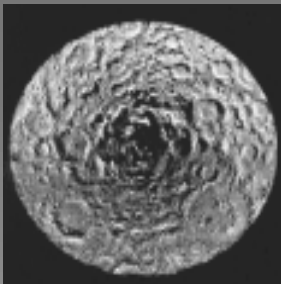
PROJECT OBJECTIVE

- **The Project Objective Is the Development of An Overall System Architecture for the Discovery, Extraction, and Utilization of Ice Found Near the North and South Poles of the Moon**
- **The Major Result of this Effort Will Be a Comprehensive Program Plan for the Acquisition and Use of Lunar Water Ice or Hydrogen and Oxygen**

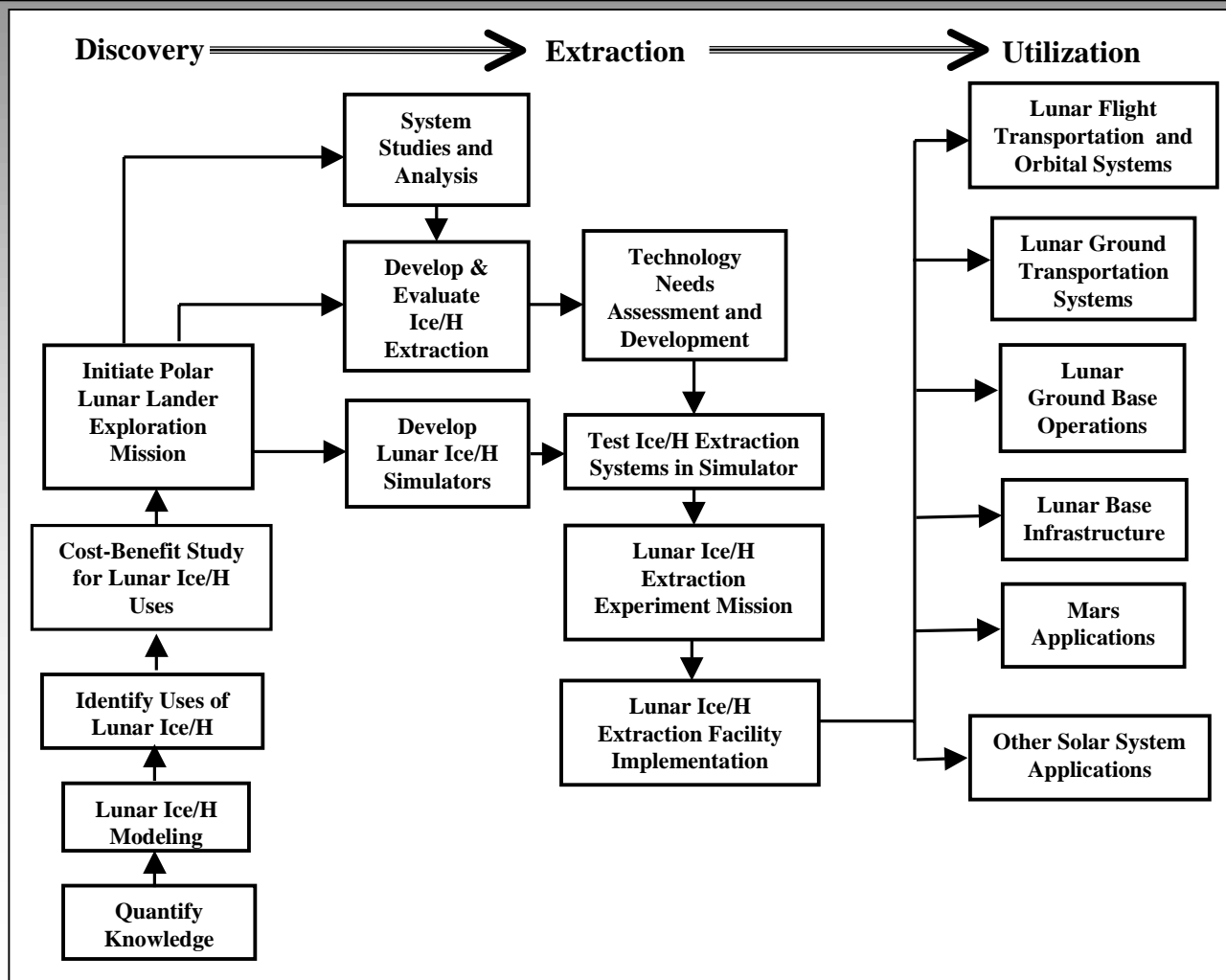


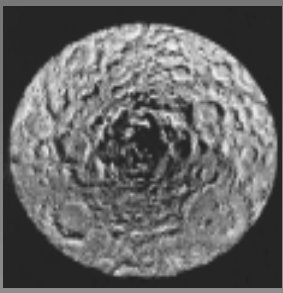
PROGRAM PLAN STATUS

- **Program Road Map**
- **Work Breakdown Structure (WBS)**
- **Milestone Schedule**
- **Funding and Personnel Resources**
- **WBS Details**



PROGRAM ROAD MAP





WORK BREAKDOWN STRUCTURE (WBS)

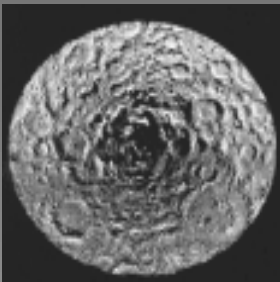
1.0 Document Current Data
2.0 Simulation Models
**3.0 Identify, Conceptualize, Assess
Uses**
4.0 Detailed Systems Studies
5.0 Technology Development
6.0 Ground Simulator Facilities
7.0 Lunar Exploration Mission

8.0 Lunar Extraction Mission
9.0 Lunar Extraction Facility
10.0 DDT&E for Lunar Uses
11.0 DDT&E for Mars Uses
**12.0 DDT&E for other Solar
System Uses**
13.0 Education and Outreach
**14.0 NASA Program
Management and Reports**



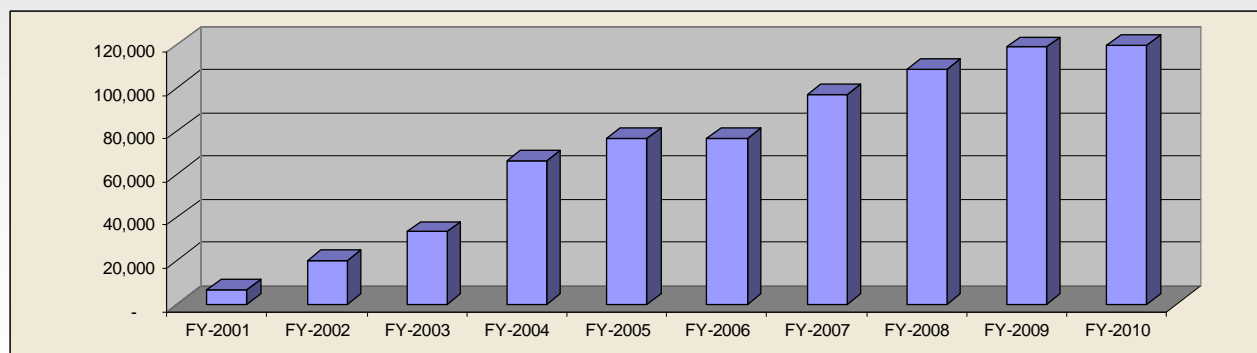
MILESTONE SCHEDULE

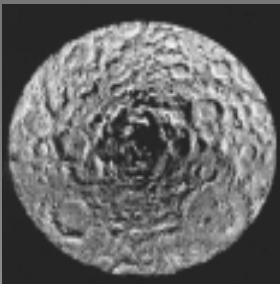
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FUNDING RESOURCES

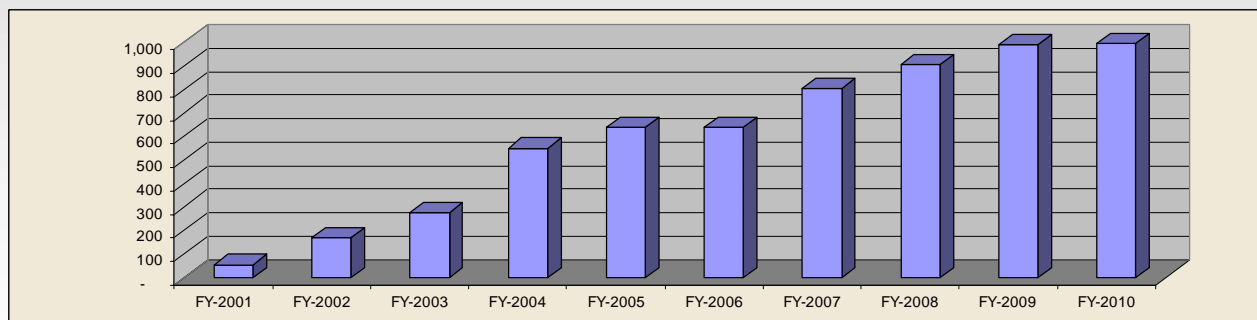
							FY-2000 Dollars						
WBS Element #	WBS Element Title			FY-2001	FY-2002	FY-2003	FY-2004	FY-2005	FY-2006	FY-2007	FY-2008	FY-2009	FY-2010
1.0	Document Current Data			100									
2.0	Simulation Models			300									
3.0	Identify, Conceptualize, Assess Uses			1,000	1,000	500							
4.0	Detailed Systems Studies				1,200	1,800							
5.0	Technology Development			3,500	7,000	7,000	3,500						
6.0	Ground Simulator Facilities			200	1,000	2,000	8,000	1,000	1,000	1,000	1,000	1,000	1,000
7.0	Lunar Exploration Flight Mssion			1,000	9,000	20,000	50,000	60,000	30,000	2,000			
8.0	Lunar Extraction Mssion					1,000	2,000	12,000	30,000	70,000	70,000	20,000	2,000
9.0	Lunar Extraction Plant Mssion						1,000	1,000	8,000	10,000	20,000	60,000	70,000
10.0	DDT&E for Lunar Uses							1,000	5,000	10,000	10,000	30,000	40,000
11.0	DDT&E for Mars Uses								500	1,000	5,000	5,000	5,000
12.0	DDT&E for other Solar System Uses									500	500	500	500
13.0	Education and Outreach			30	40	50	80	100	100	100	100	50	50
14.0	NASA Program Management and Reports			500	1,000	1,000	1,500	1,500	2,000	2,000	2,000	2,000	1,000
	Program Totals			6,630	20,240	33,350	66,080	76,600	76,600	96,600	108,600	118,550	119,550

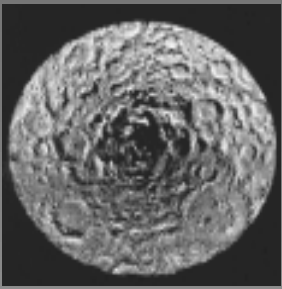




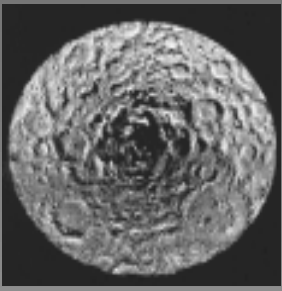
PERSONNEL RESOURCES

							Estimated Person Years					
WBS Element #	WBS Element Title		FY-2001	FY-2002	FY-2003	FY-2004	FY-2005	FY-2006	FY-2007	FY-2008	FY-2009	FY-2010
1.0	Document Current Data		1	-	-	-	-	-	-	-	-	-
2.0	Simulation Models		3	-	-	-	-	-	-	-	-	-
3.0	Identify, Conceptualize, Assess Uses		8	8	4	-	-	-	-	-	-	-
4.0	Detailed Systems Studies		-	10	15	-	-	-	-	-	-	-
5.0	Technology Development		29	58	58	29	-	-	-	-	-	-
6.0	Ground Simulator Facilities		2	8	17	67	8	8	8	8	8	8
7.0	Lunar Exploration Flight Mssion		8	75	167	417	500	250	17	-	-	-
8.0	Lunar Extraction Mssion		-	-	8	17	100	250	583	583	167	17
9.0	Lunar Extraction Plant Mssion		-	-	-	8	8	67	83	167	500	583
10.0	DDT&E for Lunar Uses		-	-	-	-	8	42	83	83	250	333
11.0	DDT&E for Mars Uses		-	-	-	-	-	4	8	42	42	42
12.0	DDT&E for other Solar System Uses		-	-	-	-	-	-	4	4	4	4
13.0	Education and Outreach		0	0	0	1	1	1	1	1	0	0
14.0	NASA Program Management and Reports		4	8	8	13	13	17	17	17	17	8
	Program Totals		55	169	278	551	638	638	805	905	988	996



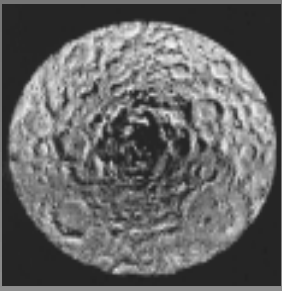


WBS DETAILS



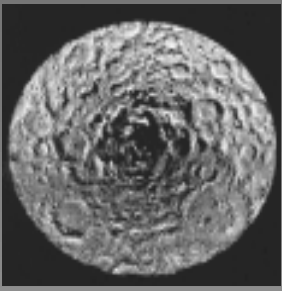
1.0 DOCUMENT CURRENT DATA

- **Summarize, Quantify, and Document All the Scientific Data Currently Available from:**
 - Apollo
 - Hubble
 - Clementine
 - Lunar Prospector
 - Earth-based Telescopes
 - Other Sources
- **Interview Leading Scientists in the Know**



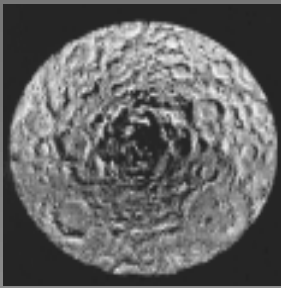
2.0 SIMULATION MODELS

- **Develop Simulation Models of the Possible Physical/Chemical Processes and Their Contributions That May Have Resulted in Polar Lunar H₂O and Polar Lunar H**
 - Solar Wind Impact on the Moon's Surface
 - Micro-Meteor and Meteor Impacts on the Surface
 - Comet Impacts



3.0 IDENTIFY, CONCEPTUALIZE, ASSESS USES OF LUNAR POLAR H₂O ICE OR LUNAR POLAR H

- **Propellant Sources for Propulsion/Power Applications**
- **Lunar Base Support Applications**
- **Quantify and Prioritize Needs**
- **Develop Concept Definitions for System/Subsystems**
- **Determine Total System Infrastructure Needs**
- **Create Mission Models for Cost-Benefit Analysis**
- **Develop a Cost-Benefit Model and Conduct Detailed Analysis**



PROPELLANT SOURCES FOR PROPULSION/POWER APPLICATIONS (Solid, Liquid, or Gas H_2 , O_2 , and H_2O_2 Propellant Combinations) (3.1)



- **Lunar Flight Transportation and Orbital Support Systems**

- Lunar Surface to Lunar Surface Transport Systems
- Lunar Surface to Lunar Orbit Transport Systems
- Lunar Orbit to Earth Orbit Transport Systems
- Lunar Orbit to Earth Reentry Transport Systems
- Lunar Surface to Earth Orbit Support Systems (SPS, ISS, etc.)
- Lunar Surface to Earth Reentry Transport Systems (exporting lunar resources)
- Lunar Orbit Communications and Remote Sensing Satellite Systems
- Lunar Orbiting Service Station (LOSS) System
- Earth Orbiting Service Station (EOSS) System

- **Mars Flight Transportation Systems and Propellant Production**

- LH_2/LO_2 Propellants for Main and Auxiliary Chemical Propulsion
- SOX/ LH_2 Propellants for Main and Auxiliary Chemical Propulsion
- CH_4/LO_2 Propellants for Main and Auxiliary Chemical Propulsion
- O_2 for Solar Electric Propulsion for Mars
- H_2O for Nuclear Steam Rocket
- LH_2 for Nuclear or Solar Thermal Rocket
- SH_2 HEDM in LHe for Chemical Propulsion

- **Lunar or Mars Ground-based Fuel Cell or Combustion-Driven Ground Transport Vehicles**

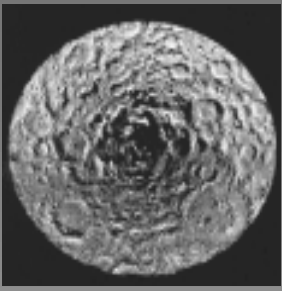
- Exploration-based Robotic and Manned Rovers
- Personnel Transporters
- ISRU Material Transporters
- Equipment Transporters
- Regolith Bulldozers
- Mining Equipment
- Winged Aircraft Powered Balloons

- **Other Solar System Transport Systems**

- LH_2/LO_2 Propellants for Main and Auxiliary Chemical Propulsion
- O_2 for Solar Electric Propulsion
- H_2O for Nuclear Steam Rocket
- LH_2 for Nuclear or Solar Thermal Rocket

- **Non-Propulsion Mars Applications Using Lunar Ice or**

- H_2O or H_2 and O_2 for Mars Crew Life Support Systems
- H_2O or H_2 for Mars Crew Food Production Systems
- H_2O or H_2 for Mars Crew Radiation Protection System
- H_2O or H_2 for Mars Outpost Power Systems
- Auxiliary or Emergency Power Systems
- H_2O for Mars Concrete Production



LUNAR BASE SUPPORT APPLICATIONS (3.2)

- **Crew Life Support Systems**

- Drinking Water
- Atmospheric Oxygen
- Atmospheric Humidity
- Washing/Bathing
- Waste Processing
- Space Suit Life Support (H_2O , O_2 , etc.)

- **Food Production Systems**

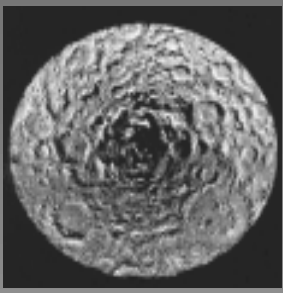
- Plant Growth
- Food Processing
- Plant Reprocessing and Resource Recovery
- Animal-Based Food Production

- **Lunar Laboratory Research**

- Plant Research
- Animal Research
- Chemistry
- Physics
- Biology/Biotechnology
- Mineralogy/Geology
- ISRU Chemical Processing Research

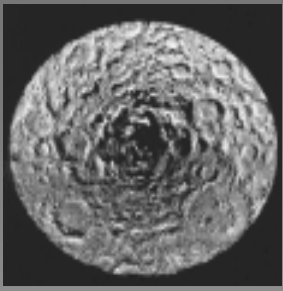
- **Lunar Base Infrastructure Needs**

- Lunar Oxygen Production with H Recovery
- Lunar Concrete Production for Roads, Buildings, Shielding
- Thermal Control Support Systems
- Oxygen or Hydrogen as Inflating Gas for Inflatable Structures
- Water Radiation Shielding for Habitats/Laboratories
- Water for Lunar Base Manufacturing Needs



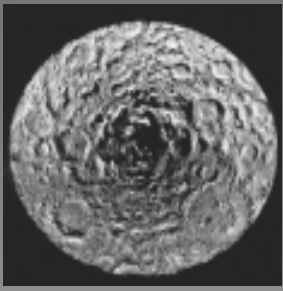
4.0 DETAILED SYSTEMS STUDIES

- **Additional Characterization and Development of Models of the Lunar Ice/H**
- **Study Cost-Benefit of Additional Lunar Orbiting Missions to Map Polar Regions**
- **Study Cost-Efficient Space Transportation Systems**
- **Study Cost-Efficient Approaches to Conducting Rover-based Exploration**
- **Study Promising Extraction Techniques/Logistics Approaches**
- **Conduct Ground-Based and Lunar In-situ Laboratory Experiments/Scientific Research**
- **Define Requirements:**
 - Simulator Designs
 - In-situ Flight Missions and Sample Returns
 - Lunar Production Facilities
- **Nuclear Thermal Device Application Assessment**
- **Resource Use and Conservation Plan**
- **Legal/Political/Treaty Issue Assessment**
- **Commercial Development and Commercial/Government Partnership Potential Assessments**
- **Lunar Environmental Impact Assessment**
- **Cost Modeling and Analysis**



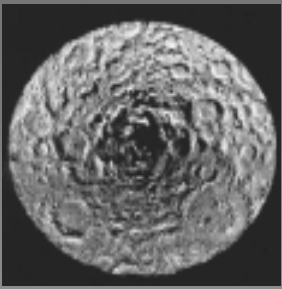
5.0 TECHNOLOGY DEVELOPMENT

- **70 K-Cold Operations of Mechanical, Electrical and Fluid Systems**
- **Application of DOE's ARPS, GPHS Brick, and other Systems for this Application**
- **Small Nuclear Reactors**
- **Microwave Energy Systems and ovens for In-situ Processing**
- **Tether Systems for Ground-based Automated Experimental and Large Automated Water Ice Acquisition and Processing Systems**
- **Technology for Materials Handling and Processing for Ground-based Automated Experimental and Large Automated Water Ice Acquisition and Processing Systems**
- **Electrolysis Systems and Fuel Cells in Zero and Partial g's**
- **Water Rocket Technologies for Orbit Transfer and Orbital Auxiliary Propulsion**
- **Distillation/Purification of Water from the Regolith in 1/6 g**
- **Solar Energy Beaming into the Cold Region**



5.0 TECHNOLOGY DEVELOPMENT (CONT.)

- **Microwave Energy Beaming into the Cold Region**
- **Water Storage and Transport/Transfer Systems**
- **Water Recovery Systems Near Lunar Launch Sites**
- **Water Recovery Systems for All Water Use Applications**
- **Lunar Sample Return Mission Technology Using Processed Water Ice for Propellants**
- **Superconducting Energy and Data Transmission**
- **Cryogenic Hardening of Electronic and Mechanical Systems**
- **Excavation Technology**
- **Ballistic and Ground-based Transporters**
- **Assess H₂O₂ Propulsion Systems for Lunar Transport Applications**
- **Hydrogen Peroxide Production in 1/6 g**



6.0 GROUND SIMULATOR FACILITIES

Phase 1 - Small-Scale Demonstration Lunar Ice Simulator

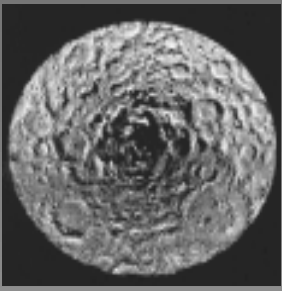
- Detailed Requirements Development
- Experiment Definition Development
- Detailed Subsystem Design and Analysis
- Facility Construction
- Research Program

Phase 2 - Medium-Scale Demonstration Lunar Ice Simulator

- Detailed Requirements Development
- Experiment Definition Development
- Detailed Subsystem Design and Analysis
- Facility Construction
- Research Program

Phase 3 - Full-Scale Lunar Ice Flight System Simulator

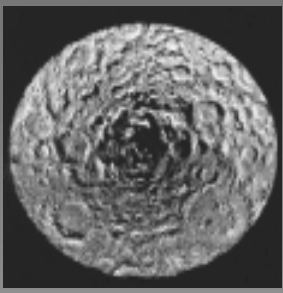
- Detailed Requirements Development
- Flight Testing Definition Development
- Detailed Subsystem Design and Analysis
- Facility Construction/Modification at JSC
- Testing Program



7.0 LUNAR EXPLORATION FLIGHT MISSION WITH SAMPLE RETURN

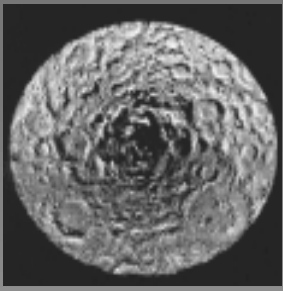


- **System Requirements and Experiment/Measurement Definition**
- **Engineering and Analysis**
- **Component Development and Testing**
- **Detailed Design**
- **Hardware Development and Checkout**
- **In-Simulator Cold Operations Testing and Performance Evaluation**
- **Flight System LV Integration**
- **Mission Flight/Sample Return**
- **Mission Operations and Data Analysis**



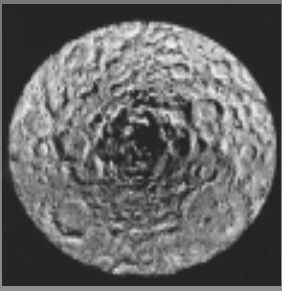
8.0 LUNAR ICE/H EXTRACTION MISSION

- **System Requirements and Production Definition**
- **Engineering and Analysis**
- **Component Development and Testing**
- **Detailed Design**
- **Hardware Development and Checkout**
- **In-Simulator Cold Operations Testing and Performance Evaluation**
- **Flight System LV Integration**
- **Mission Flight**
- **Mission Operations and Data Analysis**



9.0 LUNAR ICE/H EXTRACTION FACILITY

- **System Requirements and Production Definition**
- **Engineering and Analysis**
- **Component Development and Testing**
- **Detailed Design**
- **Hardware Development and Checkout**
- **In-Simulator Cold Operations Testing and Performance Evaluation**
- **Flight System LV Integration**
- **Mission Flight**
- **Mission Operations and Data Analysis**



10.0 DDT&E FOR LUNAR USES

- **Lunar Flight Transportation and Orbital Support Systems**

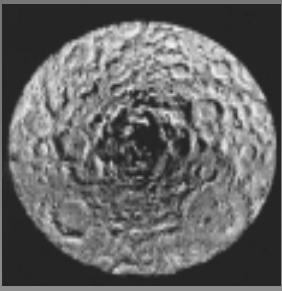
- H/O Lunar Surface to Lunar Surface Transport Systems
- H/O Lunar Surface to Lunar Orbit Transport Systems
- H/O Lunar Orbit to Earth Orbit Transport Systems
- H₂O₂ Propellants for Main and Auxiliary Chemical Propulsion
- H/O Lunar Orbit to Earth Reentry Transport Systems
- H/O Lunar Surface to Earth Orbit Support Systems (SPS, ISS, etc.)
- H/O Lunar Surface to Earth Reentry Transport Systems (exporting lunar resources)
- Lunar Orbit Communications and Remote Sensing Satellite Systems
- Lunar Orbiting Service Station (LOSS) System
- Earth Orbiting Service Station (EOSS) System

- **Lunar Ground-based Fuel Cell or Combustion-Driven Ground Transport Vehicles**

- Exploration-based (scientific and commercial) Robotic and Manned Rovers
- Personnel Transporters
- ISRU Material Transporters
- Equipment Transporters
- Regolith Bulldozers
- Mining Equipment

- **Other Lunar Base Applications Using Lunar Ice or H**

- H₂O or H₂ and O₂ for Lunar Crew Life Support Systems
- H₂O or H₂ for Lunar Crew Food Production Systems
- H₂O or H₂ for Lunar Crew Radiation Protection System
- H₂O or H₂ for Lunar Outpost Power Systems
- Auxiliary or Emergency Power Systems
- H₂O for Lunar Concrete Production for Roads, Buildings, Shielding
- Auxiliary or Emergency Power Systems
- Lunar Oxygen Production with H Recovery
- Thermal Control Support Systems
- Oxygen or Hydrogen as Inflating Gas for Inflatable Structures
- Water for Lunar Base Manufacturing Needs
- Lunar Laboratory Research (plant and animal, chemistry, physics, biology/biotechnology mineralogy/geology, ISRU chemical processing, etc.)
- Electromagnetic Launcher Systems
- Laser Propulsion Launcher Systems



11.0 DDT&E FOR MARS USES

- **Mars Flight Transportation Systems and Propellant Production**

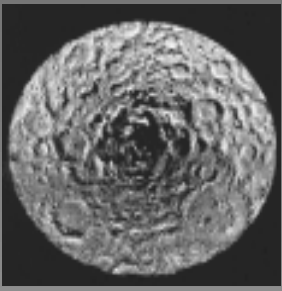
- LH₂/LO₂ Propellants for Main and Auxiliary Chemical Propulsion
- SOX/LH₂ Propellants for Main and Auxiliary Chemical Propulsion
- CH₄/LO₂ Propellants for Main and Auxiliary Chemical Propulsion
- H₂O₂ Propellants for Main and Auxiliary Chemical Propulsion
- O₂ for Solar Electric Propulsion for Mars
- H₂O for Nuclear Steam Rocket
- LH₂ for Nuclear or Solar Thermal Rocket
- SH₂ HEDM in LHe for Chemical Propulsion

- **Mars Ground-based Fuel Cell or Combustion-Driven Ground Transport Vehicles**

- Exploration-based Robotic and Manned Rovers
- Personnel Transporters
- ISRU Material Transporters
- Equipment Transporters
- Regolith Bulldozers
- Mining Equipment

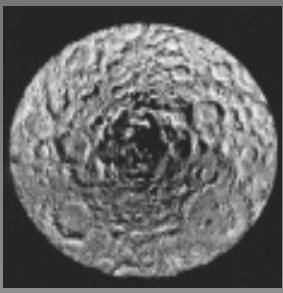
- **Non-Propulsion Mars Applications Using Lunar Ice or H**

- H₂O or H₂ and O₂ for Mars Crew Life Support Systems
- H₂O or H₂ for Mars Crew Food Production Systems
- H₂O or H₂ and O₂ for Mars Mars Laboratory Research
- H₂O or H₂ and O₂ for Mars Base Infrastructure Needs
- H₂O or H₂ for Mars Crew Radiation Protection System Outpost Power Systems
- Auxiliary or Emergency Power Systems
- H₂O for Mars Concrete Production



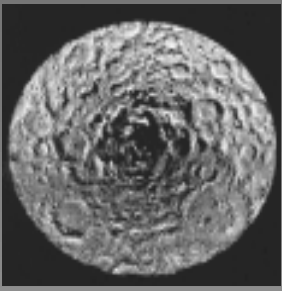
12.0 DDT&E FOR OTHER SOLAR SYSTEM USES

- **LH₂/LO₂ Propellants for Main and Auxiliary Chemical Propulsion**
- **O₂ for Solar Electric Propulsion**
- **H₂O for Nuclear Steam Rocket**
- **LH₂ for Nuclear or Solar Thermal Rocket Propulsion**



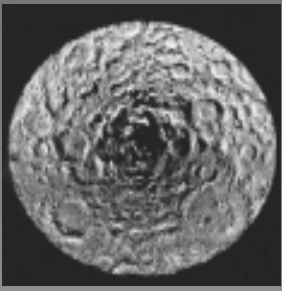
13.0 EDUCATION AND OUTREACH

- Curriculum and Educational Materials -- create materials to be distributed in two forms, classroom materials and materials for individual use
- Engineering and Experiment Design Lessons -- create materials on the design and function of the experiment itself, including its construction, the placement and function of all the instrument's sensors and how this package will accomplish the experiment goals
- Chemistry Lessons -- create materials on the chemistry of the Lunar environment and the chemical processes used to create the rocket propellants
- Physics and Rocketry -- create materials on the general concepts of rocketry as they relate to the Lunar Ice Missions
- Conventions -- distribute information regarding the program at all regional and National Science Teachers Association (NSTA) conventions as well as some major state conventions
- Technical Conferences -- distribute information regarding the program at national conferences, including AIAA, ASME, SAE, etc
- Publications -- papers written by the Program Public Affairs Officer will be distributed for publication in national Internet, education, and space publications
- NASA Educators -- informational materials will be distributed through NASA Educators
- USRA -- work closely with USRA to distribute information to the universities
- Space Grant Consortia and Universities -- will work with space grant consortia and universities to foster direct involvement by school in each state
- Direct Mailing -- in conjunction with NSTA will conduct a direct mailing to reach physics, chemistry, and physical science teachers who will benefit from the program
- Partnerships -- develop primary public partnerships: AIAA, Planetary Society, National Space Society, Mars Society, NASA's-state based Space Grant Consortia, NASA Educators, etc



14.0 NASA PROGRAM MANAGEMENT AND REPORTS

- **Program Management and Coordination**
- **Budget Control**
- **Liaison**
- **Public affairs**
- **Reports/Publications/Brochures**



CONCLUSIONS

- ❖ **Element Hydrogen (from H_2O or H_2) is Available on the Moon in Useful Abundance**
- ❖ **Lunar Base Development will be Heavily Dependent on This Resource, as a Water-based Economy/System Will Develop**
- ❖ **If Hydrogen is the Form, Then Oxygen Processing from the Regolith Will Be Necessary -- Technology for This Is Readily Available (H, C, reduction processes)**
- ❖ **Early Mars Manned Exploration and Developments Could Well Be Enhanced by Using Lunar Water/H**
- ❖ **Chemical or Nuclear-based Earth-Mars Transports May Be Economically Enhanced for Some Time**
- ❖ **Later Mars Surface Activities Would Likely Use Mars-based Resources H_2O and CO_2**
- ❖ **The Draft Program Plan for the First Ten Years Appears to be Doable Within the Expected NASA Budget**
- ❖ **International Cooperation Could Reduce the US Contribution; Commercial Interests Could Also Contribute and Reduce the Government's Funding**