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