TAMER Space

Two Planet Species

Mars Pioneering & Implications for Humans-Moon

Robert Moses
Aerospace Technologist, NASA, Retired

Off-Earth Mining Forum (OEMF2022)
University of New South Wales, Sydney, Australia
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Background

~ 1 – 2 days transit time

Communications (near real-time)

Crew exchanges

Crew supplies and logistics

Crew and atmosphere samples

Modified hardware

Emergency Crew Return

Trash

390 kilometers

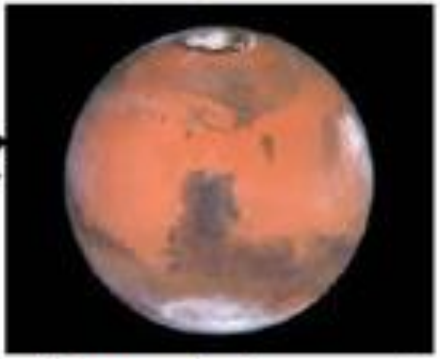
"extreme car camping in space"

EXTENSIVE HEALTH EXPERIENCE BASE IS IN LOW EARTH ORBIT

228,000,000 kilometers

~1 – 1.5 years transit time, ~2 – 3 years mission time

Communications (up to 42 minutes)



" recreate living on Earth capability"

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MARS HEALTH EXPECTATIONS ARE TIED TO MANY ASSUMPTIONS

Summary of Human Space Flight Hazards & Risks

Altered Gravity Field

Primary Effect

1. **Spaceflight-Induced Intracranial Hypertension/Vision Alteration** ★
2. Urinary Retention
3. **Space Adaptation Back Pain**
4. Renal Stone Formation ★
5. **Risk of Bone Fracture due to spaceflight Induced bone changes** ★
6. Impaired Performance Due to Reduced Muscle Mass, Strength & Endurance ★
7. **Reduced Physical Performance Capabilities Due to Reduced Aerobic Capacity** ★
8. Impaired Control of Spacecraft, Associated Systems and Immediate Vehicle Egress due to Vestibular / Sensorimotor Alterations associated with space flight. ★
9. **Cardiac Rhythm Problems** ★
10. Orthostatic Intolerance During Re-Exposure to Gravity ★
11. **Crew Adverse Health Event due to Altered Immune Response** ★
12. Adverse Health Effects due to Alterations in Host Microorganism Interaction ★

Concerns/Watch list

1. **Concern of Clinically Relevant Unpredicted Effects of Medication**
2. **Intervertebral Disc Damage**

Radiation

Primary Effect

1. **Risk of Space Radiation Exposure on Human Health** ★

Distance from Earth

Primary Effect

1. **Unacceptable Health and Mission Outcomes Due to Limitations of In-flight Medical Capabilities** ★
2. Risk of Ineffective or Toxic Medications due to Long Term Storage

Isolation

Primary Effect

1. **Risk of performance decrements due to adverse behavioral conditions** ★

Standards	
★	NASA-STD-3001, VOLUME 1, CREW HEALTH
★	NASA-STD-3001, VOLUME 2, HUMAN FACTORS, HABITABILITY, & ENVIRONMENTAL HEALTH
★	Clinical Practice Guidelines

Hostile/Closed Environment-Spacecraft Design

Primary Effect

1. **Toxic Exposure** ★
2. Acute and Chronic Carbon Dioxide Exposure ★
3. **Hearing Loss Related to Spaceflight** ★
4. Probability of mild Acute Mountain Sickness (AMS) in astronauts resulting in reduced crew performance prior to adaptation to a mild hypoxia.
5. **Injury and Compromised Performance due to EVA Operations** ★
6. Decompression Sickness ★
7. **Injury from Sunlight Exposure** ★
8. Incompatible Vehicle/Habitat Design
9. **Risk of Inadequate Human-Machine Interface** ★
10. Risk to crew health and compromised performance due to inadequate nutrition ★★
11. **Adverse Health Effects of Lunar (Celestrial) Dust Exposure** ★
12. Performance Errors Due to Fatigue Resulting from Sleep Loss, Circadian Desynchronization, Extended Wakefulness, and Work Overload ★
13. **Injury from Dynamic Loads** ★
14. Risk of electrical shock ★

★ Standards in process of review/change/addition

HMTA list in revision 2014

New Risk Assessment - NASA Report
(February 2022)

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NASA/TM–20220002905
NESC-RP-20-01589

NASA ENGINEERING & SAFETY CENTER
ENGINEERING EXCELLENCE
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Safe Human Expeditions Beyond Low Earth Orbit (LEO)

Azita Valinia/NESC
Langley Research Center, Hampton, Virginia

John R. Allen
NASA Headquarters, Washington, DC

David R. Francisco
Johnson Space Center, Houston, Texas

Joseph I. Minow
Marshall Space Flight Center, Huntsville, Alabama

Jonathan A. Pellish
Goddard Space Flight Center, Greenbelt, Maryland

Alonso H. Vera
Ames Research Center, Moffett Field, California

February 2022

- **NESC Assessment Team focused on characteristics of those Mars mission architectures that render the lowest integrated human health risk**
- **Risk Assessment included 3 main topics:**
  - **Radiation Exposure Risk**
  - **Altered Gravity Risk**
  - **Reduced Ground Support Risks**
- **Solution space centered on the possibility of fast transits for reducing time that crew spent at risk**

HOW ISRU OFFERS SOLUTION SPACES FOR THESE 3 RISKS

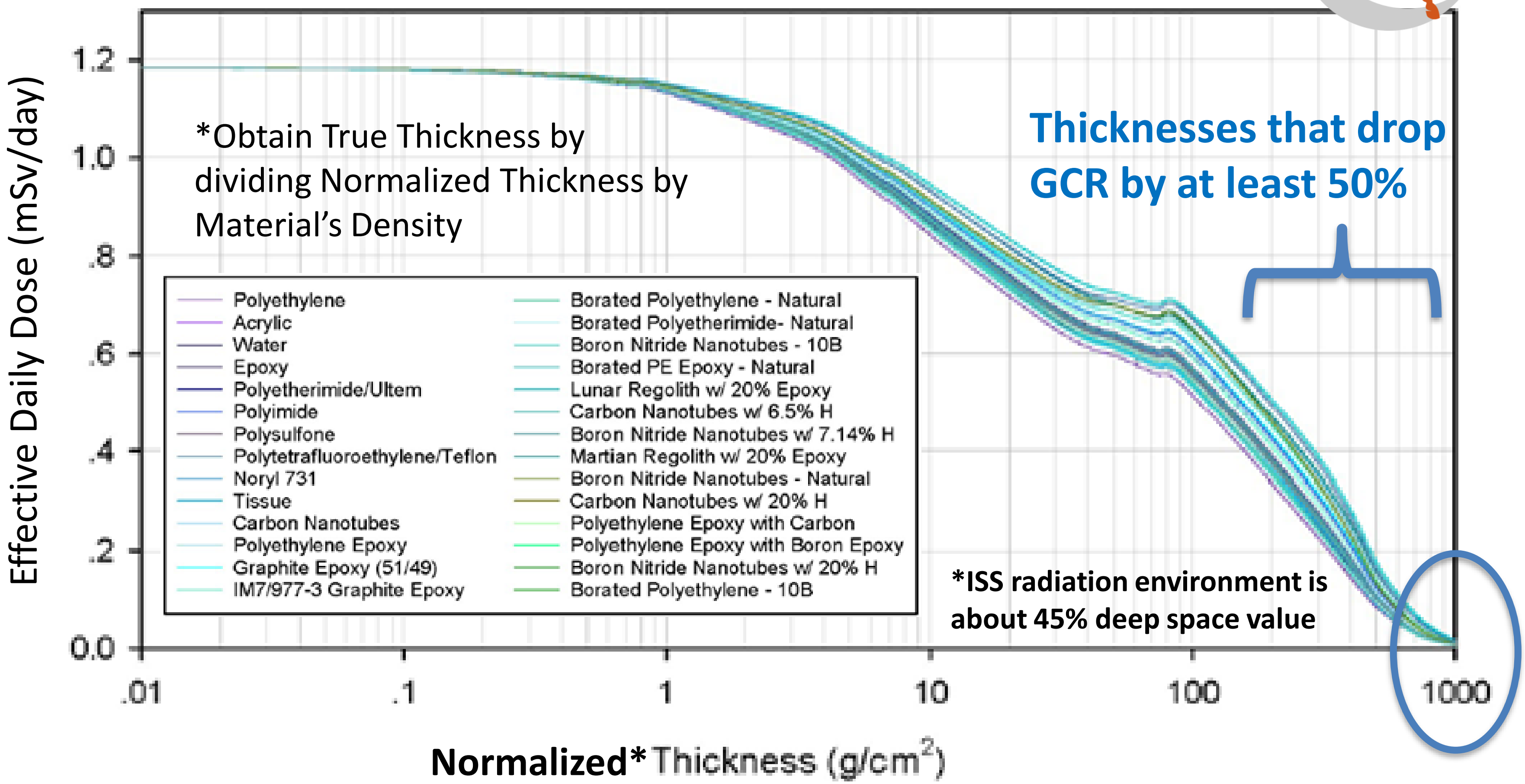
- Radiation Exposure Risk
- Altered Gravity Risk
- Reduced Ground Support Risks

GCR Shielding Requirements for Fast Transit Options – 2018 Study

GALACTIC COSMIC RAY (GCR) SHIELDING TRADE STUDY

- **For the cumulative GCR response evaluation, a preliminary GCR Shielding Design Reference Mission was created that includes 5 phases:**
  - **Cis-lunar habitat stay**
  - **Lunar surface stay**
  - **Lunar to Mars interplanetary transit**
  - **Mars surface stay**
  - **Mars to Earth return transit**
- **Some initial values for durations and overcoat material for each phase were selected for constructing an Evaluation Tool that allows total exposure to be summed up for all 5 phases**
  - Polyethylene (PE) was selected as the overcoat material for the in-space phases
  - Surface Regolith was selected as the overcoat materials for the surface stays
- **In-Space Shielding Overcoat would remain In-Space and be reused**
  - Cis-lunar habitat overcoat remains in cis-lunar orbit
  - <u>If "affordable to propel" for interplanetary transit</u>, GCR overcoat for shielded case would remain with interplanetary transport for subsequent transits to/from Mars

Overcoat Options - Polymer and Composite Response To GCR



These are massive structures!

Is anything possible for in-space interplanetary transportation portion?

Options during Surface Habitation portion of the mission?

Bottomline Summary – GCR Shielding

- **In-Space Interplanetary Transportation Portion of the Mission**
  - Placing the shielding material into LEO requires over 20 SLS launches
    - Hercules Reusable Lander Design https://arc.aiaa.org/doi/10.2514/6.2017-5288
      - Sized for landing around 20 tons to the lunar or Martian surface
      - Can place about 5 tons of regolith into orbit for lunar and Mars missions but requires ISRU refueling
      - Would require many reusable sorties to place all overcoat material into orbit
  - Would still need to assemble the shielding material into an overcoat and secure it to the interplanetary spacecraft
  - Such an overcoat is considered too massive to propel to/from Mars using current technologies
  - Hollow out or fly along side an asteroid?
  - **No substantial solution seems possible presently**

- **Surface Habitation Portion of the Mission**
  - **Mars**
    - Natural Lava Tubes
      - Accessibility from the surface is presently unknown
      - Some are indicated near ice/water
    - Ditch & Bury the habitat with regolith (or ice) with loose or constructed layer(s) https://arc.aiaa.org/doi/10.2514/6.2018-5356
  - **Moon**
    - Some natural subsurface access may be possible
    - Ditch & Bury the habitat with regolith (or ice?) with loose or constructed layer(s) https://ntrs.nasa.gov/citations/20210022632
  - **These options point to some type of surface preparation and construction using indigenous materials (i.e., ISRU)**

HOW ISRU OFFERS SOLUTION SPACES FOR THESE 3 RISKS

- Radiation Exposure Risk
- Altered Gravity Risk
- Reduced Ground Support Risks

Some Options for Altering Gravity

- **Surface Stays**
  - 1/6 Earth's gravity on the lunar surface
  - 1/3 Earth's gravity on Martian surface
  - **Space Resources naturally offer some level of gravity**

- **In-Space Portion of the Mission**
  - Exercise Devices
    - Can load the body in ways similar to gravitational forces
    - However, do not mitigate issues with fluid shifts in body that lead to other health issues https://arc.aiaa.org/doi/10.2514/6.2018-5360
  - Artificial Gravity
    - Requires rotating portions or the entire spacecraft, depending on scale
    - Large scale platforms, such as an O'Neill Cylinder, would be constructed and outfitted using materials found in Space https://en.wikipedia.org/wiki/O%27Neill_cylinder
    - **These options point to extraction and transportation of and subsequent construction using Space Resources (i.e., ISRU)**

HOW ISRU OFFERS SOLUTION SPACES FOR THESE 3 RISKS

- **Radiation Exposure Risk**
- **Altered Gravity Risk**
- **Reduced Ground Support Risks**

LITTLE TO NO HELP FROM EARTH – BUT IS EARTH NEEDED?

- **Roundtrip missions take up to years in duration due to Mars' distance from Earth**
- **Failures of many spacecraft and critical systems are likely to occur during those time frames**
- **Cannot preposition a spare for every part of every mission system?**
- **There will likely be many "Apollo XIII – like" opportunities that will tax Mission Control Centers, the astronauts, and the mission systems before the crew returns to Earth**
- **"Living Off the Land" via ISRU may offer a better risk posture for achieving safe crew return to Earth https://www.space.com/33563-nasa-mars-colonization-plan.html**
- **Adopting a new philosophy / approach leading to "Earth Independence" may offer the best solution space https://ntrs.nasa.gov/api/citations/20160005963/downloads/20160005963.pdf**

Potential Approaches to Humans-Mars

- **Prescriptive Approach to System Failures: Traditional approach used to date whereby MTBF dictate the mission requirements and risk matrix and establish protocols for pre-deployment of cargo (at Mars).**

- **Improvising Approach to System Failures: An ISRU-based approach employing the capabilities (mining, refinement, additive manufacturing, power generation, etc) whereby spare parts are made in situ using resources there or raw materials brought from Earth or obtained otherwise.**

Risk of System Failures (Using Prescriptive) for Short Duration Missions

Quantifying Risk Using the Risk Matrix

- **Risk** is the lack of certainty about the outcome of making a particular choice.
- Statistically, the level of downside risk can be calculated as the product of the **probability** that harm occurs (e.g., that an accident happens) multiplied by the **severity** of that harm (i.e., the average amount of harm or more conservatively the maximum credible amount of harm).
- In practice, the **risk matrix** is a useful approach where either the probability or the harm severity cannot be estimated with accuracy and precision.

Probability	Harm Severity			
	Negligible	**Marginal**	**Critical**	**Catastrophic**
Certain	High	High	Very High	Very High
Likely	Medium	High	High	Very High
Possible	Low	Medium	High	Very High
Unlikely	Low	Medium	Medium	High
Rare	Low	Low	Medium	Medium
Eliminated	Eliminated			

Short duration missions (Apollo) or ISS missions with abort to Earth opportunity

System Failures

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

Risk of System Failures (Anticipated using Prescriptive) for Long-Duration Missions

Probability	Harm Severity			
	Negligible	Marginal	Critical	Catastrophic
Certain	High	High	Very High	Very High
Likely	Medium	High	High	Very High
Possible	Low	Medium	High	Very High
Unlikely	Low	Medium	Medium	High
Rare	Low	Low	Medium	Medium
Eliminated	Eliminated			

Long Duration Missions (Roundtrip Humans-Mars)

System Failures

With the right spare parts ⟺ **Without** the right spare parts

Risk of System Failures (Prescriptive vs. Improvising) for Long-Duration Missions

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Long Duration Missions (Roundtrip Humans-Mars)

Probability	Harm Severity			
	Negligible	**Marginal**	**Critical**	**Catastrophic**
Certain	High	High	Very High	Very High
Likely	Medium	High	High	Very High
Possible	Low	Medium	High	Very High
Unlikely	Low	Medium	Medium	High
Rare	Low	Low	Medium	Medium
Eliminated	Eliminated			

Without any capability to make any spare part*

With the *capabilities* to make any spare part needed**

****System Failures**
With the *capabilities* to make any spare part on demand using ISRU and/or raw materials on hand

***System Failures**

With the right spare parts on hand ⇔ **Without** the right spare parts on hand

Pre-Position Capabilities (Instead of Parts Based on Guesses)

- **From a Risk Perspective, an Improvising Approach seems prudent**

- **However, what does that Improvising Approach cost compared to the traditional Prescriptive Approach?**

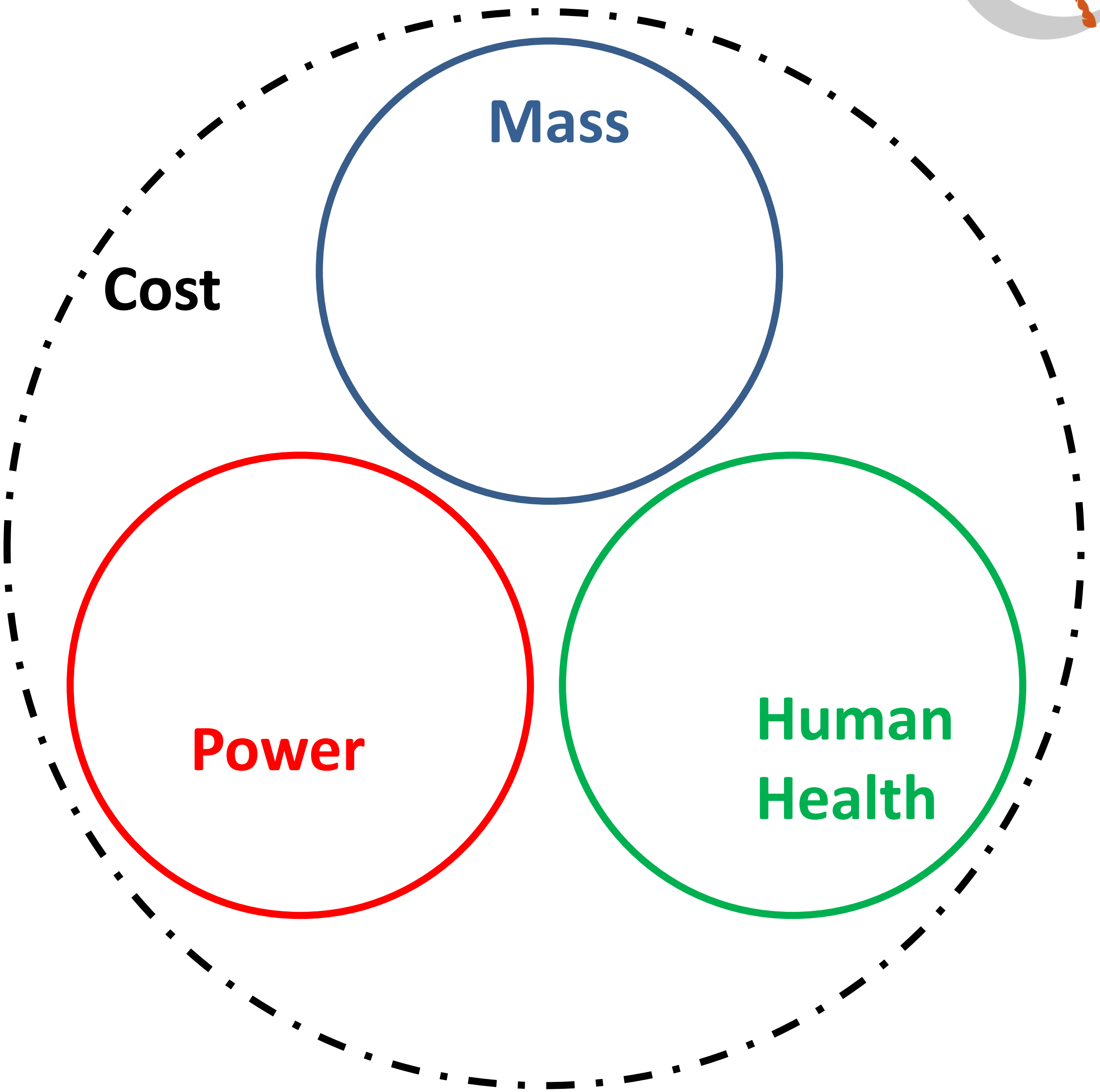
- **Cost has many phases**
  - Development
  - Fielding
  - Operational
  - Disposal
  - Other

- **Let's consider a more holistic view of Cost…**
  - Mass ($ / kg)
  - Power ($ / kW)
  - Human Health ($ / crew)

Cost ~ f($/kg) + f($/kW) + f($/crew)

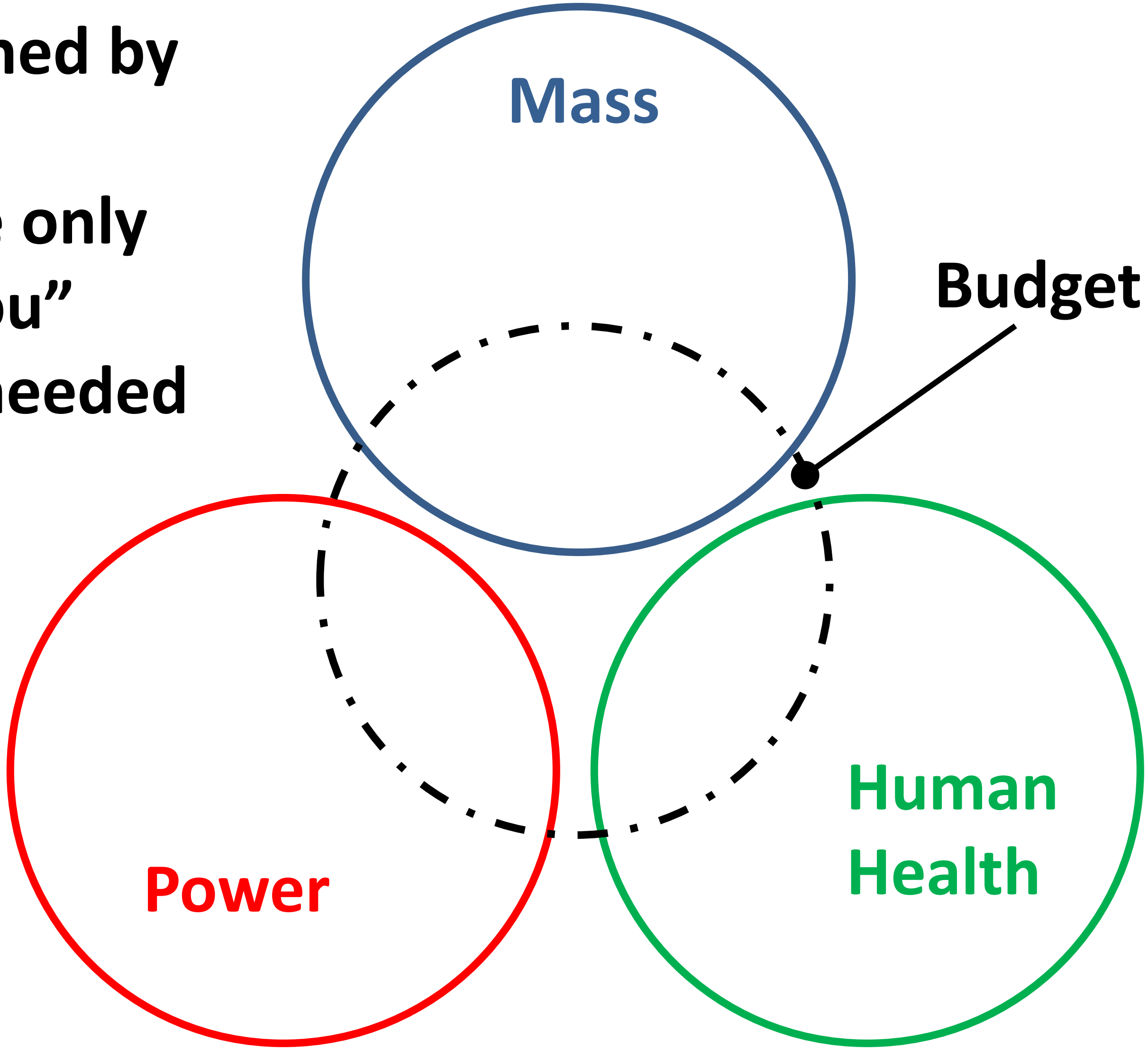
Ideal World: "Purchase It All" (Money is not an issue)

Cost is the encirclement of all 3



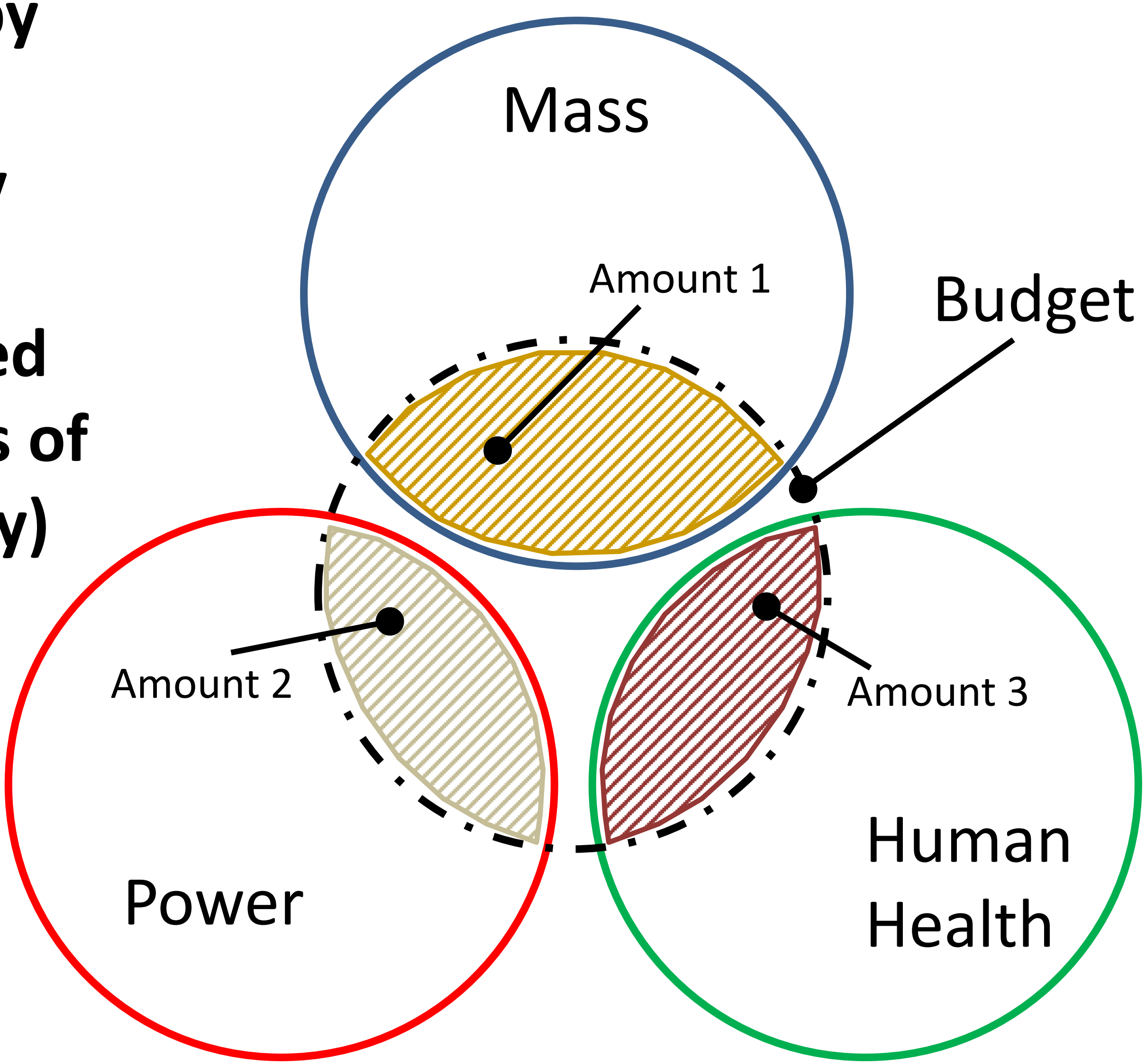
Realistic World: "Limited by Budget" (what you can afford)

Constrained by Budget: Purchase only what "you" think is needed



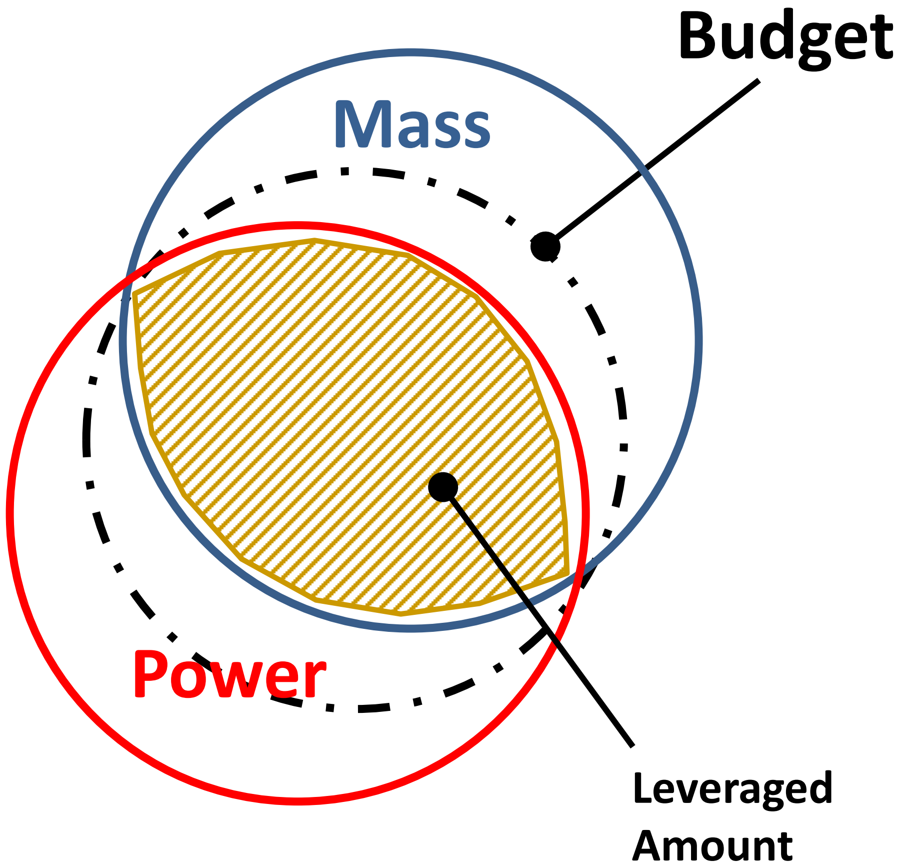
Realistic World: "Limited by Budget" (what you can afford) – Continued

Constrained by Budget:
Purchase only what "you" think is needed (The Amounts of Each May Vary)



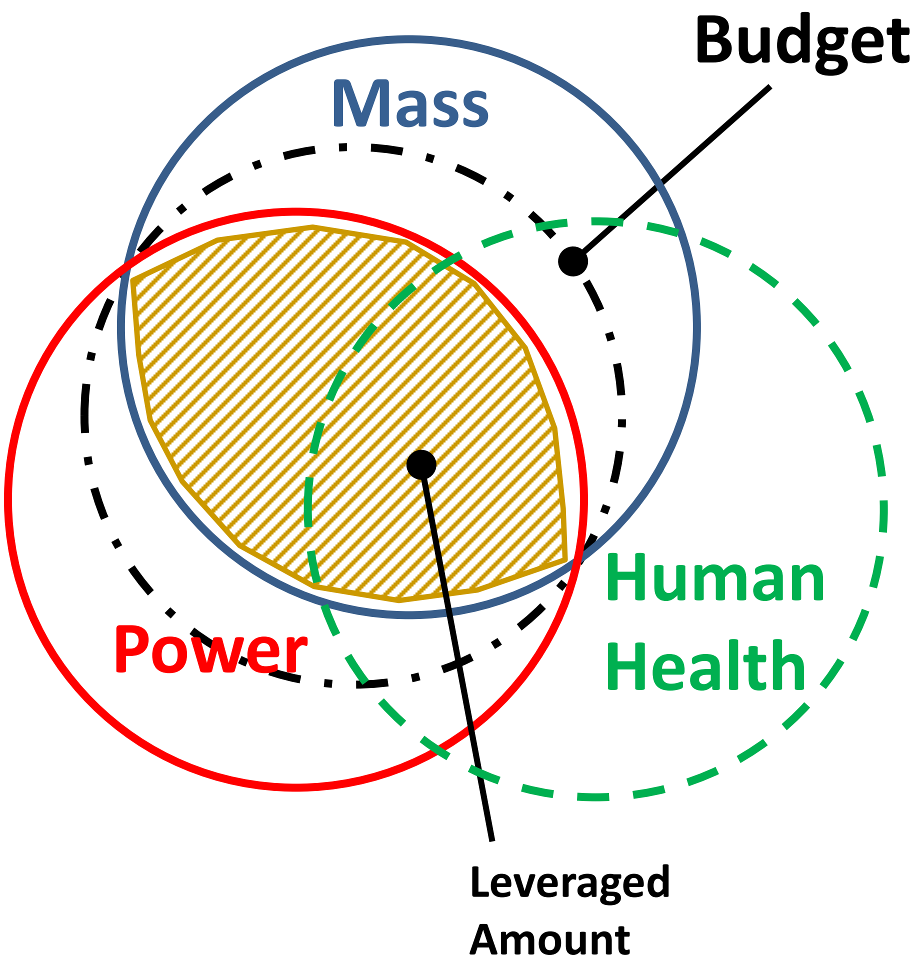
How to Fit As Much as Possible Into the Budget Circle?

- **Leveraging Scenario: The Mass is more aligned with Power (ISRU Case)**
  - Leveraged Amount exceeds previously shown Amounts 1+2 and allows for ISRU
  - Budget has not changed
  - “ISRU Case” aims to trade mass brought from Earth as consumables for Power delivered to the destination for converting in situ resources to usually products (consumables, spare parts, etc.)
  - Moon: O2, metals, glass, volatiles, fertilizer?
  - Mars: C & H2 (for plastics & propellants), O2, metals, glass, fertilizer?



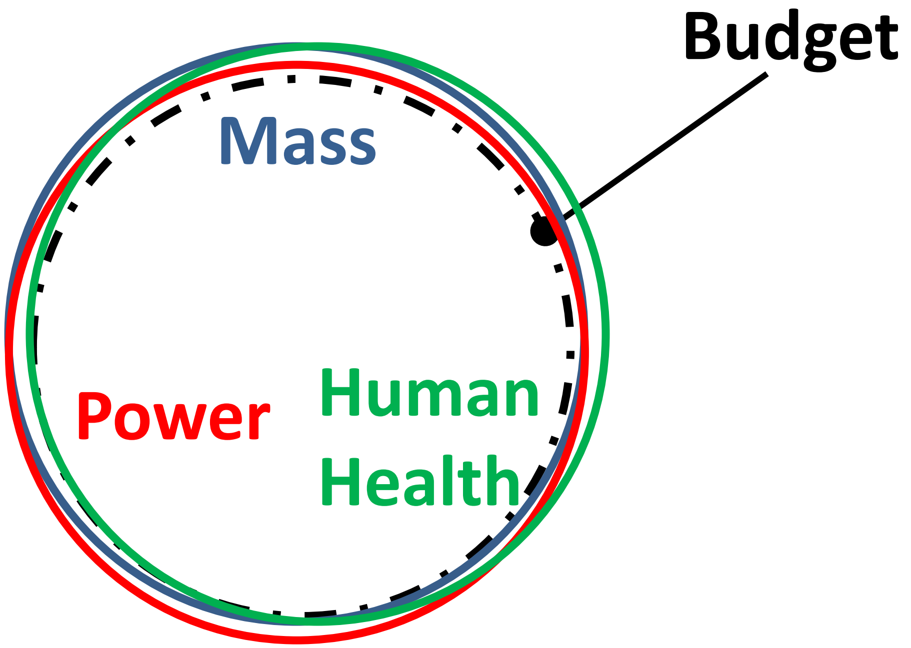
Further Leveraging Scenario: To address/cover Human Health

- **Leveraging Scenario (Continued): The Mass is more aligned with Power while attempting to address/cover Human Health**
  - "ISRU Case" now includes GCR Shielding with Regolith & Surface Construction
  - Budget has not changed
  - Costs are reallocated among specific systems necessary for implementing the additional capabilities, in this case to perform some surface construction



Goal: Achieve Sustainable Earth-Independent Pioneering within Budget

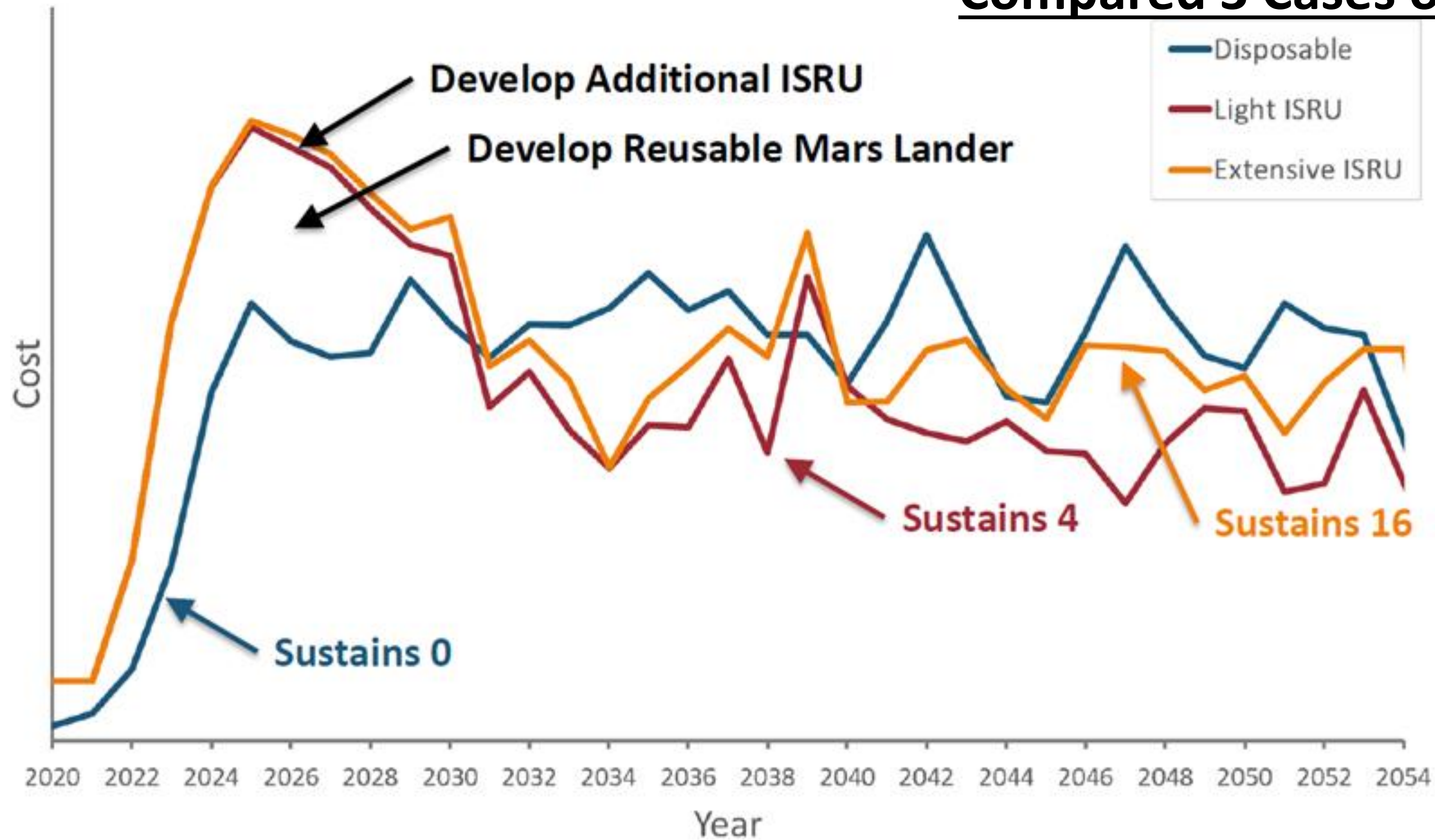
- **Leveraging Scenario (Continued): Increased Leveraging Maximizes Deployment of Budget**
  - "ISRU Case" now includes everything necessary to achieve Earth-Independent Pioneering of Mars
  - Budget has not changed
  - Costs are reallocated among specific systems necessary for implementing the additional capabilities, in this case to perform some surface construction
  - **What are the cost of these ISRU capabilities compared to the total mission costs?**



Cost of ISRU Capabilities

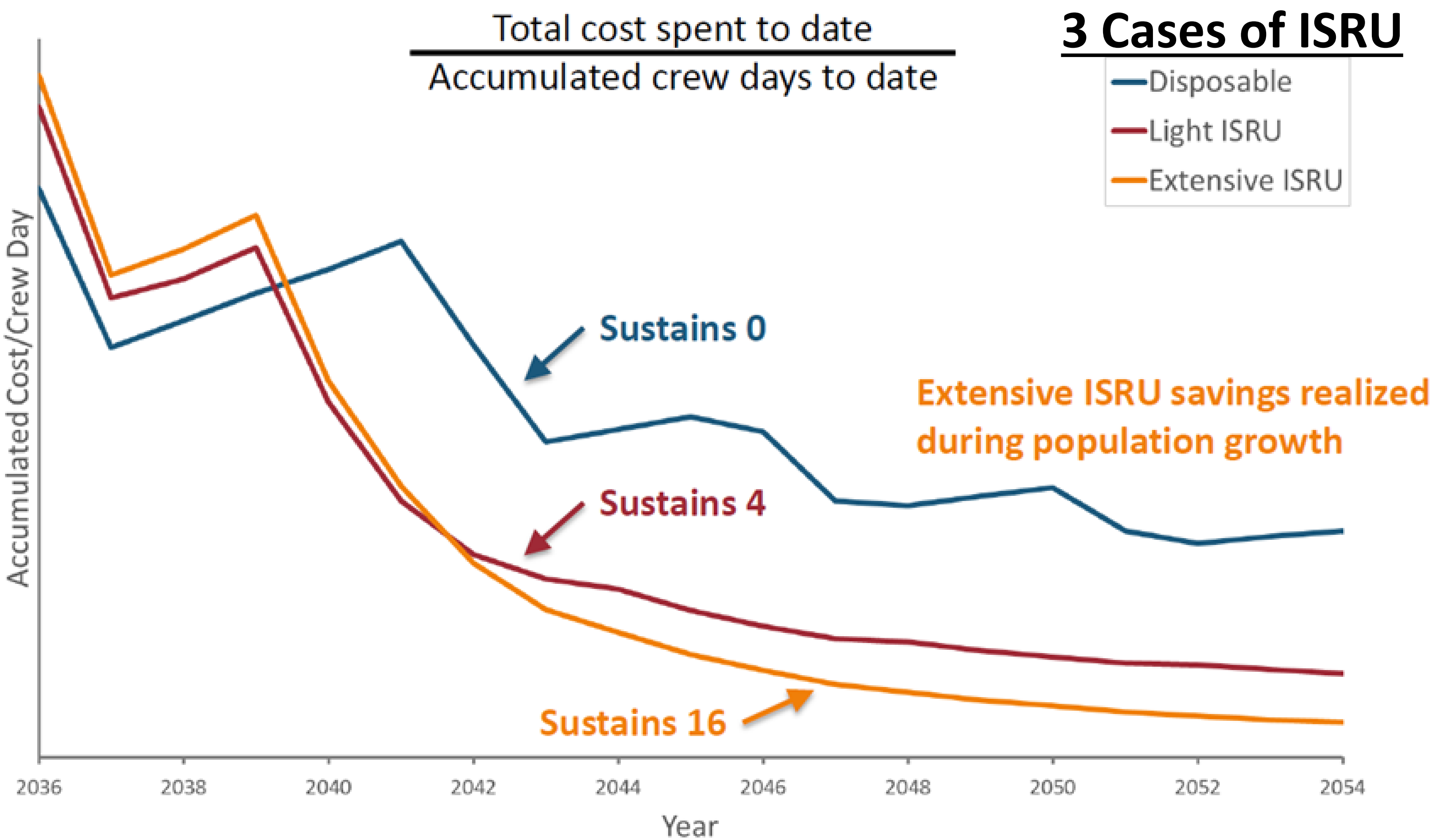
“Sustaining Human Presence on Mars Using ISRU and a Reusable Lander” https://arc.aiaa.org/doi/10.2514/6.2015-4479

Compared 3 Cases of ISRU



Cost Comparison Normalized by Accumulated Crew Days

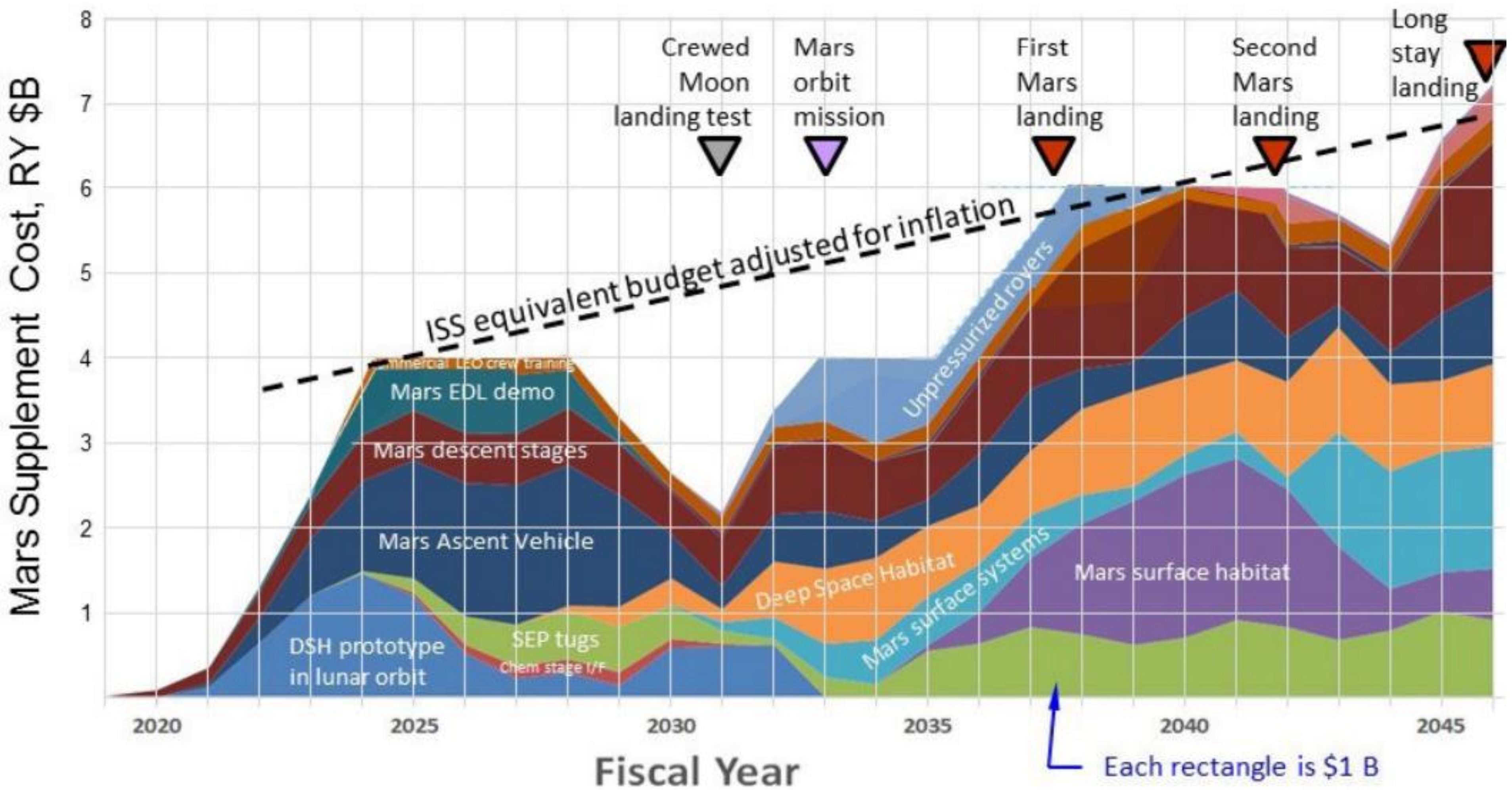
“Sustaining Human Presence on Mars Using ISRU and a Reusable Lander” https://arc.aiaa.org/doi/10.2514/6.2015-4479



Cost of a “Disposable Architecture”

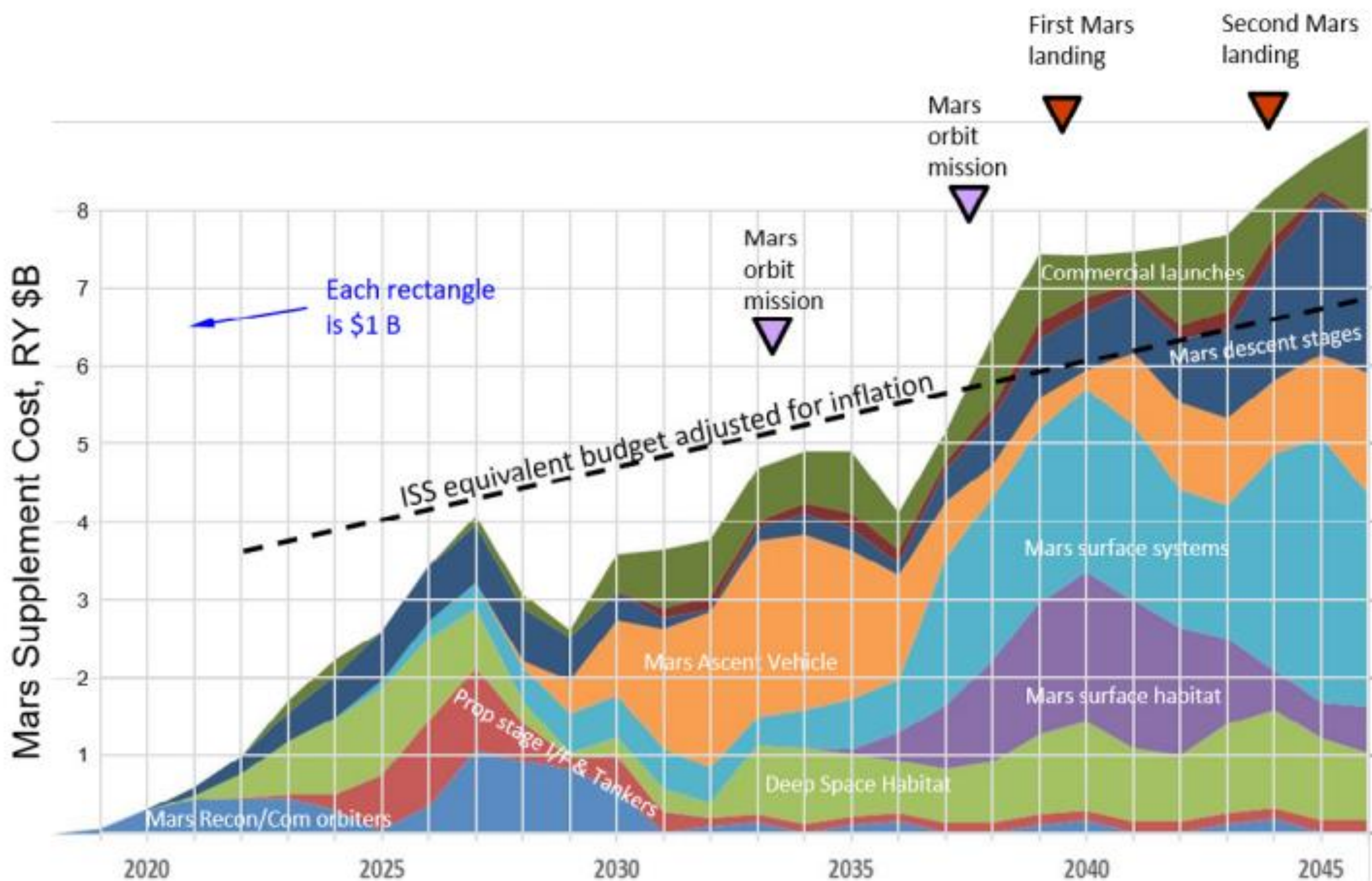
“The Fifth Community Workshop on Achievability and Sustainability of Human Exploration of Mars: Three Scenarios for the 2030s (AM V)”

https://www.exploremars.org/wp-content/uploads/2019/11/Affording-Mars-V.pdf



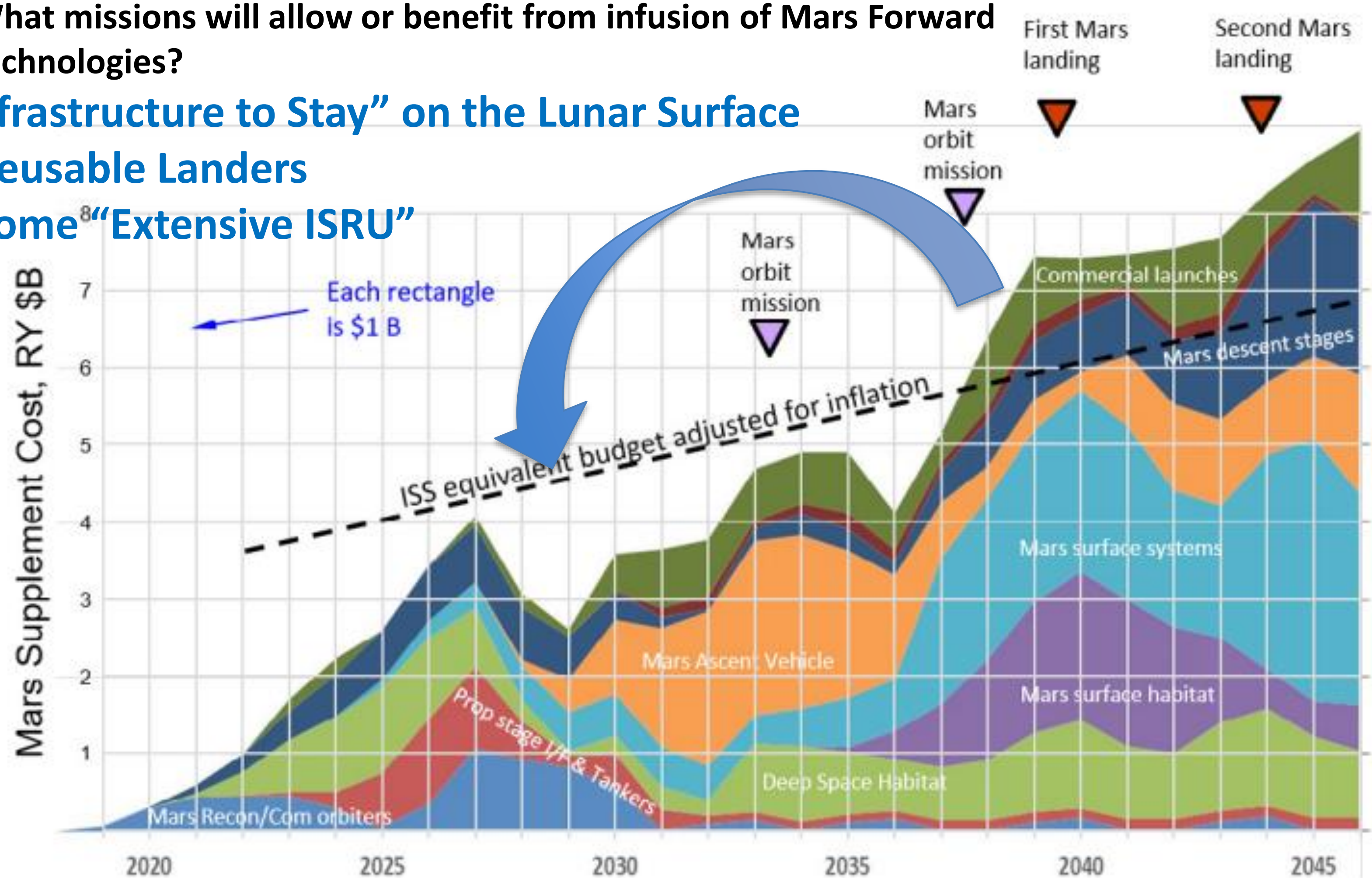
Cost of a Sustainable "Toward Earth Independent" Architecture

"The Fifth Community Workshop on Achievability and Sustainability of Human Exploration of Mars: Three Scenarios for the 2030s (AM V)"
https://www.exploremars.org/wp-content/uploads/2019/11/Affording-Mars-V.pdf



Leverage by Shifting / Spreading Some Costs Into Voids

- **Shifting and spreading the costs in the voids beneath the budget line seems practical on paper**
- **Q: What mission(s) allow for that?**
  - **What missions need similar capabilities and systems?**
  - **What missions will allow or benefit from infusion of Mars Forward technologies?**
- **A: "Infrastructure to Stay" on the Lunar Surface**
  - **Reusable Landers**
  - **Some "Extensive ISRU"**



Conclusions

- **ISRU leads to sustainable pioneering of Mars**
  - Requires power and reusable systems
  - Requires an Improvising Approach to achieve a better risk posture
- **Humans-Moon ("Infrastructure to Stay") not only allows a proving ground for Space technologies but also a shift from a Traditional Prescriptive Approach to an Improvising Approach**
  - that reduces risk to crew and mission
  - that exploits all types of Mars Forward systems that are not necessarily needed on the Moon due to its proximity to Earth
  - that expedites Earth-Independent Pioneering of Mars that would otherwise be perceived as too costly
- **Hercules Reusable Lander Design was shown feasible to support ISRU operations at both the Moon and Mars if refueling is possible**
- **Many ISRU and crew mission systems are transferrable to Mars**
  https://www.nasa.gov/directorates/spacetech/Lunar_Surface_Innovation_Initiative
- **New Paper by NASA (Pending): "Approaches To Humans-Mars Both Safe and Affordable," Bushnell, Moses, and Choi**