SEPT 14–18, 2020 vtech.asce.org | #VTech2020

ASCE Virtual Technical Conference 2020

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Planning Activities for Lunar In-Situ Surface Construction of Infrastructure at NASA

Robert Mueller, NASA Kennedy Space Center: Swamp Works

Robert Moses, Ph.D., Chair, ISCI Steer. Group, NASA Langley Research Center

Raymond Clinton, Ph.D., NASA Marshall Space Flight Center

Jennifer Edmunson Ph.D., NASA Marshall Space Flight Center

September 16, 2020

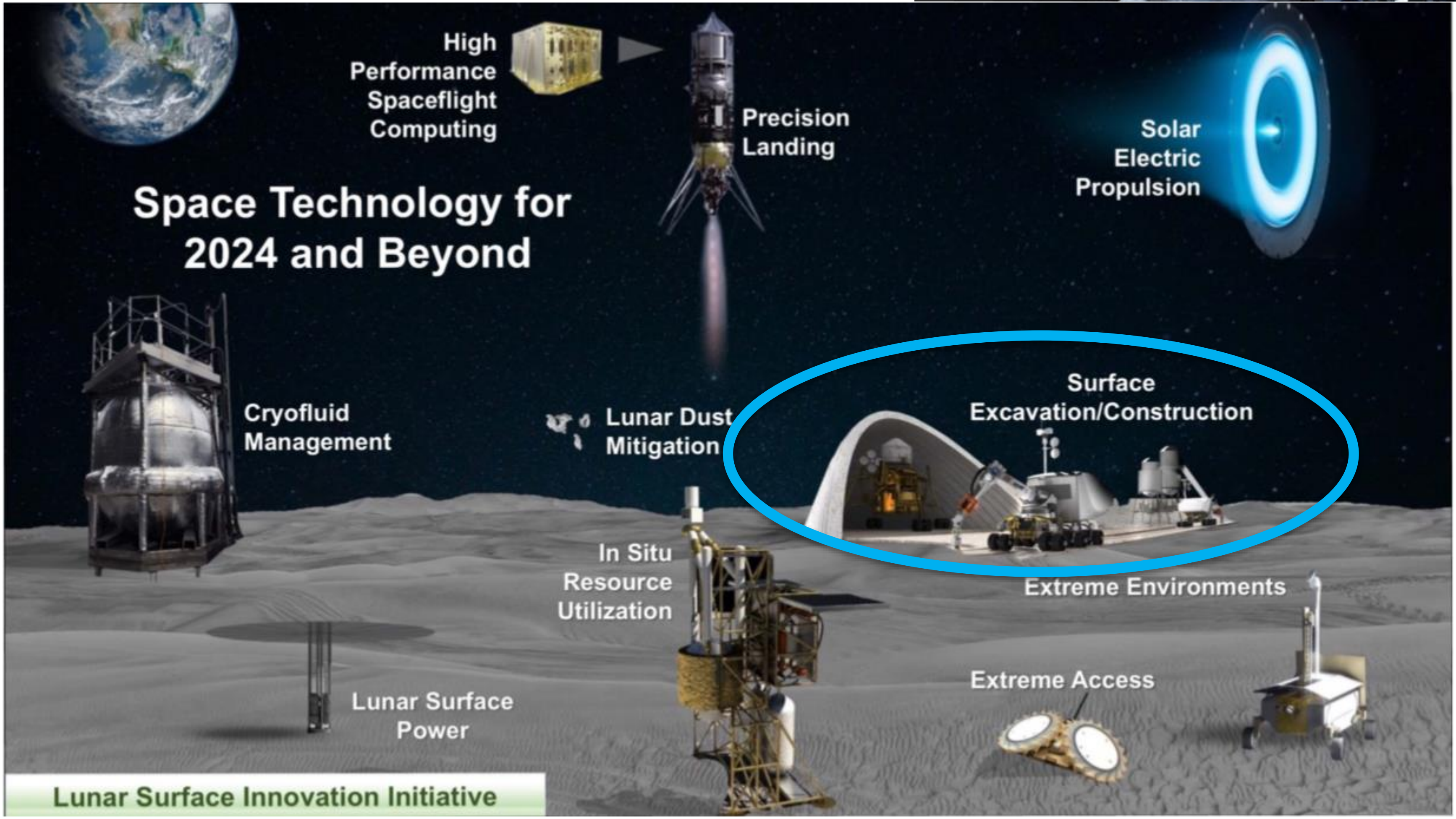
ASCE V-Tech Conference (Virtual)

Engineering, Construction and In-Situ Resource Utilization on the Moon and Mars

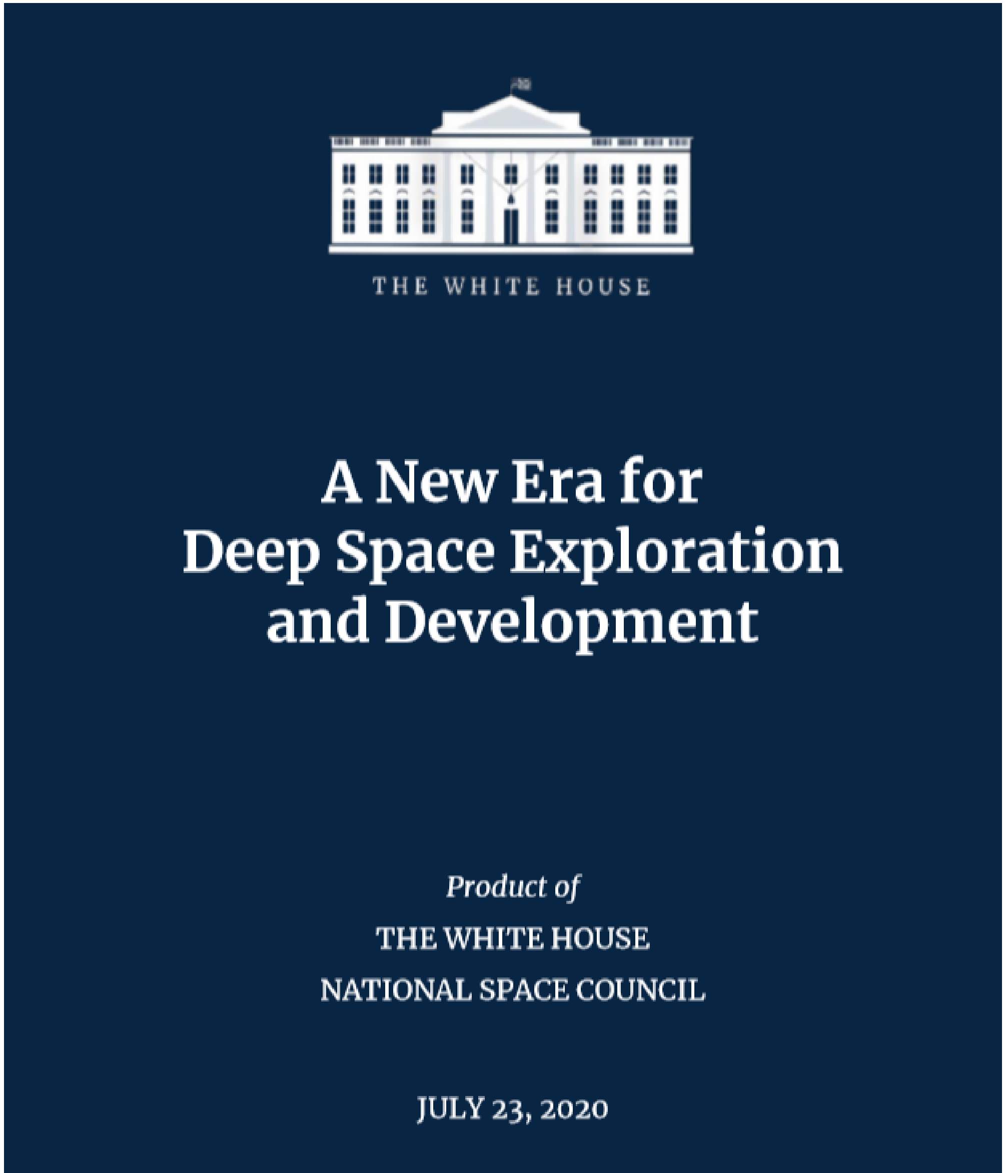
ESTABLISHING PRIORITIES

Artemis:

https://www.nasa.gov/sites/default/files/atoms/files/america_to_the_moon_2024_artemis_20190523.pdf



https://www.whitehouse.gov/wp-content/uploads/2020/07/A-New-Era-for-Space-Exploration-and-Development-07-23-2020.pdf


THE WHITE HOUSE

A New Era for Deep Space Exploration and Development

Product of

THE WHITE HOUSE

NATIONAL SPACE COUNCIL

JULY 23, 2020

This focus on further extending an extraterrestrial human and robotic presence and on the development of commercial space industries makes the Artemis Program much more than a repeat of the Apollo Program. A serious, determined approach to lunar development requires a series of pre-positioned logistics packages*. A combination of 3-D printing, telerobotics, and artificial intelligence could enable pre-positioning the equivalent of a small Antarctic scientific station. Newly arrived astronauts should have a substantial amount of resources already available and be able to spend their initial weeks building out the initial infrastructure for larger, future development teams*

Field Station Analog-McMurdo, Antarctica

British National Antarctic Expedition 1902
R.F. Scott's "winter quarters hut"

~100 Years of Development

Accelerate these timelines with commercial partnerships

Emplacement

https://commons.wikimedia.org/wiki/File:Scotts_Hut_Antarctica.jpg

Permanent occupation - 1955

Consolidation

Photo courtesy of USAP, US Gov..

Photo courtesy of NSF, US Gov..

McMurdo Station Today

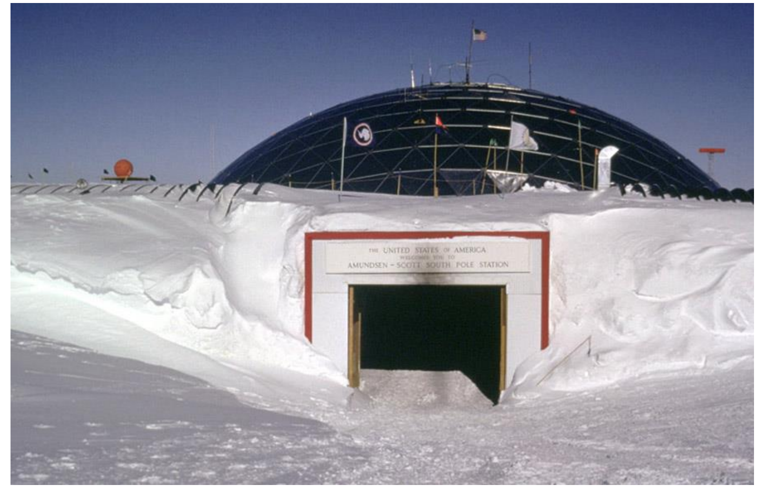
Utilization

By USGS - http://international.usgs.gov/ipy/images/ppacket/mcmurdo118.jpeg, Public Domain, https://commons.wikimedia.org/w/index.php?curid=3591282

By Gaelen Marsden - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=1391313

International Antarctica Bases Today: South Pole

By Daniel Leussler, CC BY-SA 3.0,
https://commons.wikimedia.org/w/index.php?curid=31621072



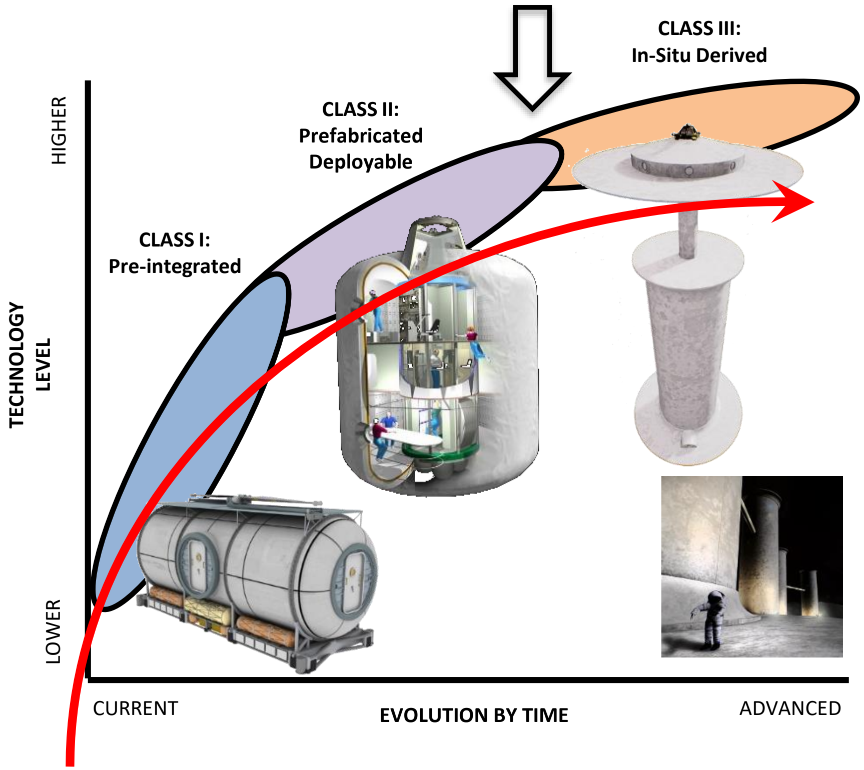
https://en.wikipedia.org/wiki/Image:Amundsen-Scott_South_Pole_Station.jpg
(https://en.wikipedia.org/wiki/Creative_Commons)

Hugh Broughton Architects
https://commons.wikimedia.org/wiki/File:Halley_VI_Antarctic_Research_Station_-_Science_modules.jpg

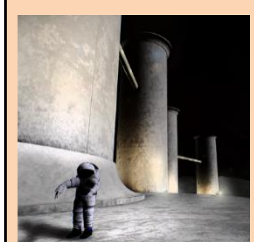
https://en.wikipedia.org/wiki/Esperanza_Base

Space Habitat Classifications

Space Architecture Tipping Point



HEDS Technology/Commercialization Initiative-
Habitation and Surface Construction NASA
~ 1997-1999.

Habitat Classification	Key Characteristics
CLASS I **Pre-integrated** 	• Earth Manufactured • Earth Assembled & Fully Outfitted • Pre-Integrated & Tested prior to Launch • Space Delivered with Immediate Habitation Capability • Launch Shroud Constrained • Limited to Launch Vehicle Payload Size Capability • Limited to Launch Vehicle Payload Mass Capability
CLASS II **Prefabricated Deployable. Space or Surface Deployed & Assembled** 	• Earth Manufactured • Requires Space Deployment, Assembly & Outfitting • Requires Robotic and Human Labor During Assembly • Partial Integration Capable for Subsystems • Requires some or all Internal Outfitting emplacement • Critical Subsystems are Earth Based and Tested prior to Launch • Requires Assembly & Checkout prior to Human Occupancy • Larger Volumes Capable • Not Restricted to Launch Vehicle Shroud Size • Restricted to Launch Mass. Deliver on multiple vehicles
CLASS III **In-Situ Derived and Constructed** 	• Manufactured In-Situ Derived with Space Resources (Lunar or Mars) • In-Space Constructed • Requires Robotic Manufacturing Capability & Infrastructure • Requires Robotic and Human Labor During Construction • Requires Integration of Subsystems • Requires all Internal Outfitting emplacement • Critical Subsystems are Earth Based and Tested prior to Launch • Requires Assembly to become Operability • Larger Volumes Capable • Not Restricted to Launch Vehicle Size • Not Restricted to Launch Mass

KJ Kennedy (2009). Chapter 2: Vernacular of Space Architecture, pp7-21. In AS Howe & B Sherwood (eds) AIAA History of Spaceflight series, Out of This World: The New Field of Space Architecture, ISBN 978-1-56347-982-3. Reston, Virginia, USA: American Institute of Aeronautics and Astronautics.

Kriss J. Kennedy, Space Architect
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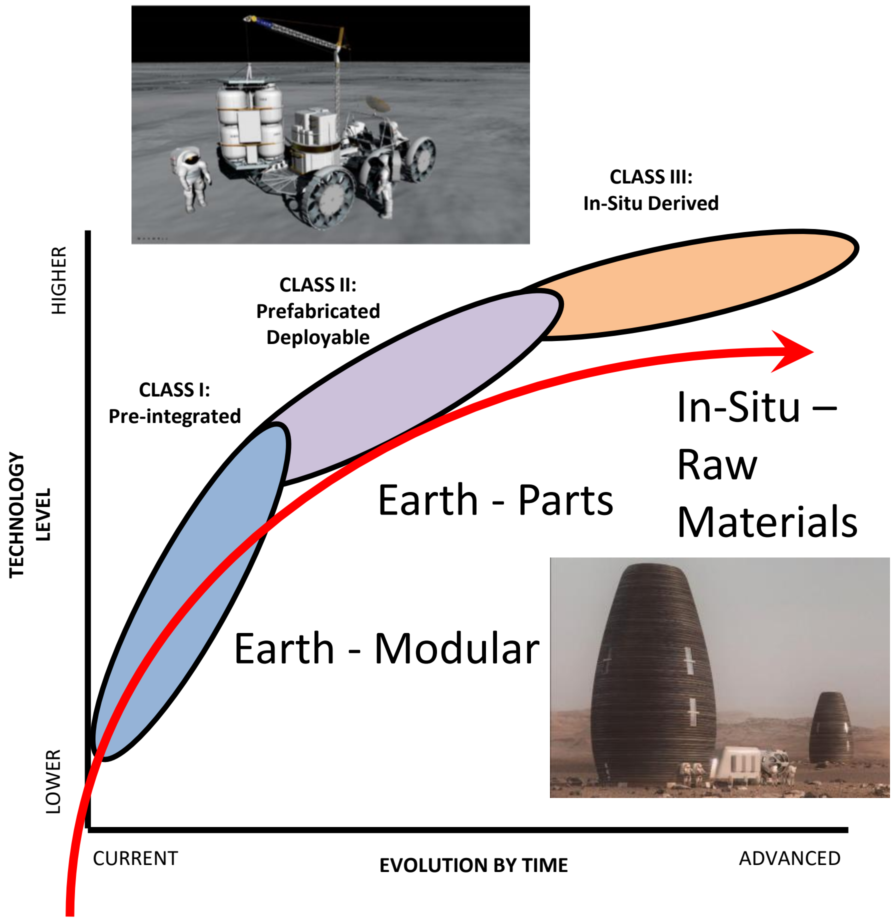
Space: Surface Construction Classifications



Raw Materials ⇨ Regolith + Volatiles

Habitat Classification	Key Characteristics
CLASS I **Pre-integrated** Modular	• Earth Manufactured • Earth Assembled & Fully Outfitted • Pre-Integrated & Tested prior to Launch • Space Delivered with Immediate Habitation Capability • Launch Shroud Constrained • Limited to Launch Vehicle Payload Size Capability • Limited to Launch Vehicle Payload Mass Capability
CLASS II **Prefabricated Deployable. Space or Surface Deployed & Assembled** Parts	• Earth Manufactured • Requires Space Deployment, Assembly & Outfitting • Requires Robotic and Human Labor During Assembly • Partial Integration Capable for Subsystems • Requires some or all Internal Outfitting emplacement • Critical Subsystems are Earth Based and Tested prior to Launch • Requires Assembly & Checkout prior to Human Occupancy • Larger Volumes Capable • Not Restricted to Launch Vehicle Shroud Size • Restricted to Launch Mass. Deliver on multiple vehicles
CLASS III **In-Situ Derived and Constructed** Raw Materials	• Manufactured In-Situ Derived with Space Resources (Lunar or Mars) • In-Space Constructed • Requires Robotic Manufacturing Capability & Infrastructure • Requires Robotic and Human Labor During Construction • Requires Integration of Subsystems • Requires all Internal Outfitting emplacement • Critical Subsystems are Earth Based and Tested prior to Launch • Requires Assembly to become Operability • Larger Volumes Capable • Not Restricted to Launch Vehicle Size • Not Restricted to Launch Mass

Getting Started on REQUIREMENTS VS CAPABILITIES

INFRASTRUCTURE: WHAT'S NEEDED? (DEFINED BY ARCHITECTURE)

- **Landing & Launch Pads**
- **Berms for Fission Power / Blast**
- **Radiation Shielding for crew and equipment**
- **Road and route ways**
- **Other infrastructure such as trenches and compacted foundations**
- **Pressurized Structures (e.g. Habitats)**
- **Non-pressurized structures such as garages, hangars, and refueling depots**
- **Dust-free zones for parking and operations**
- **Access to Energy / Power**

RESOURCES: WHAT'S THERE? (ENERGY, GEOLOGICAL MATERIALS & GEOTECHNICAL CHARACTERISICS)

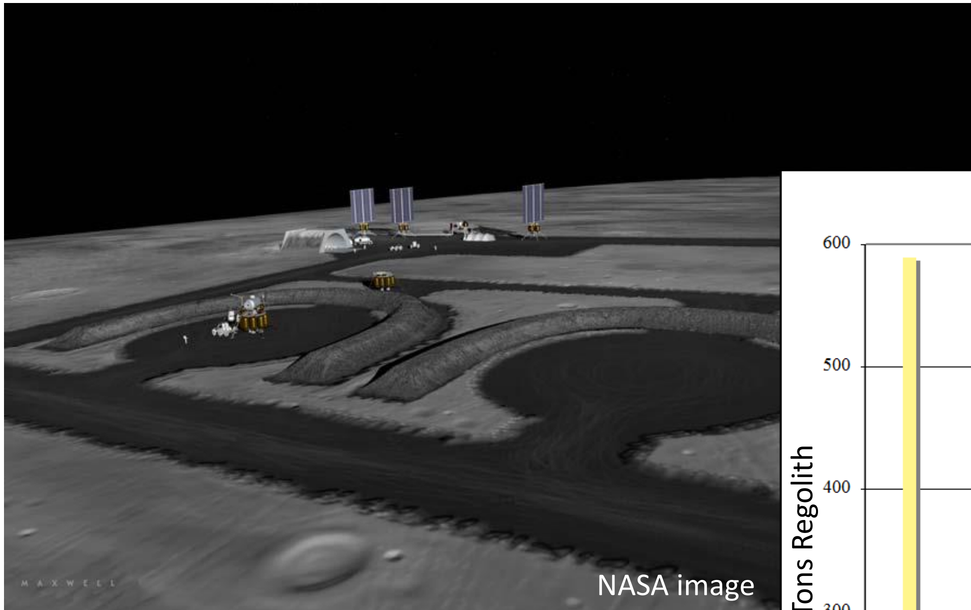
- **Natural Resources**
  - Abundant Solar Energy
  - Water & other volatiles
  - Regolith
    - Bulk material for construction
    - Extracted metals from minerals
    - Basalt glass fiber for composites
  - Thermal Deltas, Vacuum, Location etc
- **Capabilities, Tools & Processes**
  - Regolith Simulants
  - Cone penetrometer/ shear vane
  - Seismic
  - Ground Penetrating Radar
  - Borings
  - Sample Assays
  - Mining & Size sorting, beneficiation
  - Production & Storage
  - Other capabilities & tools being developed

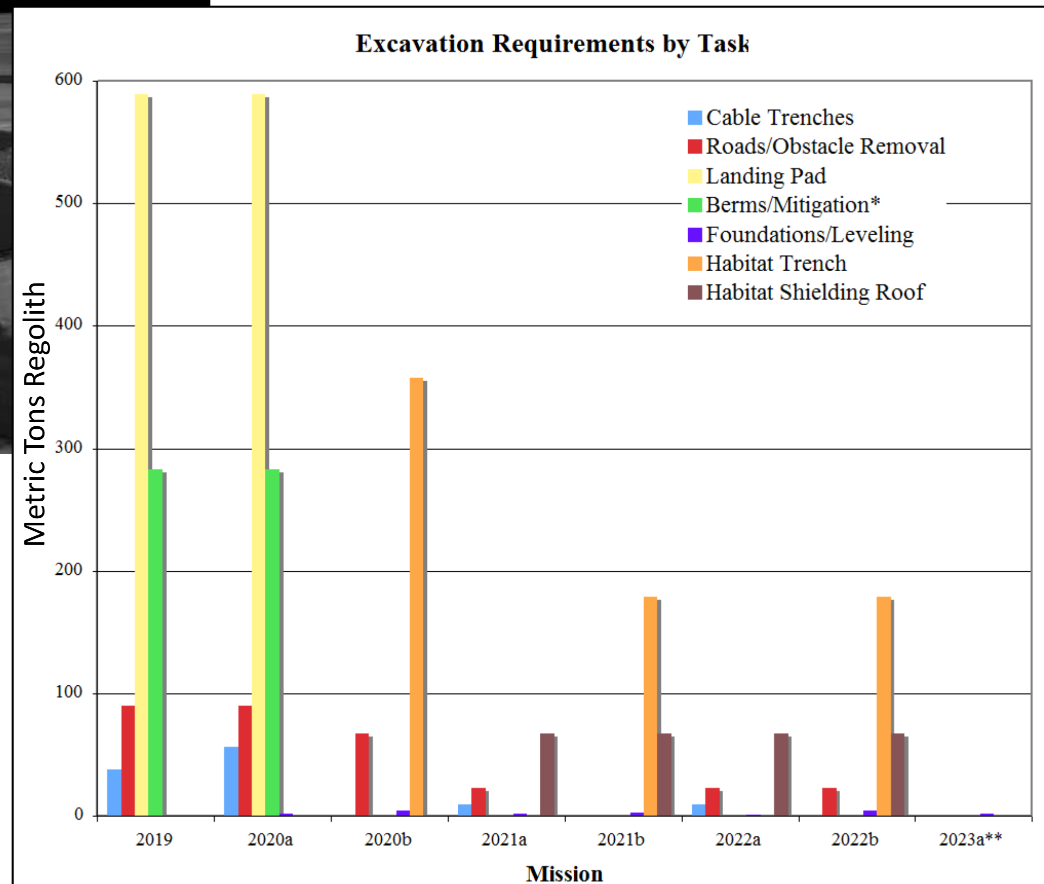
Functional Capabilities Needed

- Long-distance communication, monitoring, and control
- Increased autonomy/automation of operations
- Improved user experience/ease of operation (i.e. reduced training load)
- Multi-material printing & related control systems
- Increased transportability / mass reduction
- Expanded environmental range
- Design for field reparability
- Software Design Platform
- Dust mitigation
- Shielding / Ballistic Protection
- Jobsite Mobility
- Off-foundation construction / foundation delivery

Scale of Lunar Surface Construction Tasks: Moving Regolith

Criteria for Lunar Outpost Excavation
R. P. Mueller and R. H. King
Space Resources Roundtable –SRR IX
October 26, 2007
Golden, Colorado





SUMMARY	
Task	%
Trenching	4
Clearing and Compacting	48
Building Berms	18
Habitat Shielding	31
	100
Ice Mining	17
Regolith Mining	83
Construction	84
Mining	16

PROPOSED NEW FUNCTIONAL CAPABILITIES WBS

- 4.0 In-Situ Construction
  - 4.1 Site Planning and Design *
    - Site Survey & Characterization
    - Architecture Layout & Master Planning
    - Civil Engineering Design
    - GIS Configuration Control
    - Construction Techniques and Methods
    - Access & Handling Equipment
    - Robotic/Human Construction Equipment
  - 4.2 In-Situ Construction Materials *
    - Raw Material
    - By-product Material
    - Processed Material
    - Re-purposed Material
    - Stockpiling & Material Logistics
  - 4.3 Site Prep
    - Terrain Shaping, Grading, & Rock Clearing
    - Soil Stabilization
    - Below Grade Operations
  - 4.4 Horizontal Construction (2D) & Pads
    - Road Construction
    - Foundation Construction
    - Utilidor Construction
    - Landing / Launch Pad
  - 4.5 Vertical Construction (3D) & Shielding
    - Underground structures
    - Above Ground Structures
    - Shielding
    - Landing / Launch Pad Infrastructure
  - 4.6 Maintenance & Life-cycle *
    - Inspection & Compliance
    - Integrity & Preventative Maintenance
    - Lifecycle Operations
    - Facility Management
    - Waste Management
    - Decommission and Re-planning / Salvage

* Cross Cutting

Uses Construction industry terminology

Current NASA In-Situ Construction Projects

- **Several Game Changing Development (GCD) Programs, some new starts for FY21, focused on "Lunar Surface to Stay"**
  - Moon-to-Mars Planetary Autonomous Construction Technologies (MMPACT) (MSFC Led): Broad Effort using Applicable Technologies
  - In-Situ Construction (KSC Led): Focused on Polymer Concrete Construction
  - Lunar Safe Haven (LaRC Led): Developing NASA system level requirements

- **Several ACO / Tipping Point proposals currently in review**
- **NASA Centennial Excavation, Manufacturing & Construction "EMC" Challenge currently focusing on an "E" Challenge**
- **SBIR subtopics being considered now**
- **STMD continues its gap analysis for functional capabilities that include Surface Construction**

- **International Space Exploration Coordination Group (ISECG) is conducting a separate gap analysis for In Situ Resource Utilization (ISRU) that includes Construction & Manufacturing elements (Sanders & Moses participate for NASA)**

Current NASA In-Situ Construction Projects

- **University Collaborations**
  - MSFC Cooperative Agreement Notice (CAN’s) Efforts
    - University of Mississippi – Ionics Liquids Extraction for Lunar Concrete Binder Materials
    - University of Mississippi – Effects of Lunar Seismic Activity on Landing Pads
    - Mississippi State University – Lunar Steel Production
    - University of Nevada Las Vegas – Ionic Liquids Extraction of Metals from Lunar Regolith
    - Drake State Technical School – Development of an Additive Construction Workforce
    - University of Alabama in Huntsville – Testing of Large Scale Structures
    - Kappler – Environmental Control During Curing of Lunar Concretes

Thank you for your attention!

NASA is looking forward to collaboration with industry, academia and other government agencies