Analysis for Lithium-Combustion Power Systems for Extreme Environment Spacecraft

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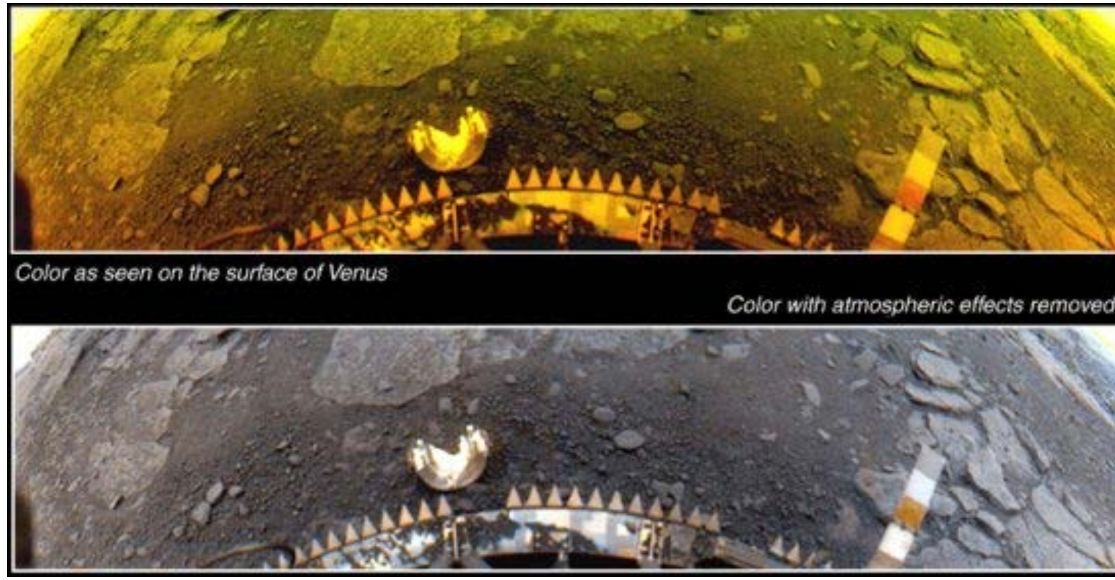
A longer duration mission to the surface of Venus will require a different power system



Venus Surface:

- 740 K
- 92 Bar
- ~1-2 m/s wind speeds
- 96.5% CO_2, 3.5% N_2, other trace gases

Venera 13:

- Battery powered lander
- Planned duration: 32 minutes
- Actual duration: 127 minutes

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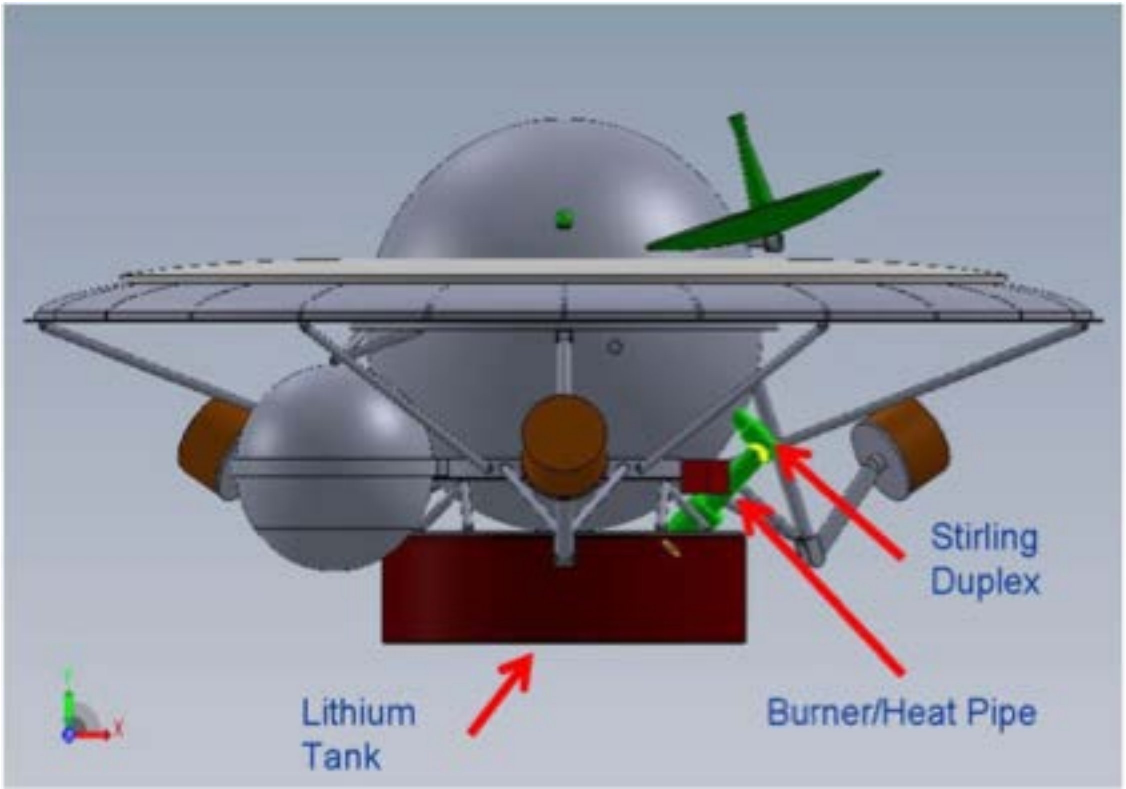
ALIVE mission concept could enable a 5 day surface mission without high temperature electronics

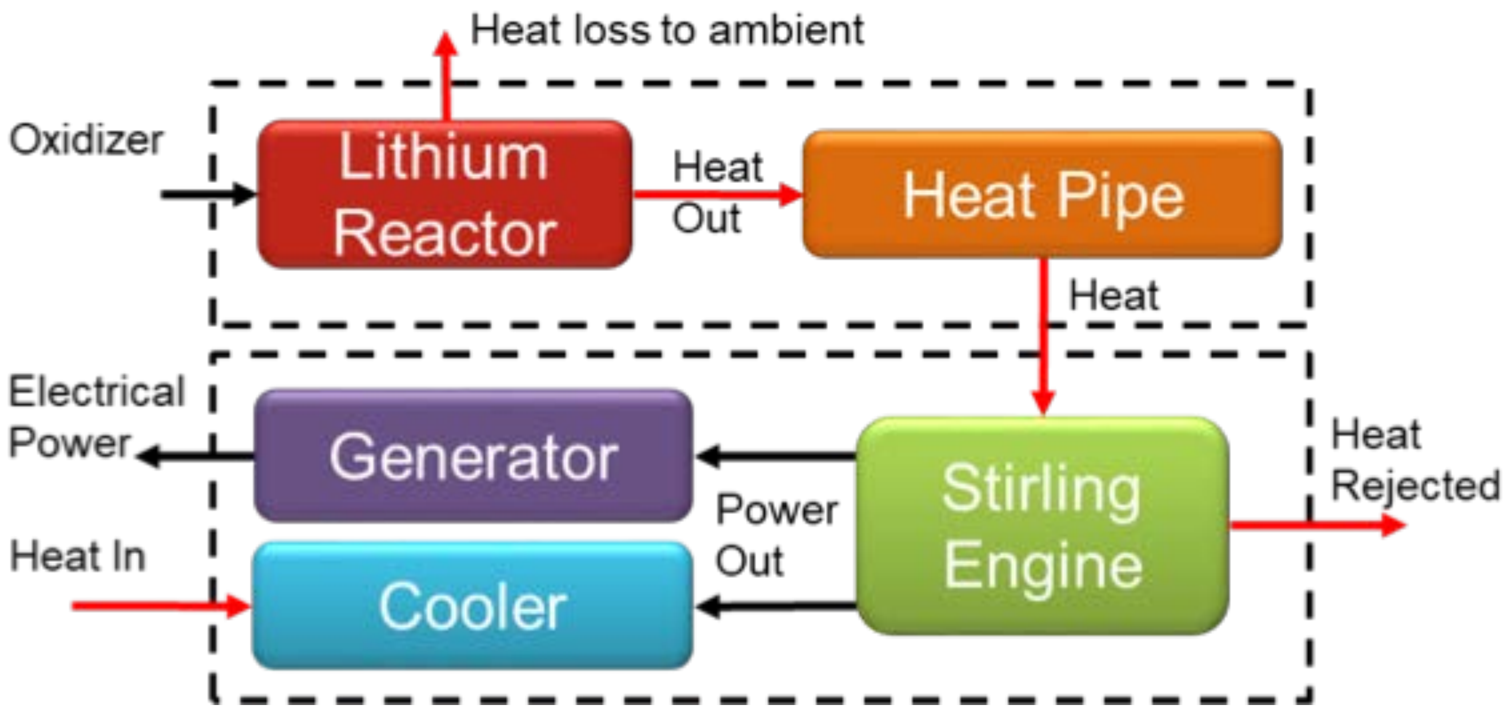


[1] S. R. Oleson and M. Paul, "COMPASS final report: Advanced Lithium Ion Venus Explorer (ALIVE)," Glenn Research Center, NASA, Cleveland, Ohio, 2012.

Power plant requirements:

- 13.3 kW_{th} at 850C
- 120 hour duration
- Total 213 kg
- Duplex Stirling engine for cooling (2.0 kW_{pv}) & power (0.33 kW_e)

Lithium combustion systems provide greater energy density systems than alternative options



<u>Combustion Reaction [2] [3]</u>:

$5Li + CO_2 \rightarrow 2Li_2O + 0.5Li_2C_2 + Heat$

$Li_2 + CO_2 \rightarrow Li_2CO_3 + Heat$

<u>Energy Density [3]</u>:

Li/CO_2 Burner

- 650 kW-hr/m^3 system energy density

NaS Battery:

- 350 kW-hr/m^3 system energy density

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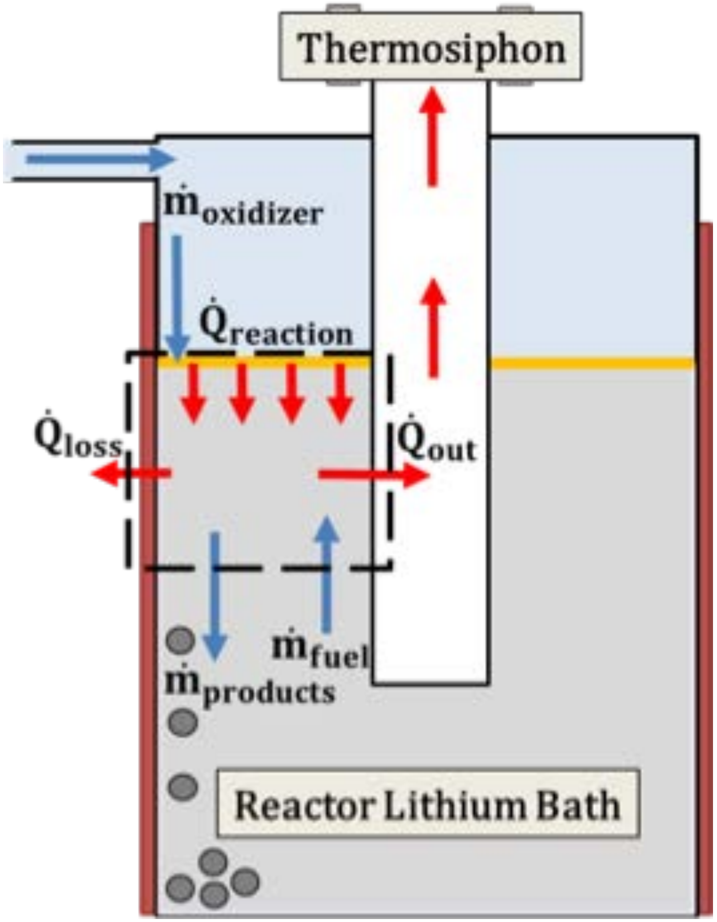
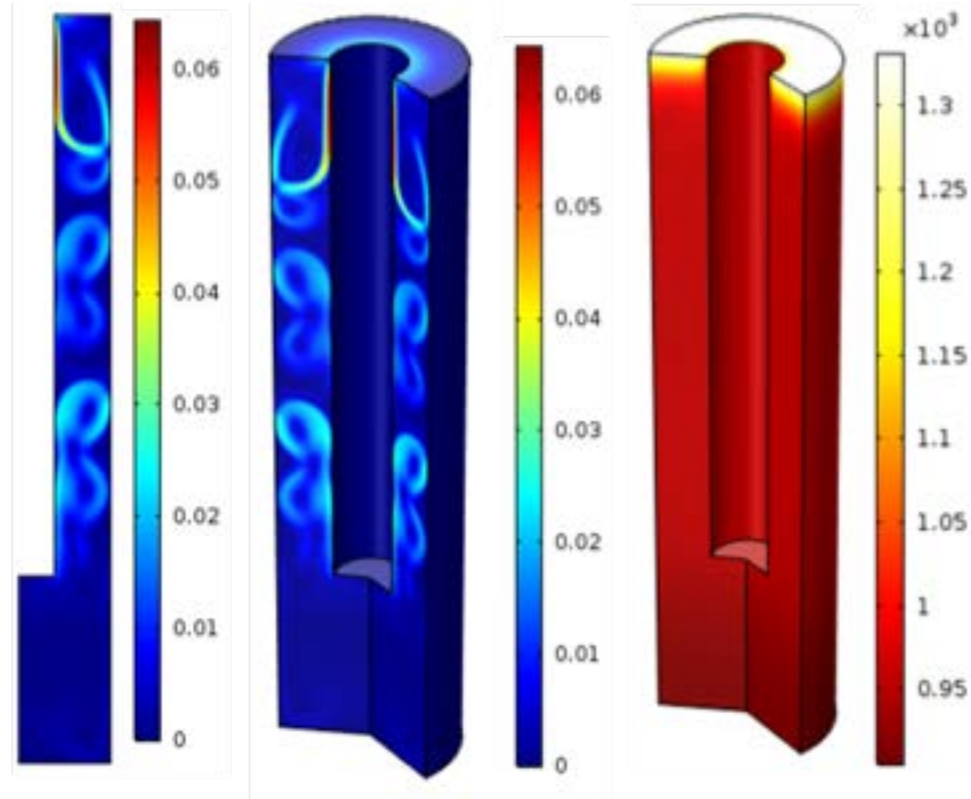
Computational analysis were performed for the energy/mass balance and natural convection in the reactor



EES: Control Volume Analysis



COMSOL: Natural Convection Model

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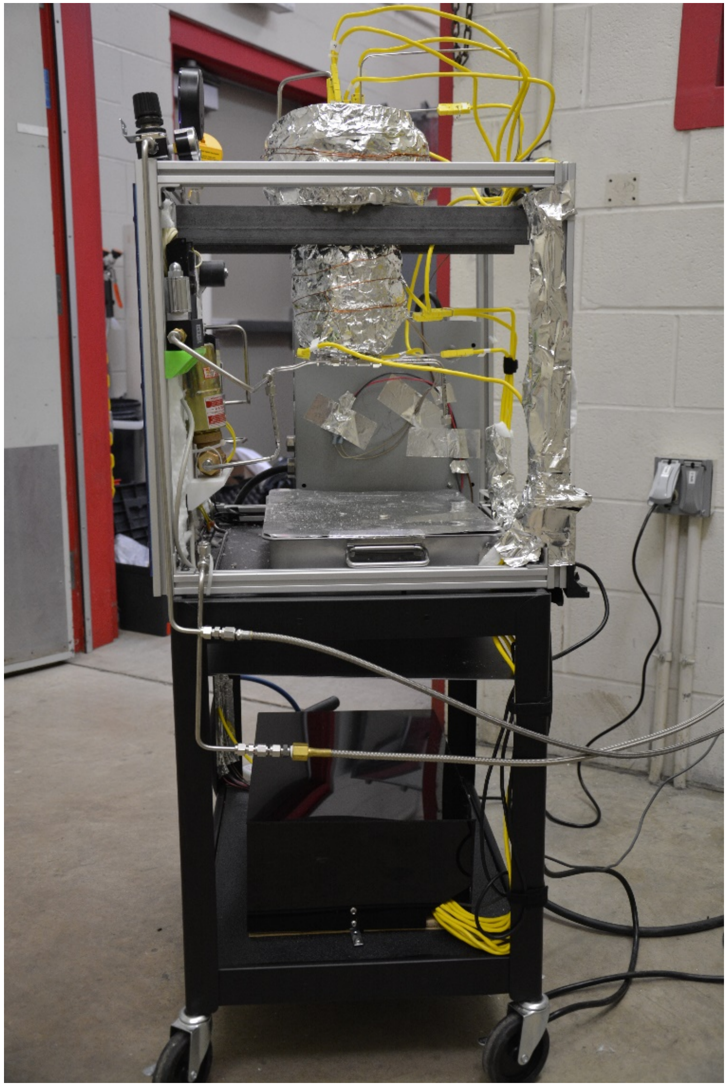
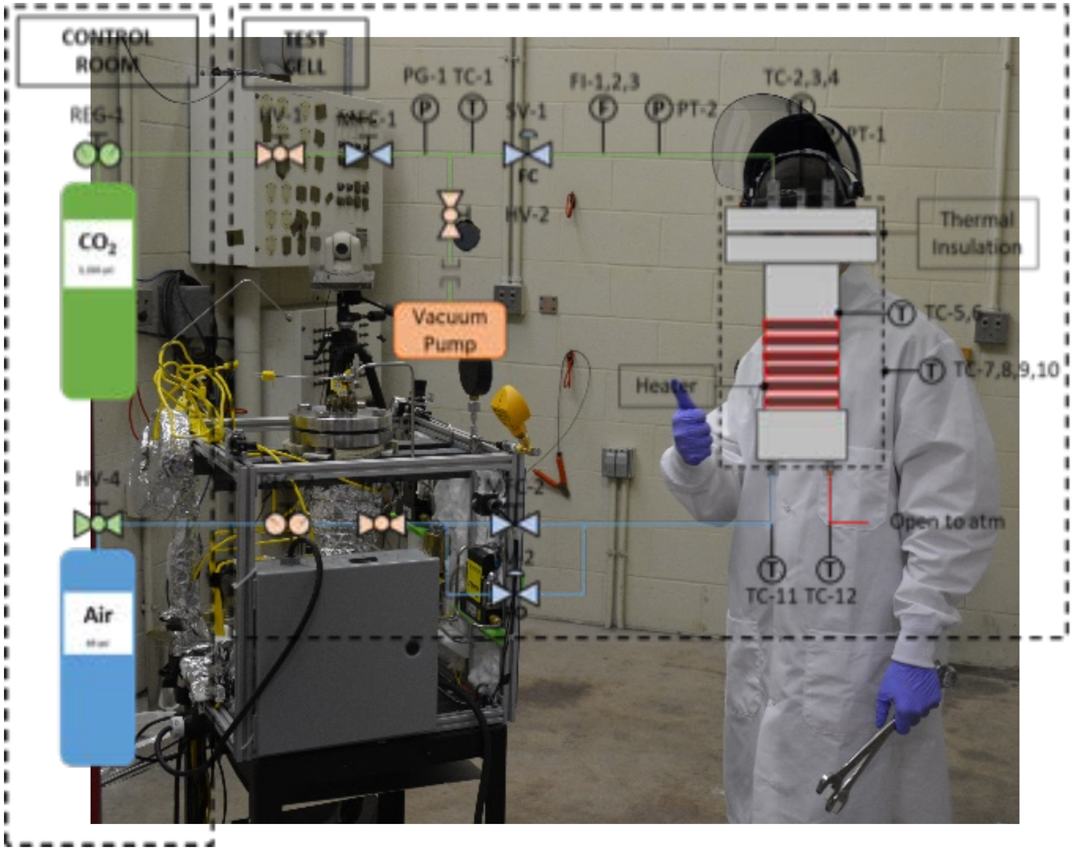
Acta Astronautica Publication Link [4]:
https://doi.org/10.1016/j.actaastro.2018.05.039

Experimental testing was performed to validate model data and to prove the concept





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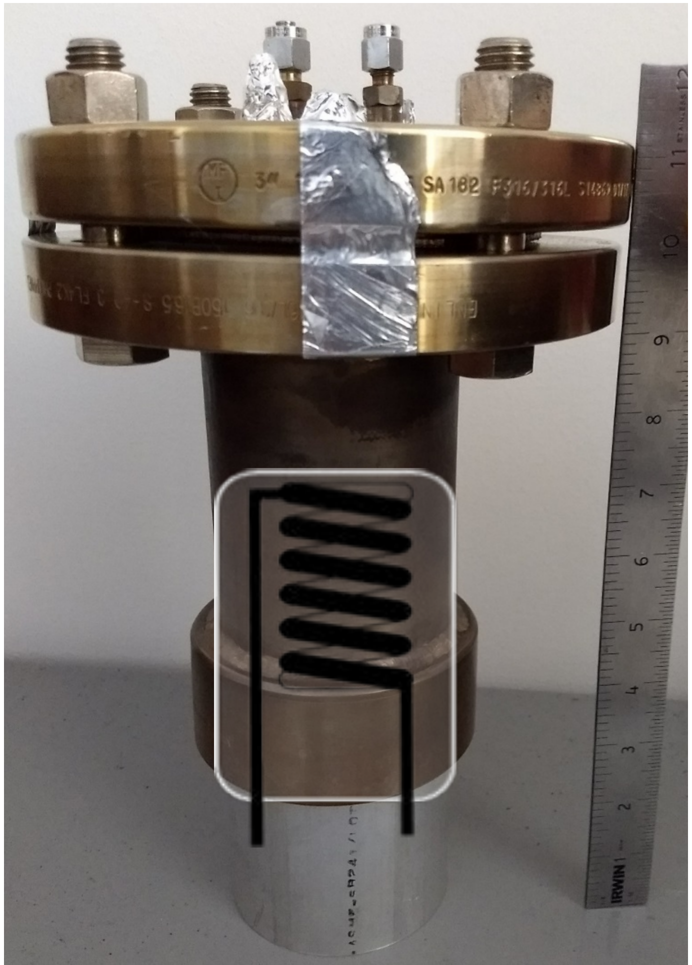
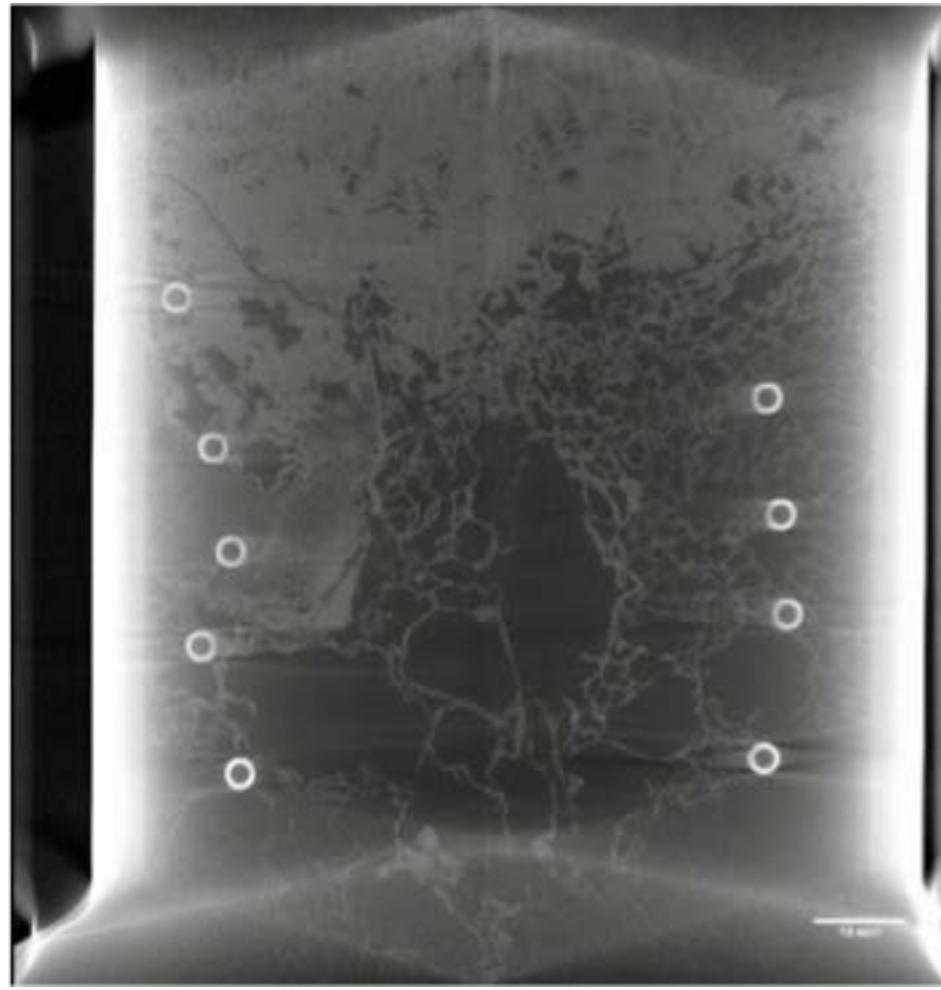
Reactor 1.0: Controlled burn of lithium and carbon dioxide while removing heat





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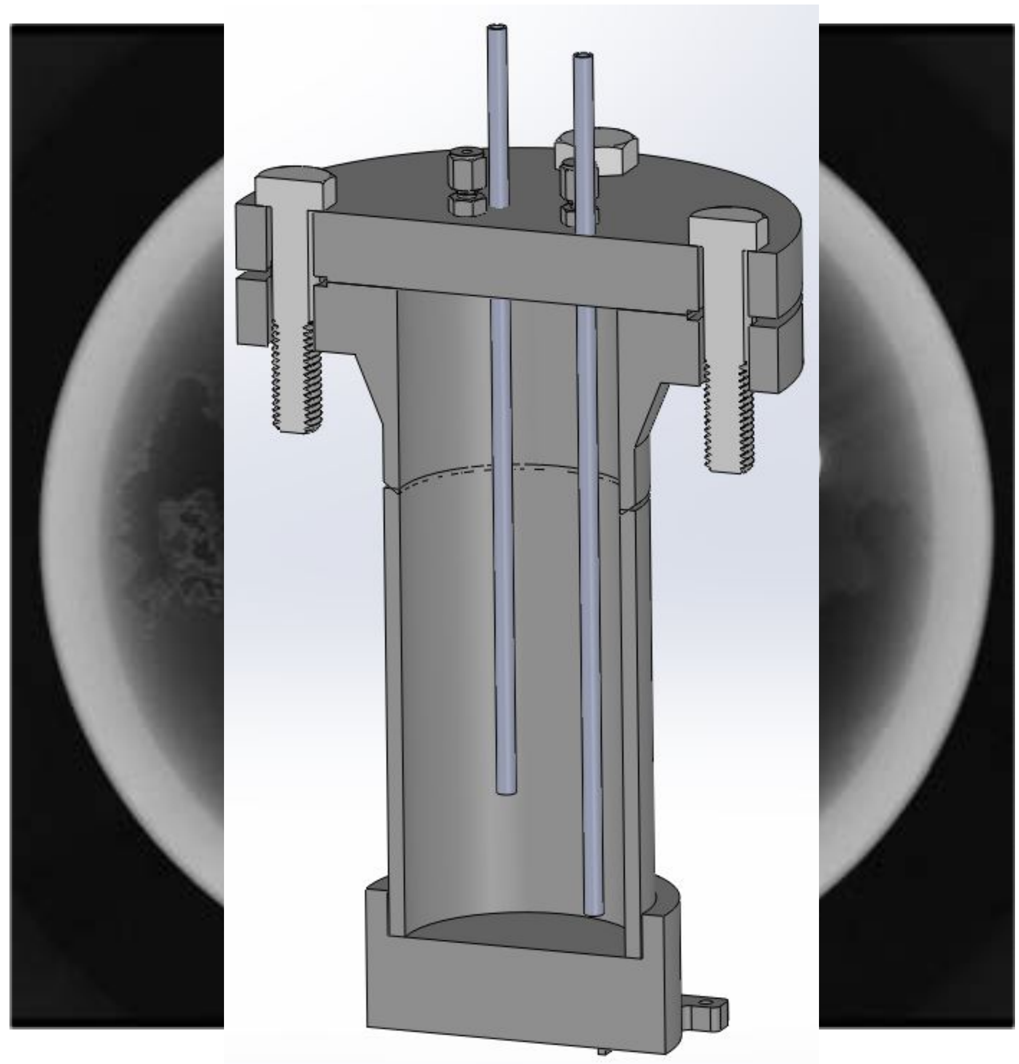
Reactor 2.0: Controlled burn of lithium and carbon dioxide producing electricity with a TEG



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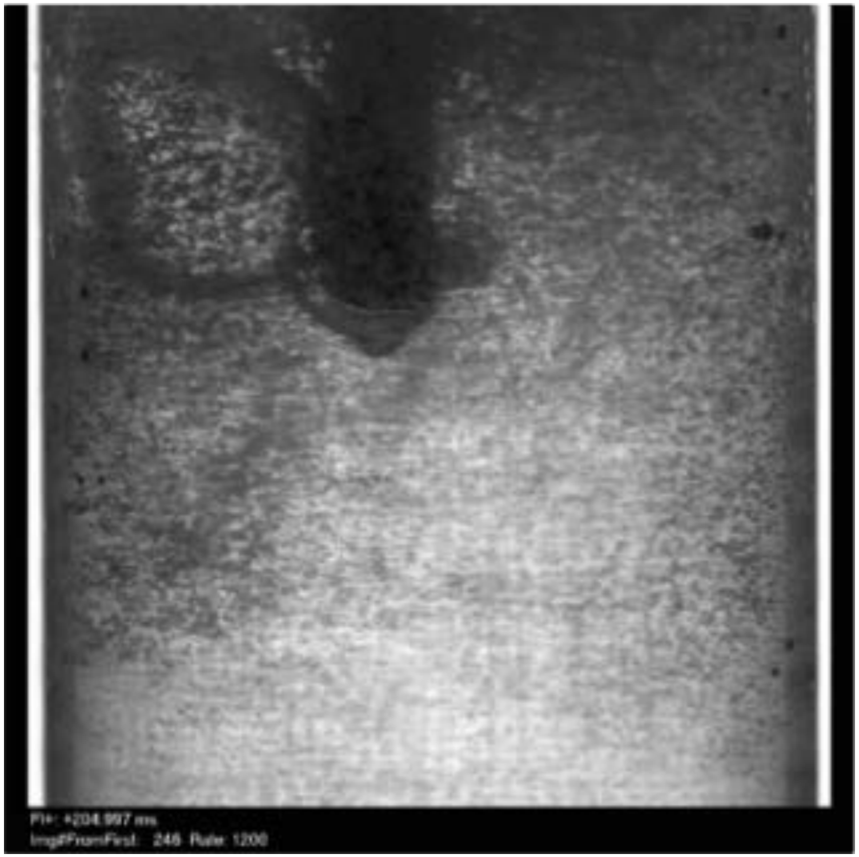
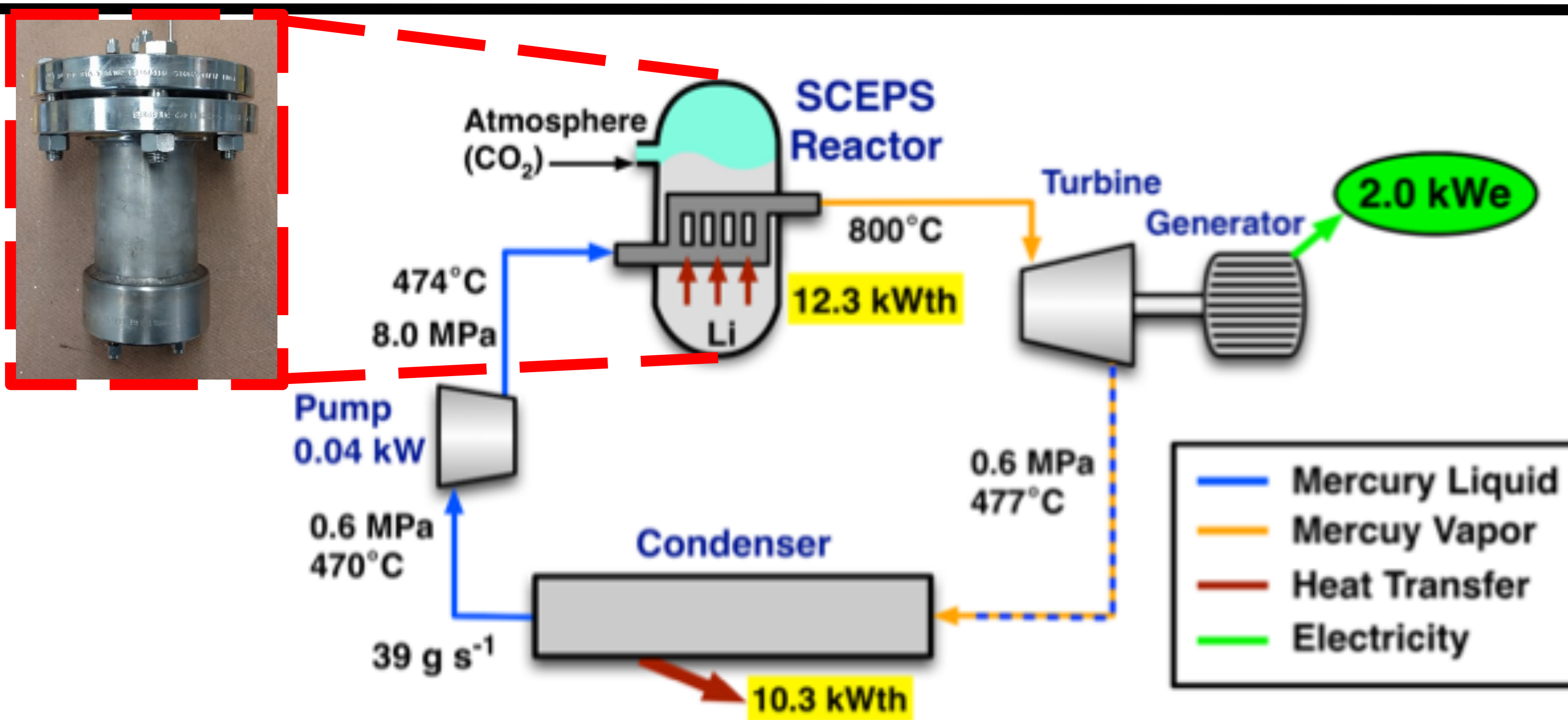
Reactor 3.0: The next reactor test will require a new injector mechanism



Injector test with chamber at vacuum pressure

Injector test with chamber at 30 psig

Future Work: Selected proposal for NASA SMD's Hot Operating Temperature Technology (HOTTCH)



- HOTLINE project (Hot Operating Temperature Lithium combustion for IN situ Energy and Power)

- Designing a lithium combustion reactor driven mercury vapor turbine power cycle with an integrated cooling system

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- IPPW for supporting me with a student scholarship

References

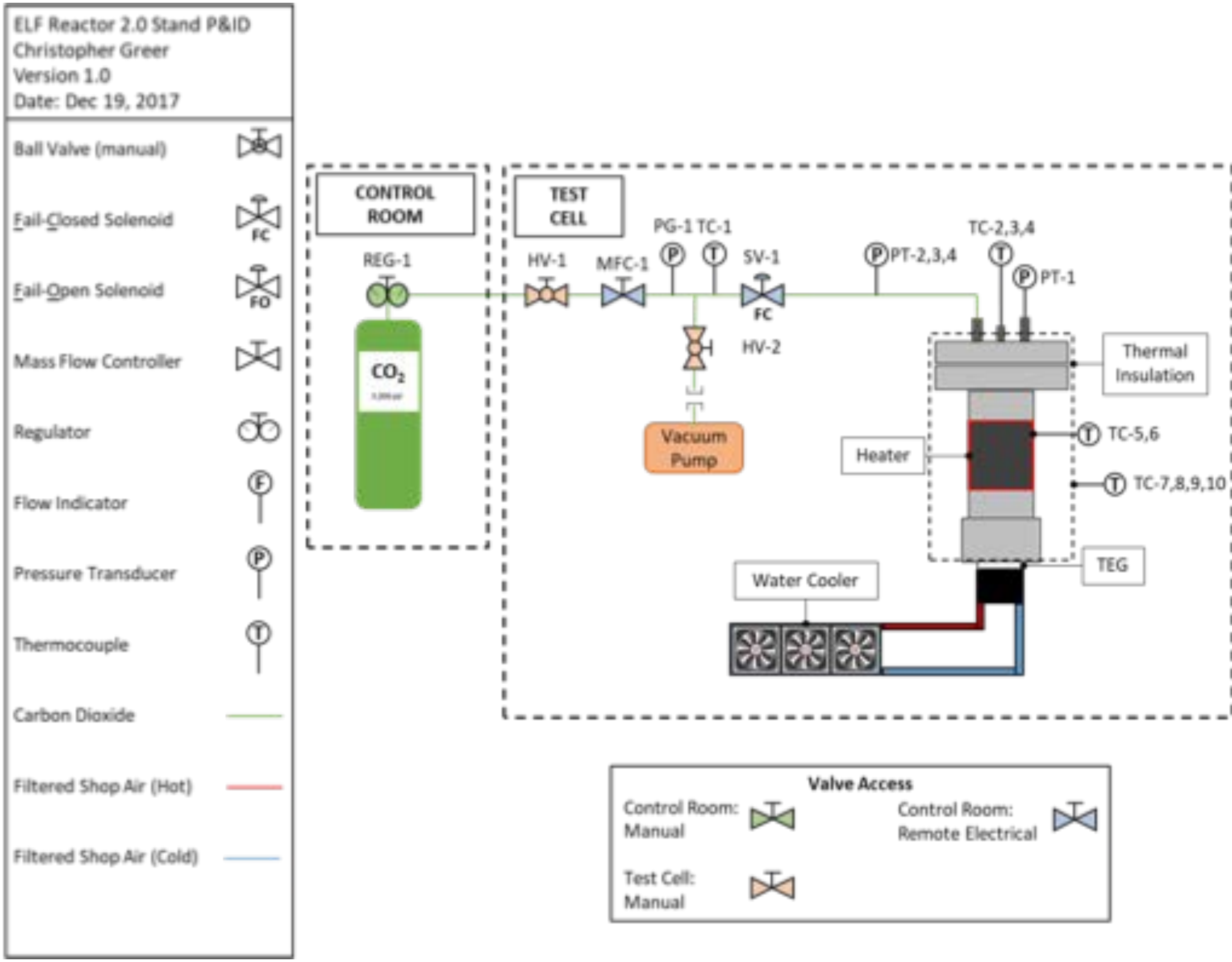
[1] S. R. Oleson and M. Paul, “COMPASS final report: Advanced Lithium Ion Venus Explorer (ALIVE),” Glenn Research Center, NASA, Cleveland, Ohio, 2012.

[2] T. Baker, T. F. Miller, M. Paul, and J. A. Peters, “The Use of Lithium Fuel with Planetary In Situ Oxidizers,” in 10th Symposium on Space Resource Utilization, 2017, no. January, pp. 1–11.

[3] T. F. Miller, M. V. Paul, and S. R. Oleson, “Combustion-based power source for Venus surface missions,” Acta Astronaut., vol. 127, pp. 197–208, 2016.

[4] C. J. Greer, M. V. Paul, and A. S. Rattner, “Analysis of lithium-combustion power systems for extreme environment spacecraft,” *Acta Astronaut.*, vol. 151, May 2018.

Backup



Name	Description
Valves	
HV-1	Oxidizer Isolation Valve
HV-2	Oxidizer Vacuum/Vent Valve
MFC-1	Oxidizer Mass Flow Controller
REG-1	Oxidizer Regulator
SV-1	Fail Closed Solenoid Valve
Instrumentation	
FI-1,2,3	Flow Indicators
PG-1	Oxidizer Pressure Gauge
PT-1	Reactor Pressure Transducer
PT-2,3,4	Oxidizer Inlet Transducer
TC-1	Oxidizer Thermocouple
TC-2,3,4	Reactor Bath Thermocouples
TC-5,6	Reactor Wall Thermocouple
TC-7,8,9,10	Reactor Insulation Thermocouples
Other	
Vacuum Pump	Reactor Vacuum Pump
Heater	Reactor Cable Heater

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