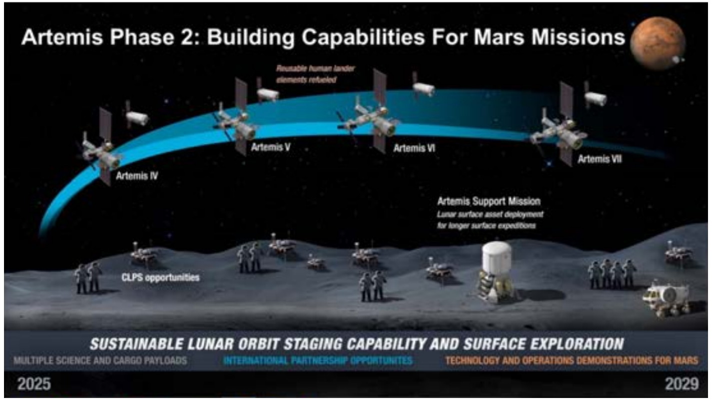
Vertical Solar Array Technology (VSAT)

"10 kW in a Box"

PM Chuck Taylor PI Richard Pappa Co-I Anna-Maria Pal

Why Now?,….None of this happens without surface power!



Why Solar?

There are several critical metrics used to differentiate power systems

Continuity:

- » Continuous power can not always be guaranteed by solar arrays, this is where nuclear, batteries, and fuel cells "shine"

Specific Mass:

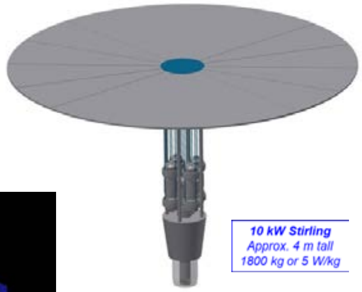
- » Solar arrays dominate nuclear in the 10-40kW regime, they also dominate Regenerative Fuel Cells given energy "harvest" is still accomplished via the array

Cost:

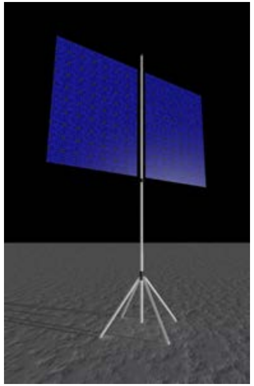
- » Both non-recurring and recurring costs are considerably less for the solar arrays due to both inherent materials and present TRL

TRL:

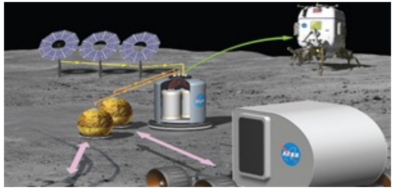
- » All three are under development and various TRL's have been claimed, but solar arrays are the only technology in the space with definite TRL 9 heritage



Kilopower



10kW VSAT
< 150 kg
~75 W/kg



Regenerative Fuel Cell Concepts
~25-75 Wh/kg

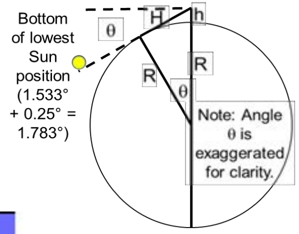
Underlying Themes to Lunar Sustainment Period

- **We will be at South Pole**
  - Low solar grazing angle will dominate solar solution space
  - Uneven terrain exacerbates issue with grazing angle, but also introduces concerns related to stability
- **Most, if not all, Lunar Sustainment Mission Concepts depend on solar arrays deployed away from lander**
  - Autonomy is likely to be necessary
  - Packaging and removal from Lander is a design consideration
  - Movement to eventual deployment site is also a design consideration
  - Retraction/Redeployment seems like an obvious long term need that should be integral to initial design
- **Mission will be subject to traditional Space related mission architecture concerns**
  - Mass, you are at the ugly end of the gear ratio
  - Temperature extremes, stand alone system must provide its own thermal management
  - Lunar dust, deployment mechanisms and minimal electronics must be survivable
- **Mission CONOPS is not known, and will not be known for several years**
  - Requires flexibility in design architecture

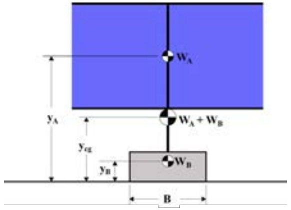
Mission Use Cases Point Toward Modular/Adaptable Array Design Coupled with Mast Based Deployment/Redeployment Scheme

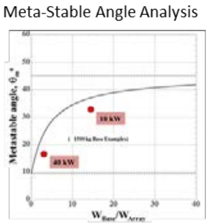
Requirements for South Pole Power
South Pole Mission Drivers

- **Array Line of Sight Concerns**
  - **Sun within 1.5 deg of horizon year round (Best case at pole)**
  - **Uneven terrain increases likelihood of obstructions**
  - **These issues force consideration of:**
    - **Extended mast for deployment (~10m)**
    - **“Smart Array” technology to increase array performance and minimize array size**



- **Uneven terrain drives further concerns related to stability**
  - **Desire for stability devolves into considerations of CG on 10m solar array**
  - **Mass and width of base relative to this CG,…competes with desire for minimal launch mass**





- **Classical Space Mission Technology Drivers**
  - **Launch Mass**
  - **Environment, ….dust and temperature extremes**
  - **Systems Integration**

The degree of difficulty in any individual technological requirement is likely overshadowed by the need to create a “system solution” for the Lunar Mission

VSAT Key Performance Parameters (KPPs)

KPP	Threshold Value	Goal
Stable Vertical Deployment on Uneven Terrain	10 Degree Incline with 5m Mast	15 Degree Incline with 10m Mast
Vertical Extension Mast	5m	10m
Array Retractability	Five Retraction-Redeployments During Mission Operational Life (5 yr)	10 Retraction-Redeployments During Mission Operational Life (10 yr)
Operational Life	5 Years	10 Years
Sun Tracking	Single Axis 360 degree rotation with Sun Tracking	
Array Thermal Environment	System must be capable of surviving and operating in Lunar South Pole thermal environment (-180C^0 to 175C^0) without external systems	
Array Power	10kW BOL (Lunar Surface South Pole 10yr Mission)	
System Specific Volume	45kW/m3 BOL (Lunar Surface South Pole 5yr Mission)	65kW/m3 BOL (Lunar Surface South Pole 10yr Mission)
System Specific Power	75W/kg BOL (Lunar Surface South Pole 5yr Mission)	100W/kg BOL (Lunar Surface South Pole 10yr Mission)

VSAT Approach: Develop and Test Concept Designs

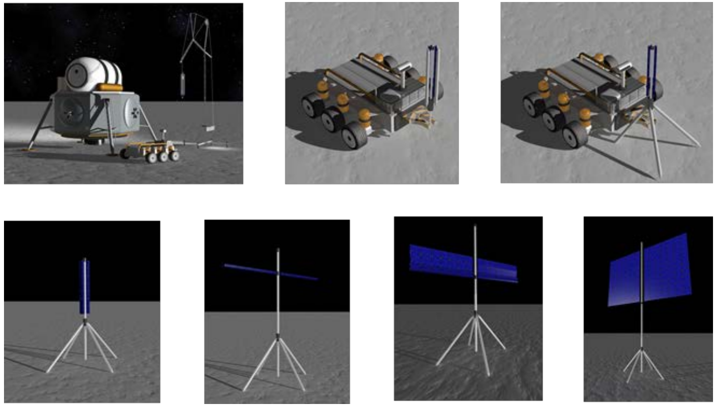
- **Project designs will focus on modular/adaptable 10kW arrays**
  - **Easily off-loaded from lander, transported to needed sites, and relocatable upon demand**
  - **Suitable for Lunar South Pole Mission Concepts**
  - **Plug and Play with eventual mission architecture**

- **Industry**
  - **Two Phased Solicitation with multiple contractors**

- **NASA Center Research**
  - **Creation of reference designs**
  - **Research innovative concepts using SBIRs and in house efforts**

- **Three year development cycle**
  - **Deliver TRL 6 hardware by 2024 for eventual 2028 Lunar Mission**

- **Major Deliverables:**
  - **Designs for system concepts, in less than 12 months**
  - **Prototype hardware for ambient testing in 1 G, within 24 months**
  - **TRL 6 hardware for deployment testing in expected environment, i.e. TRL qualification, within 30 months**



VSAT Government Reference Design

Challenge: Develop Stationary Surface Power for Environmental Control, Life Support, ISRU, & Science

Metrics:

Required:
- 40 kW Continuous Power Contained in 4 x 10kW modular units
- Vertically Deployed > 10m off lunar surface
- Sun Tracking (Primary Axis)
- Survivable on Lunar Surface (Dust & Temperature)
- Operational Life > 5 years

Desired:
- Retractable and mobile
- Specific Mass > 100 W/kg
- Specific Stowed Volume > 60kW/m3
- "Smart Array" Technology to combat shading
- Grid Compatible with Mobile Asset Power Systems