Human Exploration of Mars: Challenges, Opportunities, and Progress

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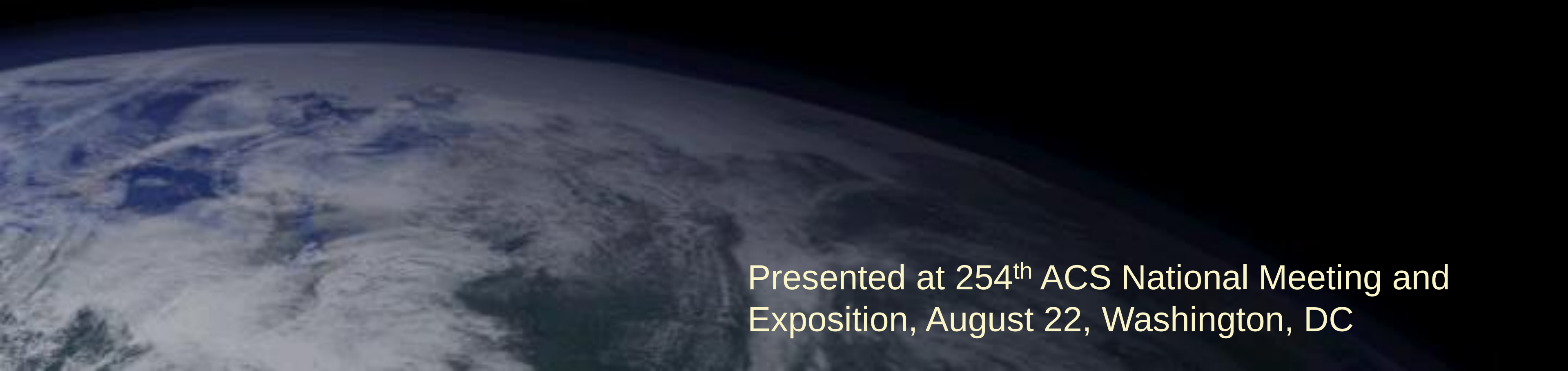

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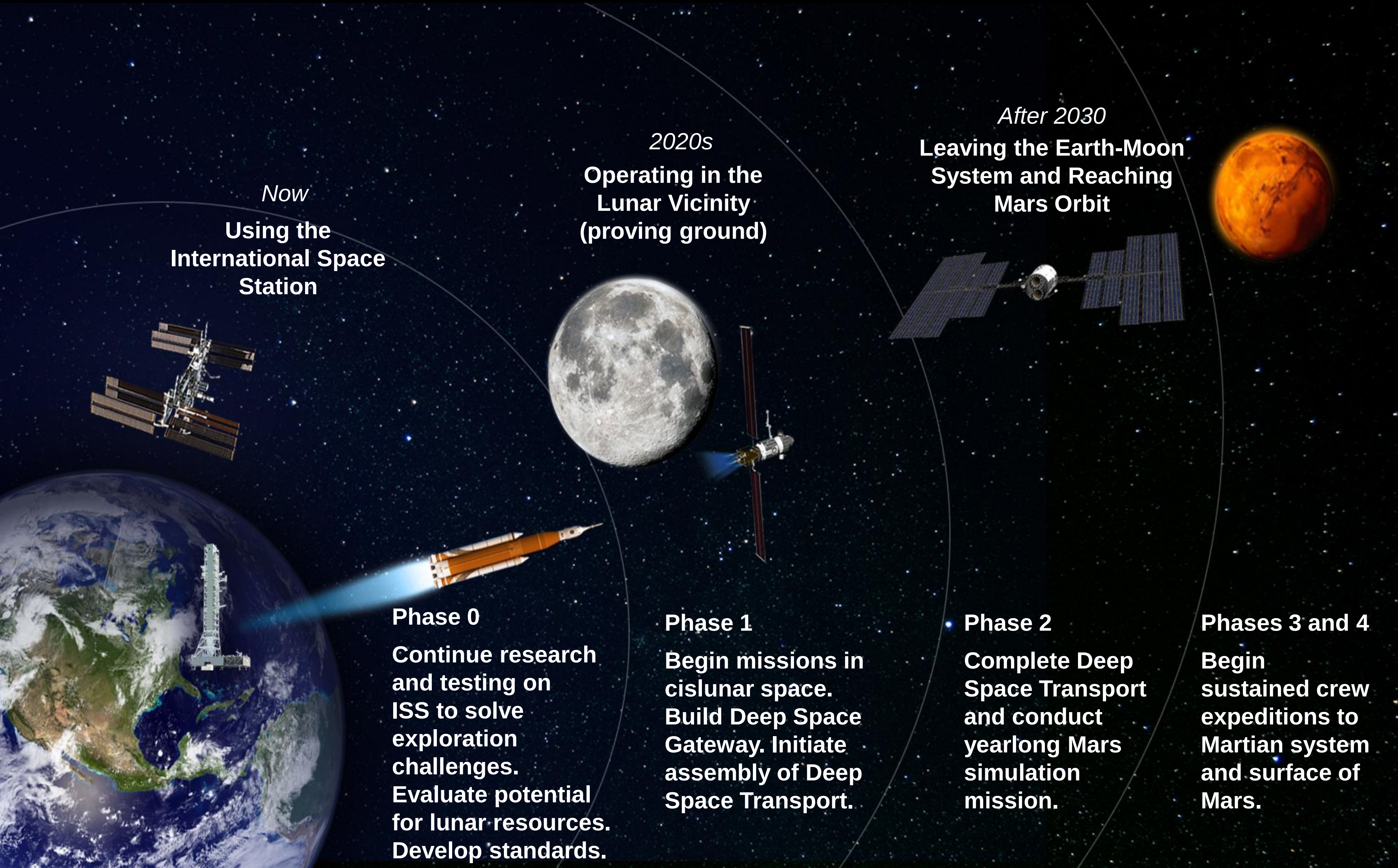
Journey to Mars



Now

Using the International Space Station

2020s

Operating in the Lunar Vicinity (proving ground)

After 2030

Leaving the Earth-Moon System and Reaching Mars Orbit

Phase 0

Continue research and testing on ISS to solve exploration challenges. Evaluate potential for lunar resources. Develop standards.

Phase 1

Begin missions in cislunar space. Build Deep Space Gateway. Initiate assembly of Deep Space Transport.

Phase 2

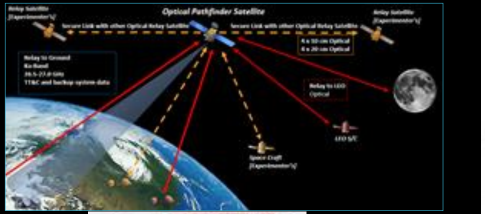
Complete Deep Space Transport and conduct yearlong Mars simulation mission.

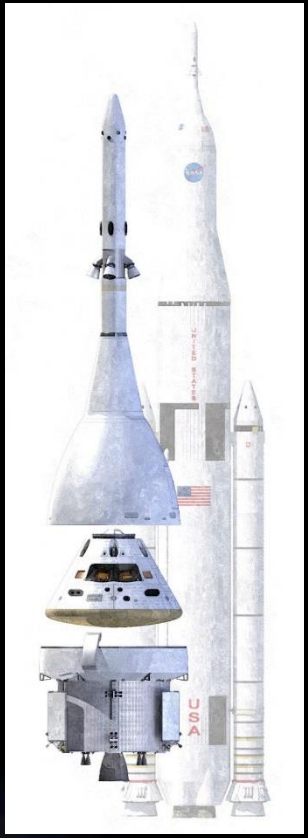
Phases 3 and 4

Begin sustained crew expeditions to Martian system and surface of Mars.

Key Challenges for Human Exploration of Mars

- Transportation
- In-space Propulsion
- Entry, Descent, and Landing
- Communication and Navigation
- Human Robotics/Autonomous System
- In-situ Resource Utilization
- Surface Power
- Habitats and Surface Mobility
- Crew Health

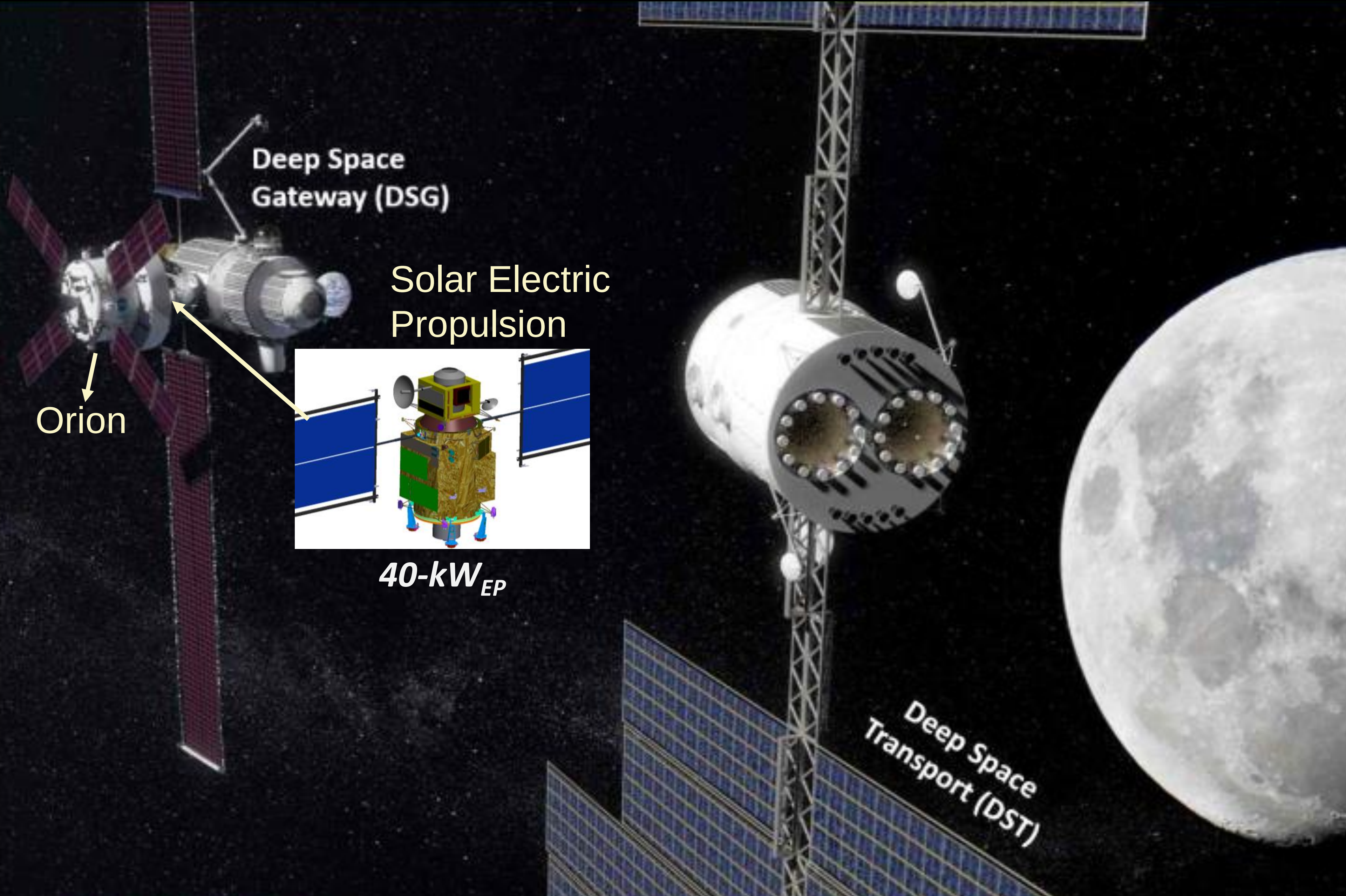




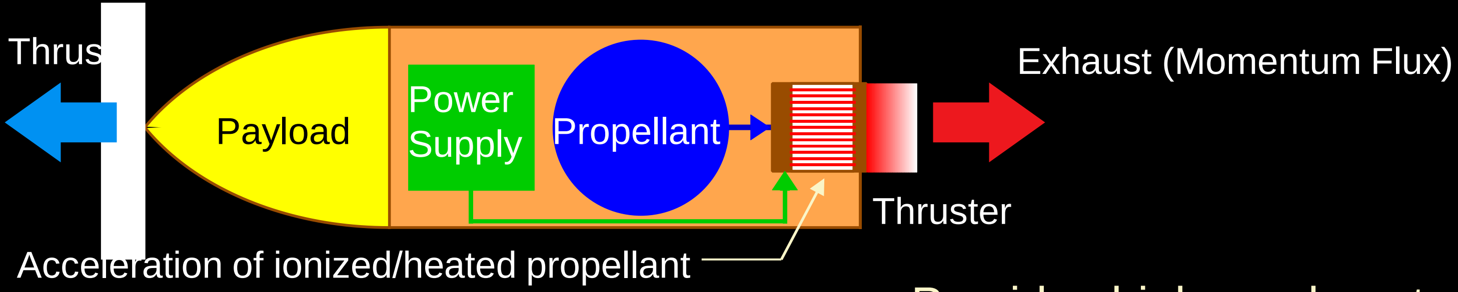
Focus of This Presentation

- In-space propulsion
- Surface power
- In-situ resource utilization
- Crew health
- Materials technologies

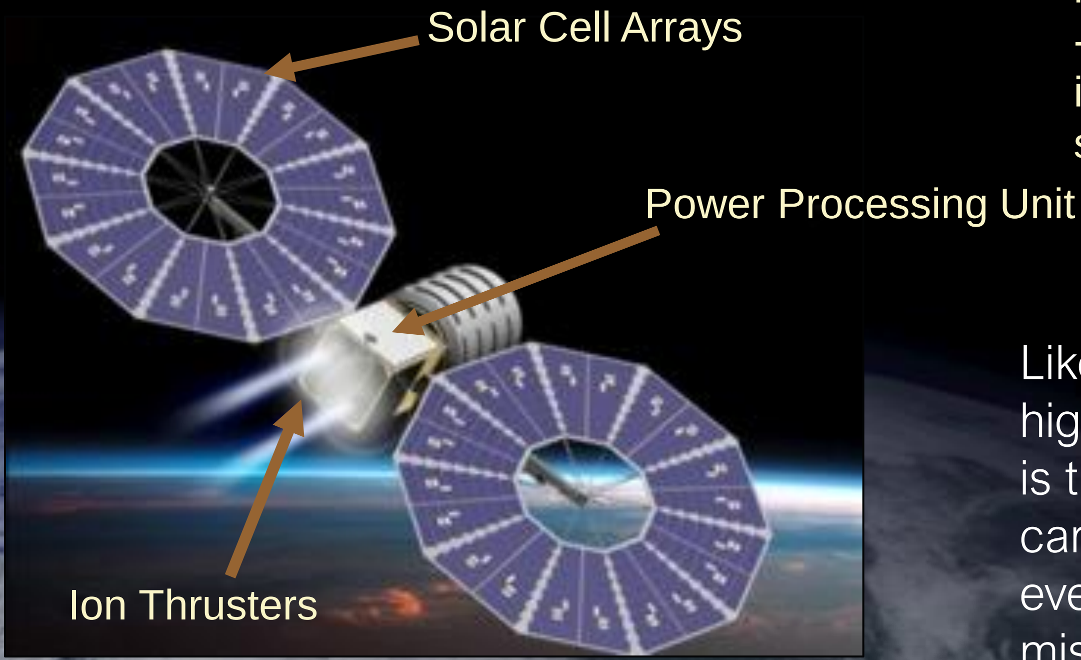
Deep Space Gateway and Deep Space Transport



Solar Electric Propulsion (SEP)



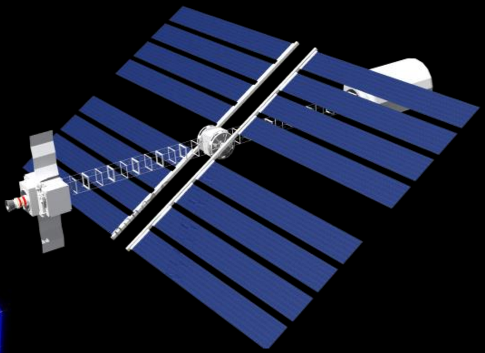
- Provides higher exhaust velocities than chemical engines
  - -Reduces propellant mass needed to provide a given impulse
  - -Allows reduction in launch mass <u>or</u> increase in payload; can provide substantial benefits in mission cost



Like an automobile that has extremely high “miles per gallon” efficiency, SEP is the best (lowest cost) way to deliver cargo to deep-space destinations – even multiple destinations in a single mission

Solar Electric Propulsion Evolution

2015-2020: 50kW Class capability



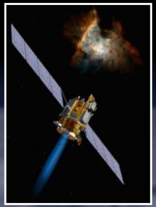
2020-2030: 50 - 100 kW Class capability

2030-2040: 100 - 500 kW Class capability payloads)

- **2008 SMART-1: 1.5kW ESA Tech demo, lunar science**

- **2007 Dawn: 2kW (10kW @ 1AU) NASA science mission,**

- **2003 Hayabusa: 2kW JAXA Tech demo, asteroid sample/return**



- **1998 Deep Space-1: 2kW NASA Tech demo, asteroid comet flyby**

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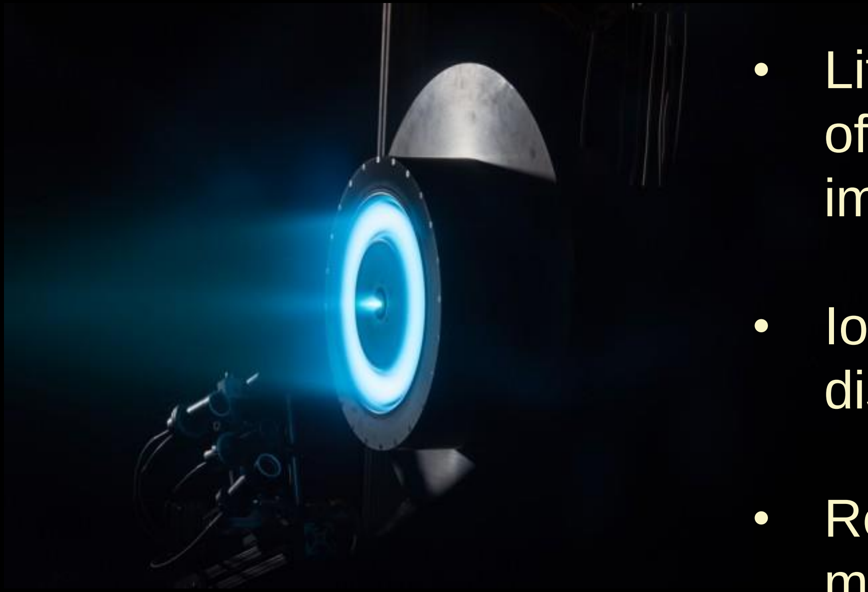
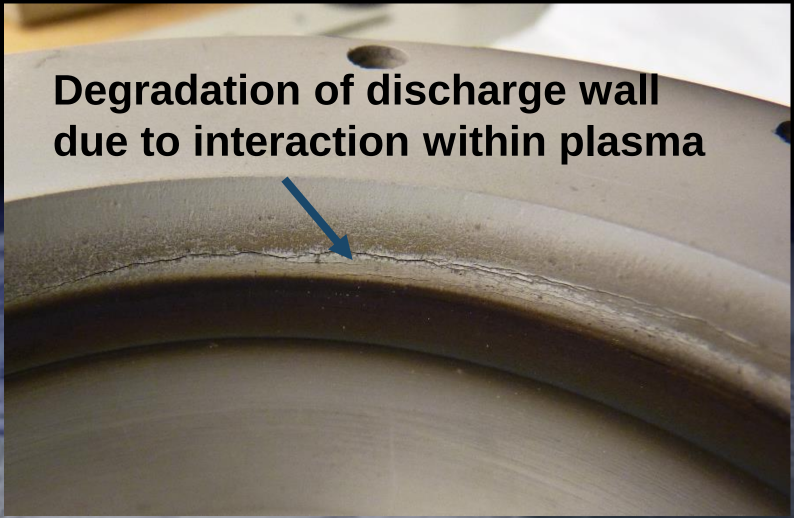
Challenges for High Power Solar Electric Propulsion:
- Lightweight, deployable solar arrays
- High power density electric propulsion and power processing unit
- Long-term durability

Life Limiting Mechanism in Hall Thrusters

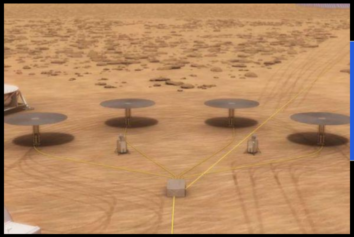




Degradation of discharge wall due to interaction within plasma

- Life limiting mechanism is erosion of discharge channels due to ion impact
- Ions cause sputtering of ceramic discharge channel walls
- Research on understanding and modeling interaction of ions with materials
- Need better materials with (1) high voltage isolation capability, (2) low sputter yield at all temperatures, and (3) low secondary electron emission

Surface Power on Mars



Nuclear Fission Surface Power

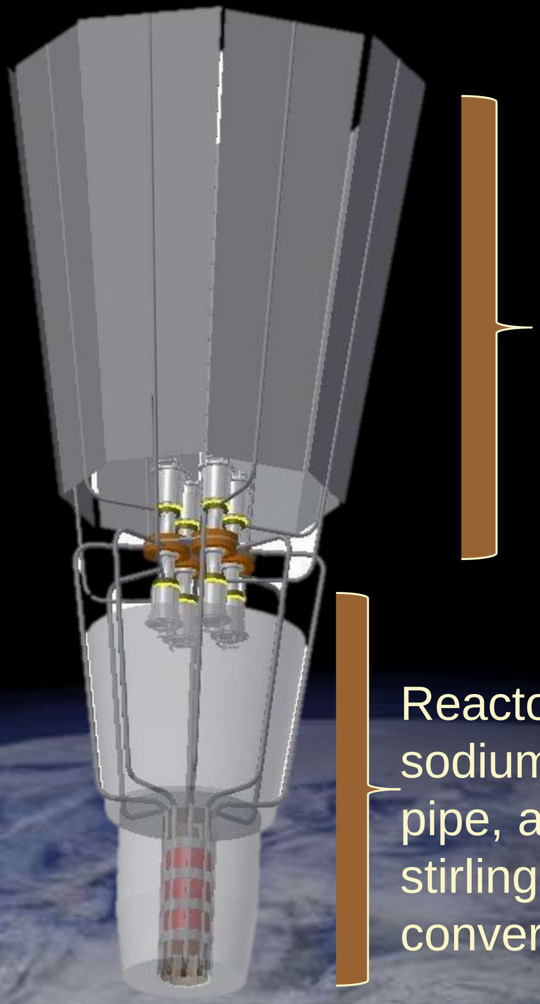
Regenerative Fuel Cell for Surface Power

Batteries for EVA

Batteries for Rovers and Mobility System

Fuel Cell for Mobile Systems

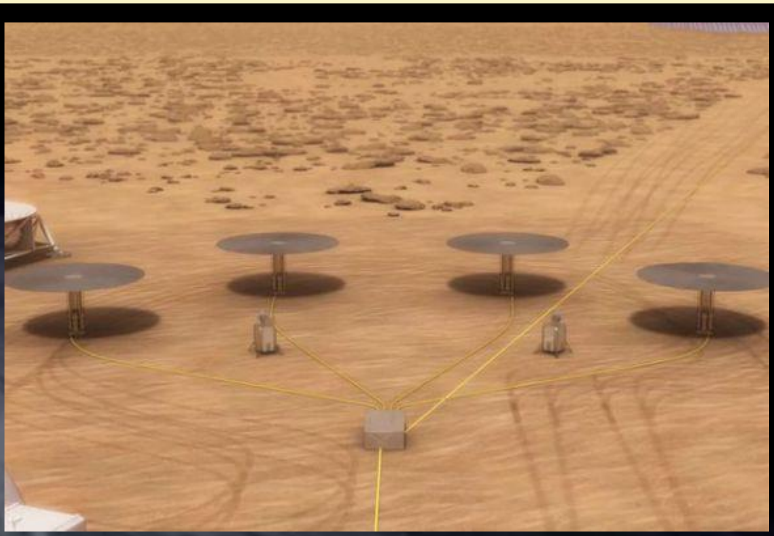
Development of 1- 10 kWe Fission Power System



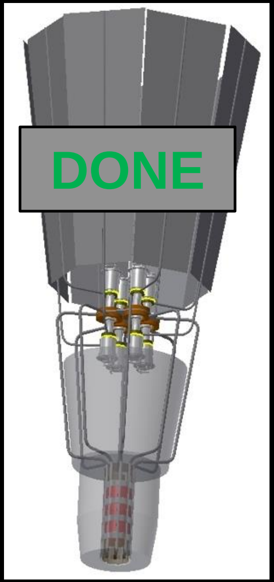
Variable conductance heat pipe radiator

Reactor core, sodium heat pipe, and stirling converter

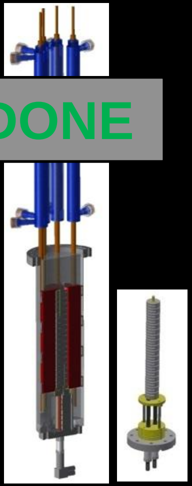
- Compact, low-cost, scalable fission power system that provides modular options for Mars surface operations
- Enabled by novel integration of available U235 fuel form, passive heat pipes, and flight-ready stirling converters for converting heat to electricity



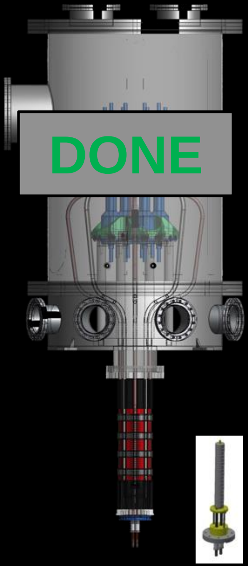
Progress in kWe Fission Power System



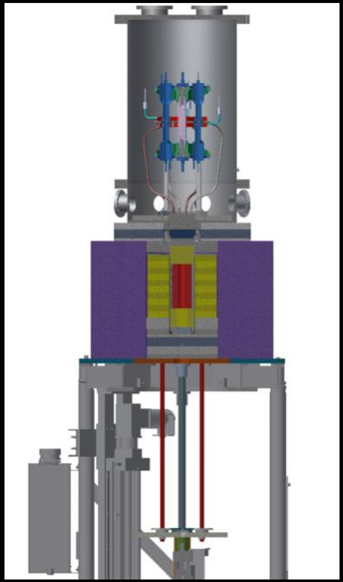
Notional Flight System Concept



Thermal Prototype & Materials Testing (2015)



Thermal-Vac System Test with Depleted Uranium Core at GRC (2016)



Reactor Prototype Test with Highly-Enriched Uranium Core at NNSS (October 2017 – February 2018)

- Verify system-level performance of flight-like U-Mo reactor core, sodium heat pipes, and Stirling power conversion at prototypic operating conditions (temperature, heat flux, power) in vacuum
- Establish technical foundation for 1 to 10 kW-class fission power systems

NASA

NNSA National Nuclear Security Administration

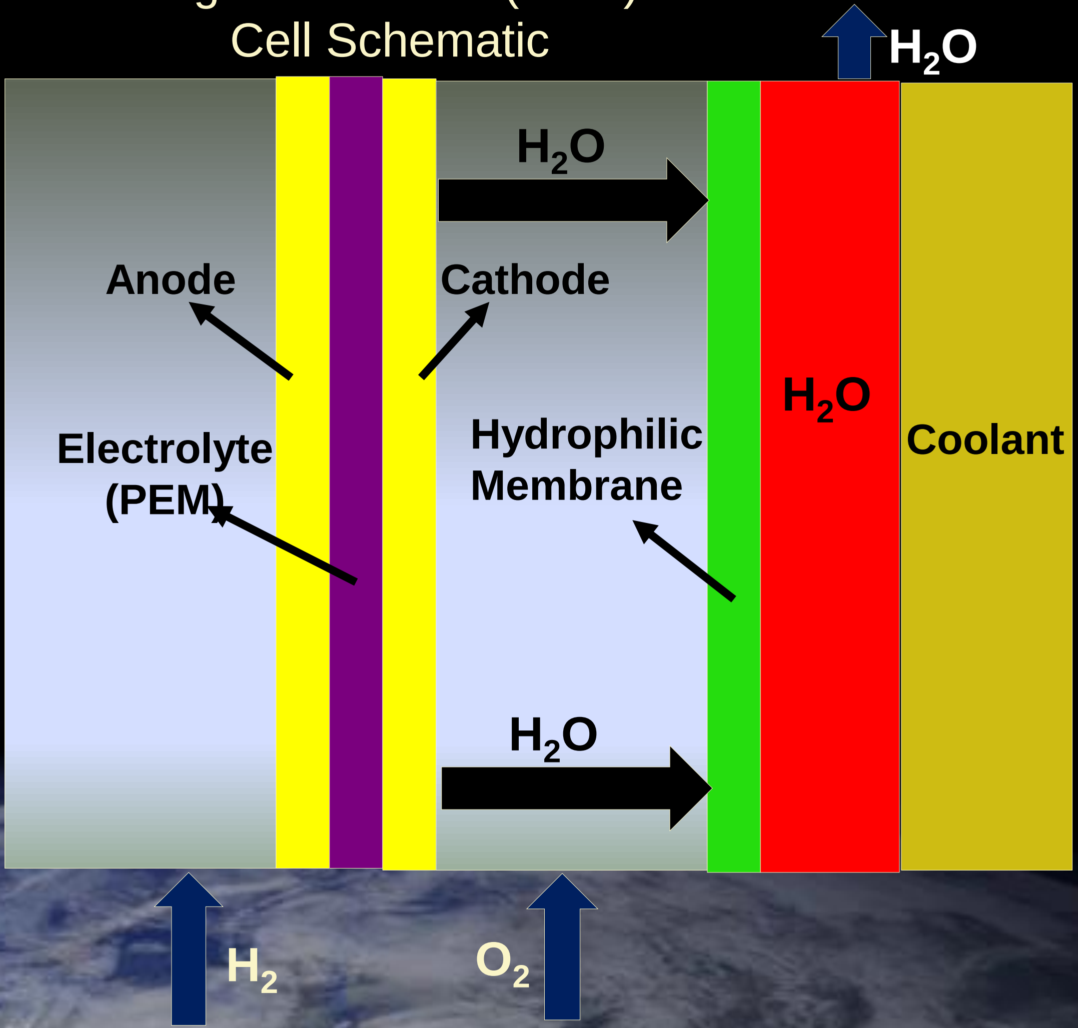
Los Alamos NATIONAL LABORATORY EST.1943

Y-12 National Security Complex

NNSA Nevada National Security Site

Fuel Cell for Rovers and Surface Power

Non Flow-Through Proton Exchange Membrane (PEM) Fuel Cell Schematic



H_2O

H_2O

Anode

Cathode

Electrolyte (PEM)

Hydrophilic Membrane

H_2O

Coolant

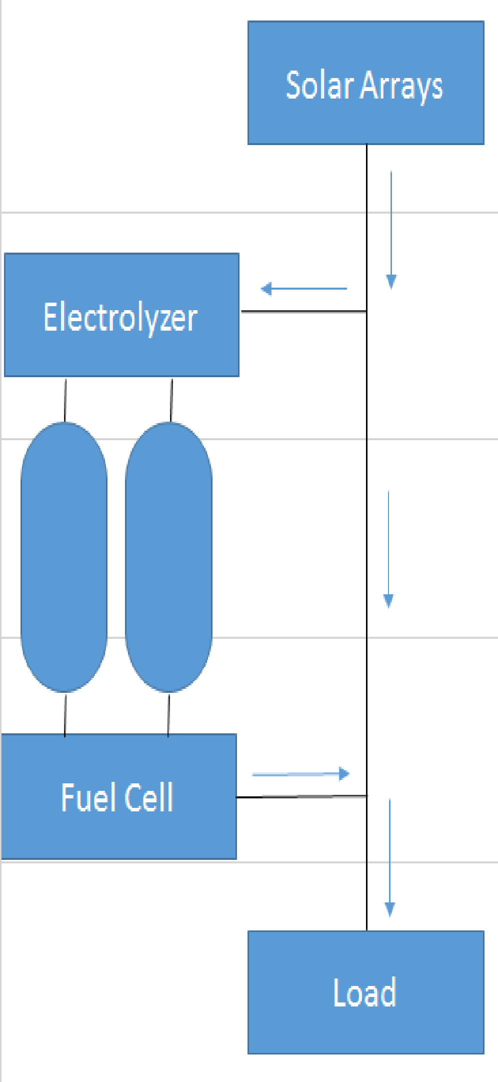
H_2O

H_2

O_2

Fuel Cell: $H_2 + \frac{1}{2} O_2 = H_2O$

Electrolyzer: $H_2O = H_2 + \frac{1}{2} O_2$



Regenerative Fuel Cell

Progress and Challenges in Development of Fuel Cell for Space Power Application

Successful demonstration of 1 kW power, non flow-through Proton Exchange Membrane (PEM) fuel cell in Scarab rover field demonstration

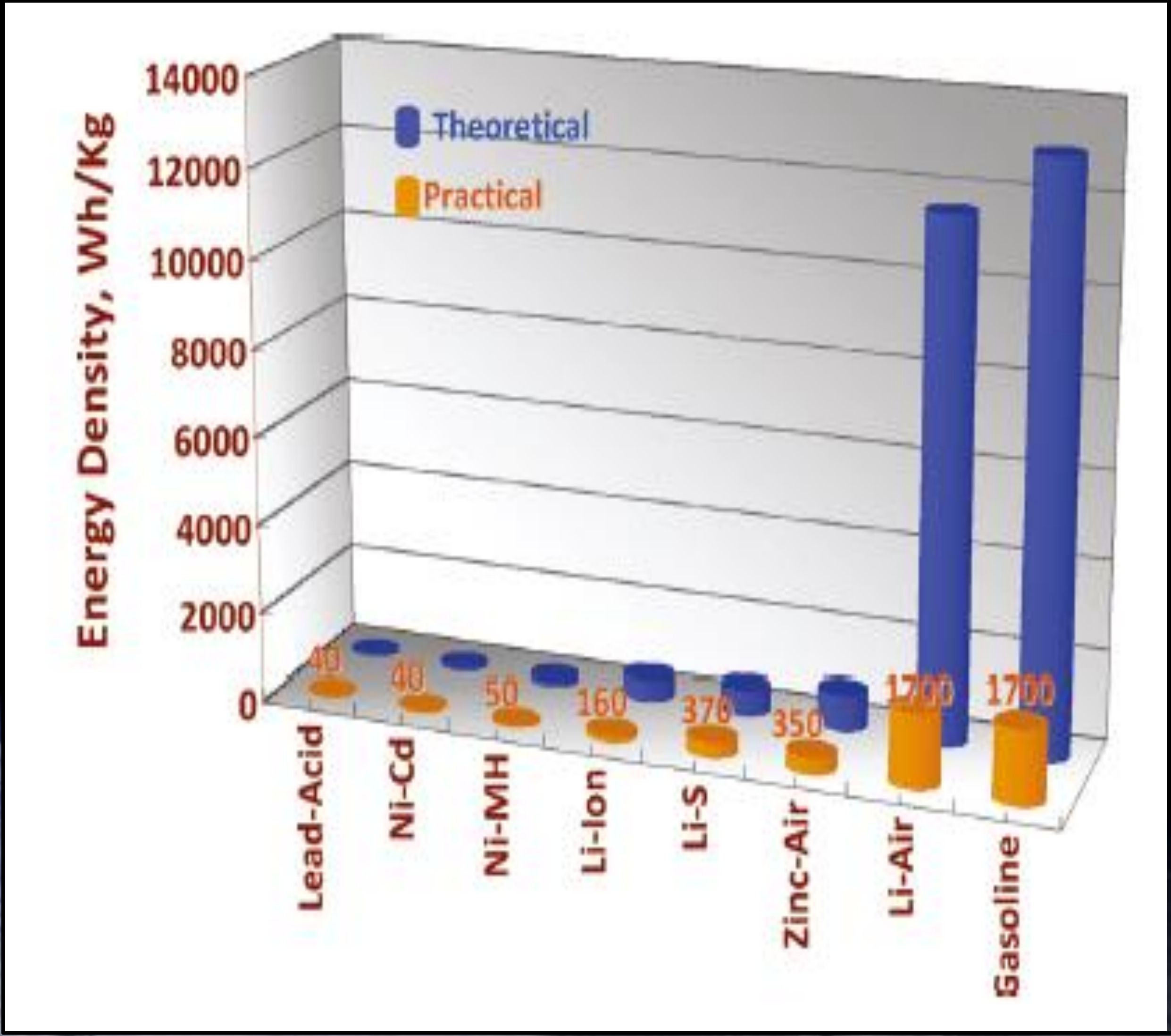
Goals:

- Power level of 10 kW
- 12 years operational life, > 60,000 hr for fuel cell and > 46,000 hr for electrolyte
- > 100 W/kg for fuel cell and > 30W/kg for regenerative fuel cell

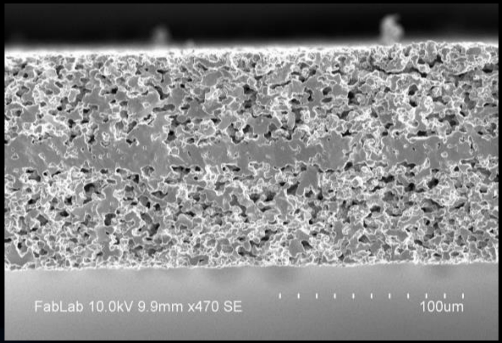
Challenges and Opportunities:

- Increasing power density by incorporation of lightweight materials and integration of components
- Thermal management – decreasing the size of the radiator
- Understanding and modeling of degradation mechanisms and finding solutions to improve durability
  - Understanding of degradation of polymer membrane due to chemical interaction and mechanical stresses and of catalysts due to oxidation of carbon and loss of Pt catalyst
- New materials to minimize degradation of polymer membrane, catalyst, and gas diffusion layer

Batteries for Mars Surface Applications



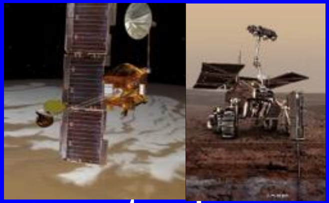
- Batteries with energy densities greater than 300 wh/kg needed for Mars surface applications
- Li-S and Li-air are candidates



Solid state Li-S battery under development

In-Situ Resource Utilization (ISRU) on Mars

Resource Assessment (Prospecting)



Assessment and mapping of physical, mineral, chemical, and water resources, terrain, geology, and environment

Resource Acquisition

Excavation, drilling, atmosphere collection, and preparation/ beneficiation before processing

Resource Processing/ Consumable Production

Extraction and processing of resources into products with immediate use or as feedstock for construction & manufacturing

- Propellants, life support gases, fuel cell reactants, etc.

In Situ Manufacturing

Production of replacement parts, complex products, machines, and integrated systems from feedstock derived from one or more processed resources

In Situ Construction

Civil engineering, infrastructure emplacement and structure construction using materials produced from *in situ* resources

- Radiation shields, landing pads, roads, berms, habitats, etc.

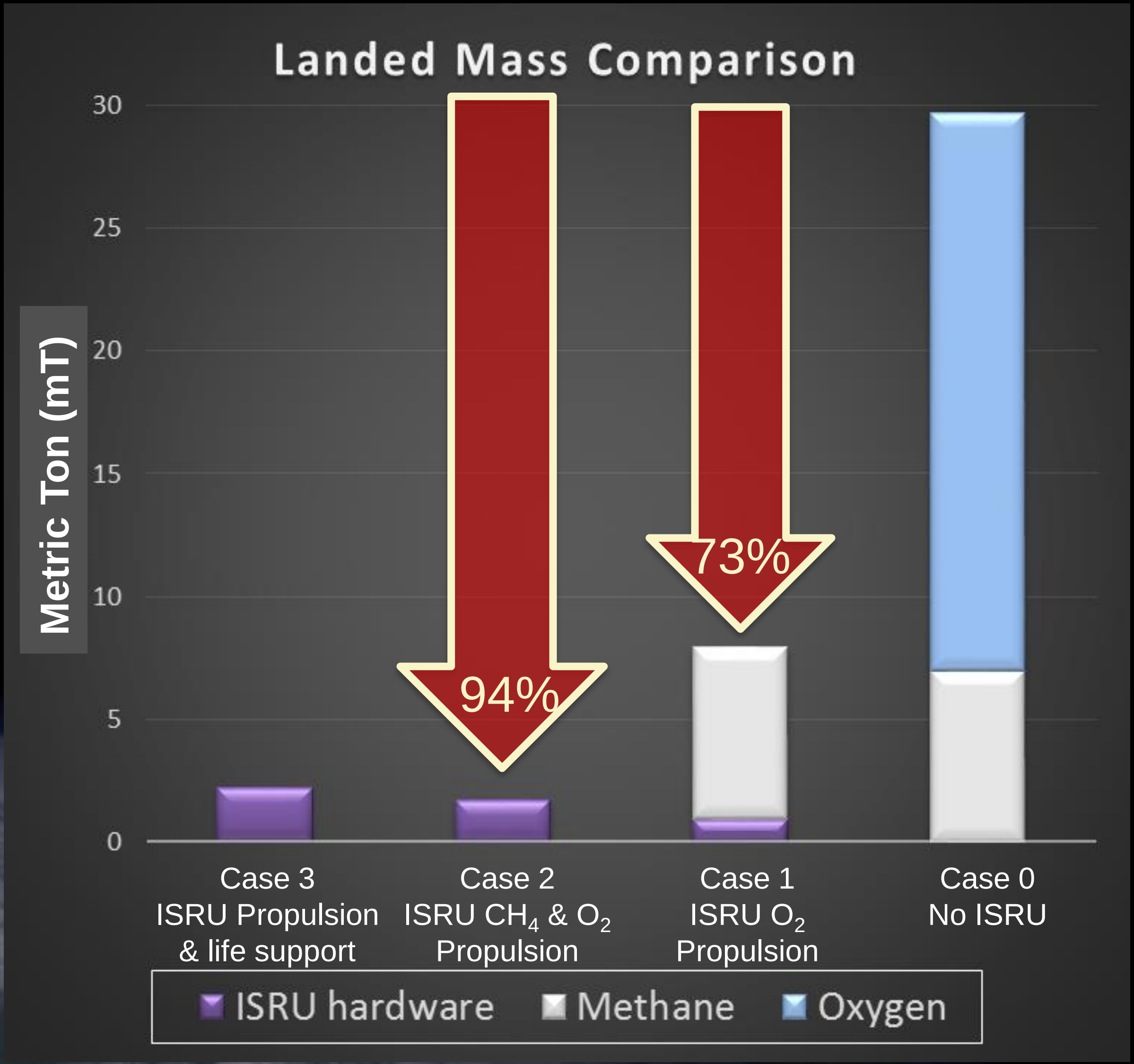
In Situ Energy

Generation and storage of electrical, thermal, and chemical energy with *in situ* derived materials

- Solar arrays, thermal storage and energy, chemical batteries, etc.

ISRU Propellant Production System for Mars Ascent Vehicle

- Methane and oxygen can be produced using resources available on Mars (water from soil and carbon dioxide from Mars atmosphere)
- Mass savings in LEO is about 10kg per every 1 kg of propellant produced
  - Reduces cost and eliminates several heavy lift launch vehicles



Chemistry of Mars ISRU

Resources:

- Water in Mars soil
- Carbon dioxide in Mars atmosphere

Oxygen and hydrogen production:

$CO_2 = CO + 1/2O_2$

$H_2O = H_2 + 1/2O_2$

Methane production:

$CO_2 + 2H_2O = CH_4 + 2O_2$

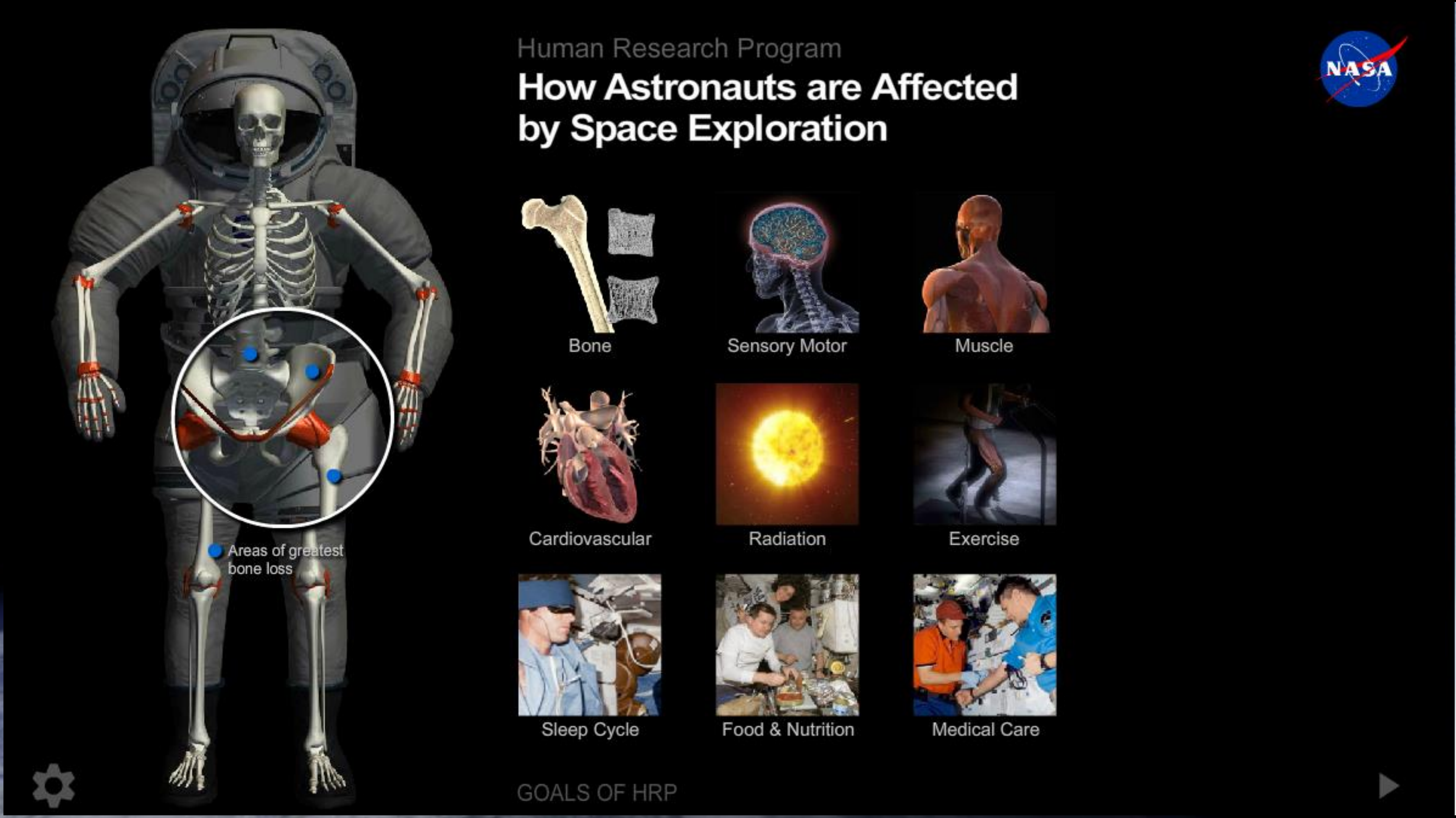
$CO_2 + 4H_2 = CH_4 + 2H_2O$

$CO + 3H_2 = CH_4 + H_2O$

Other hydrocarbon fuel production:

$CO + 2H_2 = CH_3OH$

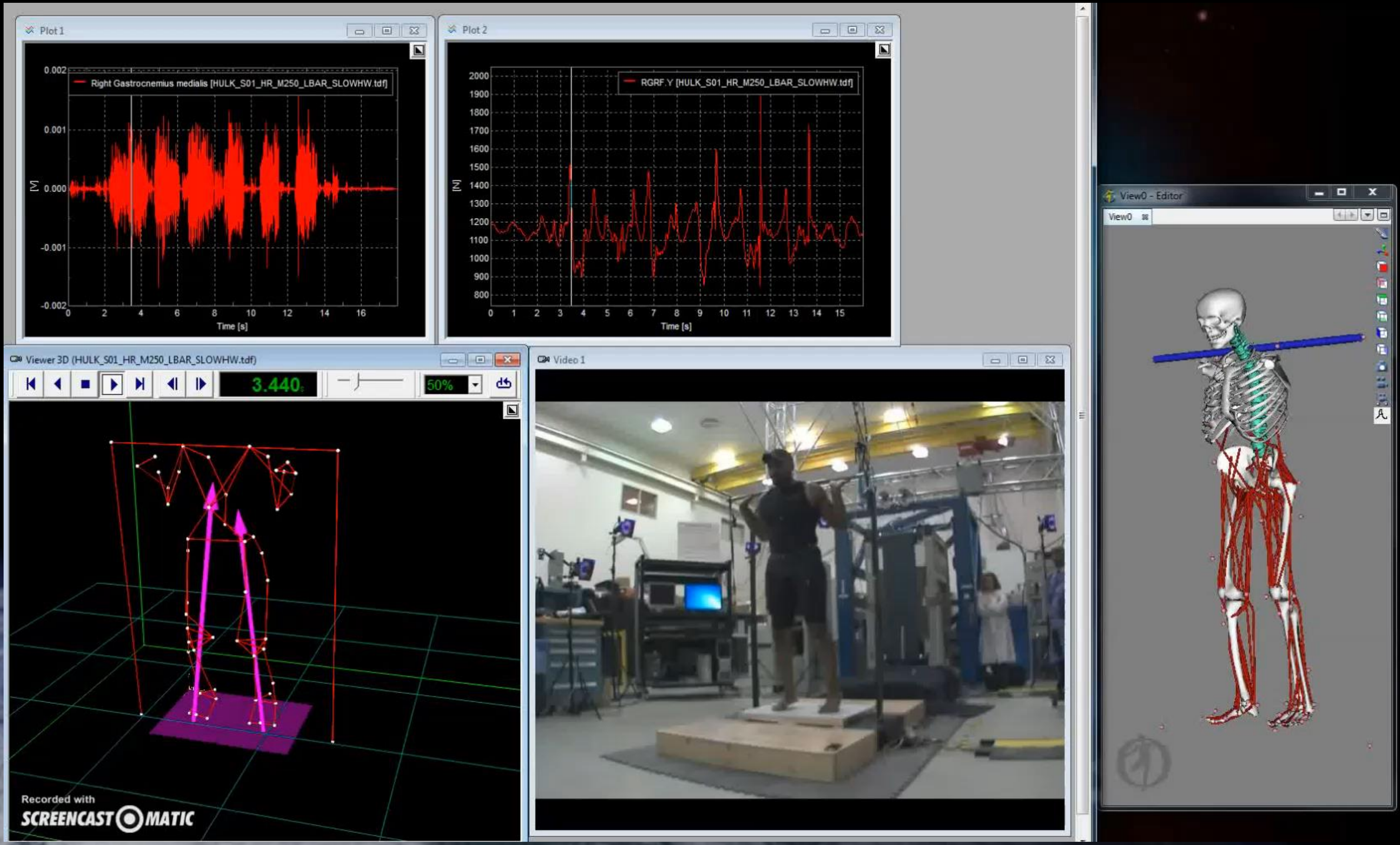
$CO_2 + 3H_2 = CH_3OH + H_2O$



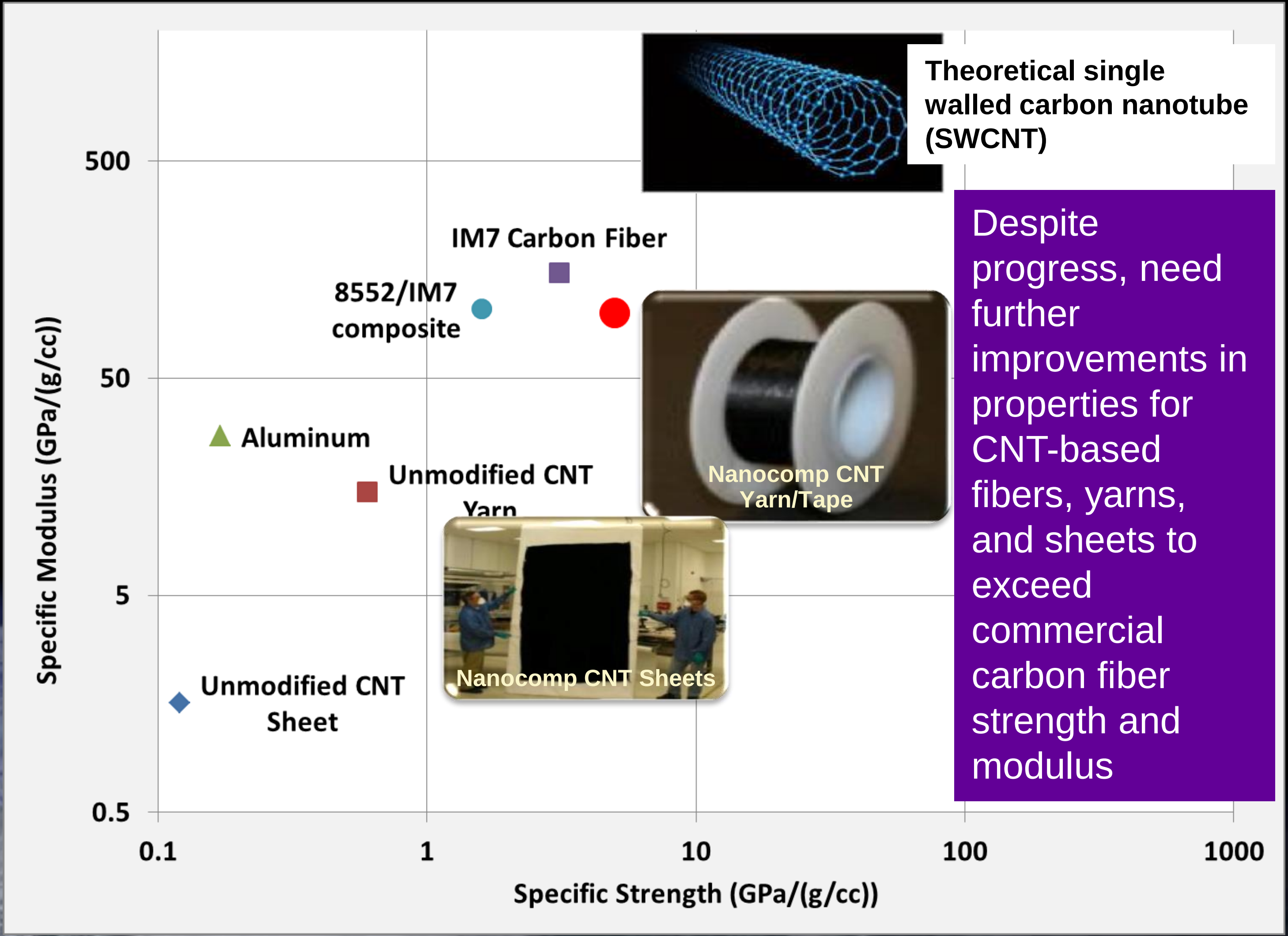
Human Research Program

How Astronauts are Affected by Space Exploration

Digital Astronaut – Biomechanical Modeling



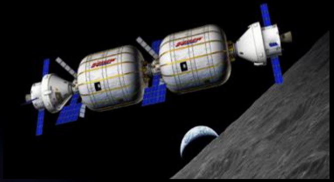
Carbon Nanotube(CNT) -Reinforced Polymer Matrix Composites - Next Generation of Structural Composites



Despite progress, need further improvements in properties for CNT-based fibers, yarns, and sheets to exceed commercial carbon fiber strength and modulus

Crew Module

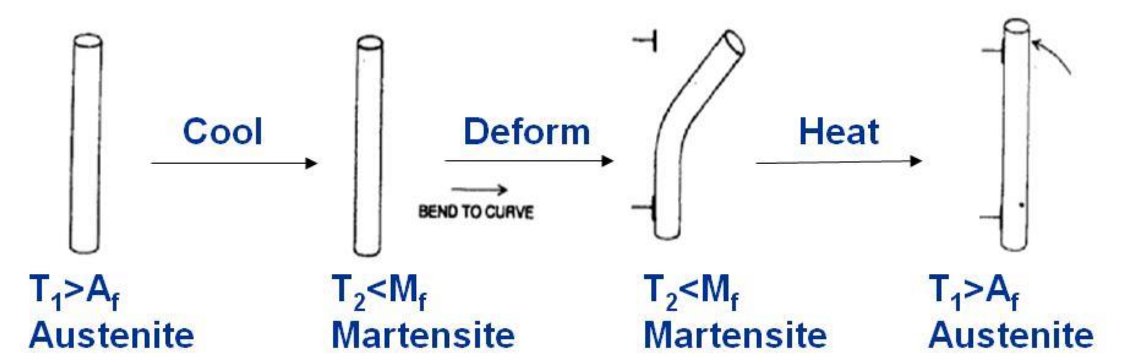
Composite Cryotank

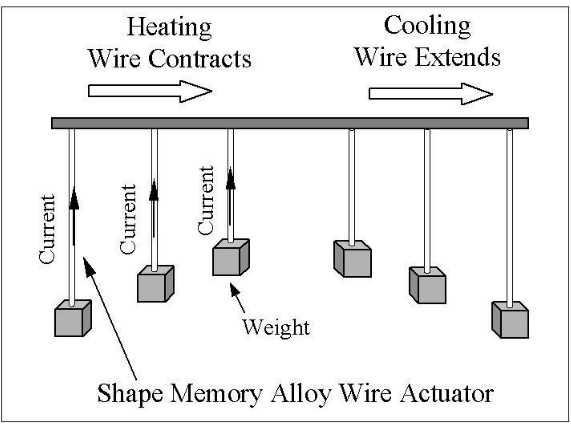


Deep Space Habitat

Shape Memory Alloys for Actuation Devices

Alloys that have a "memory." These materials can be deformed at low temperature and they will recover their original shape upon heating.





Advantages:

- **High force to weight ratio**
- **Lower volume and weight**
- **No hydraulic actuation**
- **Robust performance in harsh environments**
- **No lubrication required**
- **Some alloys have superelastic properties**

Deployable Structure

Robot Arm Actuation

Smart Rover Tire

Movie on performance of shape memory alloy rovers in rough terrain

Chemistry and materials play an important role in Mars exploration:

- Improving durability of thrusters used for in-space propulsion
- Chemically compatible materials for fission power
- Developing fuel cells with higher power density and long-term durability
- Increasing specific energy of batteries
- Developing high temperature chemical processes for in-situ resource utilization
- Keeping astronauts healthy
- Developing lightweight and smart materials for reducing weight