



Lunar South Pole Regenerative Fuel Cell System Efficiency Analysis

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Introduction



Why...regenerative fuel cells?

...focus on efficiency?

...the lunar south pole?

previous paper, NASA/TM-20210014627 on RFC Efficiency at lunar equator, covered

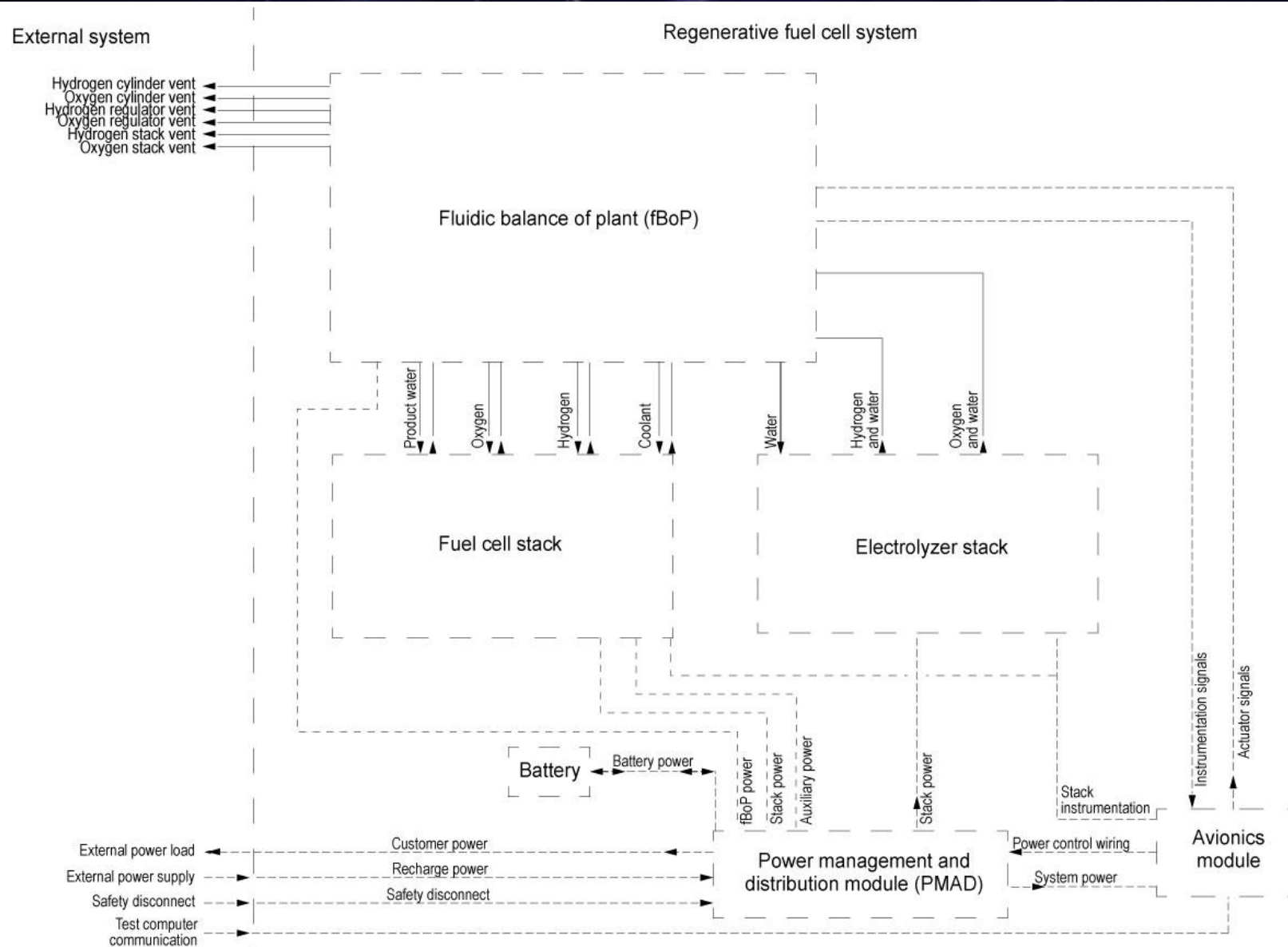
- (1) fuel cell sizing decisions, such as active area and current density design point,
- (2) component decisions, such as reactant storage vessel configuration, solenoid valve operation and type, and voltage converters, and
- (3) reactant storage decisions, such as gas versus cryogenic storage and storage vessel temperature.

What is modeled here

- PEM RFCs of various size scales from 100 W to 50 kW
- Results focused on electrolyzer decisions, including active area, membrane thickness, operational pressure and temperature, and charge duration.



RFC System Overview





Effect of Efficiency Changes

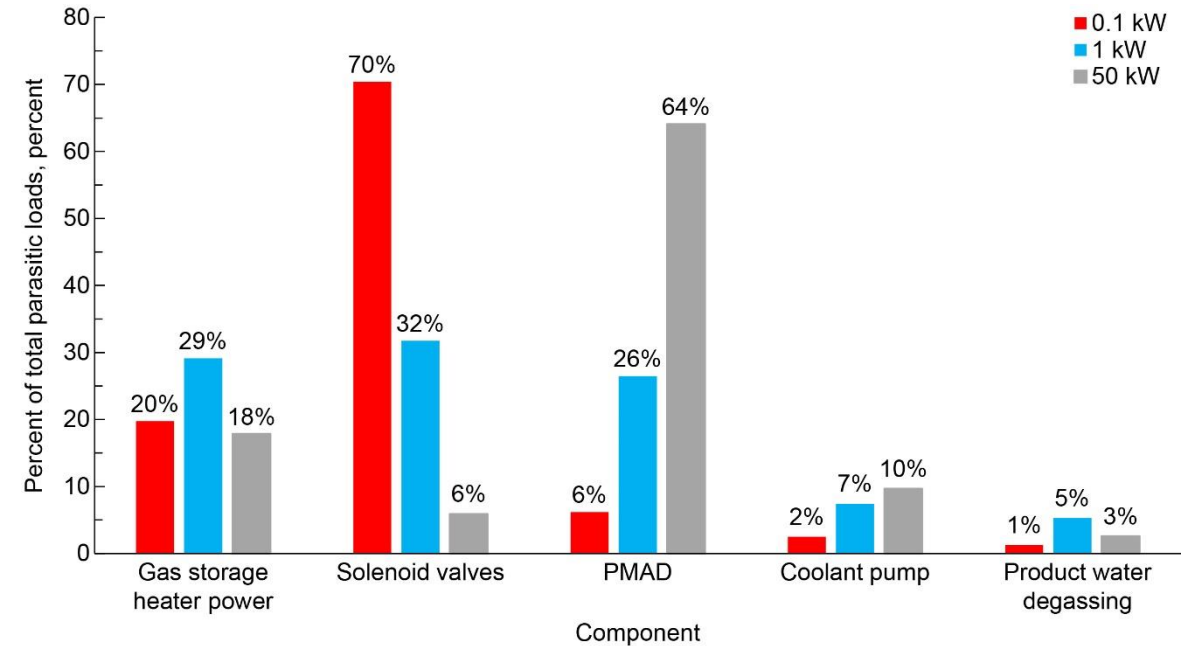
Round-trip efficiency (RTE) effect on required system mass for a 1 kW system

Efficiency change, percentage points	Reactant mass, kg		Total system mass, kg	Mass change
	Hydrogen	Oxygen		
-2%	7.6	56.7	267.6	2.8%
-1%	7.5	55.7	264.3	1.5%
Baseline	7.3	54.7	260.3	0.0%
1%	7.2	53.9	257.4	-1.1%
2%	7.1	53.0	253.9	-2.5%



Fuel Cell Parasitic Loads

Component	Power consumption, W		
	0.1 kW RFC	1 kW RFC	50 kW RFC
Gas storage heater power	16	55	695
Solenoid valves	57	60	230
PMAD	5	50	2500
Coolant pump	2	14	377
Product water degassing	1	10	100

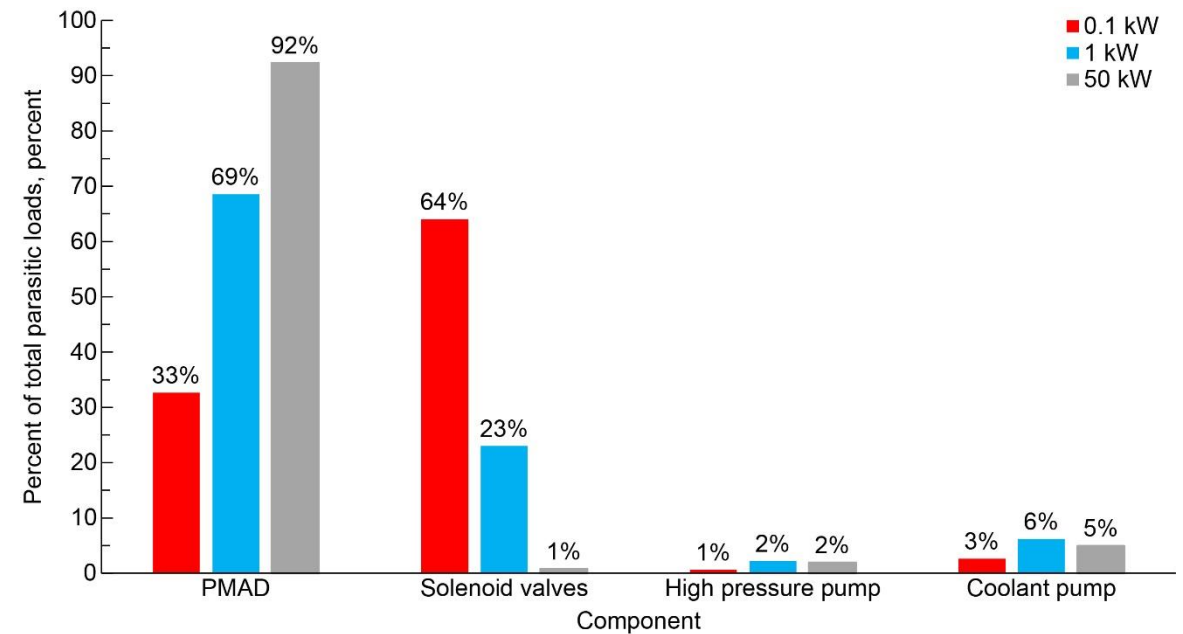


The percentage of each nominal parasitic load relative to the parasitic load total during fuel cell operation for regenerative fuel cells at 0.1 kW, 1 kW, and 50 kW nominal power levels.



Electrolysis Parasitic Loads

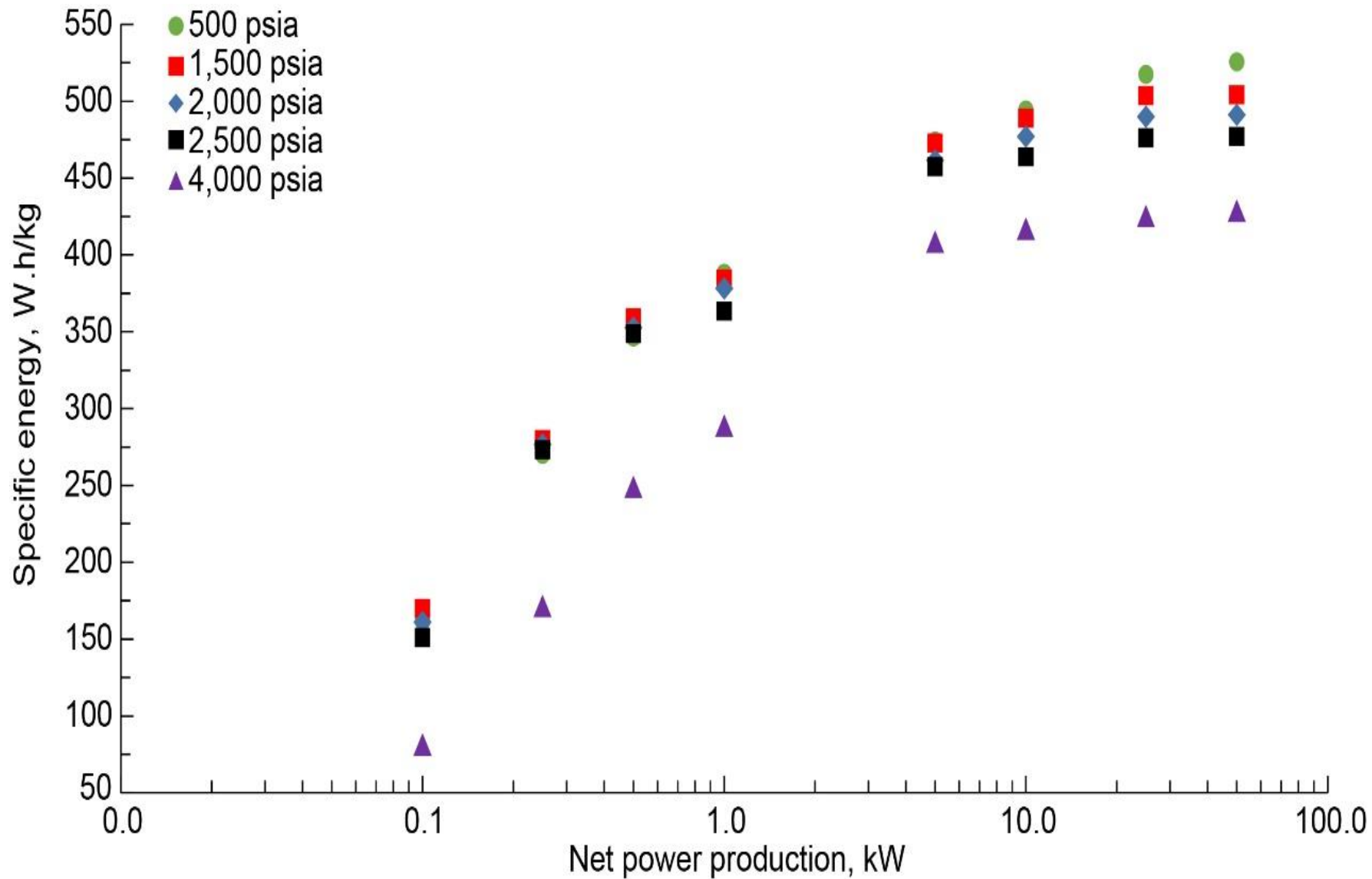
Component	Power consumption, W		
	0.1 kW RFC	1 kW RFC	50 kW RFC
PMAD	25	155	7,019
Solenoid valves	49	52	61
High pressure pump	0.5	5	145
Coolant pump	2	14	377



The percentage of each nominal parasitic load relative to the parasitic load total during electrolyzer operation for regenerative fuel cells at 0.1 kW, 1 kW, and 50 kW nominal power levels.

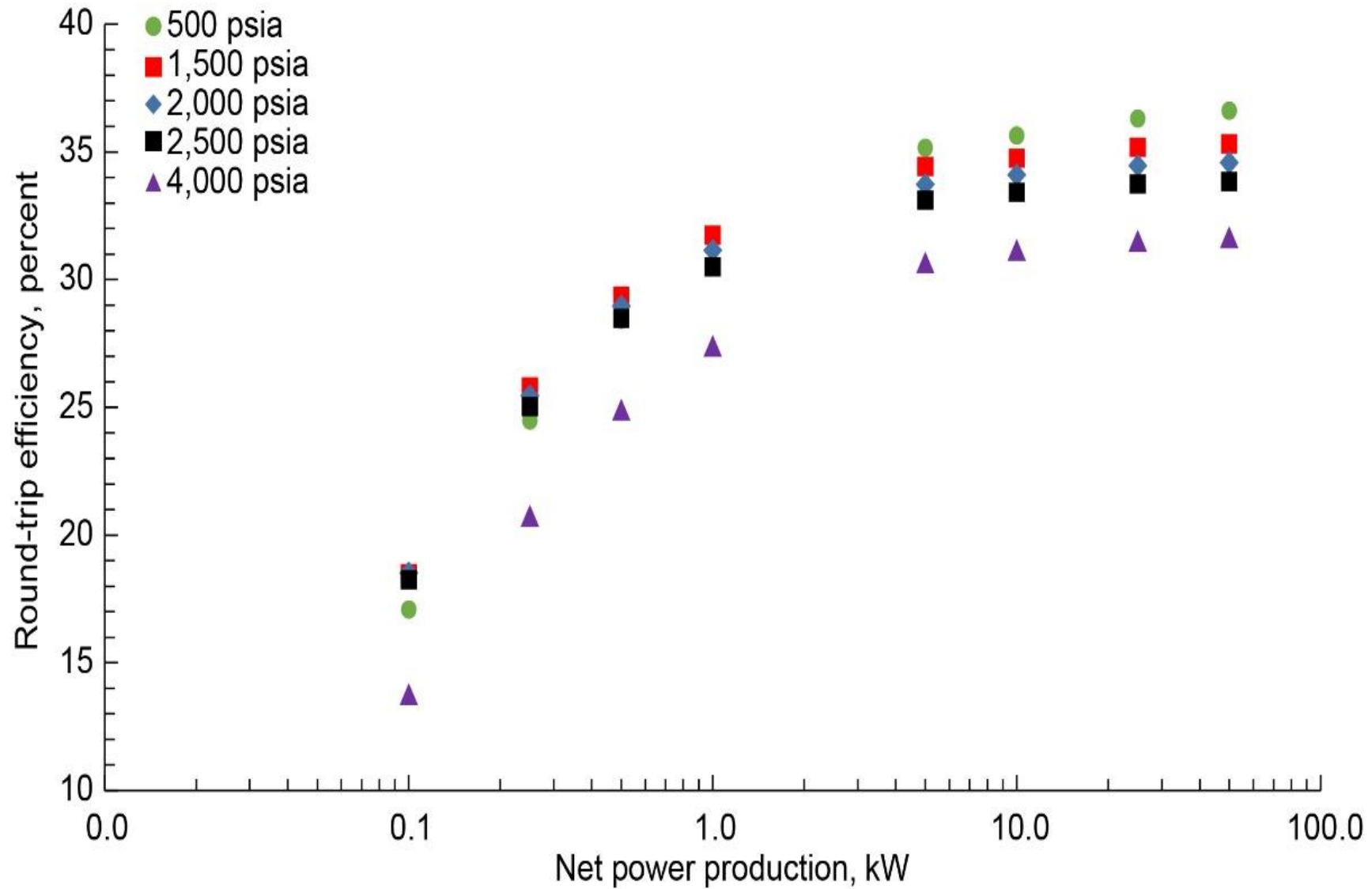


Operational Pressure

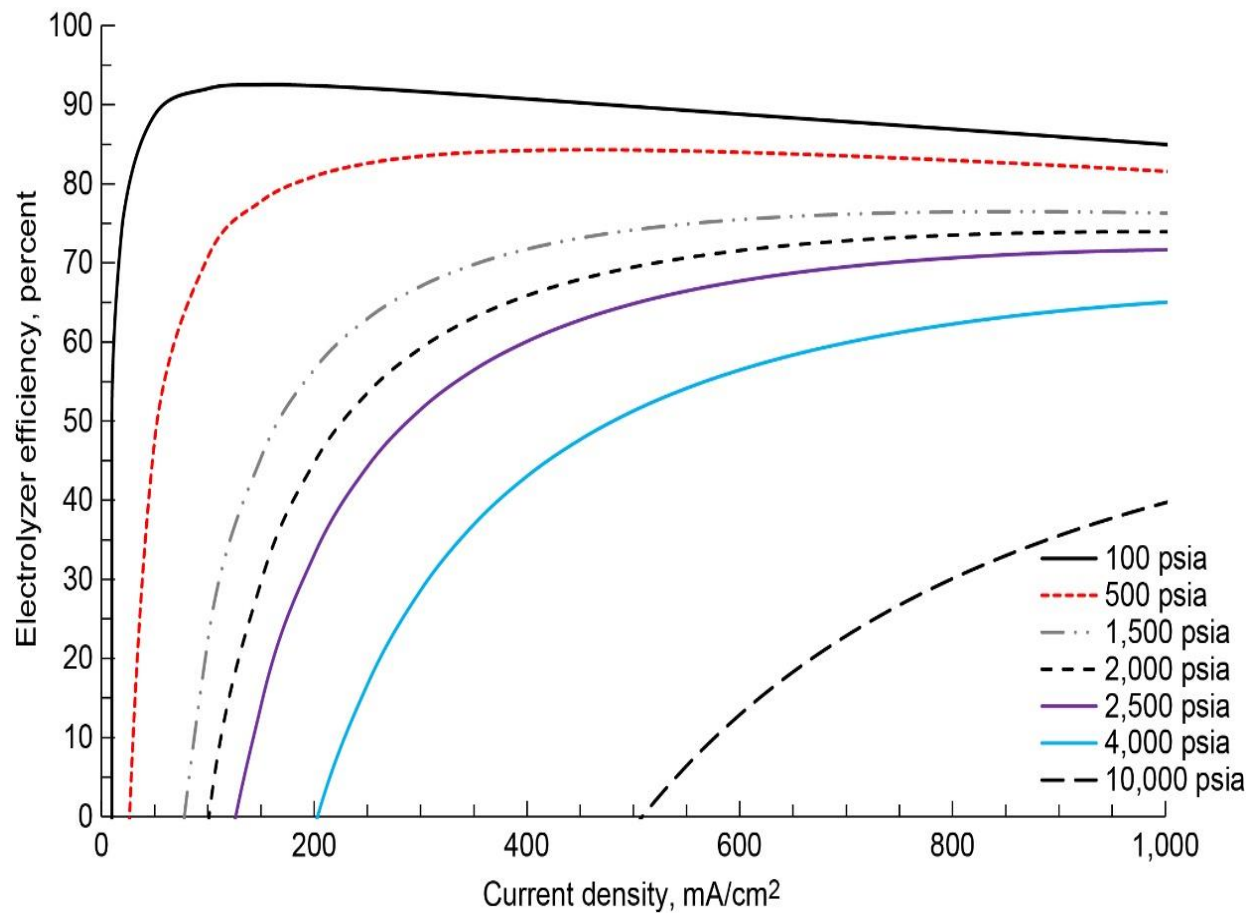




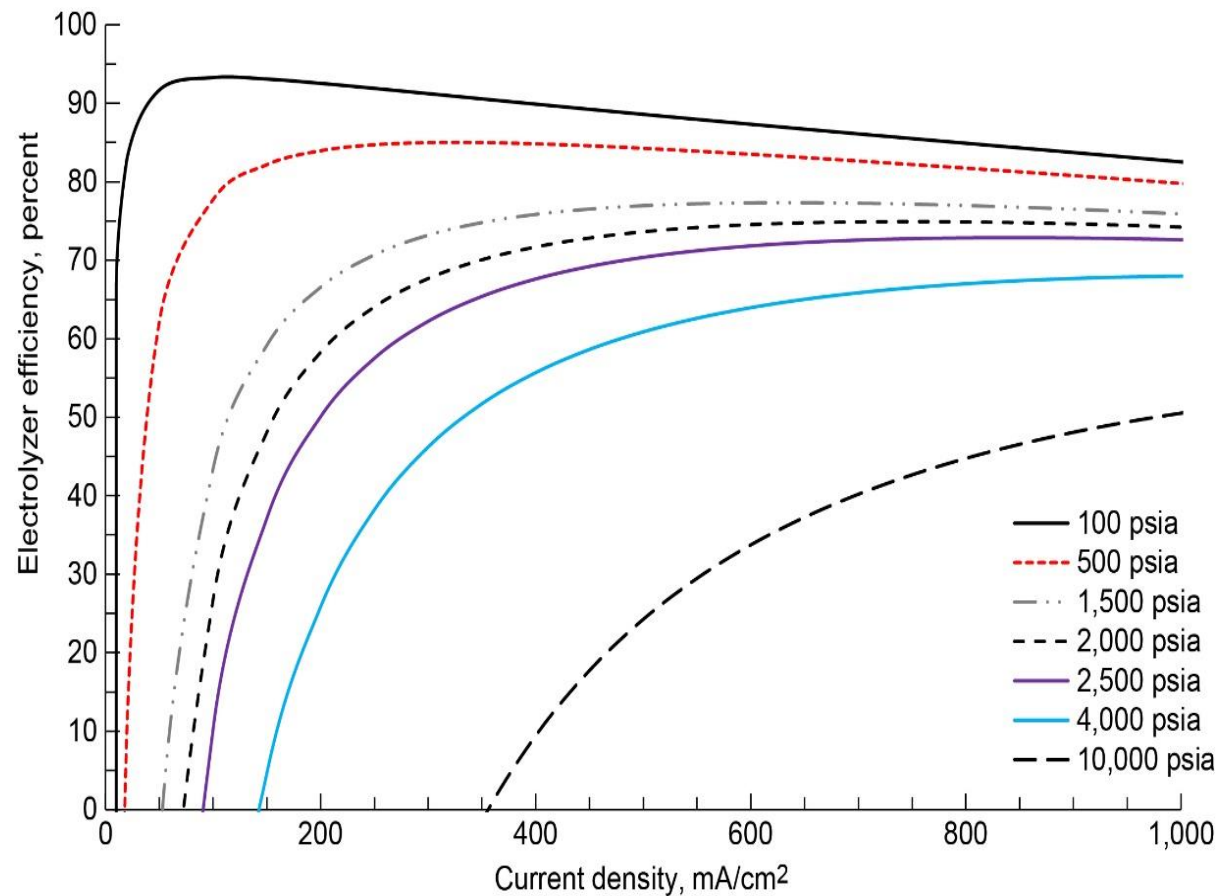
Operational Pressure



Membrane Thickness



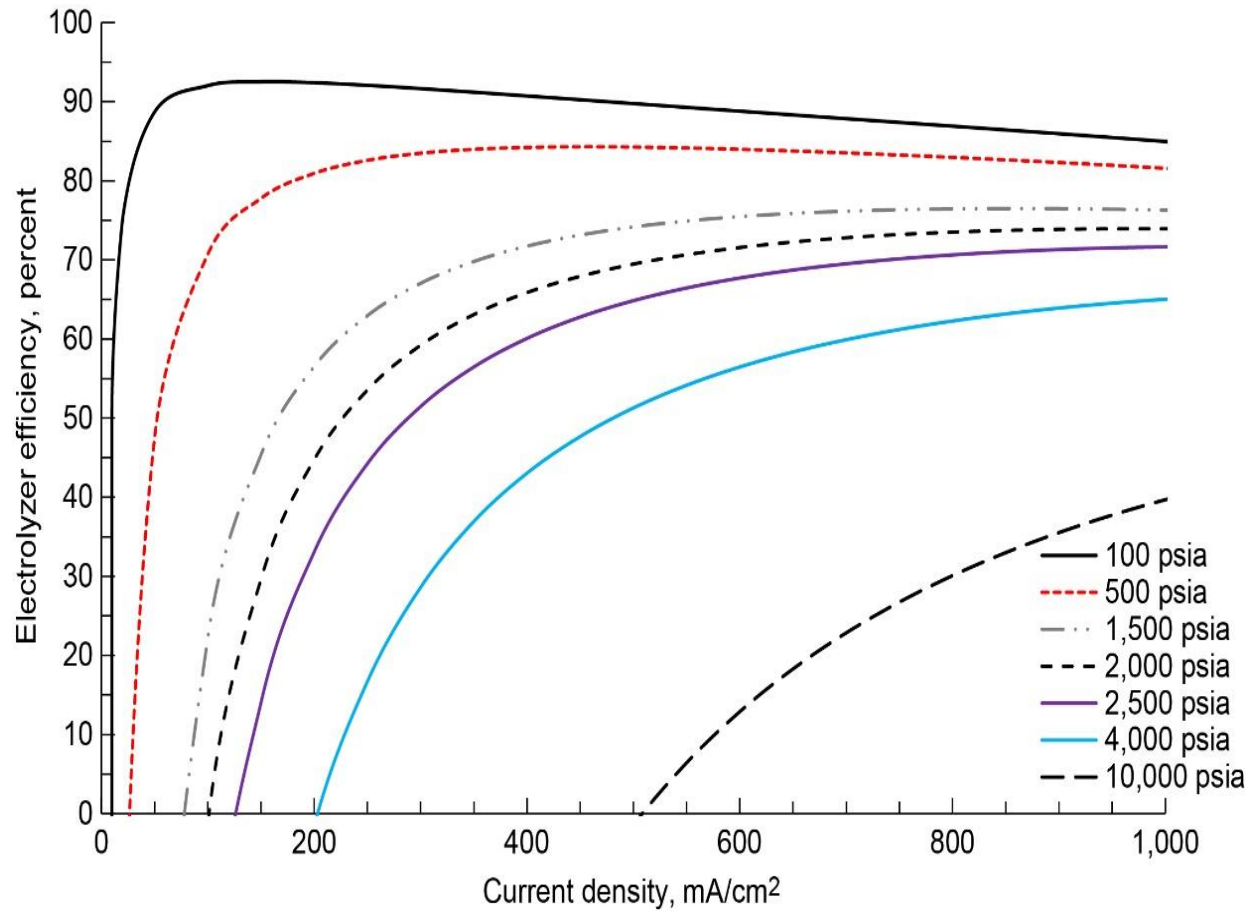
7 mil membrane thickness



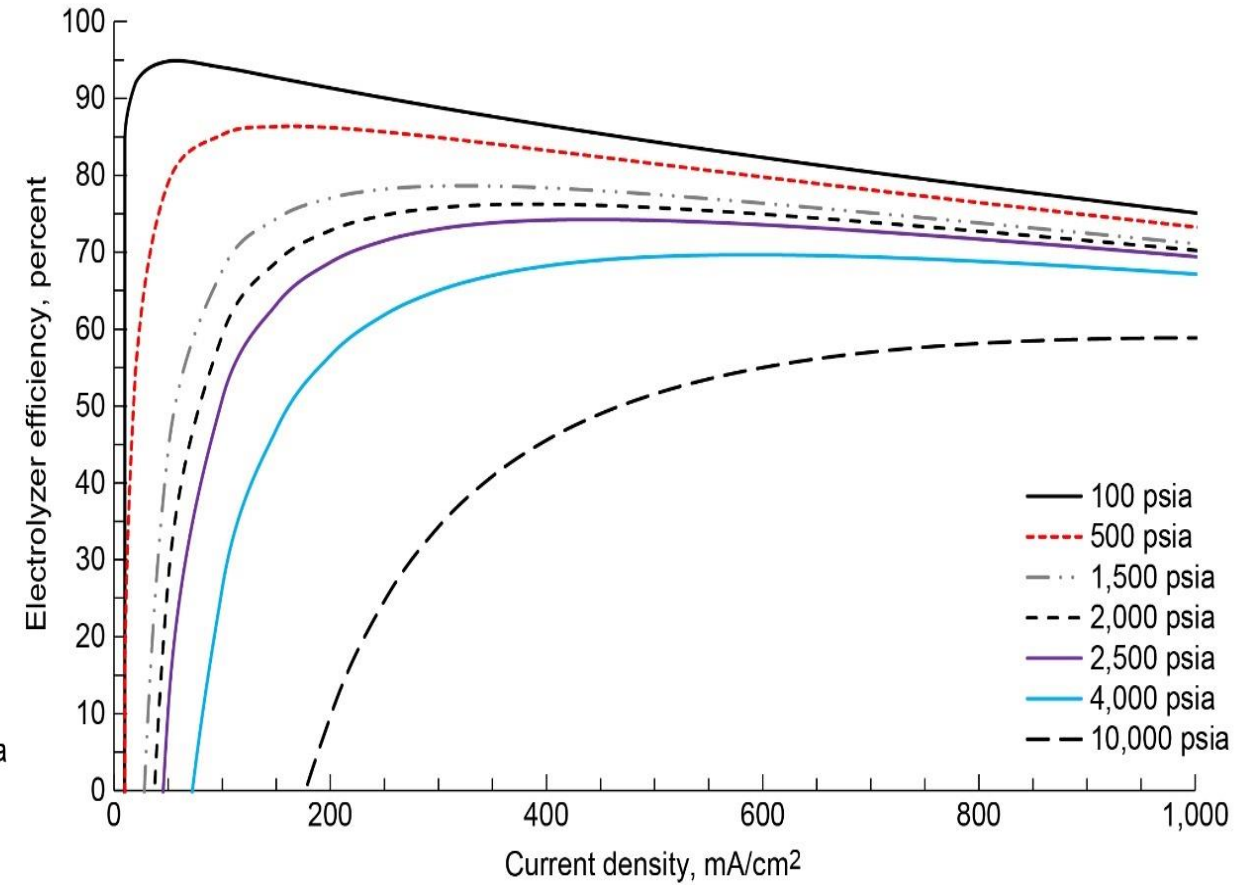
10 mil membrane thickness



Membrane Thickness



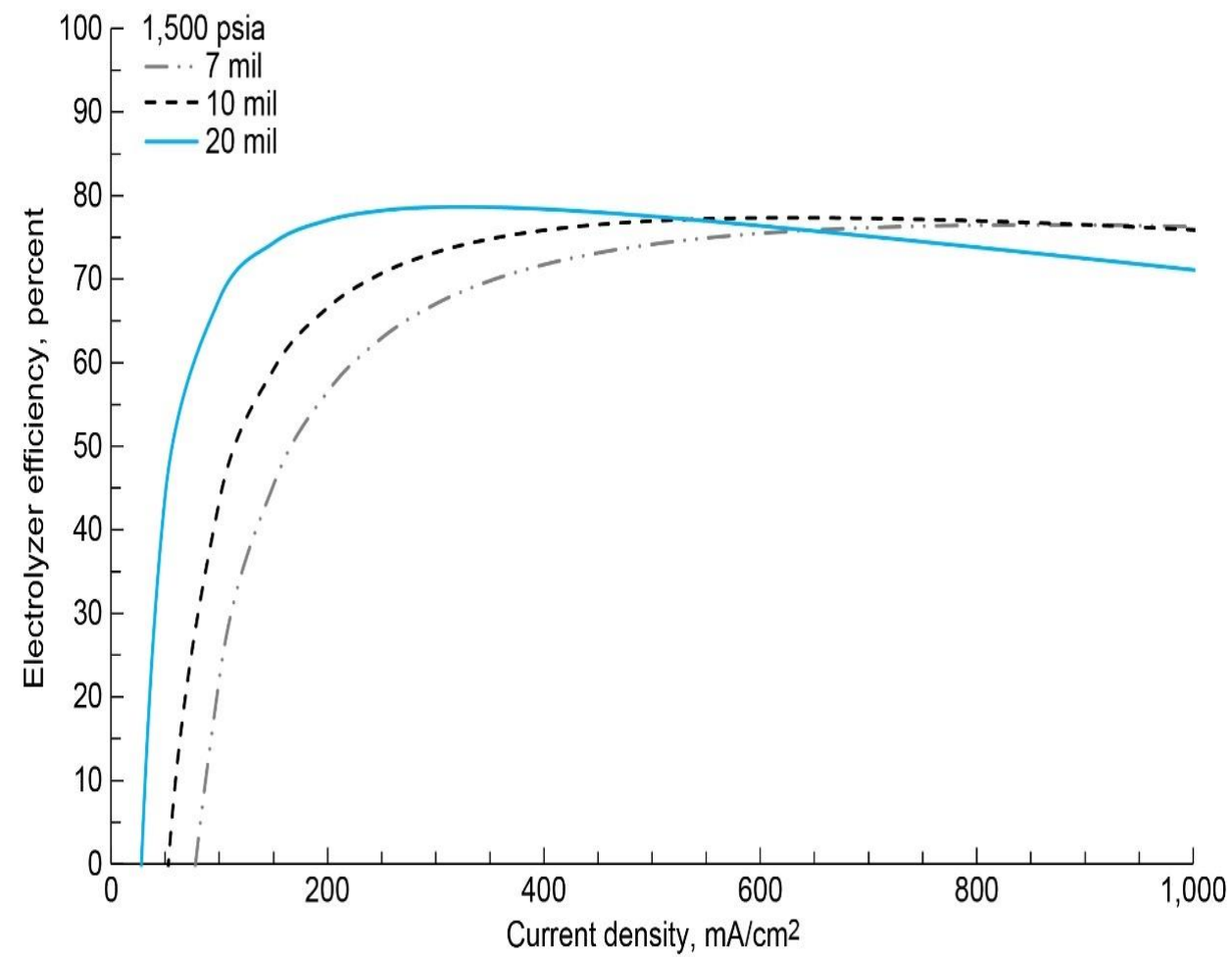
7 mil membrane thickness



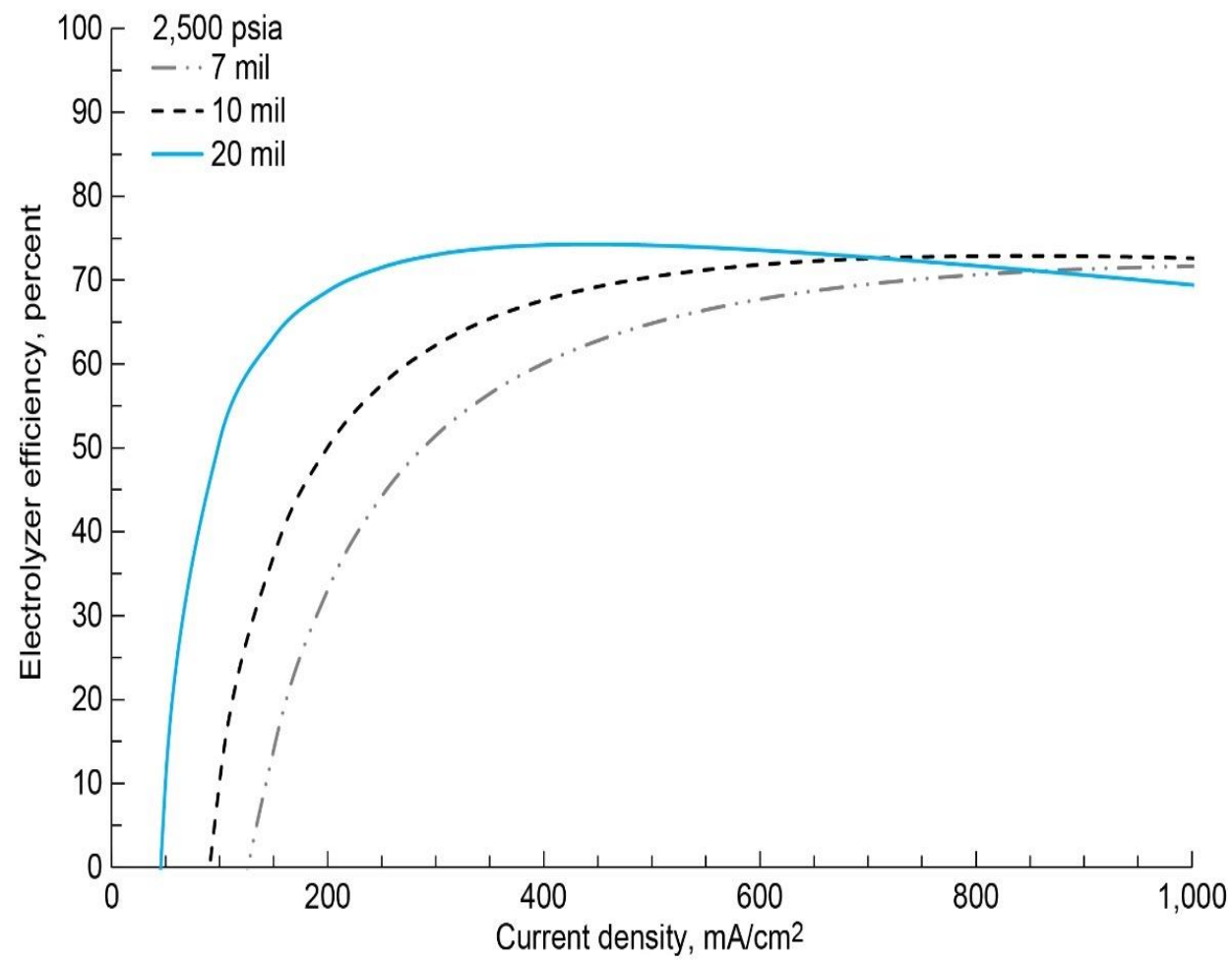
20 mil membrane thickness



Membrane Thickness



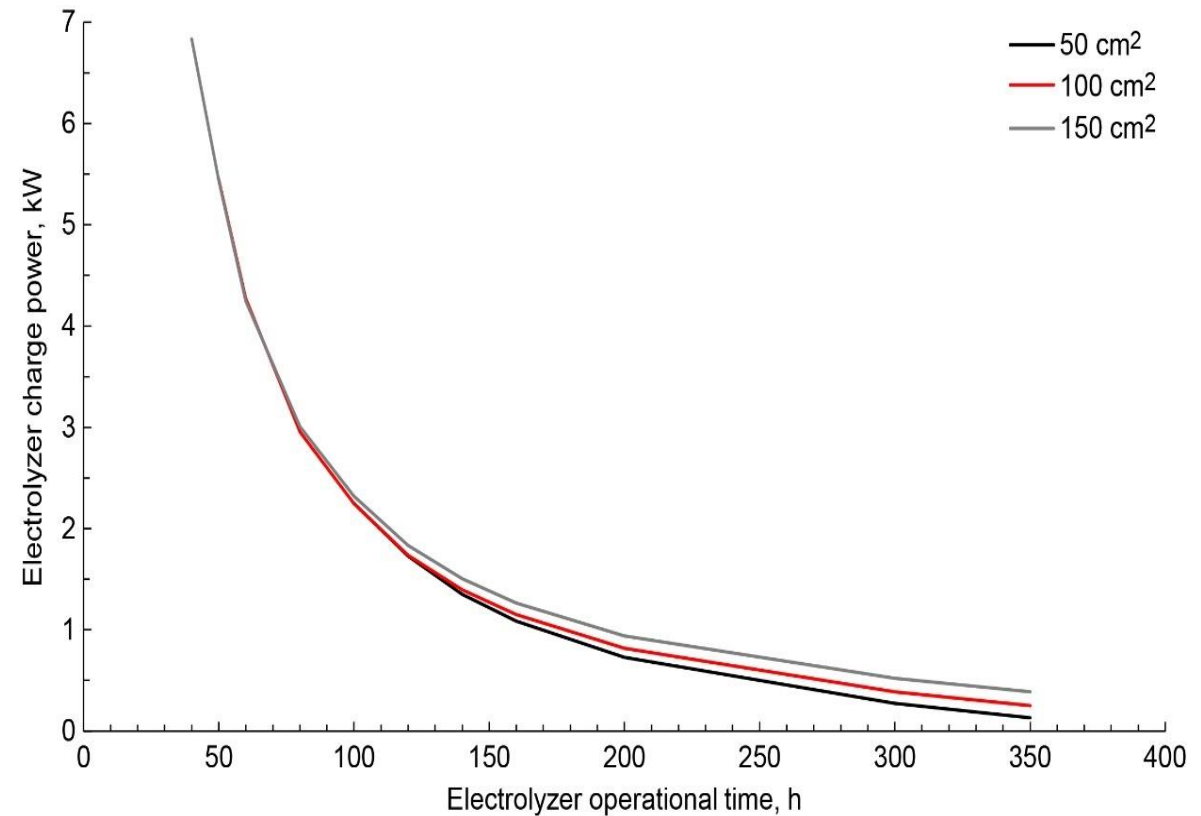
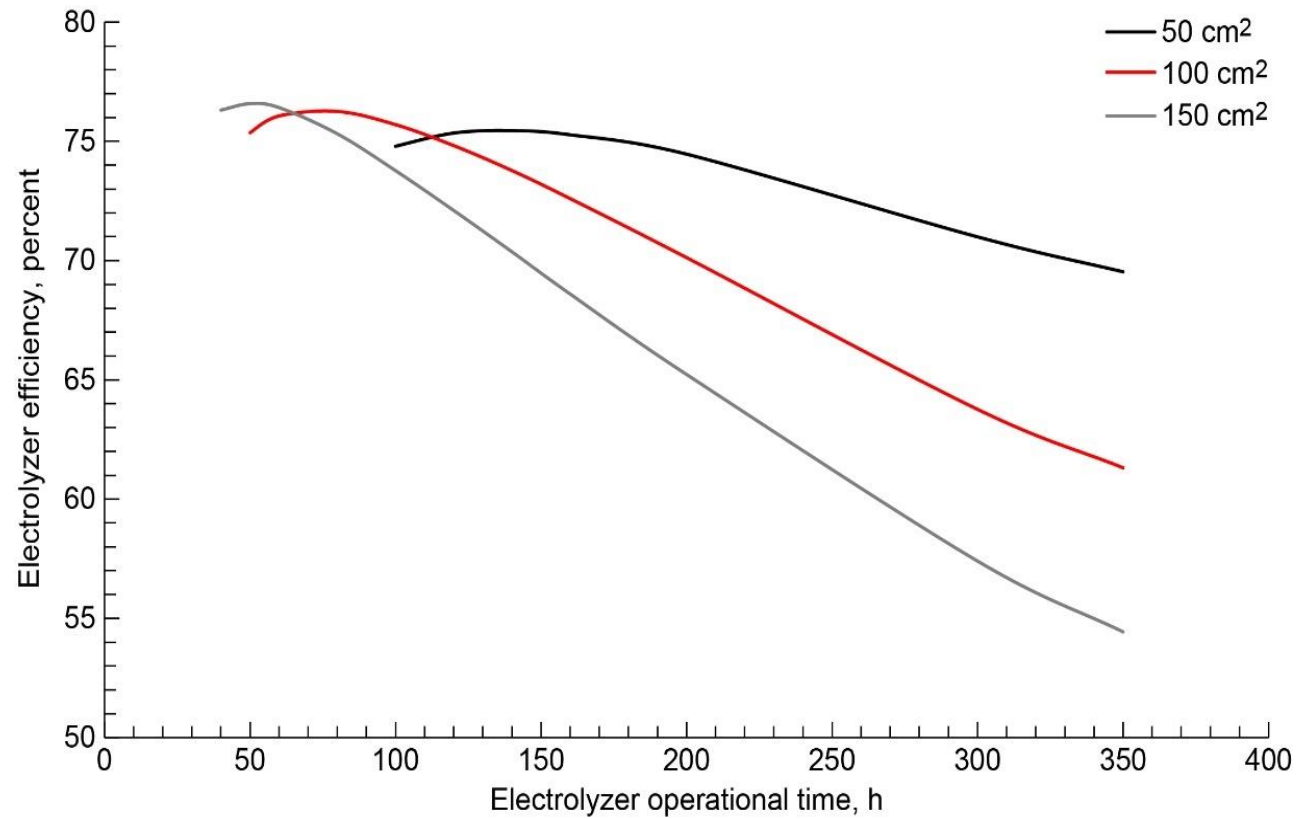
1500 psia



2500 psia



Electrolyzer Stack Sizing

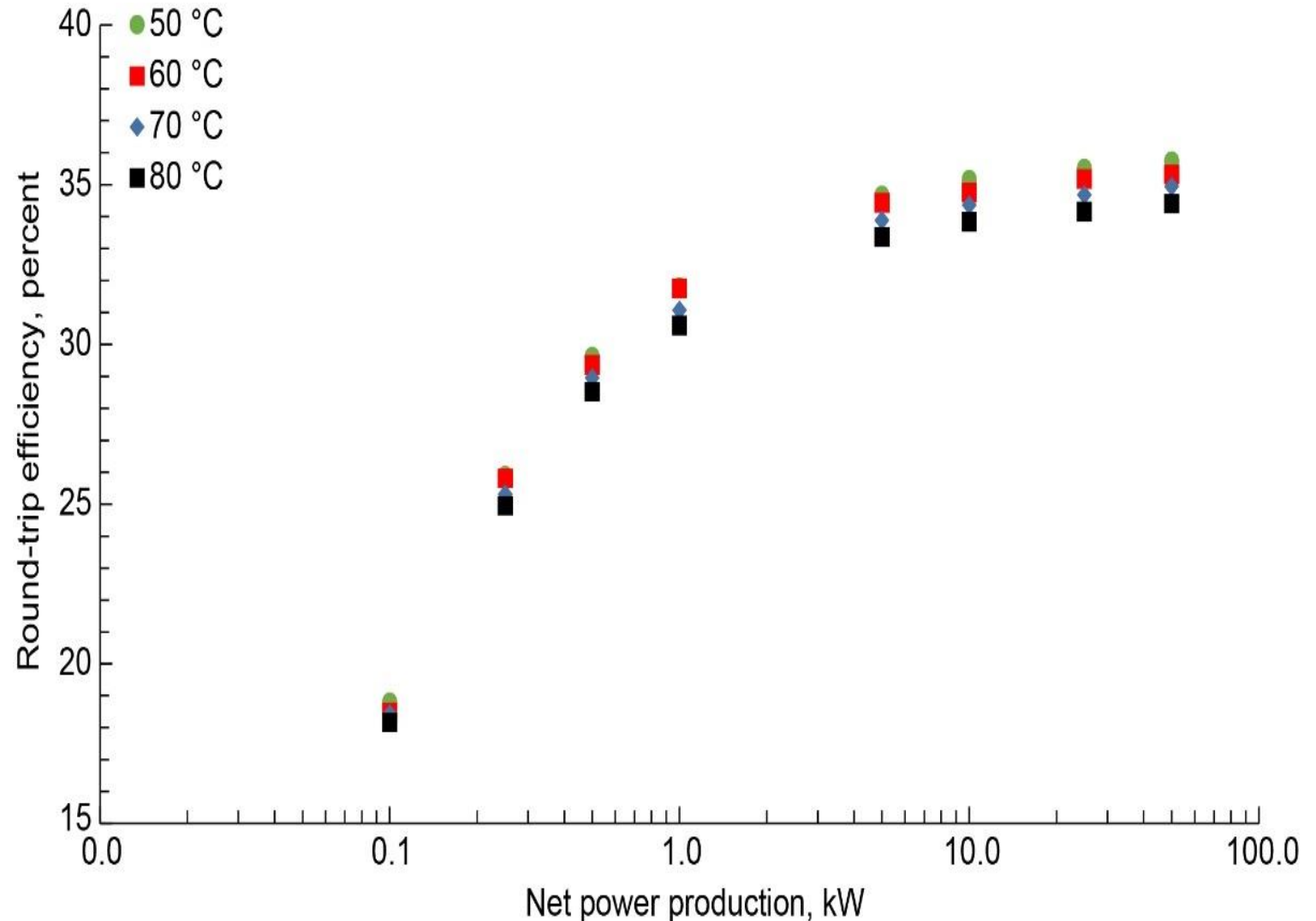




Electrolyzer Operational Temperature

EZ operational temperature is a trade-off among:

- System-level round trip efficiency
 - Electrochemical efficiency
 - Compression/pumping efficiency
 - Thermal system parasitic loads
 - PMAD system parasitic loads
- Operational life
 - Stack operational life
 - Thermal system operational life
- Mass
 - Reactant mass
 - Thermal system to operate the electrolyzer at such a low temperature during the lunar day
 - PMAD system (particularly DC/DC converters)





Conclusions

Improving RTE benefits specific energy, reduces required charge energy, and reduces system mass.

For a small scale RFC, such as the 0.1 kW class unit, the primary parasitic loads are related to solenoid valves, power management voltage converters, and reactant storage vessel heating. As RFC power increases, voltage conversion losses dominate, but the valves become much less impactful.

Electrolyzer considerations

- Higher EZ operational pressure most negatively impacts both RFC RTE and specific energy.
- Thinner electrolyzer membranes benefit efficiency at lower pressures, but the increased reactant crossover at higher pressure must be negated by use of thicker membranes to maximize efficiency and make operation practical.
- Reduced electrolyzer operational temperature improves efficiency at the expense of increased radiator size.
- For a given RFC scale, there is an RTE benefit to specifying larger electrolyzers and recharging at higher rates, but only if the RFC can be coupled with a corresponding power source.