Graphene-based Energy Storage Devices for Space Applications

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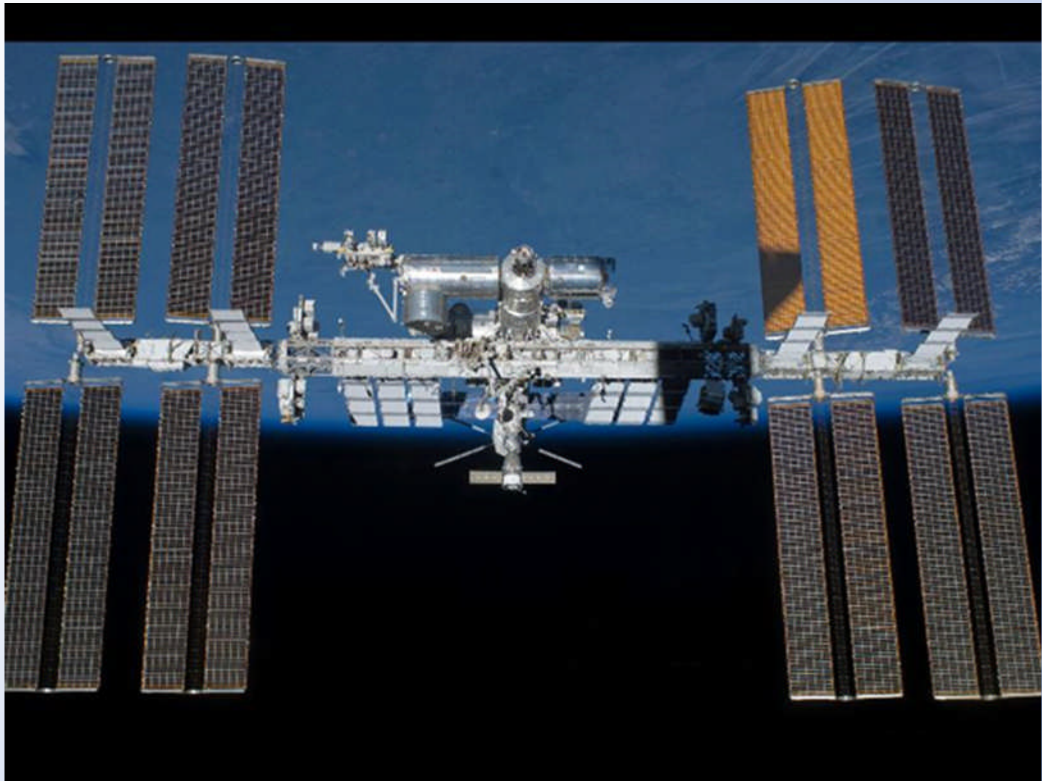
Energy Storage in Space

- Desirable characteristics
  - High energy density
  - Stable, Reliable, Safe
  - Wide operating temperature
  - Rapid recharge

Evolving Technology

International Space Station



Nickel-hydrogen (Ni-H_2)

Charge-use cycle of 90 minutes

Expected replacement to lithium in 2017

One lithium ORU to replace two nickel-hydrogen ORU's

Evolving Technology

Curiosity/Mars Science Laboratory

Lithium

Charge-use cycle multiple times per day

Peak power demands exceed MMRTG power Source

Graphene

- High intrinsic capacitance
  - 21 μF/cm^2
- Large surface area
  - ~2,600 m^2/g
- Versatile
  - Grown on or transferred to a wide variety of substrates
- High temperature and chemical stability

Laser Scribed Graphene

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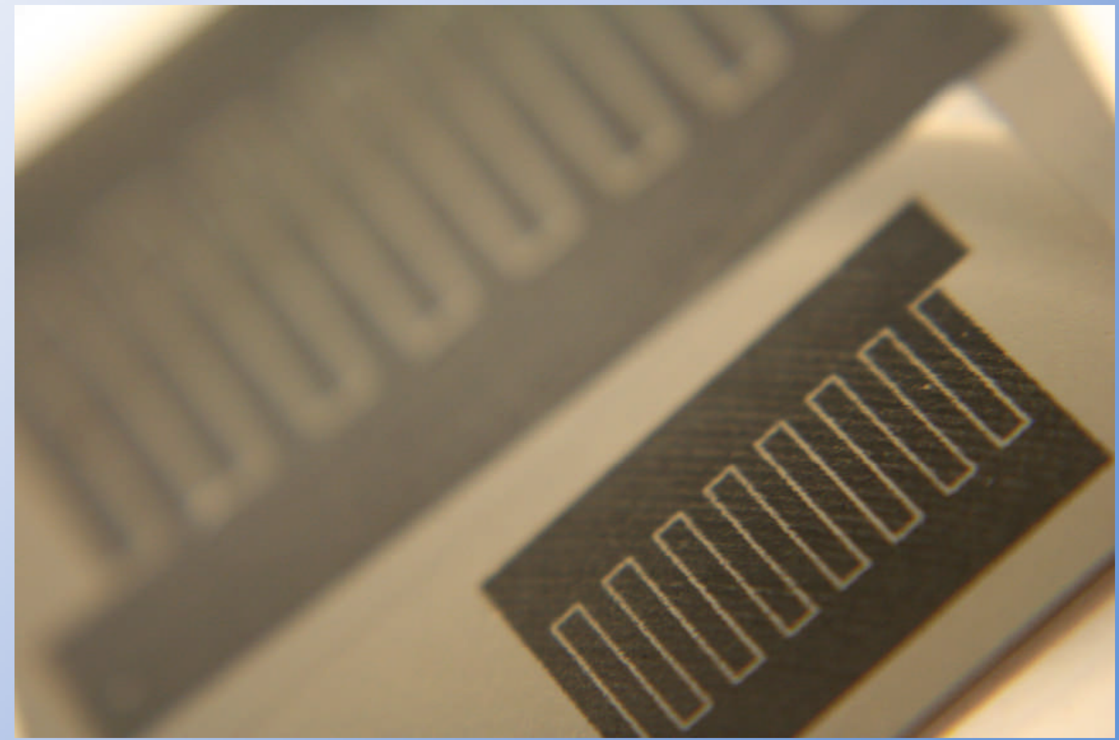
- Use of laser to reduce Graphene Oxide
  - Exfoliates layers while removing oxygen
  - Result is a large surface of area of graphene crystals

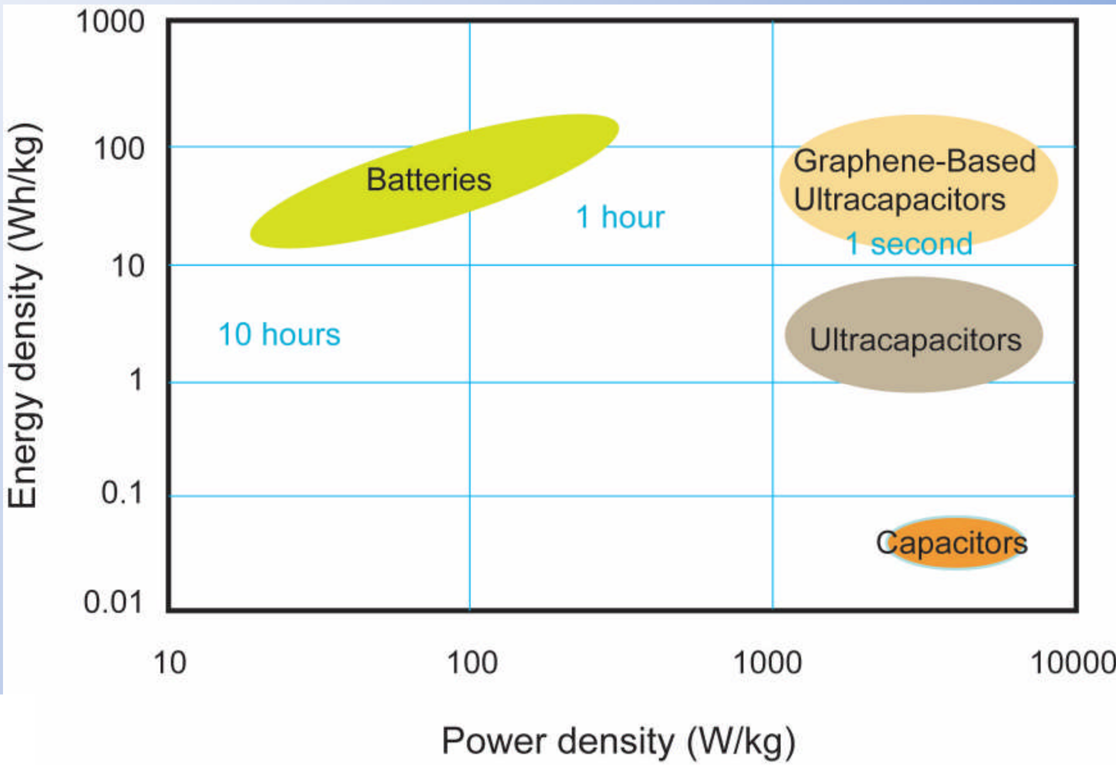


Picture credit: Rachel E Cox, NASA

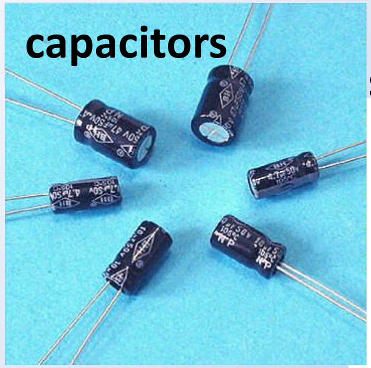
Expected Performance

Graphene-based ultracapacitors:

- High power densities
- High energy densities



Energy and power density comparison for batteries, conventional ultracapacitors, and the expected performance of graphene-based ultracapacitors. Charging times are shown in blue.



supercapacitors

Slide courtesy of UCLA, Kaner Laboratory

Comparison of LSG, AC, Thin-film Li

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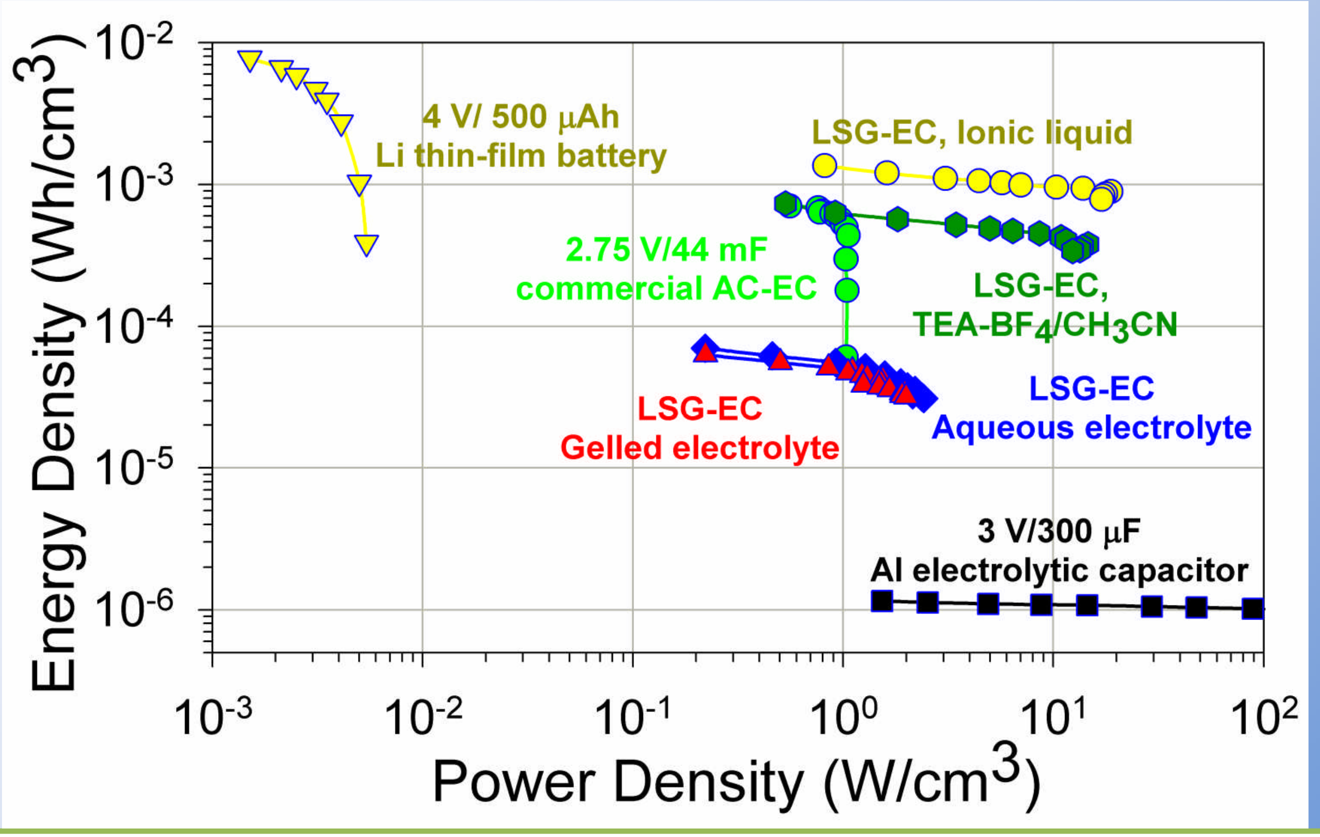

- The plot shows the energy density and power density of the stack for all the devices tested (including current collector, active material, electrolyte and separator).
- Additional features: flexible, lightweight, current collector free and binder free

Slide courtesy of UCLA, Kaner Laboratory

Cycling and Shelf-Life

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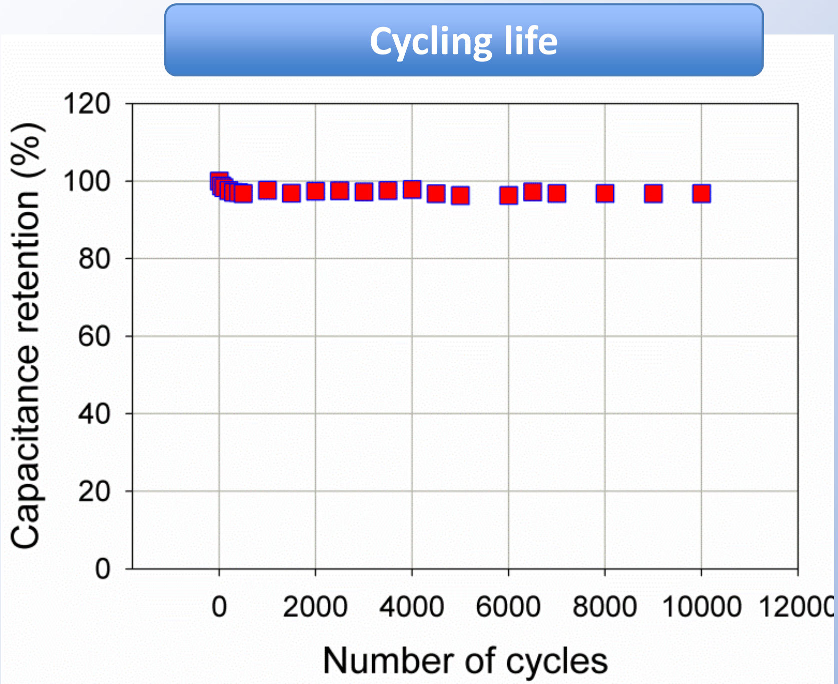

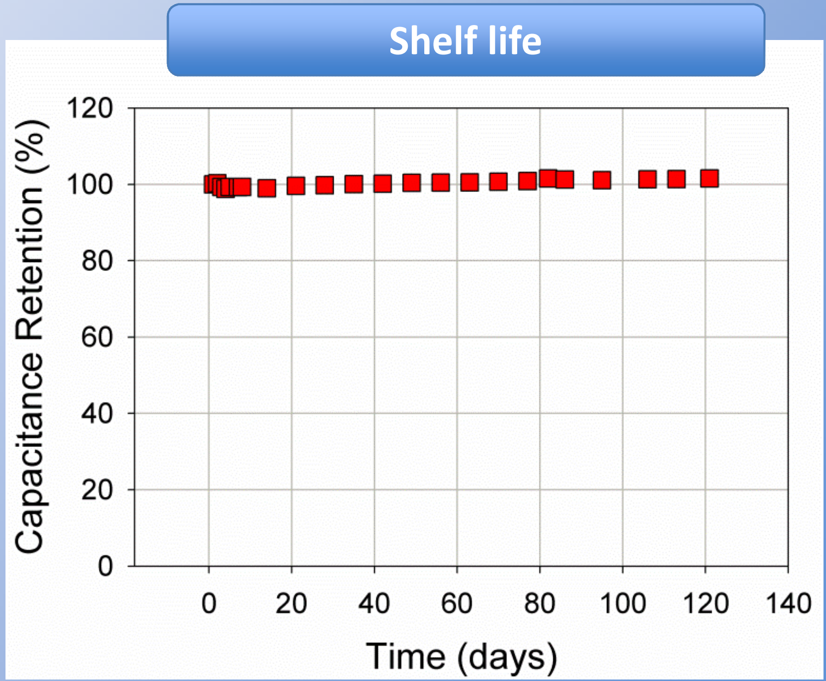

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Current Work

- Increased surface area
- Conductive substrates
- Better electrolytes
- Operating voltage primarily a limitation of the electrolyte
- Ionic liquids can offer exceptionally high thermal stability to 200°C [Kolsmulski *et al.* 2004]

Future Work

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RASSOR

Regolith Advanced Surface Systems Operations Robot

Regolith includes dust, sand and rock

High power robotics designed to extract compact and icy regolith frozen mixtures

ISRU

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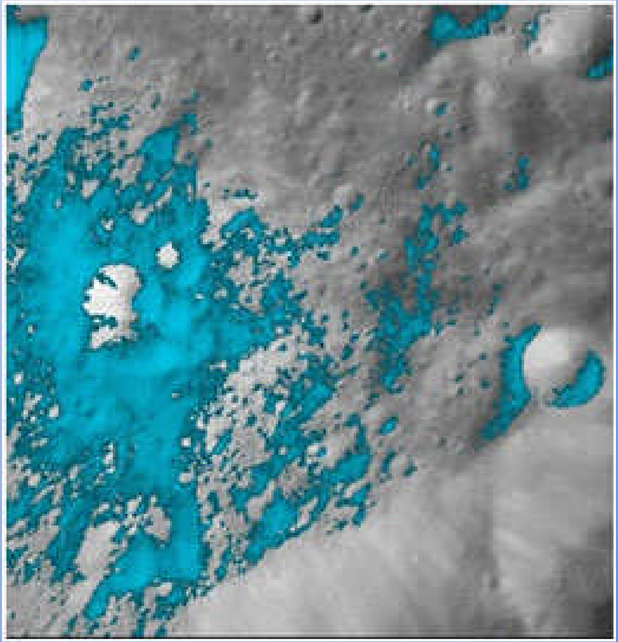
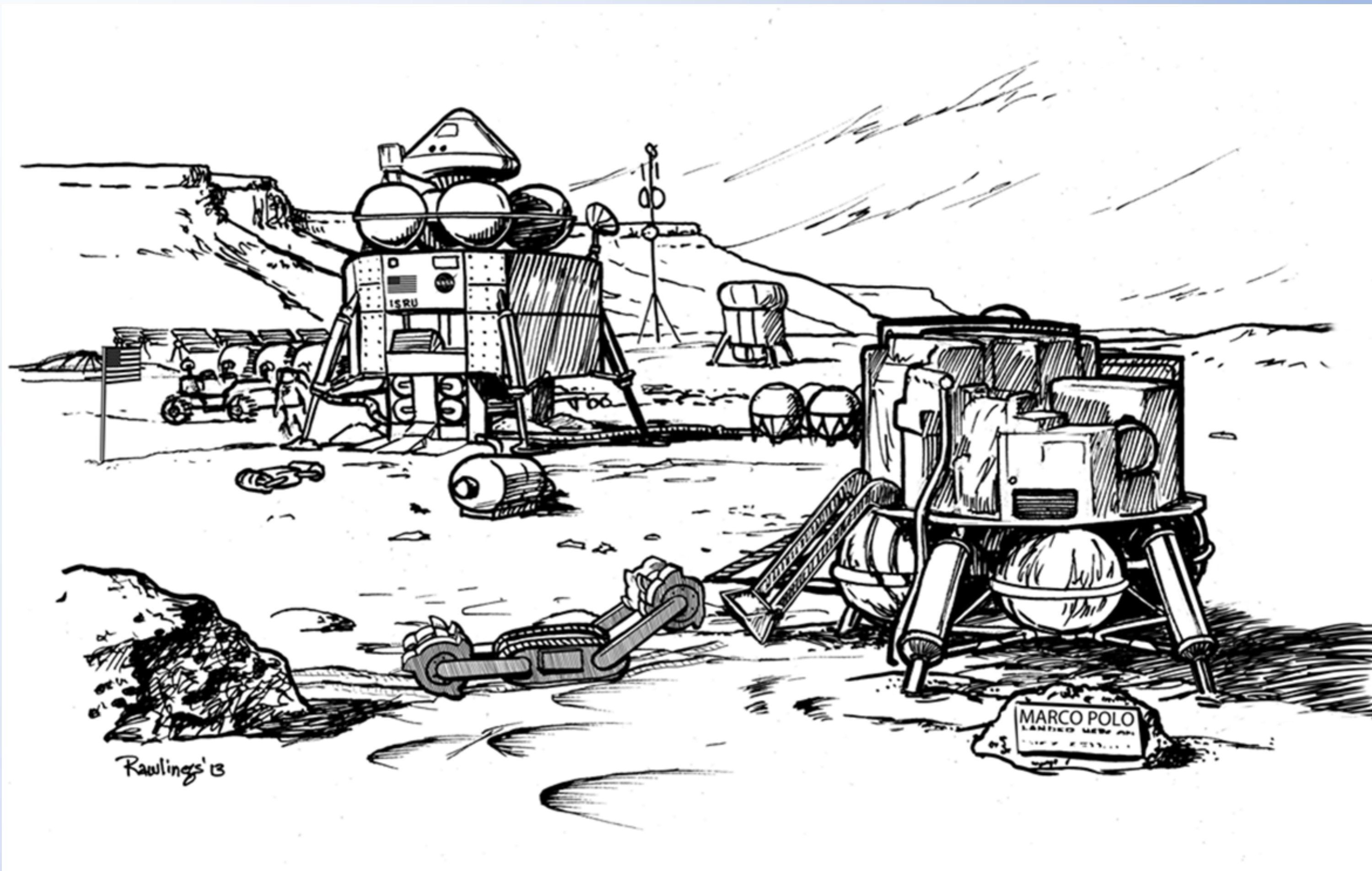
- In-Situ Resource Utilization (ISRU) is the identification, acquisition, and utilization of in-situ resources whether they be naturally occurring or man-made.
- This lunar crater image from the M3 mapper shows water-rich minerals in blue.



(Image: NASA/Brown University)

End-to-End ISRU



Excavation, collection and processing for methane/oxygen bipropellant

Application to Space

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- Higher power density will enable a new class of operations
- Potential for much wider temperature operation: carbon melting point (4900K)
- Increased safety-margin due to reduced fire and toxicity risk
- In-situ resource available from regolith or waste stream

The Vision

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- Every exploration plan calls for a sustainable exploration architecture.

Contributors

UCLA

SWAMP WORKS
NASA KENNEDY SPACE CENTER

BACKUP

Current Missions

Hubble

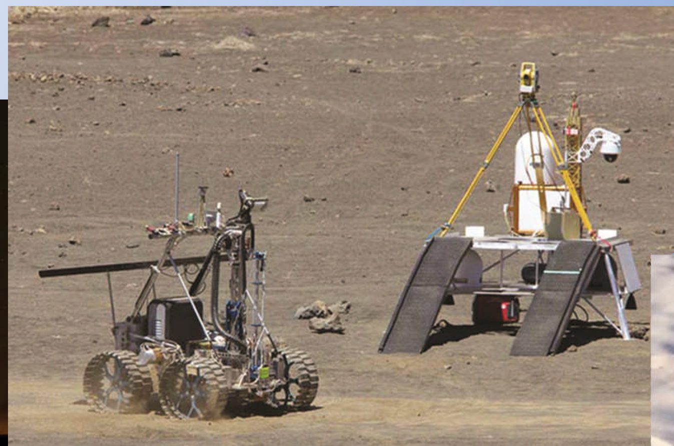
Nickel-hydrogen (Ni-H_2)

Charge-use cycle of
97 minutes

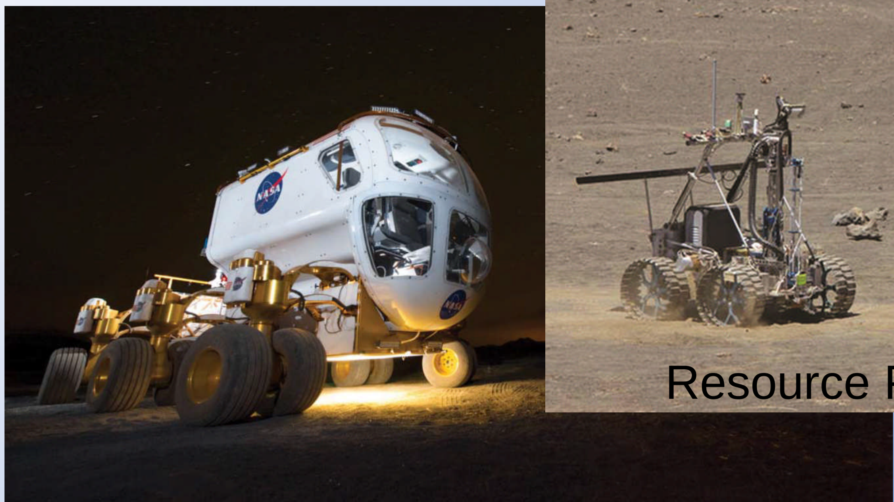
Reliable
Deep discharge capability

Potential Future Missions

- Future missions will require higher energy and power density to enable:
  - High power robotics
  - In-Situ Resource Utilization (ISRU)
  - Exploration



Resource Prospector



Space Exploration Vehicle (SEV)

RASSOR

ISRU

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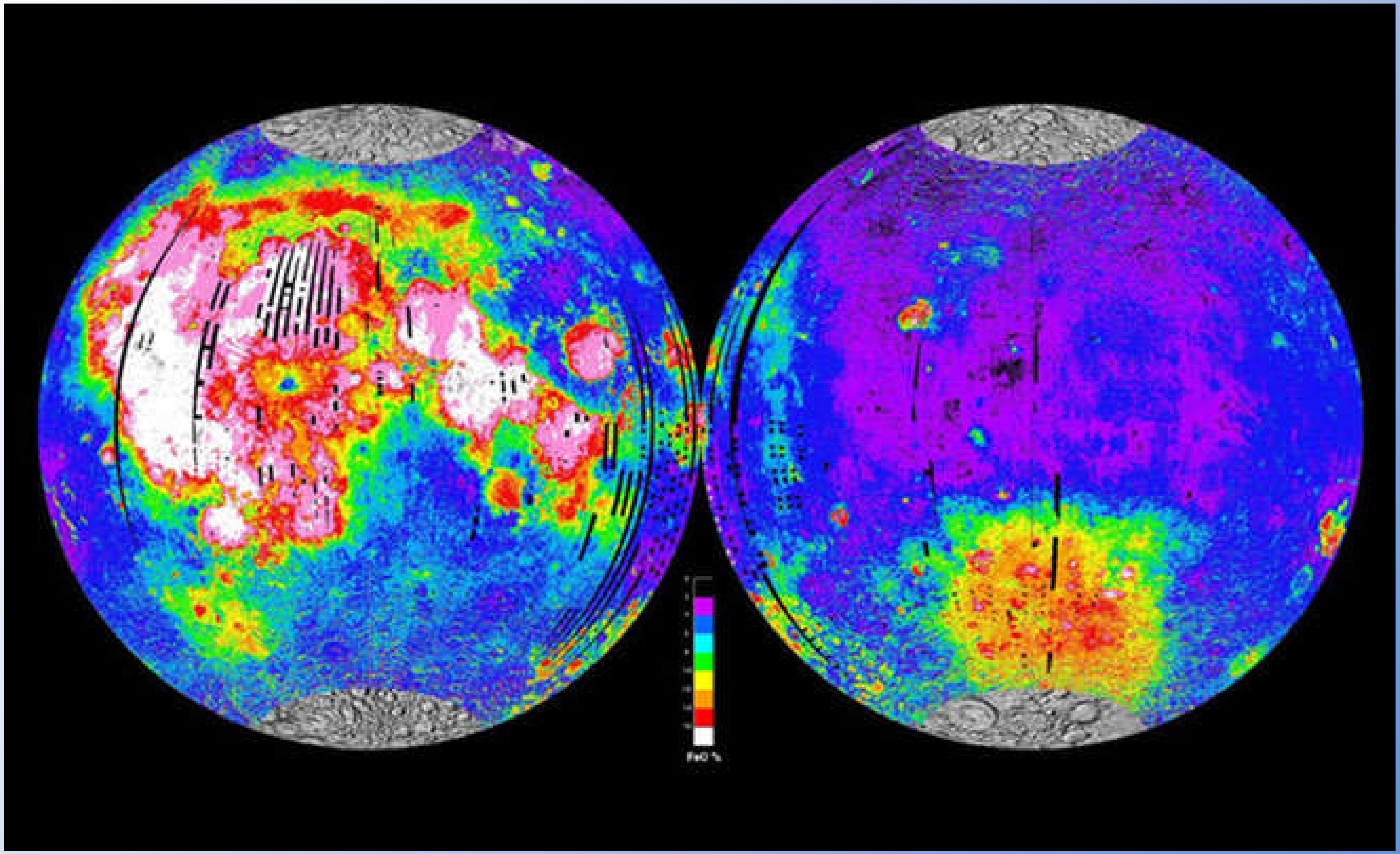

Global map of the iron concentration on the lunar surface
Black (0%) to white (16%). (Source: NASA/Clementine)