Development of the Moon and Cislunar Space

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I. Introduction and summary of topic from New Views I

II. The Moon as an enabling asset
- A. Moon's proximity – allows easy and routine access, close for teleops
- B. Resources accessible, in forms needed and in useful quantities
- C. Use lunar resources to create permanent cislunar-lunar surface-LEO trans. system

III. Strategy of resource incorporation into lunar architecture based on ISRU
- A. Water for propellant
  - a. Where to process water into propellant (lunar surface only v. lunar surface plus orbit)
  - b. Other propellant options (Methane?)
- B. Terrain-shaping for outpost activity
  - a. Berms
  - b. Landing pads
  - c. Thermal enclosures
  - d. Radiation protection
  - e. Waste stream use/disposal
- C. Water for Crew Use
- D. Materials for basic structure (parts)
- E. Materials for load-bearing structures (un-pressurized)
- F. Materials for internal pressurized volumes
- G. Volatile fluids for pressurization and/or crew use
- H. Regolith as base product for organics growth
- I. Solar Cell processing
- J. Others?

IV. ISRU Hardware Implementation approaches, process options, status, maturity
- A. Water Ice Ore extraction
- B. Ore transport
- C. Water extraction from ore
- D. Water storage
- E. Water electrolysis
- F. Propellant storage – boil-off issues
- G. Material Ore extraction
- H. Material Ore processing
- I. 3-D Printing
- J. Volatile extraction, transport, processing, and storage
- K. Bulk regolith movement and shaping
- L. Surface regolith treatment (sintering, etc)

V. Resource utilization-based architectures and comparisons
- A. ISRU spliced architecture (Constellation, ESA?)
- B. Commercial ISRU architectures (e.g., Shackleton Energy Inc.)
- C. MIT architecture (Grogan et al., 2011)
- D. ISRU Requirements-driven architectures (e.g., Spudis and Lavoie, 2011; Miller et al., 2015; Wingo, 2016)
  1. Principles
     - small incremental steps
     - lead with robotics, pick site from precursor data
     - begin water harvesting and processing prior to human arrival
     - construct turn key outpost
  2. First steps
     - robotic precursor and prospecting (orbital, landed, roving, site landing beacon)
     - orbital infrastructure (nav-comm constellation)
     - Earth orbital prop depot, translunar stage
  3. Early stage
     - ISRU demos
     - heavy robotic lander (diggers, haulers)
     - water collection, heat separation (ovens)
     - storage of product
  4. Middle stage
     - Electrolysis and cryogenic facilities
     - habitat modules, thermal control systems, electrical cabling
     - Robotic outpost assembly
     - Lunar orbital prop depot
  5. Late stage
     - propellant manufacture
     - reusable large lander (cargo + human)
     - first human missions
     - equipment maintenance and optimization
  6. Advanced stage
     - reusable components (translunar transfer stage, lunar lander)
     - aerobraking for propellant import to LEO depots
     - intralunar ballistic transport (global hopper)
     - mass driver capability for lunar surface launch to LLO

VI. Phases in the development of the Moon and cislunar space
- A. Robotic lunar return phase – prospecting, mining, construction
- B. ISRU concept demonstration phase – power emplacement, water and propellant processing and storage
- C. Cislunar space-based infrastructure phase – propellant depots, solar farms, water cracking, habitats, staging nodes
- D. Lunar surface preparation phase – crew habitats, power emplacement, ancillary element staging, surface shaping, crew landers, cislunar crew transport
- E. Lunar surface operational phase – sintering (pads, roads), maintenance and repair,

ceramics manufacture, metals production, 3-D printing for piece parts and outpost facilities

F. Deep space construction phase – solar array farms, depot facilities, tended habitats, communication complexes, planetary human vehicle staging and assembly

G. Government-Private sector opportunities, roles and responsibilities

H. International partnerships

VII. Considerations in the development of the Moon and cislunar space

A. Government-Private sector opportunities, roles and responsibilities

B. International partnerships

C. Launch vehicle availability in shaping architectures (size v. cost v. orbit depot use)

C. Lunar-developed property rights ownership

D. Affordability

E. Government-funded Lunar campaign success criteria