ISRU & Civil Engineering Needs for Future Human Mars Missions

Briefing for

First Landing Site/Exploration Zone Workshop for Human Missions to the Surface of Mars

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Contents

- ICE WG Purpose
- ICE WG Membership
- ICE WG Meeting Schedule and Presentation Topics
- Assumptions
- ISRU and CE Objectives for Site Selection
- ISRU and CE Site Criteria: Threshold
- ISRU and CE Site Criteria: Qualifying

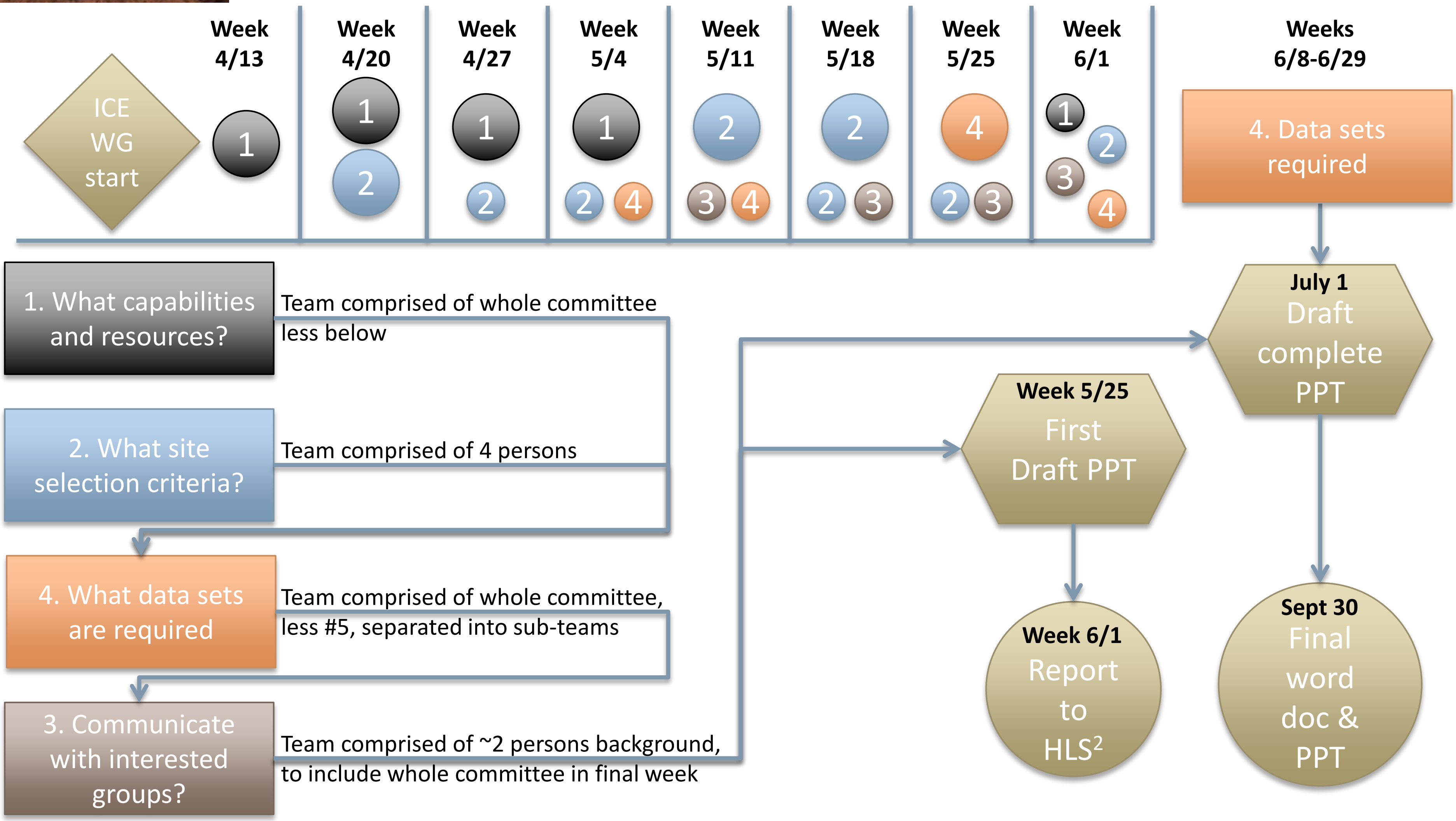
ICE WG Purpose

- The purpose for the ICE WG is:
  1. Identify capabilities and resources that will be key to establishing a sustainable human presence on Mars;
  2. Characterize activities that must be carried out on the surface of Mars in order to advance these capabilities to a level where they can be relied upon without routine support from Earth;
  3. Describe the characteristics (e.g., concentration of targeted mineral types, slopes, rock size distribution, overburden depth of targeted mineral types, etc.) of Mars surface sites that are necessary to support this capability advancement.
  4. Describe the data sets needed to support site selection to support human surface missions

ICE WG Membership

Member Name	Center/ Institution
Working Group Co-Chairs	
Stephen Hoffman, PhD	Johnson Space Center (Science Applications International Corp)
Rob Mueller	Kennedy Space Center
User Communities Representatives	
Brand Griffin	Marshall Space Flight Center (Gray Research, Inc.)
John Gruener	Johnson Space Center
Don Henninger, PhD	Johnson Space Center
Scott Howe, PhD	Jet Propulsion Laboratory
Chris Jones	Langley Research Center
Laura Kerber, PhD	Jet Propulsion Laboratory
Doug Ming, PhD	Johnson Space Center
Jim Murphy, PhD	New Mexico State University
Paul Niles, PhD	Johnson Space Center
Michelle Rucker	Johnson Space Center
Jerry Sanders	Johnson Space Center
Laurent Sibille, PhD	Solar System Exploration Research Virtual Institute (SSERVI)
Ray Wheeler, PhD	Kennedy Space Center
Brian Wilcox	Jet Propulsion Laboratory
Ex Officio	
Ben Bussey, PhD	NASA HQ / HEOMD
Rick Davis	NASA HQ / SMD

Charter Tasks Detailed Flow & Schedule



Human Missions to Mars: Current Planning

- Current planning for human Mars missions (commonly referred to as the Evolvable Mars Campaign or EMC) is different from DRA 5.0
  - DRA 5.0: Three missions lasting ~500 sols on the ground to three different locations with a crew of 6
  - EMC: a single surface site will be visited by *multiple* crews (total number is TBD) for durations ranging from ~300 sols to ~500 sols
  - Both scenarios assume that small pressurized rovers that allow the crews to venture to distances of ~100 km from their base for durations of ~14 sols
  - The EMC has taken on the added objective of learning how to live and work on Mars for extended periods, including infrastructure improvements using local resources and gradually breaking the logistical chain with Earth
- As a consequence of visiting the same site by multiple crews, site selection takes on added significance to maximize the ***potential*** for on-going scientific research and gradually breaking the logistical chain with Earth

ISRU and CE Objectives for Mars Surface Mission

- Demonstrate the ability to prospect for and extract useful commodities from local materials in a cost effective and sustainable fashion and begin using those commodities in nominal operations as soon as possible
  - Highest priority: water
  - Secondary priority: metals, structural building materials
    - Rationale: water can be used for multiple purposes that are mission enhancing or enabling (propellant/fuel cell reactant production, life support, radiation shielding, plant growth). Metals will be important for in-situ fabrication of spare parts and repairs. Oxygen, buffer gases and carbon dioxide are obtained from the atmosphere
- Demonstrate the ability to manipulate the surface for infrastructure emplacement and protection of hardware
  - Highest priority: foundation improvement and surface stabilization (including landing pads, roads, berms, etc.)
  - Secondary priority: structures, radiation shielding
    - Rationale: Each candidate site will exhibit strengths and weaknesses. For example, landing plume cratering may be significant if the site has substantial amounts of loose surface material or lacks any exposed bedrock; cratering must be adequately addressed to remove the concern. Berms and roads may be required to minimize mobility maintenance and allow for consolidation of delivered infrastructure. While very important, radiation shielding may be enhanced using water walls before surface material is required. Thus each candidate site will be assessed for factors such as these and an overall site plan will be developed noting where improvements are required.
- Demonstrate capabilities that reduce reliance on supplies from Earth using indigenous materials, resources, and the environment
  - Highest priority: food production
    - Rationale: one of the largest (the largest?) consumable items that must be imported from Earth in current mission scenarios
  - Secondary priority: in-situ manufacturing and construction with in-situ derived feedstock
    - Rationale: To minimize long term costs, logistics, and risk to crew

ISRU and CE site criteria: threshold (i.e., must have) 1/4

- The Exploration Zone <u>must</u> show ***potential*** for at least <u>one</u> water resource feedstock
  - Feedstock can be either water ice, ice/regolith mix, or hydrated minerals
    - Potential for hydrated minerals with a high concentration (greater that 5% by weight)
      - » Rationale: Based on maintaining same power infrastructure as atmosphere only processing)
    - Potential for ice or ice/regolith mix
    - Desired resolution for mineral and water content <100 m desired, <1000 m required
  - Resource feedstock deposit must allow for initial mission use and long term surface operations.
    - Single primary water resource must be sufficient to support radiation shielding, life support, EVA, and propulsion needs for several human missions
      - » Rationale: ~20000 kg required for each Mars ascent, initial radiation shielding, EVA support, and crop growth
  - Resource feedstock must be in a form that is minable by systems that are highly automated
    - Rationale: The feedstock deposit is preferred to be in a form that is easily excavated. Mining equipment or techniques requiring extensive crew time to operate or to supervise is highly unlikely.

ISRU and CE site criteria: threshold (i.e., must have) 2/4

- The Exploration Zone must show ***potential*** for at least one water resource feedstock (continued)
  - Initial resource feedstock located within 1-3 km (TBR) of ISRU processing plant and power infrastructure
    - Terrain features must not prevent direct-line-of-site communications between ISRU processing system and rover/excavators if possible (adds need for communication repeaters)
    - Rationale: resource economics decreases with increased distance (i.e., transportation costs) from processing point or utilization point; Risk in initial mission operations and product availability require initial resources to be nearby and located outside of natural deep features such as canyons, deep craters (note: lava tubes are not excluded)
  - Resource feedstock located within 0-1 meters (TBR) of surface
    - Rationale: resource economics decreases with increased cost to excavate feedstock. Deeper than 1 meter requires extensive removal of overburden and/or multiple segment drill. Also depth penetration of neutron spectrometers is typically <1 m
  - Resource feedstock located in accessible location
    - Sufficiently flat to permit excavation and soil storage <10° (TBD based on rover stability and loading design)
    - Major natural obstacles along the most direct traverse between resource feedstock and usage area must not be present that exceed planned mining mobility platforms such as canyons, cliffs, vertical outcrops, and wide crevices
    - Rock size must not allow impact to rover mobility <30 cm (TBD based on rover clearance)
    - Rock distribution must not allow for impact to excavation operations

ISRU and CE site criteria: threshold (i.e., must have) 3/4

- Access to at least one region where infrastructure construction can be emplaced or constructed
  - Flat and stable terrain with sparse rock distribution
    - An area of at least (approximately) 25 sq km (TBR) with these characteristics:
      - Slope less than 10 deg (on a TBD baseline – TBR) over at least 60% (TBR) of this area
      - Rock distribution (need descriptor similar to slope: a specified characteristic over some TBD fraction of the area)
      - Exposed bedrock or soil/regolith bulk density greater than (TBD) over at least 40% (TBR) of this area
      - No indication (or minimal indication?) of seasonal changes over at least 60% (TBR) of this area
    - Rationale: flat terrain and sparse rock distribution minimizes amount of terrain modification required prior to infrastructure construction. Bedrock for safer landing and strong foundation for infrastructure
    - Rationale: stable terrain required for adequate foundation
  - Located within 5 km (TBR) of landing site location
  - Rationale: minimizes transportation requirements

ISRU and CE site criteria: threshold (i.e., must have) 4/4

- The Exploration Zone must show ***potential*** for metal/silicon resources
  - Resources of primary interest are iron, aluminum, and silicon; titanium and magnesium are of secondary interest. (see table on next page)
  - Mineral resources should be near surface 1 to 2 meters:
    - Rationale: Allowable depth is 1 to 2 meters based on limitations in sampling technique and economics of extraction. Deeper resources will require higher concentrations, but are allowed due to the smaller quantity of resource required.
  - Terrain guidelines same as for water resources; can be relaxed for resource evaluation purposes only.
  - Resource feedstock must be in a form that is minable by systems that are highly automated.
    - Rationale: The feedstock deposit is preferred to be in a form that is easily excavated. Mining equipment or techniques requiring extensive crew time to operate or to supervise is highly unlikely.

ISRU and CE site criteria: qualifying (enhancements to threshold) 1/4

- The Exploration Zone <u>should</u> have ***potential*** for <u>multiple</u> sources of water resources
  - Feedstock can be combination of water ice, ice/regolith mix, and/or hydrated minerals
    - Concentrations should be greater than 5% by weight to justify extended range operations from processing location or from point of use
    - Visual and/or remote sensing evidence of level of hydration or presence of ice and associated minerals
  - Resource feedstock can be located >5 km (TBR) from processing location or from point of use
    - Rationale: distance allowed will be a function of resource concentration and desire to evaluate different forms of water resources
  - Resource feedstock located within 0-3 meters (TBR) of surface
    - Rationale: Allowable depth of resource will be a function of resource concentration and desire to evaluate different forms of water resources.
  - Resource feedstock located in accessible location
    - Same as previous requirements
    - Terrain guidelines can be relaxed to those of robotic and human mobility system capabilities for water resource evaluation only purposes

ISRU and CE site criteria: qualifying (enhancements to threshold) 2/4

- The Exploration Zone should have ***potential*** for multiple sources of water resources (continued)
  - Distance between resource location and Consolidation location must be traversable
    - Rock size must not allow impact to rover mobility <30 cm (TBD based on rover clearance)
    - A plausible traverse route must be evident (Detailed assessments of traversability will be conducted separately)
    - Surface material at these locations must allow for repeated rover operation over same spot without concern for wheel slippage/sinking
    - Terrain features must not prevent direct-line-of-site communications between ISRU processing system and rover/excavators if possible (adds need for communication repeaters)
    - Slopes, rock size/distribution, and soil properties should allow for road/path construction between resource excavation location and centralized ISRU processing systems if required for sustained use

ISRU and CE site criteria: qualifying (enhancements to threshold) 3/4

- From civil engineering
  - Northern hemisphere <40 latitude
    - Rationale: less extreme climate variations and higher solar flux
  - Evidence for access to an abundant source of cobble sized [64-256 mm (2.5-10 in)] or smaller rocks and bulk, loose regolith
    - Rationale: raw material (e.g., sand, cobbles, bulk regolith) for a variety of construction techniques such as leveling roadways, enhancing roadway surfacing, constructing berms, burying habitats for radiation protection, etc.
  - Natural terrain features in close proximity to the landing site that can be used for radiation protection or other civil engineering enhancements
    - Examples: shallow depressions, narrow (but accessible) valleys, lava tubes, etc.)

ISRU and CE site criteria: qualifying (i.e., enhancements to threshold) 4/4

- From food production
  - Low latitude
    - Rationale: more consistent lighting throughout the year
  - No local terrain feature(s) that could shadow light collection facilities
    - Rationale: Gathering natural light for crop production could be a significant efficiency improvement over all artificial lighting
  - Access to water (preferable water ice to minimize processing)
  - Access to dark, minimally altered basaltic sands
    - Rationale: For use as soil base for crop growth; augmented with other material to improve crop growing potential
    - Quantity is estimated at 32 m^3
  - Avoid heavily weathered and/or altered soils (e.g., hydrothermal or fumarolic vent/system)
    - Rationale: Using local materials as a soil base for crop growth is highly desirable but heavily weathered and/or altered soils have been shown by MER to be more deficient in plant essential nutrients

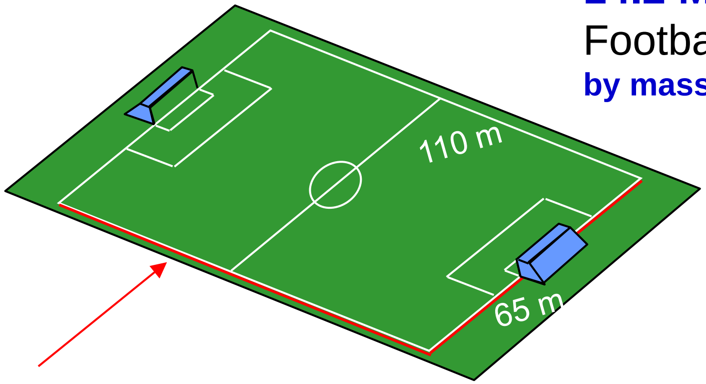
BOE for water quantity requirement

- The 100 MT of water was an estimate based on several factors and intended to give various groups an indication of the magnitude of water human crews could reasonably expect to need and use.
- This value was based on an "expert opinion" estimate by a group that has been working this problem for many years.
- We know that each crew will need:
  - propellant for its ascent vehicle,
  - coolant for EVAs,
  - radiation protection (and possibly construction), and
  - for crop growth (if we expand into truly Earth-independent operations)
- Each ascent vehicle needs an estimated 20 MT of methane and LOX propellant (based on current designs).
  - If water is used to make these propellants then you need approximately 10 MT of water for each crew.
- Cooling water will depend on the number of EVAs so this is difficult to quantify, but could be many tons per crew.
- Water is a good moderator of SPE and GCR radiation sources and improves with thickness.
  - We have not finalized habitat designs but we do expect to use "water walls" on the habitat and the small pressurized rovers to protect the crews. This is a one-time quantity that we need and will depend on the habitat geometry but the magnitude is likely to be many tons.
  - If we use water as a construction material, as has been proposed by recent NASA Centennial Challenge winners, we will need quite a lot.
- Finally, crop growth will need water proportional to the amount of food we decide to grow.
  - This water can probably be recycled, so it may be a one-time amount just like the radiation protection.
  - crop growth is likely to start small and increase over time as we gain experience with crops on Mars. So the quantity needed will grow over time.
- To come up with a total quantity needed we picked 5 crews as a reasonable number of crews we could expect to use a Mars surface base
  - it could be more but probably not less, given the investment we are likely to put into this facility.
- When we added up our estimates in each of the categories described above we came up with an amount in the 80 MT range. We decided to give ourselves some margin for things we forgot and likely inefficiencies/losses in the processes that turn an amount of water on the surface into water the crew could use.

ISRU Examples and Analogies

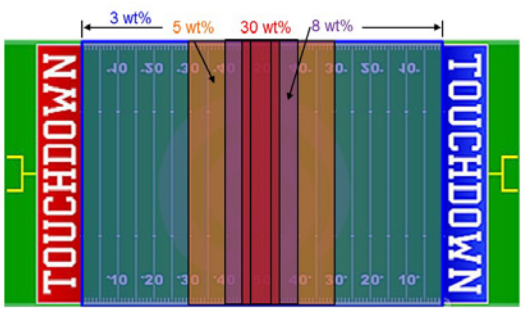
- Excavation rates required for 10 MT O_2/yr production range based on extraction efficiency of process selected and location
  - H_2 reduction at poles (~1% efficiency): 150 kg/hr
  - CH_4 reduction (~14% efficiency): 12 kg/hr
  - Electrowinning (up to 40%): 4 kg/hr
- Excavation rates required for 14.2 MT H_2O/mission production range based on water content
  - Hydrated soil (3%): 41 kg/hr
  - Icy soil (30%): 4 kg/hr

- Cratos & LMA rovers: 10 to 20 kg/bucket in <5 min.at field test in Hawaii
- Robotic Mining Challenges:
  - 2009: 437 kg in 30 min.; remote operation
  - 2015: 118 kg in 20 min; autonomous operation
- Soil Processing
  - ROxygen: 5-10 kg/hr
  - PILOT: 4.5-6 kg/hr
  - Pioneer SBIR: 4 kg/hr
  - MISME: 0.2 kg/hr



10 MT of oxygen per year requires excavation of a Soccer field to a depth of **0.6 to 8 cm!**
(14% to 1% efficiencies)

14.2 MT of water per mission requires excavation of a Football field to a depth of **1.1 to 9.6 cm! (30% to 3% water by mass)**



H_2O	1.238 kg/hr		Soil	1500 kg/m3					
	480 days		Ice	940 kg/m3					
Water wt%	Soil wt%	Water kg	Soil kg	Total kg	Extraction 80%	Ave Density kg/m3	Tot Vol m3	FB Depth cm	FB Field yds
3	97	14261.76	461130.2	475392.0	594240.0	1483.20	400.65	9.58	100.00
5	95	14261.76	270973.4	285235.2	356544.0	1472.00	242.22	5.79	60.46
8	92	14261.76	164010.2	178272.0	222840.0	1455.20	153.13	3.66	38.22
30	70	14261.76	33277.4	47539.2	59424.0	1332.00	44.61	1.07	11.14
70	30	14261.76	6112.2	20373.9	25467.4	1108.00	22.99	0.55	5.74

How much Martian basaltic sands for a Mars greenhouse?

- Assume 40 m2 of plant growth area per person for 80% of required food (based on previous studies)
- For a crew of four: 160 m^2 of plant growth area required
- Assume 10 cm deep plant growth trays: 16 m^3 of sands required (565 ft^3, 21 yd^3)
- Assume sand bulk density = 1300 kg/m^3
- *20.8 mt of sands required to supply 80% of required food for a crew of four*

Summary

- For ISRU and Civil Engineering purposes, we are looking for
  - Resources
    - Primarily water; secondarily metals and other mineral
  - Construction materials
  - Soil and water for crop growth
  - Relatively flat area, relatively free of difficult terrain or hazards, and in a relatively compact area
- Will need the ability to establish the quantity and quality of the resource feedstock
  - From orbit to the greatest extent possible
  - On the surface with the minimum number of landed missions
  - Depth estimate will be part of this process for both orbital and surface missions