Low-Temperature Power Sources for Outer Planets Exploration

National Aeronautics and Space Administration

Erik Brandon
Jet Propulsion Laboratory, California Institute of Technology

erik.j.brandon@jpl.nasa.gov
Web: electrochem.jpl.nasa.gov

Ratnakumar Bugga
Jet Propulsion Laboratory, California Institute of Technology

Keith B. Chin
Jet Propulsion Laboratory, California Institute of Technology

John-Paul Jones
Jet Propulsion Laboratory, California Institute of Technology

Simon Jones
Jet Propulsion Laboratory, California Institute of Technology

Charlie Krause
Jet Propulsion Laboratory, California Institute of Technology

Barry Nakazono
Jet Propulsion Laboratory, California Institute of Technology

Raymond A. Ontiveros
Jet Propulsion Laboratory, California Institute of Technology

Jasmina Pasalic
Jet Propulsion Laboratory, California Institute of Technology

Marshall C. Smart
Jet Propulsion Laboratory, California Institute of Technology

Thomas I. Valdez
Jet Propulsion Laboratory, California Institute of Technology

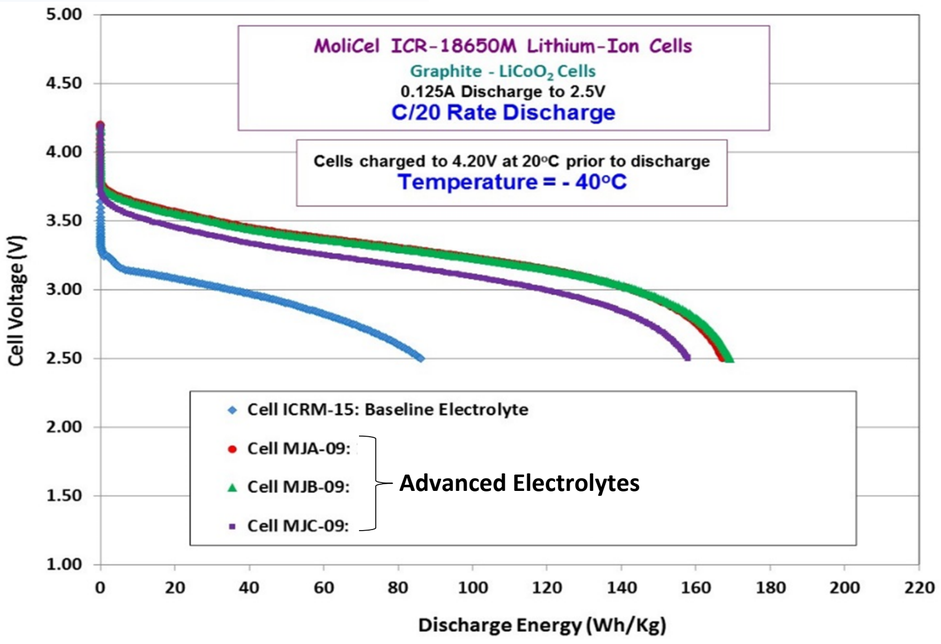
William C. West
Jet Propulsion Laboratory, California Institute of Technology

Larry D. Whitcanack
Jet Propulsion Laboratory, California Institute of Technology

Low-Temperature Rechargeable Batteries

- State-of-practice Li-ion cells exhibit low specific energy at low temperatures
- Risk of lithium plating a concern during low-temperature charging
- JPL is developing and demonstrating high specific energy Li-ion cells, using electrolytes formulated for low-temperature operation (see below)
- Potential to eliminate battery control board required to balance cells
- Reduce thermal management (equivalent of 22% of the mass of the battery is currently used for thermal management hardware for Li-ion/solar array based energy storage)

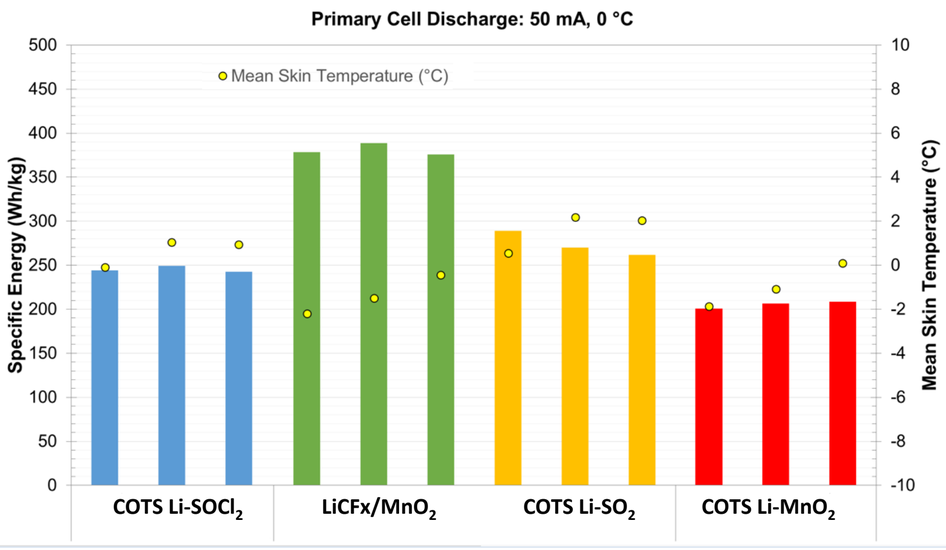
Performance Metrics	State-of-practice Rechargeable Batteries	Proposed Rechargeable Low Temperature Li-Ion Batteries	Proposed Rechargeable Low Temperature Li-Ion Batteries (stretch goal)
Cell Specific Energy at +20˚C (Wh/kg)	130-150	150-200	150-200
BOL Cell Specific Energy at Low Temperature (Wh/kg, discharge)	95-115 at -20˚C	≥100 at -40˚C	75-100 at -60˚C
Cycle Life	>500	300	300
Lower Temperature Charging Limit (˚C)	-20 to -30	-40	-60
Operational Temperature (˚C)	-30 to +35	-40 to +35	-60 to +35
Shelf Life (Years)	15	15	15
Heritage	Phoenix, InSight Li-ion		



Small, cylindrical Li-ion cells with custom electrolytes outperform both COTS parts and space-rated prismatic cells, delivering a higher capacity at temperatures down to -40°C (at C/20 discharge rates)

Low Temperature Primary Batteries

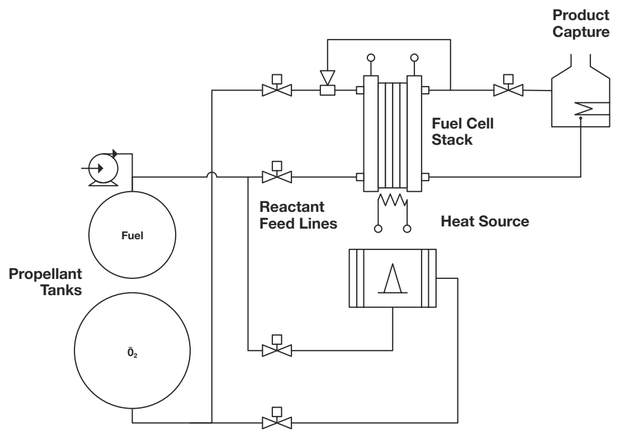
- New power options are needed for moderate-duration surface missions
- Primary batteries traditionally support mission operations over several hours (e.g., Galileo and Huygens probes)
- Future missions will need primary batteries to provide power for days, requiring higher specific energy cells relative to state-of-practice
- Advanced primary chemistries are under development (see below)



Advanced Li-CFX/MnO_2 cells outperform COTS/space-rated primary cells at 0°C, delivering more capacity using the same D-cell format

Primary Fuel Cells

- Primary fuel cells may offer advantage relative to primary batteries
- Harvesting of unused propellants offers one means to provide additional surface power
- Heat generation during operation provides thermal management options
- Currently studying several configurations to prolong surface operations (see table below)

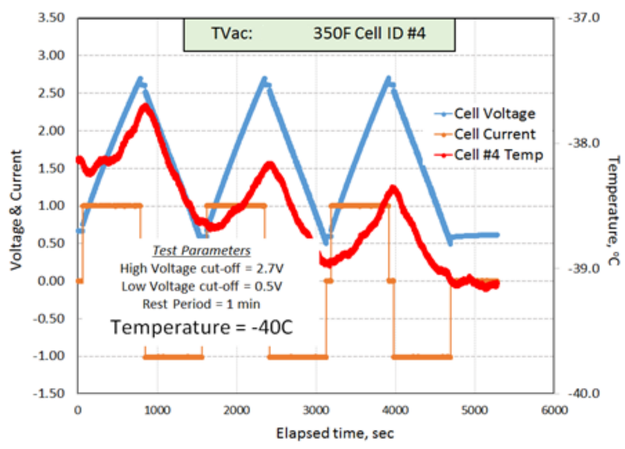


Schematic view of a fuel cell system using propellant harvesting

	Fuel Cell System	Fuel Cell Technology	Energy Densities @ 7,200 Whr		TRL	Complexity
			Wh/kg	Wh/L		
Other	MeOH-O_2*, **	DMFC	188	150	5	Moderate
	MeOH-H_2O_2**	DMFC	217	331	3	Moderate
	Alane (H_2-Storage)-O_2**	PEM	480	570	5	Low
	H_2-Chlorate, Candle**	PEM	514	326	4	Low
	H_2-Chlorate, Aqueous**	PEM	587	352	4	Low
Bi-Prop	H_2-H_2O_2(90%)**	PEM	464	366	3	Moderate
	H_2-O_2**	PEM	708	315	9	Low
	CH_4-O_2**	SOFC	674	373	5	Low
	MMH-NTO	SOFC	315	347	2	Low
Mono-Prop	LMP-103s-O_2*	DMFC	109	95	1	Moderate
	Hydrazine-O_2	PEM	792	628	3	Low

Low-Temperature Supercapacitors

- Supports high current pulses with and high specific power (>1 kW/kg)
- Excellent low-temperature performance due to double-layer charge storage mechanism (vs. intercalation/de-intercalation processes)
- Performance extended to -80°C with custom electrolytes
- Also evaluating COTS parts under Tvac conditions
- Can be coupled with Li-ion batteries for a high specific energy/high specific power hybrid power source



Low ESR and linear discharge, even at low temperatures (>350°F cells and ~5-10 mΩ at -40°C)

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov