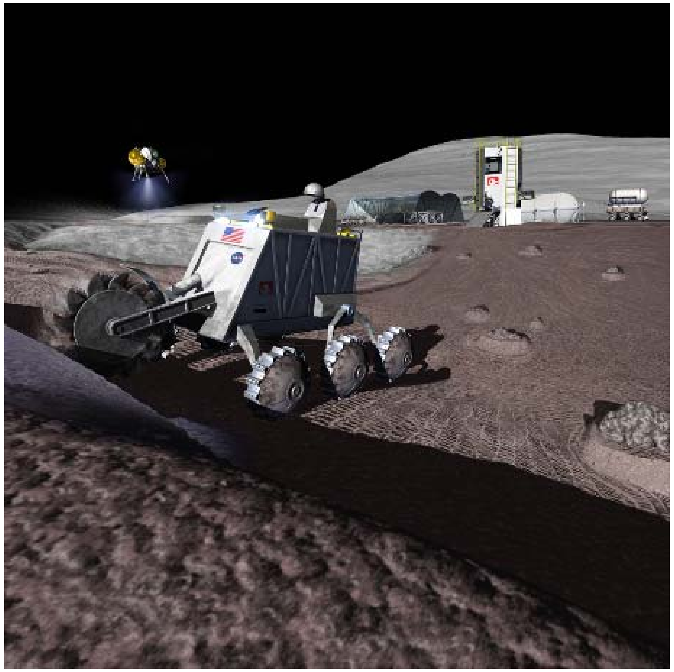
NASA In-Situ Resource Utilization (ISRU) Project Overview



Presentation at Lunar Regolith Simulant Workshop

Oct. 10, 2007, Huntsville, AL

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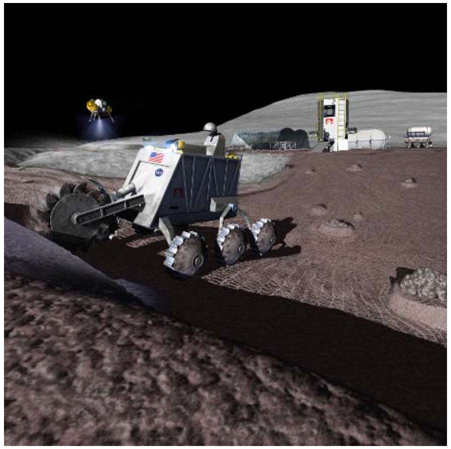
ISRU: Decisions from Lunar Architecture Development

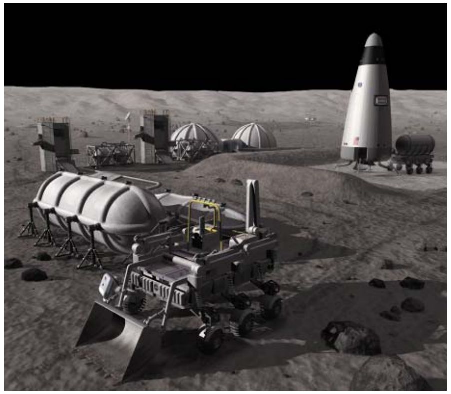
- **ISRU is a critical capability and key implementation of the VSE and sustained human exploration**

- **At the same time, ISRU on the Moon is an unproven capability for human lunar exploration and can not be put in the critical path of architecture until proven**

- **Therefore, ISRU (as an end in and of itself) is manifested to take incremental steps toward the desired endstate**

- **Architecture is designed to be open enough to take advantage of ISRU from whatever source when available**





What is Lunar In-Situ Resource Utilization (ISRU)?

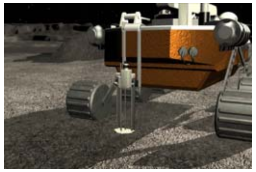
ISRU involves any hardware or operation that harnesses and utilizes 'in-situ' resources to create products and services for robotic and human exploration

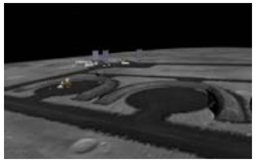
In-Situ Lunar Resources

- **'Natural' Lunar Resources:**
  - Regolith, minerals, metals, volatiles, and water/ice
  - Sunlight, vacuum, thermal gradients/cold sinks
- **Discarded Materials**
  - LSAM descent stage fuel residual scavenging, tanks, material, etc. after landing
  - Crew trash and waste (after Life Support processing is complete)

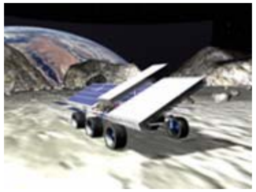
Lunar ISRU Products and Services

- **Site Preparation and Outpost Deployment/Emplacement**
  - Site surveying and resource mapping
  - Crew radiation protection (In-situ water production or bulk regolith)
  - Landing area clearing, surface hardening, and berm building for Lunar Lander landing risk and plume mitigation
  - Area and road clearing to minimize risk of payload delivery and emplacement
- **Mission Consumable Production**
  - Complete Life Support/Extra Vehicular Activity closure for Oxygen (O_2) and water
  - Propellant production for robotic and human vehicles
  - Regenerate and storage life support and fuel cell power consumables (in conjunction with Life Support and Power)
- **Outpost Growth and Self-Sufficiency**
  - Fabrication of structures that utilize in-situ materials (in conjunction with Habitats)
  - Solar array, concentrator, and/or rectenna fabrication (in conjunction with Power)
  - Thermal energy storage & use from processed regolith (in conjunction with Power)
  - Production of feedstock for fabrication and repair (in conjunction with Sustainability)









Three Pronged Approach to ISRU Development & Incorporation

- **Identify how ISRU fits into Architecture for Sustained human presence on the Moon**
  - Non-critical path initially with fall back strategy
  - Evolutionary with growth in:
    - Capability
    - Criticality
    - Ties to Mars
    - Ties to Space Commercialization
- **Build confidence in ISRU early and often**
  - Multiple generations of hardware and systems developed
  - Extensive ground and analog site testing for operations, maintenance, and interconnectivity
  - Robotic precursors if possible to reduce risk AND
    - Tie to common science objectives for regolith, mineral, and volatile characterization
    - Tie to long-term operations associated with Outpost deployment and operation
- **Early NASA involvement in all aspects of ISRU with transition to industry**
  - Ensures NASA is 'smart' buyer
  - Ensures lessons learned from ground and flight demonstrations are transferred to all of industry (unless pre-agreement established for commercialization aspect)
  - Ensures long-term industry involvement for spin-in and spin-off applications

ISRU Consumable Production for Lunar Architecture

- **O_2 Production from Regolith**
  - 2 MT/yr production rate for surface mission consumables – 1 MT/yr for ECLSS/EVA and 1 MT/yr to make water
  - Capability manifested on 6th landed mission (before start of permanent presence)
  - Increased production to 10 MT/yr during Outpost operation could also support refueling 2 ascent vehicles per year to further increase payload delivery capability
- **In-Situ Water Production**
  - Scavenge minimum of 55 kg of hydrogen (max. ~252 kg) from each LSAM descent stage after landing and add to in-situ oxygen to make 1 MT/yr of water
  - Polar water extraction not evaluated in Lunar Architecture Phase II effort. Not needed unless large scale in-situ propellant (O_2 & H_2) production is required
- **In-Situ Methane Production**
  - Pyrolysis processing of plastic trash and crew waste with in-situ oxygen can make methane
  - Capability supports LSAM Ascent 'top-off' in case of leakage, power loss, or increased payload to orbit

ISRU Processing Requirements	kg/yr (min.)
Oxygen Production	
For ECLSS & EVA	1000
For Water Production	800
For LSAM Ascent Propulsion	7600
Water Production	
For ECLSS & EVA (from in-situ O_2 + Scavenged H_2)	900
Required H_2 Scavenged from LSAM Descent Stage	100
For radiation shielding (*one time production need)	1000 to 2000*
Water Electrolysis	
For ISRU	1125
For Night time Power	7335
For Pressurized Rover Power (45 kg/mission)**	1260
Methane Production	
For LSAM Ascent Propulsion (max)	2160

** 28 excursions per year with at least 1 MPU

Possible Excavation Needs & Requirements for the Outpost

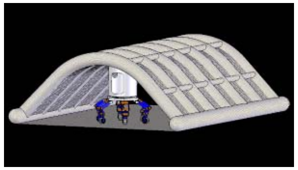
- **Excavation for Oxygen Production**
  - Evaluated a number of excavation options
  - Parametrics presented are based on a front-end/overshot loader that scoops and dumps into bin on back of chassis
  - If operate continuously, primary difference between small and large chasses is rate of drain on battery
    - Very inefficient to dig slowly/small amounts per scoop - lifting arm and dumping into bin is primary energy drain

- **Excavation for Outpost: Landing pads and berms**
  - Largest outpost emplacement excavation requirement over life of Outpost
  - If landers are not moved, a new pad needs to be prepared *every 6 months*
  - Capability Manifested on 1st landed mission

- **Excavation for Outpost: Habitat protection**
  - Multiple options if regolith shielding for radiation or thermal is desired
  - Trenching and inflatable covers evaluated for excavation impact

- **Excavation for Outpost Emplacement**
  - Excavate ramp or hole for nuclear reactor emplacement/shielding
  - Prepare pathways for transferring cargo from lander
  - Prepare trenches for cables

- **Excavation for Science**
  - Prepare trenches for subsurface geologic/strategraphy access for Science
  - Core extraction drilling for subsurface sample acquisition (resource characterization)
  - Site preparation for antenna deployment



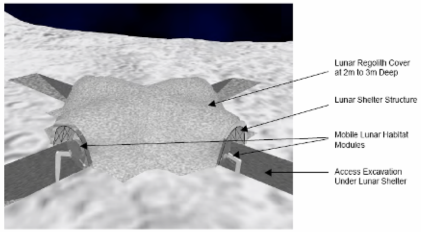
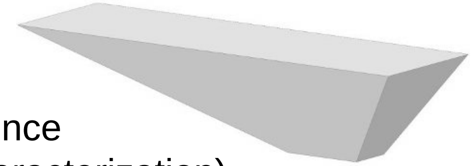
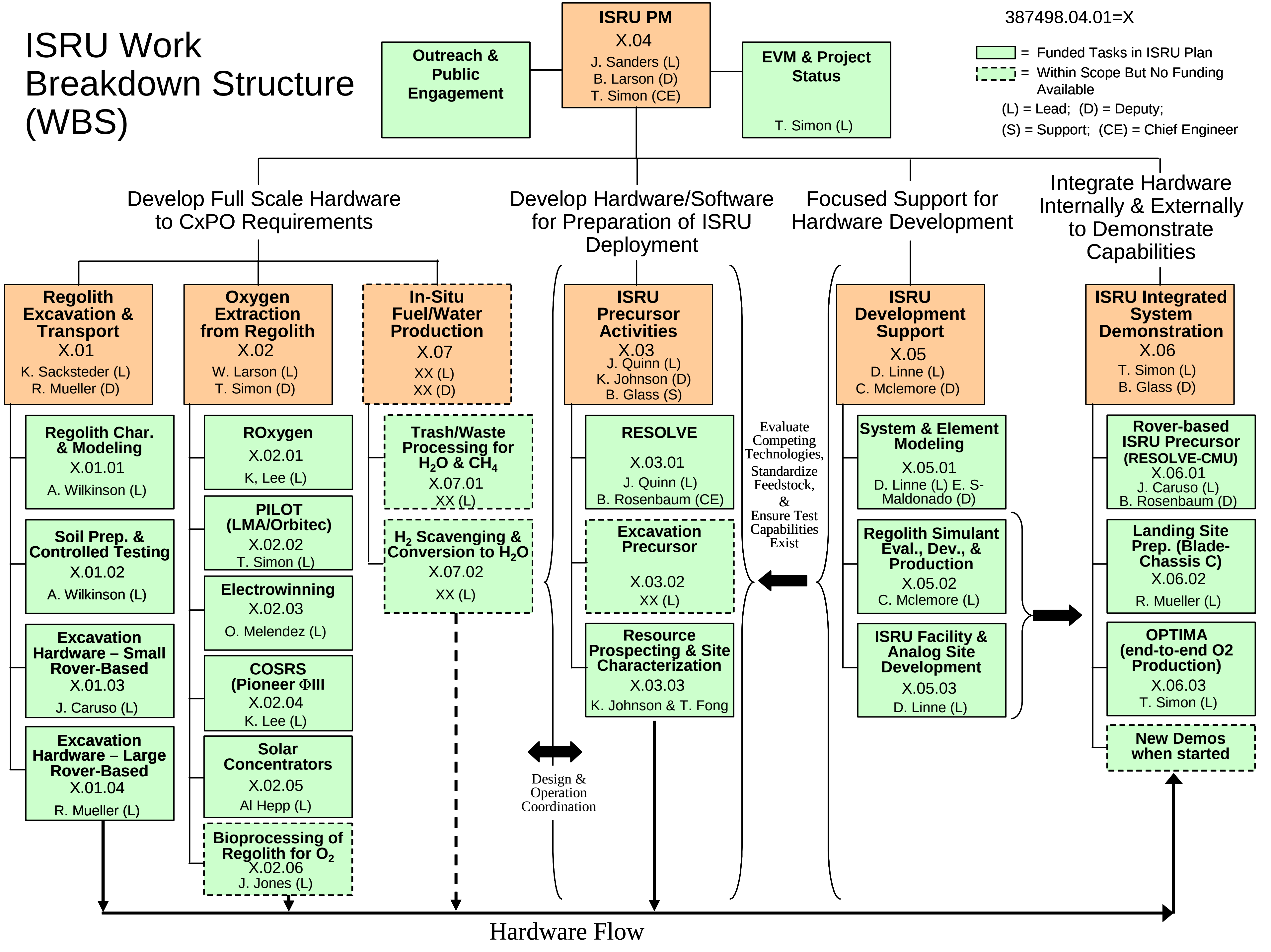


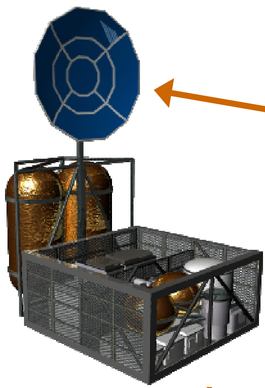
FIGURE 7. Completed Shelter Providing Protection for Mobile Lunar Habitat Modules.




ISRU Work Breakdown Structure (WBS)
387498.04.01=X
= Funded Tasks in ISRU Plan
= Within Scope But No Funding Available
(L) = Lead; (D) = Deputy;
(S) = Support; (CE) = Chief Engineer
ISRU PM
X.04
J. Sanders (L)
B. Larson (D)
T. Simon (CE)
Outreach & Public Engagement
EVM & Project Status
T. Simon (L)
Develop Full Scale Hardware to CxPO Requirements
Develop Hardware/Software for Preparation of ISRU Deployment
Focused Support for Hardware Development
Integrate Hardware Internally & Externally to Demonstrate Capabilities
Regolith Excavation & Transport
X.01
K. Sacksteder (L)
R. Mueller (D)
Regolith Char. & Modeling
X.01.01
A. Wilkinson (L)
Soil Prep. & Controlled Testing
X.01.02
A. Wilkinson (L)
Excavation Hardware – Small Rover-Based
X.01.03
J. Caruso (L)
Excavation Hardware – Large Rover-Based
X.01.04
R. Mueller (L)
Oxygen Extraction from Regolith
X.02
W. Larson (L)
T. Simon (D)
ROxygen
X.02.01
K, Lee (L)
PILOT (LMA/Orbitec)
X.02.02
T. Simon (L)
Electrowinning
X.02.03
O. Melendez (L)
COSRS (Pioneer ΦIII
X.02.04
K. Lee (L)
Solar Concentrators
X.02.05
Al Hepp (L)
Bioprocessing of Regolith for O_2
X.02.06
J. Jones (L)
In-Situ Fuel/Water Production
X.07
XX (L)
XX (D)
Trash/Waste Processing for H_2O & CH_4
X.07.01
XX (L)
H_2 Scavenging & Conversion to H_2O
X.07.02
XX (L)
ISRU Precursor Activities
X.03
J. Quinn (L)
K. Johnson (D)
B. Glass (S)
RESOLVE
X.03.01
J. Quinn (L)
B. Rosenbaum (CE)
Excavation Precursor
X.03.02
XX (L)
Resource Prospecting & Site Characterization
X.03.03
K. Johnson & T. Fong
Design & Operation Coordination
Evaluate Competing Technologies, Standardize Feedstock, & Ensure Test Capabilities Exist
ISRU Development Support
X.05
D. Linne (L)
C. Mclemore (D)
System & Element Modeling
X.05.01
D. Linne (L) E. S-Maldonado (D)
Regolith Simulant Eval., Dev., & Production
X.05.02
C. Mclemore (L)
ISRU Facility & Analog Site Development
X.05.03
D. Linne (L)
ISRU Integrated System Demonstration
X.06
T. Simon (L)
B. Glass (D)
Rover-based ISRU Precursor (RESOLVE-CMU)
X.06.01
J. Caruso (L)
B. Rosenbaum (D)
Landing Site Prep. (Blade-Chassis C)
X.06.02
R. Mueller (L)
OPTIMA (end-to-end O2 Production)
X.06.03
T. Simon (L)
New Demos when started
Hardware Flow

Lunar Architecture ISRU Systems & Technologies

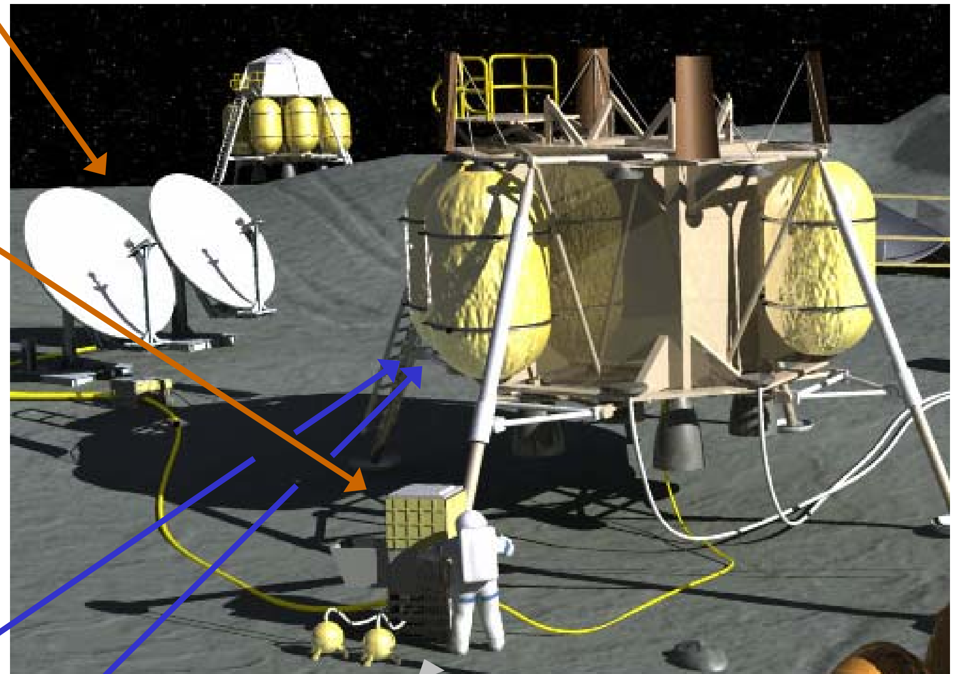
Solar Concentrators
- Lightweight or inflatable collectors
- Thermal management

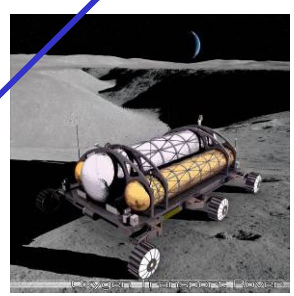


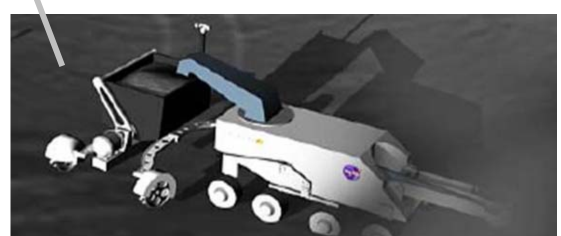
Oxygen Extraction from Regolith
- Solid/gas processors
- Water electrolysis
- CO_2/methane processors & reagent regeneration
- Contaminant removal
- Thermal management & Radiators
- Dust tolerant sealing

H_2 Scavenging to Make Water
- Dust tolerant O_2 disconnects
- Dust tolerant H_2 disconnects

Oxygen Storage-Transfer
- High pressure O_2
- O_2 cryocoolers
- Liquid O_2 storage
- Thermal management
- Dust tolerant O_2 disconnects

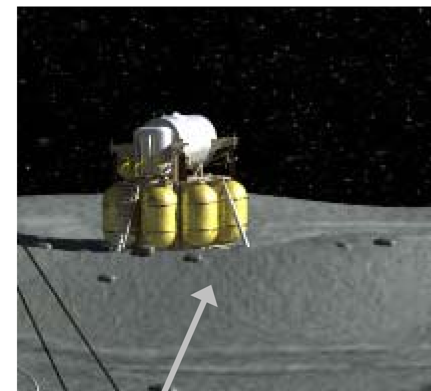


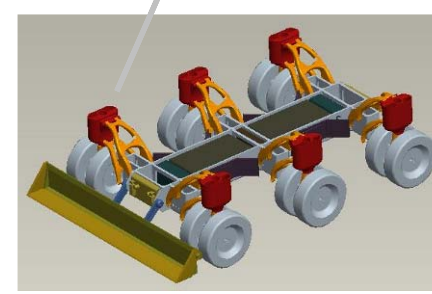




Regolith Excavators/Haulers
- Surface mobility platforms
- High-cycle life, high-power density power systems
- End-effectors w/ dust tolerant mechanisms
- Autonomous control

Site Preparation, Berm Building, & Reactor Burial
- Surface Mobility
- High-cycle life, high-power density power systems
- End effectors w/ dust tolerant mechanisms
- Autonomous control





Small vs Large Rovers

In-Situ Resource Utilization Simulant & Dust Issues

"ISRU needs not only to mitigate lunar regolith & dust but embrace it"

- **Regolith Excavation and Material Handling**
  - Rotating and sliding mechanisms for actuators; wide temperature extremes as well as temperature cycles are possible
  - Regolith movement and storage: auger binding, bin plugging, etc.
  - Uncertainty in regolith and dust properties impacting operation and performance
  - Rover excavator and other ISRU hardware operation in 'dust clouds' due to regolith excavation, dumping, and transfer.

- **Regolith Processing**
  - Oxygen Extraction Performance: mineral type and concentration effects process energy, efficiency, and duration of operations
  - Volatile Extraction Performance: concentration and method for bounding volatiles effects process energy, efficiency, and duration of operations
  - Sealing : Multi-use, low leakage.
    - For oxygen extraction from regolith, high temperatures 900 C to +1600 C
    - For polar volatile extraction, low temperatures down to 40 K
  - Regolith movement and storage: auger binding, bin plugging, etc.
  - Gas stream filtration: prevent dust from 'poisoning' downstream processes
  - Energy transfer during operation: degradation of solar collectors, lasers, and light/solar energy transfer/windows

In-Situ Resource Utilization Simulant & Dust Issues (Cont.)

- **Thermal management**:
  - Dust changing thermal conduction and emissivity changes for radiators
  - Heat recuperation from processed regolith is important for process efficiency

- **Product Storage & Transfer**
  - Change in heat leak and emissivity of cryogenic tanks changes power required
  - Dust in oxygen disconnects for life support, fuel cell reactant, and propellant consumable transfer can cause both operation (leakage) and safety (fire) concerns

Integrated Capability and Analog Site Demonstrations

Utilize laboratory and analog site demonstrations to:

- Demonstrate needed capabilities and operations for Lunar Outpost and technology/system 'customers'
- Demonstrate evolution and incremental growth in technologies and systems for Capabilities (ex. digging deeper); Performance (ex. lower power); and Duration (ex. more autonomy or more robustness).
- Unite separate technology development efforts within NASA
- Develop partnerships and relationships across NASA and other US government agencies, and with International Partners, Industry, and Academia

	2007						2008												2009											
	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Site Preparation & Outpost Construction																														
COTS blade on Chariot rover @ JSC							◆																							
Inflatable habitat burial									⬟																					
Area clearing/berm building filed demonstration												◆																		
Reactor mockup burial																											▲			
Oxygen Extraction from Regolith																														
PILOT H_2 reduction reactor field test @ Desert RATS															▲															
- Includes: excavator & O_2 liquefaction & storage																														
ROxygen H_2 reduction field test @ Desert RATS															▲															
- Includes: excavator & high pressure O_2 storage																														
Integrated Carbothermal reduction reactor & Solar Concentrator															▲															
RESOLVE H_2 reduction field test																	▲													
Upgraded ROxygen reactor with Solar Concentrator																											▲			
Full-scale Carbothermal reduction reactor & Solar Concentrator																											▲			
Site Characterization & Resource Prospecting																														
K10s with GPR and 3D lidar at Haughton	◆																													
RESOLVE drill integration onto CMU rover at CMU			▲																											
K10s with GPR and Neutron Spectrometer at ARC					◆																									
RESOLVE drill/CMU rover field test at CMU						▲																								
Combined K10 and RESOLVE/CMU field test												▲					▲													

▲ = In-Situ Resource Utilization (ISRU)-led Demo ◆ = Human-Robotic Systems (HRS)-led Demo ⬟ = Structures & Mechanics-led Demo

ISRU System & Surface Operations Ground Demo Plan

2007	2008	2009	2010	2011

Site Preparation & Outpost Deployment

Inflatable Shelter concept

Cover inflatable shelter with material using Caterpillar and micro-excavator before inflation

(At JSC)

Perform area clearing and berm building with Chassis C & ISRU Blade

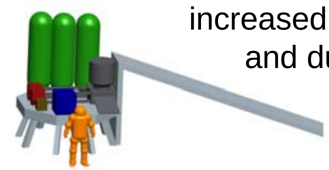
(At JSC & Hawaii)

Add Autonomy & increased capabilities (ex. dig hole for reactor)

Oxygen Extraction from Regolith

Excavation and oxygen production from regolith with H_2 Reduction at 250 kg to 1000 kg per year rate for 1 to 5 days

(At Meteor Crater)



Add Autonomy & increased capabilities and durations

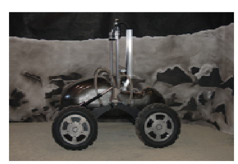
Excavation and oxygen production from regolith using carbothermal reduction at 250 to 1000 kg per year with solar power

(At Meteor Crater or Hawaii if in-situ material can be used)

ISRU Precursor & Site/Resource Characterization

Integrate RESOLVE drill on CMU rover

(At CMU)

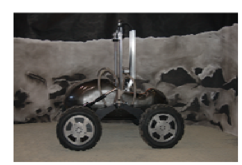


Integrate complete RESOLVE package on CMU rover

(At Hawaii- permafrost)

Possible:

1. Add Advanced Power system to Rover
2. Perform joint demo with ARC K-10 rovers



Notional: Integrate other science instruments for prospecting on single platform (ex. GPR, Neutron Spec. etc.)