Regenerative Fuel Cells for Space-Rated Energy Storage

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Manhattan Beach, CA

Presentation Outline

- Recent History of Fuel Cell and Electrolyzer Development at NASA
- The Regenerative Fuel Cell
- Space-Rated Energy Storage
- An Integrated Regenerative Fuel Cell System (AIRS)
- Presentation Summary

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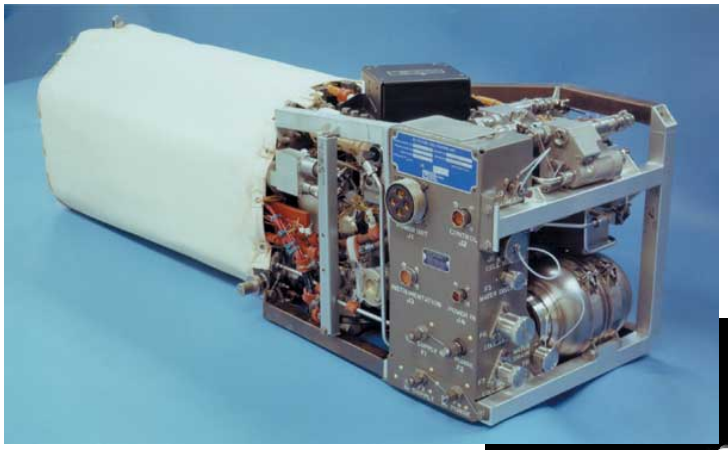
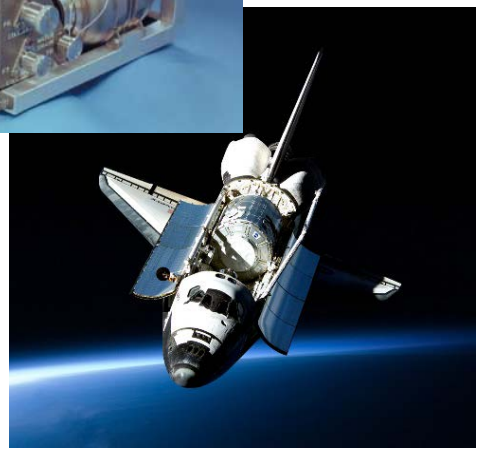
Memorable Fuel Cell Applications

Allis Chalmers Fuel Cell Tractor (1959)

Space Shuttle Fuel Cell (1981 to 2011)





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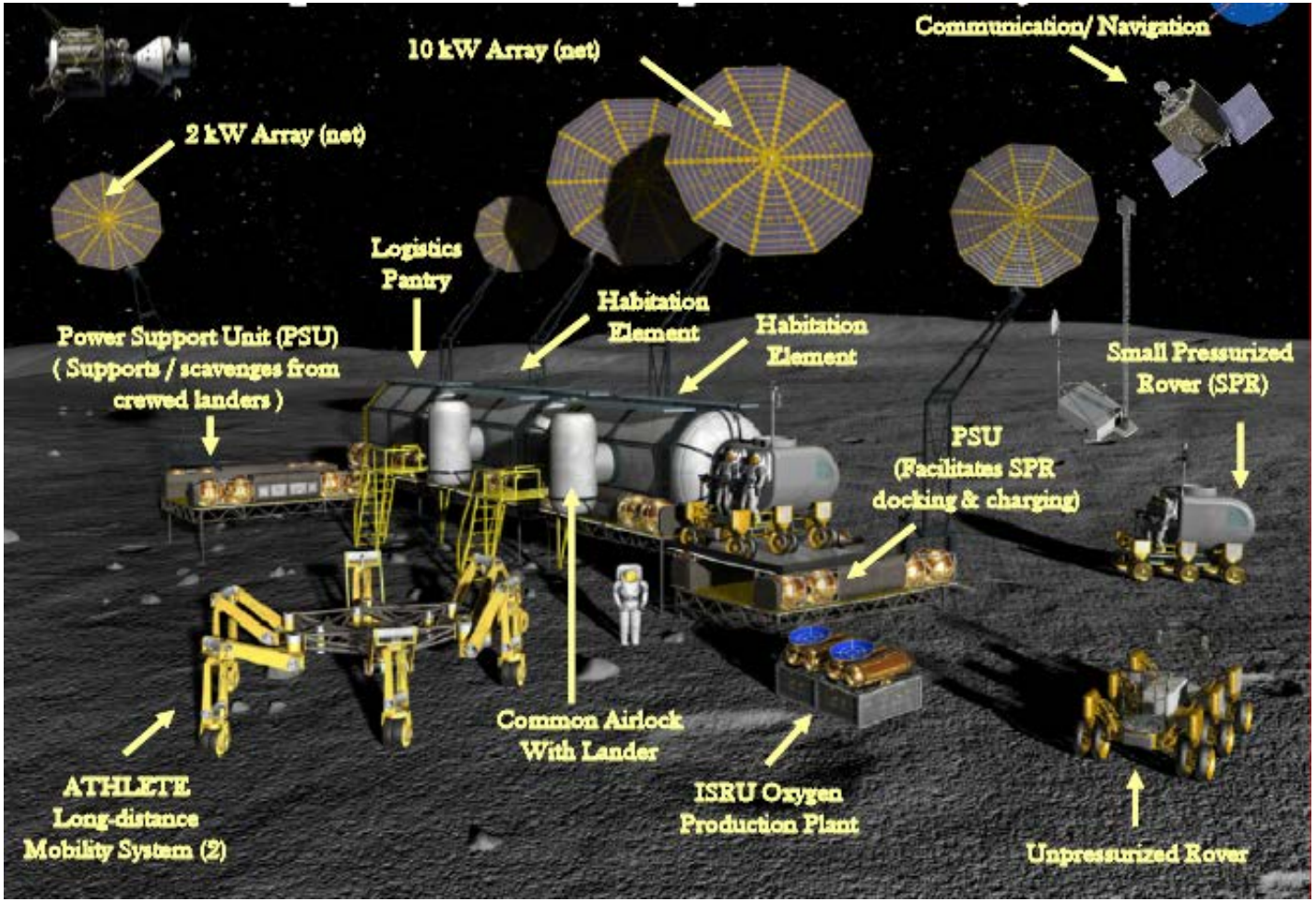
Conceptual Lunar Outpost Surface System



C. R. Mercer, A. L. Jankovsky, C. M. Reid, T. B. Miller, and M. A. Hoberecht, Energy Storage Project, Final Report, NASA/TM-2011-216963, 2011

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Key Performance Parameters, Energy Storage Project

Customer Need	Performance Parameter	SOA (alkaline)	Current Value* (NFT PEM)	Threshold Value** (@ 3 kW)	Goal** (@ 3 kW)
Altair: 3 kW for 220 hr continuous, 5.5 kW peak.	System power density				
	Fuel Cell	49 W/kg	44 W/kg	88 W/kg	136 W/kg
	RFC (without tanks)	n/a	n/a	25 W/kg	36 W/kg
	Fuel Cell Stack power density	n/a	51 W/kg	107 W/kg	231 W/kg
	Fuel Cell Balance-of-plant mass	n/a	2 kg	21 kg	9 kg
Lunar Surface Systems: TBD kW for 15 days continuous operation	MEA efficiency @ 200 mA/cm^2				
	For Fuel Cell	73%	72%	73%	75%
	Individual cell voltage	0.90 V	0.89 V	0.90 V	0.92 V
Rover: TBD	For Electrolysis	n/a	83%	84%	85%
	Individual cell voltage	n/a	1.48	1.46	1.44
	For RFC (Round Trip)	n/a	60%	62%	64%
	System efficiency @ 200 mA/cm^2				
	Fuel Cell	71%	64%	71%	74%
	Parasitic penalty	2%	8%	2%	1%
	Regenerative Fuel Cell***	n/a	n/a	43%	54%
	Parasitic penalty	n/a	n/a	10%	5%
	High Pressure penalty	n/a	n/a	20%	10%
Maintenance-free lifetime Altair: 220 hr (primary) Surface: 10,000 hr (RFC)	Maintenance-free operating life				
	Fuel Cell MEA	2500 hr	13,500 hr	5,000 hr	10,000 hr
	Electrolysis MEA	n/a	n/a	5,000 hr	10,000 hr
	Fuel Cell System (for Altair)	2500 hr	n/a	220 hr	220 hr
	Regenerative Fuel Cell System	n/a	n/a	5,000 hr	10,000 hr

*Based on non-flow-through test hardware with 4-cells and heavy end plates, scaled to 3 kW

**Threshold and Goal values based on full-scale (3 kW, 300 cm^2) fuel cell and RFC technology.

***Includes high pressure penalty on electrolysis efficiency 2000 psi

C. R. Mercer, A. L. Jankovsky, C. M. Reid, T. B. Miller, and M. A. Hoberecht, Energy Storage Project, Final Report, NASA/TM-2011-216963, 2011

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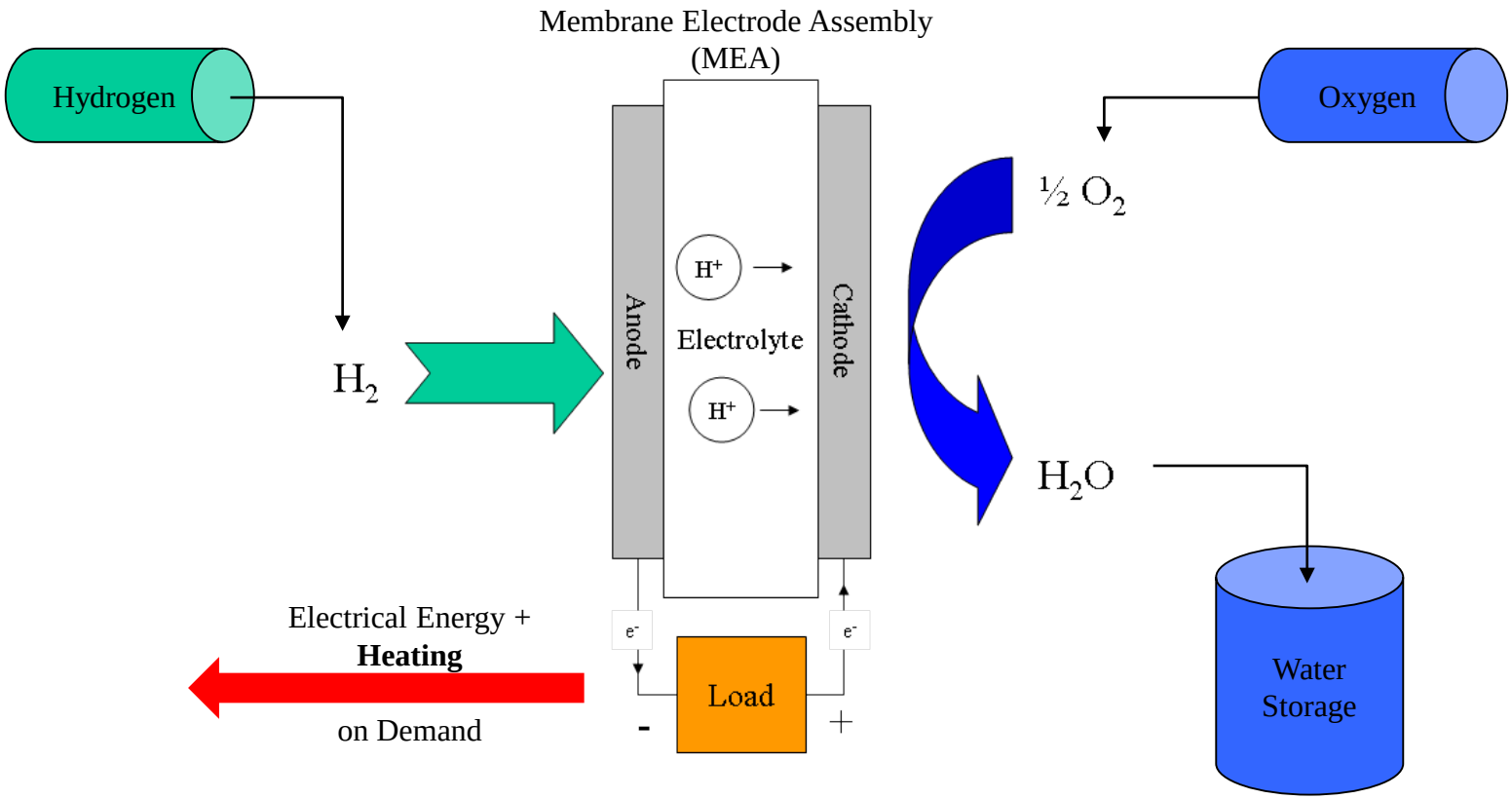
The Hydrogen-Oxygen Fuel Cell



- A fuel cell converts chemical energy to electrical energy

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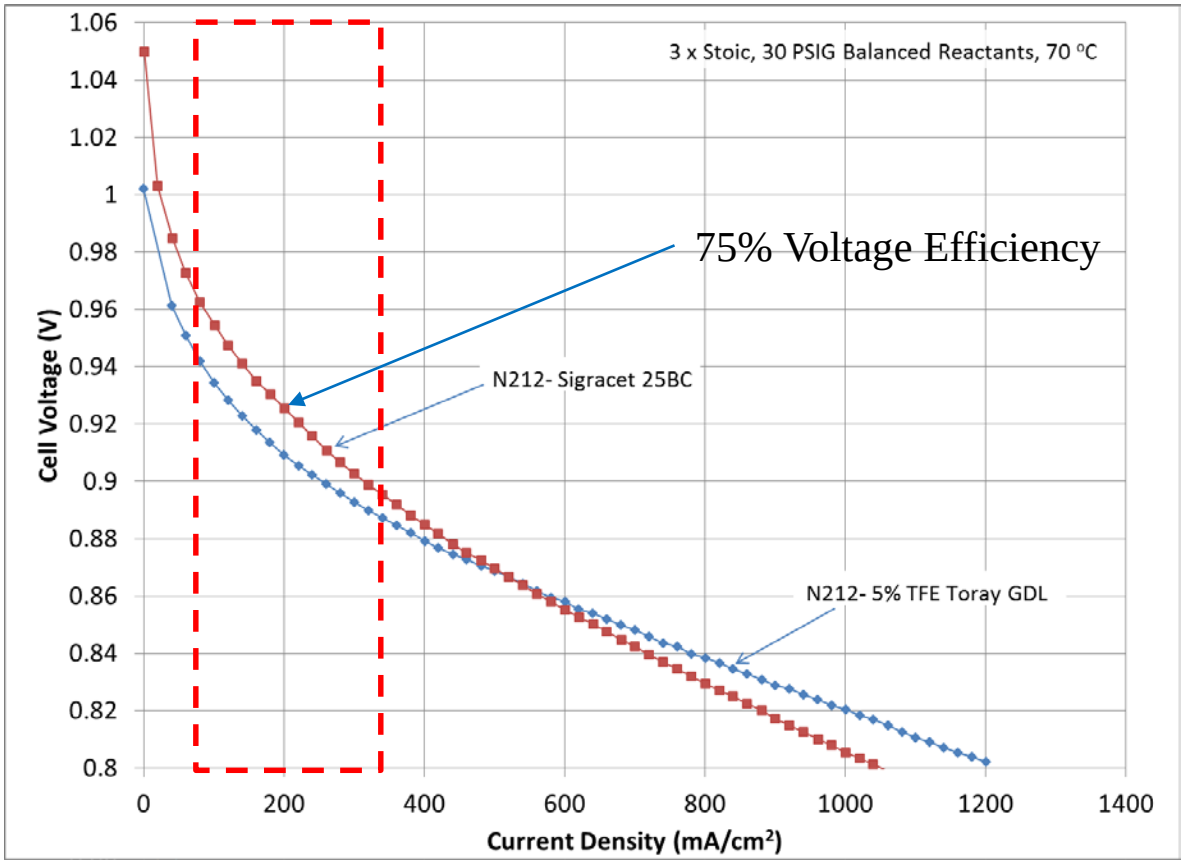
Advanced Fuel Cell MEAs: Gas-Diffusion Layer Studies



•The expected voltage efficiency for a fuel cell MEA would be in the range of **71 to 75%** operating at current densities between 100 to 300 mA/cm^2.

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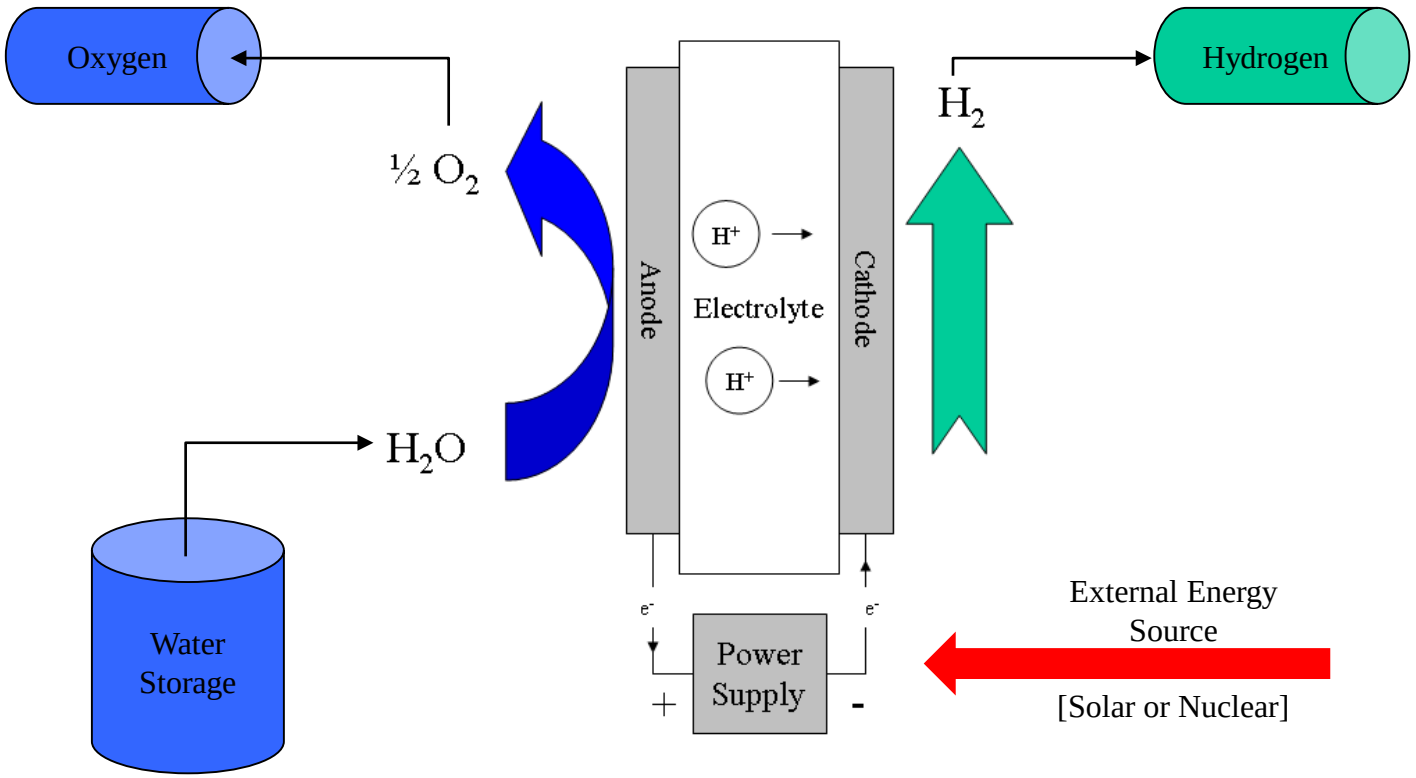
The Water Electrolyzer



- An electrolyzer takes energy and converts water into hydrogen and oxygen gas

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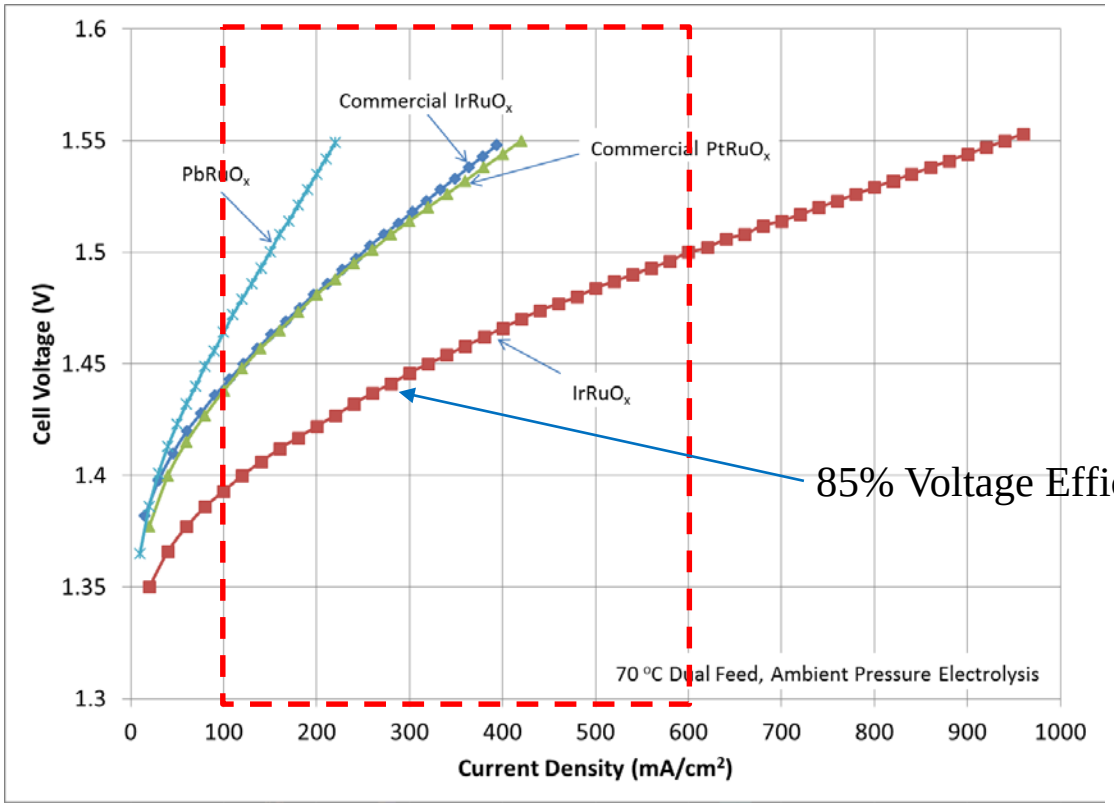
Advanced Electrolyzer MEAs: Oxygen Evolution Reaction (OER) Catalysts Studies



- To maximize durability, it is expected that electrolysis MEAs would operate between 1.4 to 1.5 volts at an applied current density in the range of 100 to 600 mA/cm^2
- The expected voltage efficiency for this electrolysis MEA would be in the range of 88 to 82%

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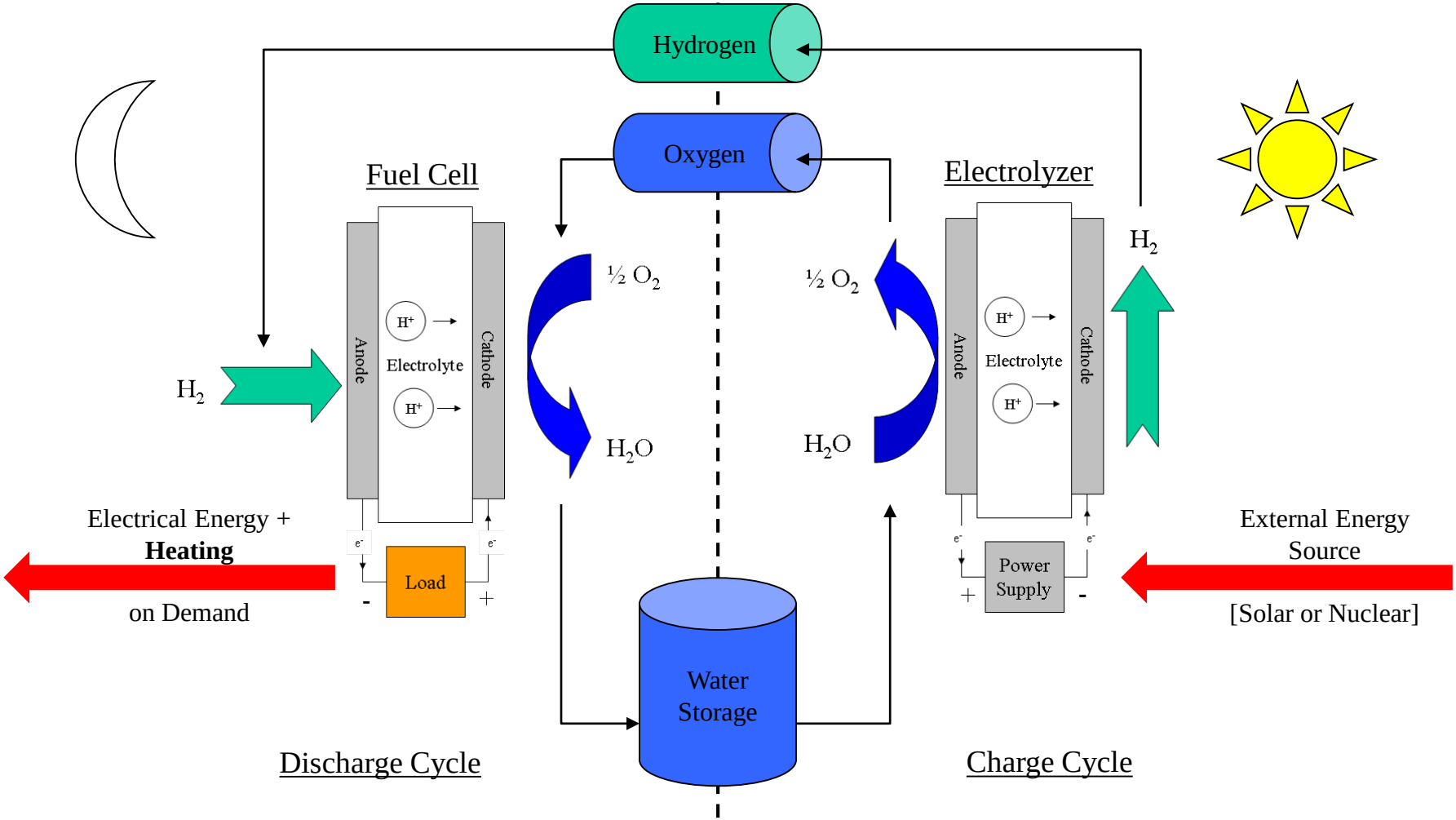
The Regenerative Fuel Cell (RFC) Concept



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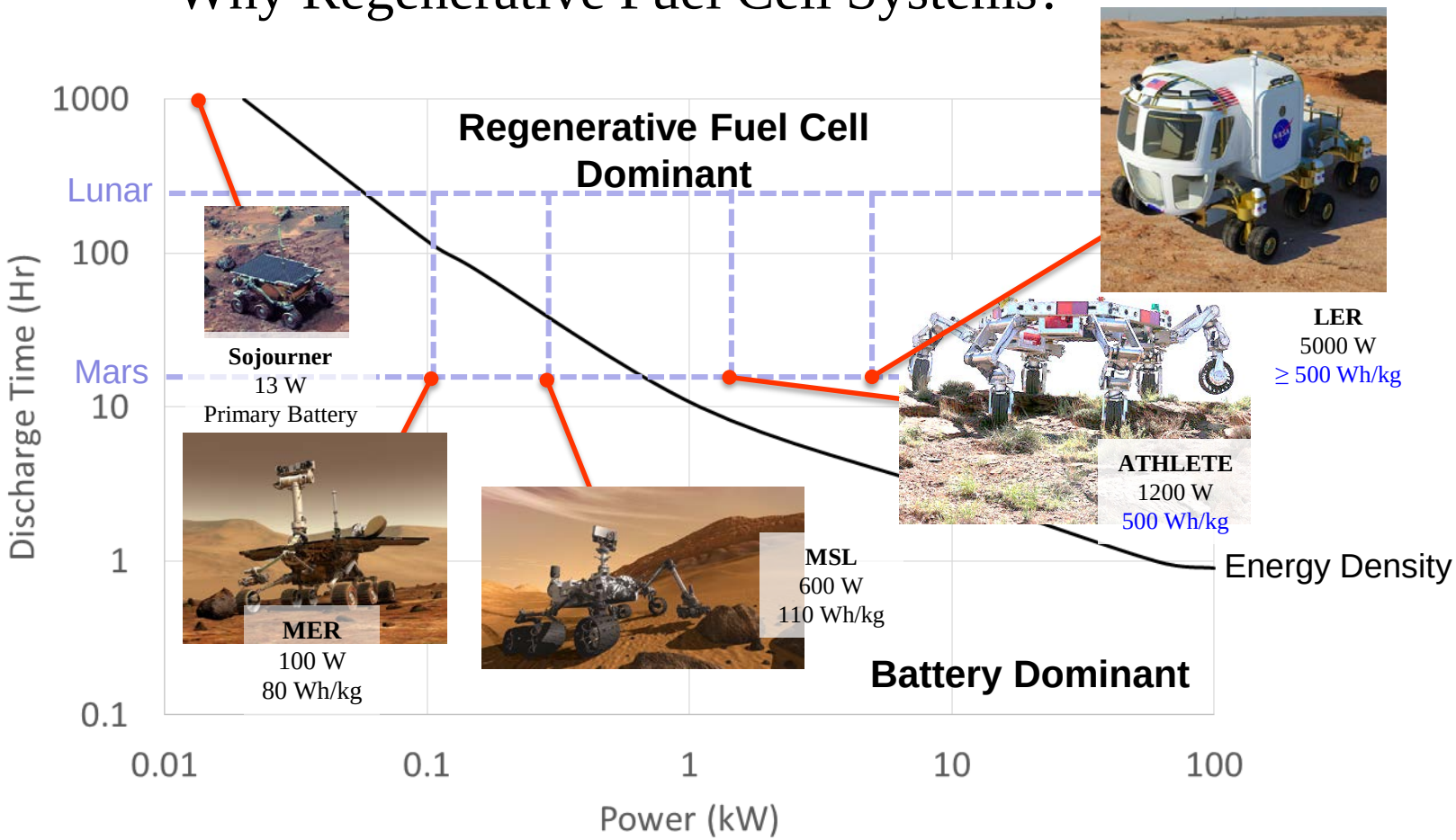
Why Regenerative Fuel Cell Systems?



- Regenerative fuel cell systems are the best option for high power and long discharge time applications

Adapted from: S. Markgraf et al., J. Power Sources 201 (2012) 236-242

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Regenerative Fuel Cell Systems for Landed Systems

- Regenerative fuel cell systems could support habitats and ISRU systems
- For a landed mission operating on solar power, the RFC could store energy for night use
- For a landed mission operating on nuclear power, the RFC could be used for “power grid” load leveling

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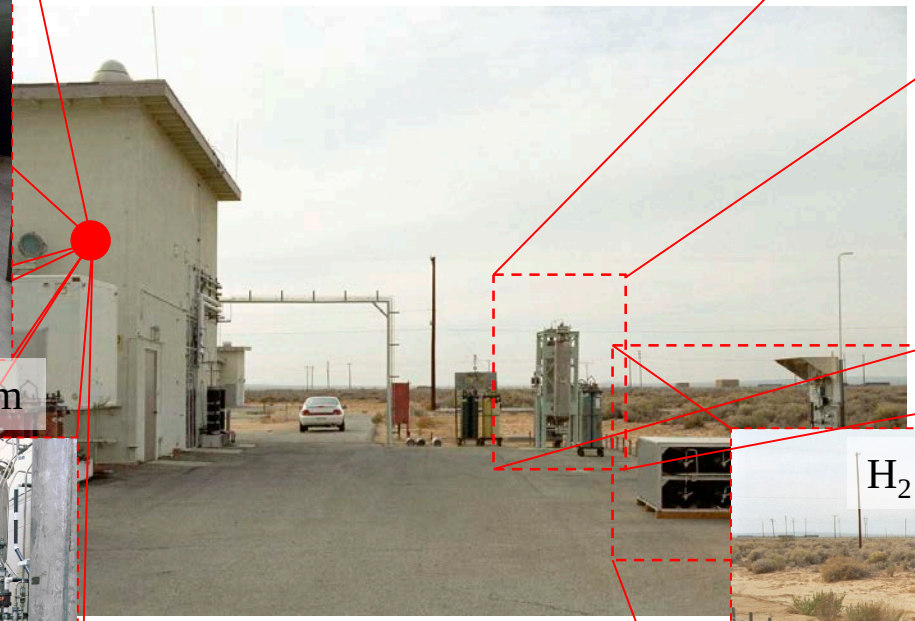
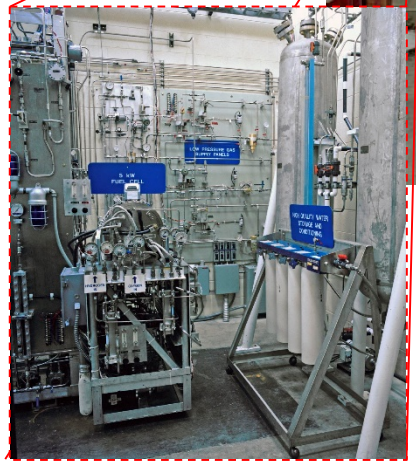
Traditional Regenerative Fuel Cell Systems Are Large

Electrolysis System





Fuel Cell System

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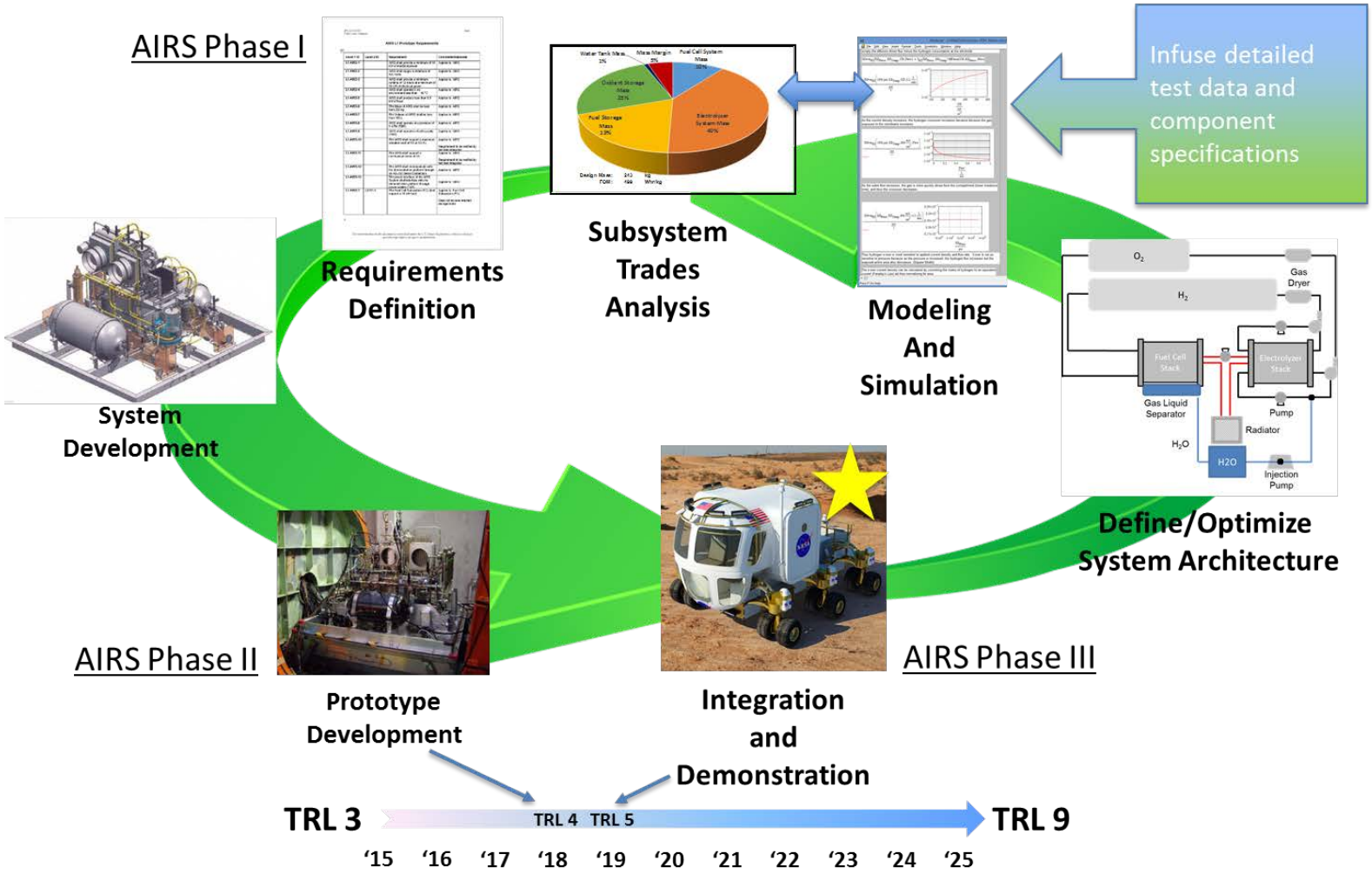
Stages in System Development

An Integrated Regenerative Fuel Cell System (AIRS)



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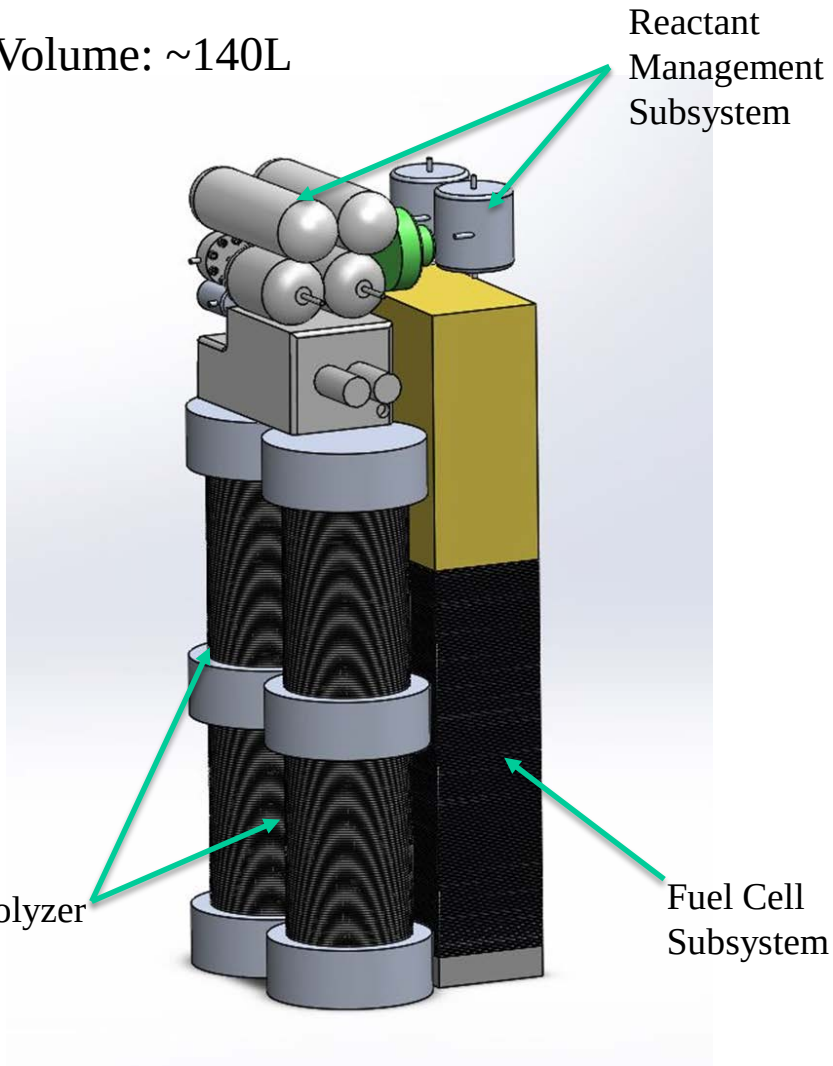
An Integrated Regenerative Fuel Cell System (AIRS)

- AIRS Energy Storage System
- Operation Temperature: -40 ^{o}C
- Optimized Efficiency (RT 55%):
  - Output Power: 10 kW
  - Recharge Power: 18.3 kW
- Grid-Level Load Leveling Capability:
  - Output Power: 50 kW (Max Continuous)
  - Load Absorbing Capability: 36 kW (Max Continuous)
- Teledyne Energy Systems, Passive Flow-Through Stack Technology
- Proton Onsite 3600 PSIG electrolyzer with common endplate design
- System Energy Density:
  - > 360 Wh/kg @ 120 kWh storage (24 hr cycle)
  - ~ 850 Wh/kg @ 3,600 kWh storage (30 day cycle)

Volume: ~140L



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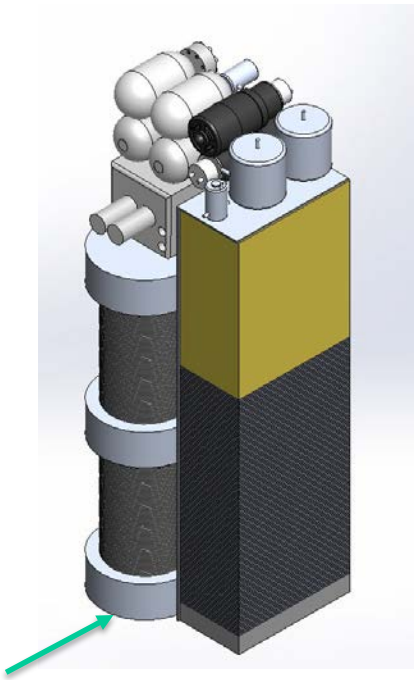
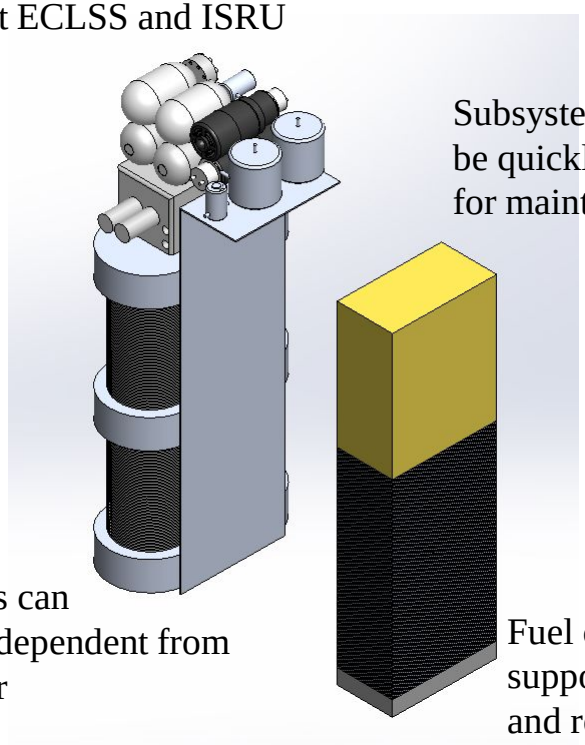
AIRS: Modular Subsystem Design



Integrated system for
habitat grid load balancing and
energy storage

Electrolyzer system to
support ECLSS and ISRU



Subsystems can
be quickly disassembled
for maintenance

Subsystems can
function independent from
one another

Fuel cell system to
support human mobility
and robotic exploration

- Each subsystem has an integrated balance of plant
- Subsystem can be separated to match required activity or to support efficient system maintenance

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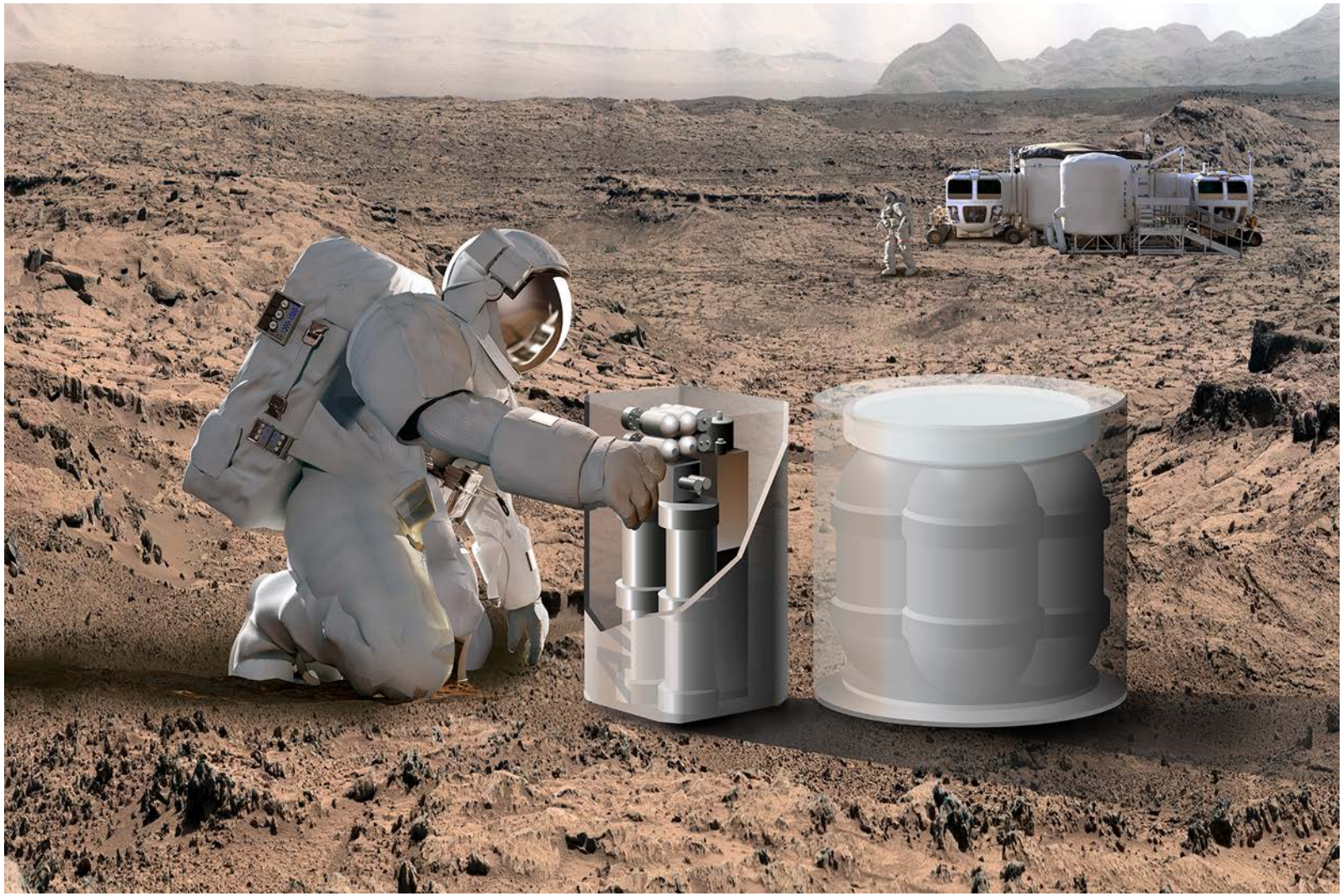
AIRS: Modular Energy Storage



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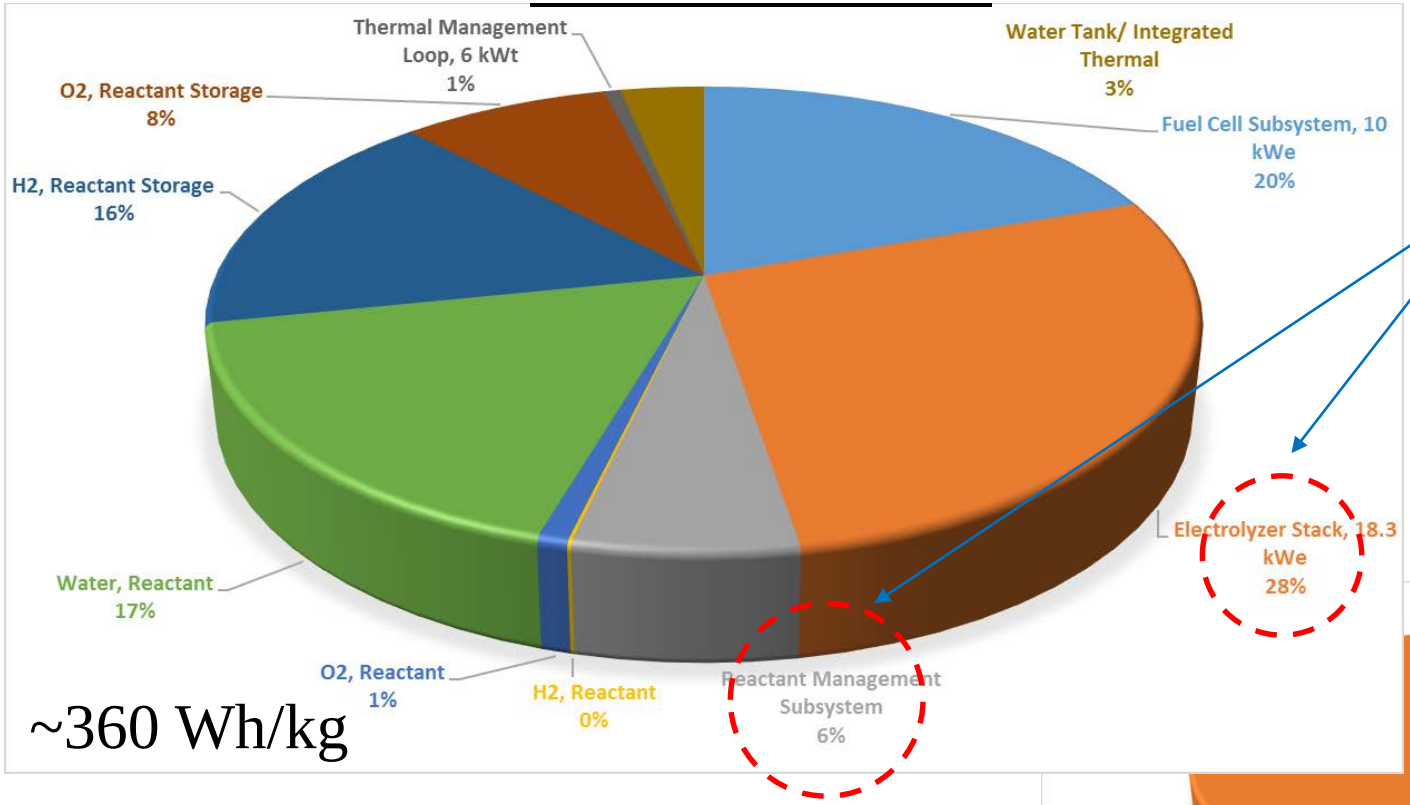
AIRS: System Mass and Volume Distribution

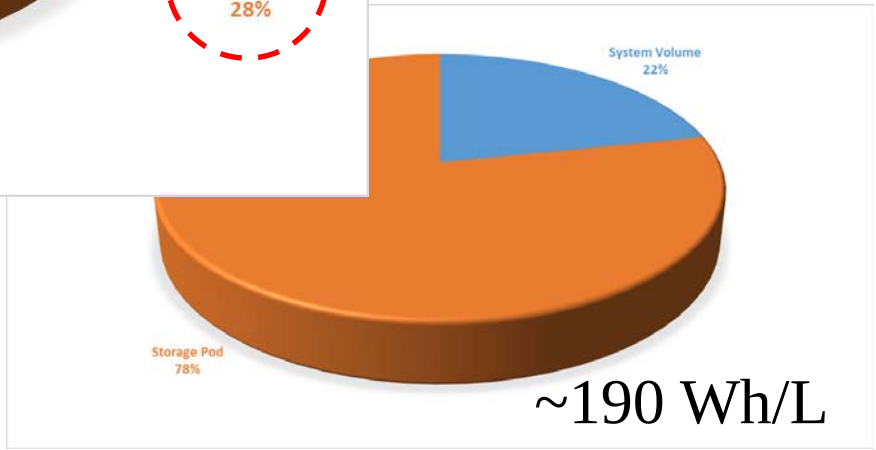
Mass Distribution



~360 Wh/kg

Electrolyzer and Reactant Management ~ 32% of system mass

Volume Distribution



~190 Wh/L

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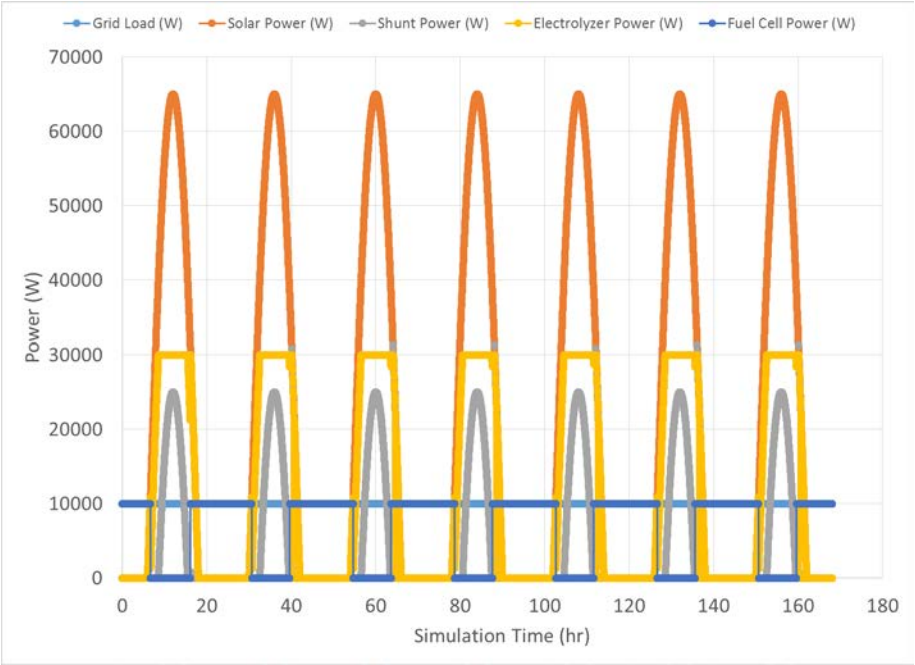
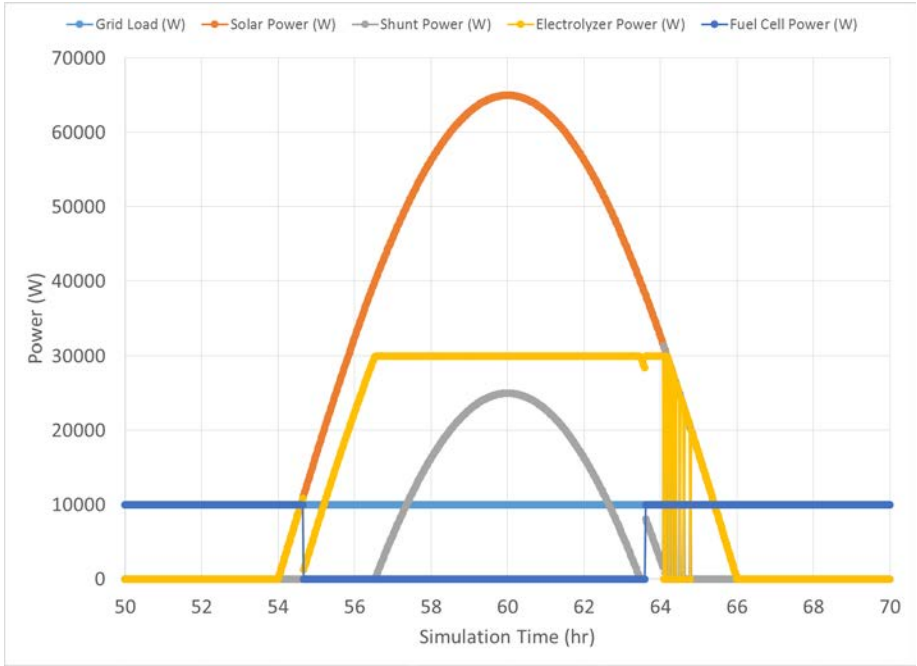
AIRS: Simulations

7- Sol Cycle



Power Distribution at constant load



- **Reactant mass balance maintained over several Sols**
- **CONOPS:**
  - Electrolyzer is used to shunt excess grid power (Energy required: 18.3 kW, 12 hr)
  - Fuel cell limits upper pressure on storage tanks

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Presentation Summary

- Regenerative fuel cells provide a pathway to energy storage system development that are game changers for NASA missions
- Regenerative fuel cells offer advantages for applications involving high power or long run times
- System round trip efficiency (~55%) is function of both fuel cell and electrolyzer performance, <u>electrolyzer dominates system design</u>
- When both thermal and electrical energy are used, system round trip efficiency > 90%

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Acknowledgments

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