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In-Situ Electrochemical Generation and Utilization of Hydrogen Peroxide for Disinfection

Santosh H. Vijapur , Timothy D. Hall , EJ Taylor , Santosh R. More
Faraday Technology Inc., Englewood, OH 45315, USA

Jeffrey J. Sweterlitsch , Michael K. Ewert , Sarah L. Castro-Wallace
NASA Johnson Space Center, 2101 NASA Parkway, Houston, TX 77058, USA

Vicky Byrne
KBR, 2101 NASA Parkway, Houston, TX 77058, USA

Brandon J. Dunbar
GeoControl Systems, Inc., Houston, TX 77054, USA

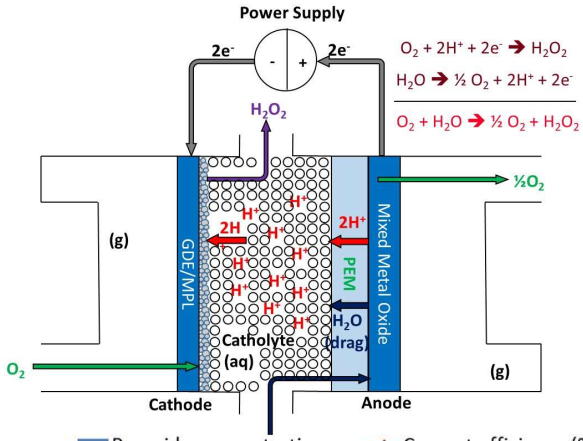
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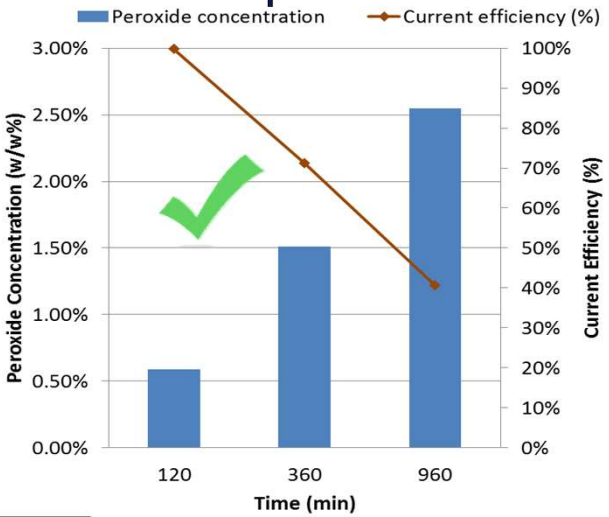
Hang N. Nguyen , Melanie J. Smith
JES Tech, Houston, TX 77058, USA

Big Picture

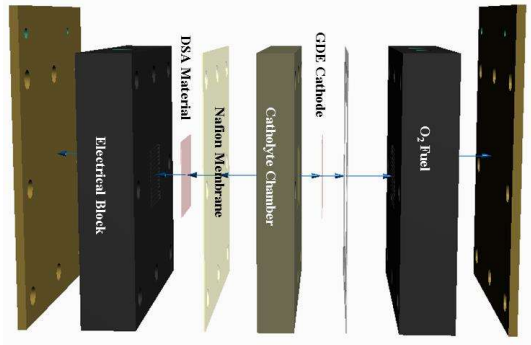
- Demonstration of a method to produce H_2O_2 On-Demand using available life support supplies of O_2 and water.

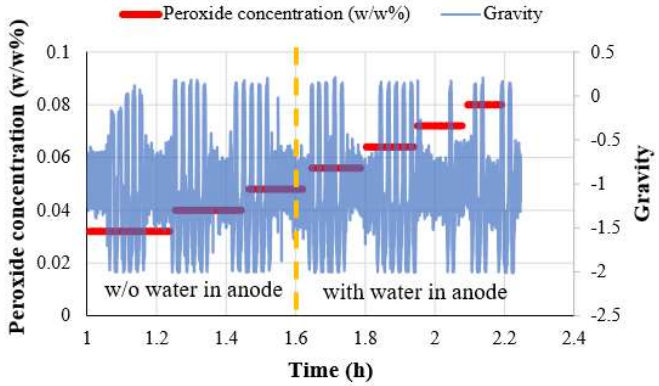
Phase I
(Proof of Concept)

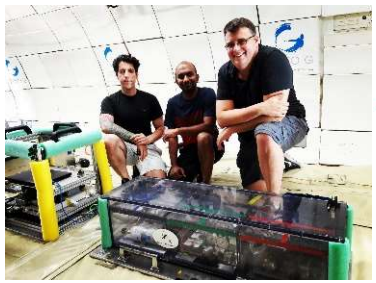




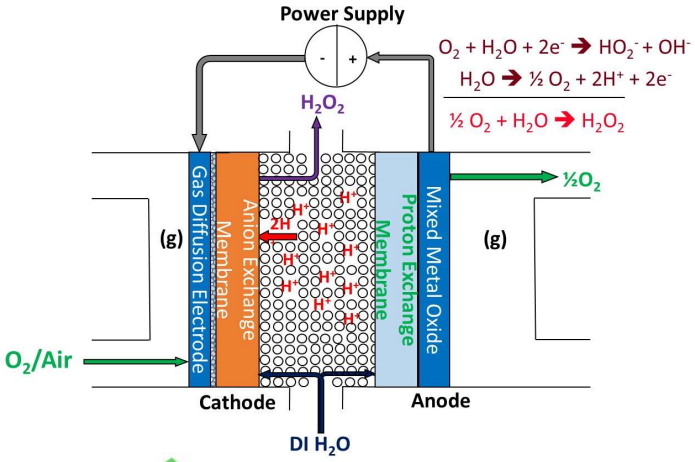
Phase II
(Initial Scale/
Zero G Demonstration)



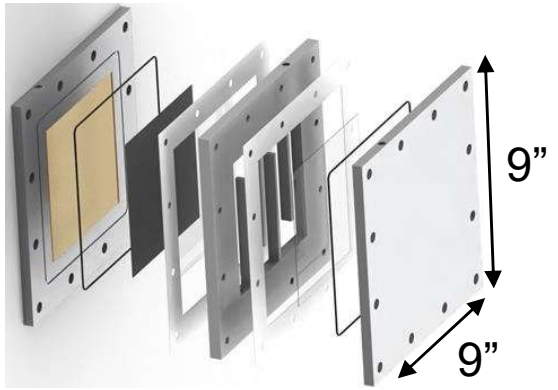




Phase III/IIE
(Mission Alignment/
System Scale and Deliver)



1L of 2 w/w% H_2O_2 per Day



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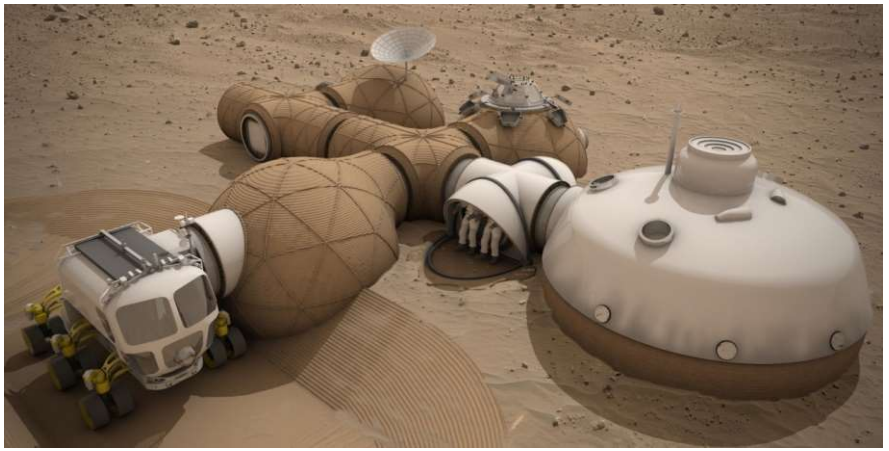
Space Challenges

International Space Station



nasa.gov

Potential Martian Habitat

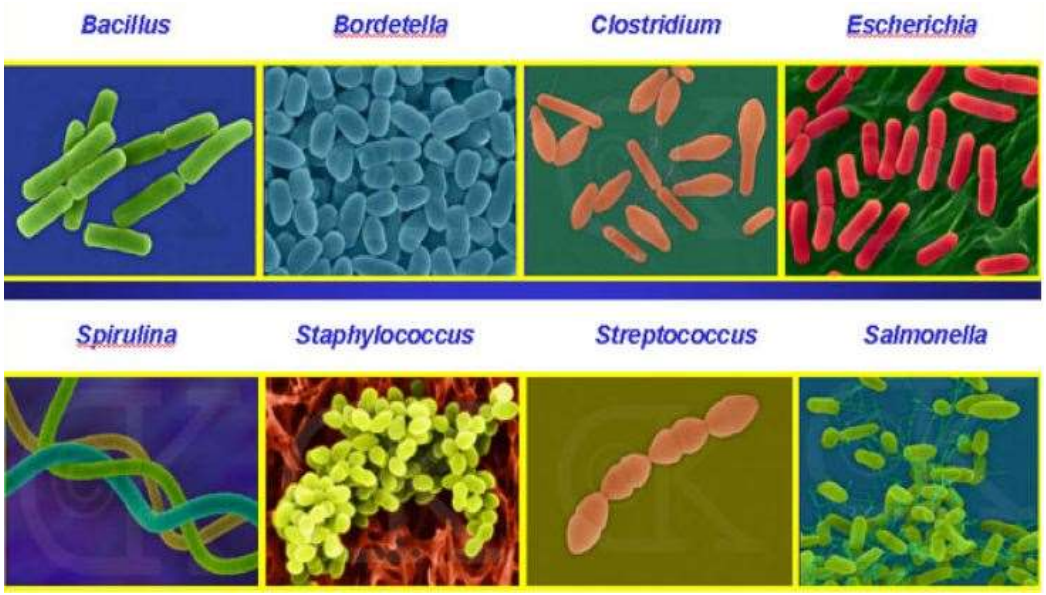


http://3dpchallenge.tumblr.com/post/128731340573/team-lavahive-awarded-third-place-lavahive-is-a

Novel technologies with limited earth support are required to enable energy-efficient maintenance of closed air, water, and waste systems in manned microgravity spacecraft habitats, like Mars.

Focus Problem

- One area of need for the interplanetary travel community is cleaning/sanitizing supplies to meet personal hygiene requirements
- Currently accomplished through the use of pre-packaged, disposable, wetted wipes, or ion exchange cartridges



http://hsc.sca.nsw.gov.au/biology/water-pathogens



"Chris Hadfield's Space Kitchen." Canadian Space Agency. Audiovisual content posted on Youtube.com. Online resource: https://www.youtube.com/watch?v=AZx0RIV0wss. Accessed 4 Jan 2016.

Opportunity

Develop efficient and non-toxic hydrogen peroxide generation device to provide necessary cleaning/sanitizing solutions for long term manned NASA Missions.

- *in-situ* system for on-demand peroxide generation
- utilize on-board resources for reducing pay-load



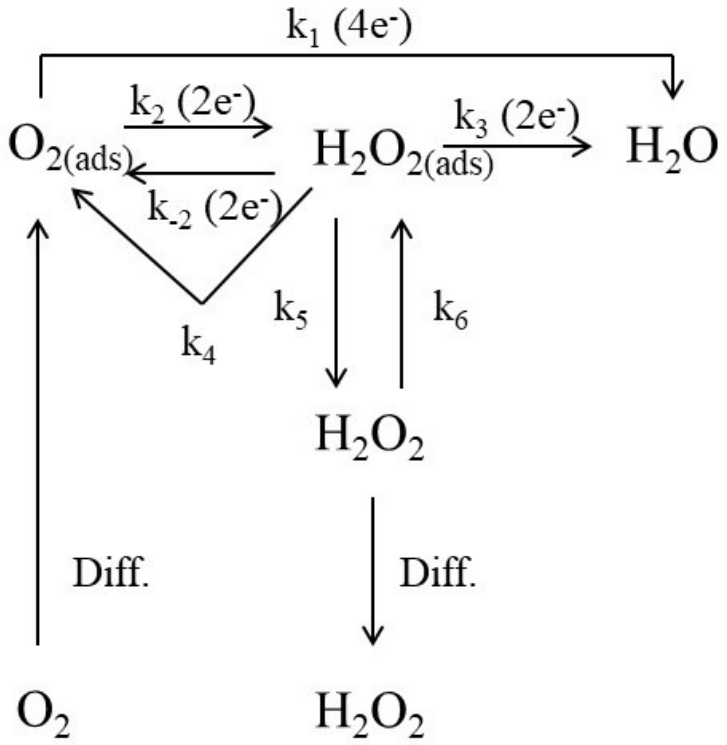
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NASA Peroxide Applications

System	Application	Is 3 w/w% H_2O_2 adequate?	Quantity Needed for a crew of 4 (ml)	Need Interval
Habitation	Disinfecting wipes	Y	525	regular - weekly
Clothes Cleaning	Stain treatment	Y	25	occasional
Exploration Medical	Wound care	Y	120	occasional
Exploration Medical	Equipment disinfection	Y	120	occasional
Plant Growth	Equipment sanitization	Y	300 ml once every 28 days	regular - monthly
Class D Plant Chambers	Biofilm prevention in payload subsystems	Y	200 ml once every 150 days	regular
Water	Urine pretreatment	Y	16.5ml/flush*7flush/day *4crew=460 mL/day	regular - daily
Water	Wastewater biocide	Y		
Water - Bioreactors	Biofilm prevention; equipment sanitization of bioreactors	Y	300 ml+ once every 50 days	regular
Planetary Protection	Cleaning tools and instruments used to collect and study Mars material	TBD	TBD	TBD

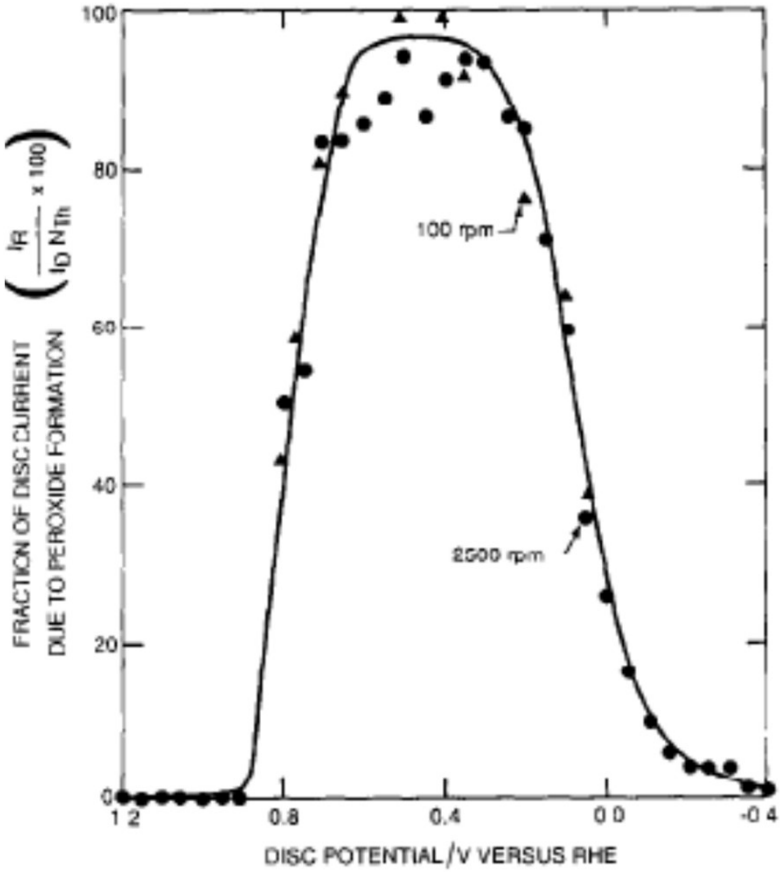
H_2O_2 Generation:
Oxygen Reduction Mechanism

O_2 Reduction Pathways



O_2 reduction on Au disc in alkaline solution (other catalysts include Carbon, BDD)

➔ 2 electron to H_2O_2



Vilambi and Taylor, "Quantitative detection of peroxide formation during oxygen reduction on platinum in alkaline media" E*lectrochimica Acta,* 34(10) 1449-1454 (1989).
Vilambi and Taylor, "CPRM: a new method for detection of peroxide formation during oxygen reduction using the rotating ring-disc electrode technique" *J. Electroanal. Chem.,* 270 61-77 (1989).

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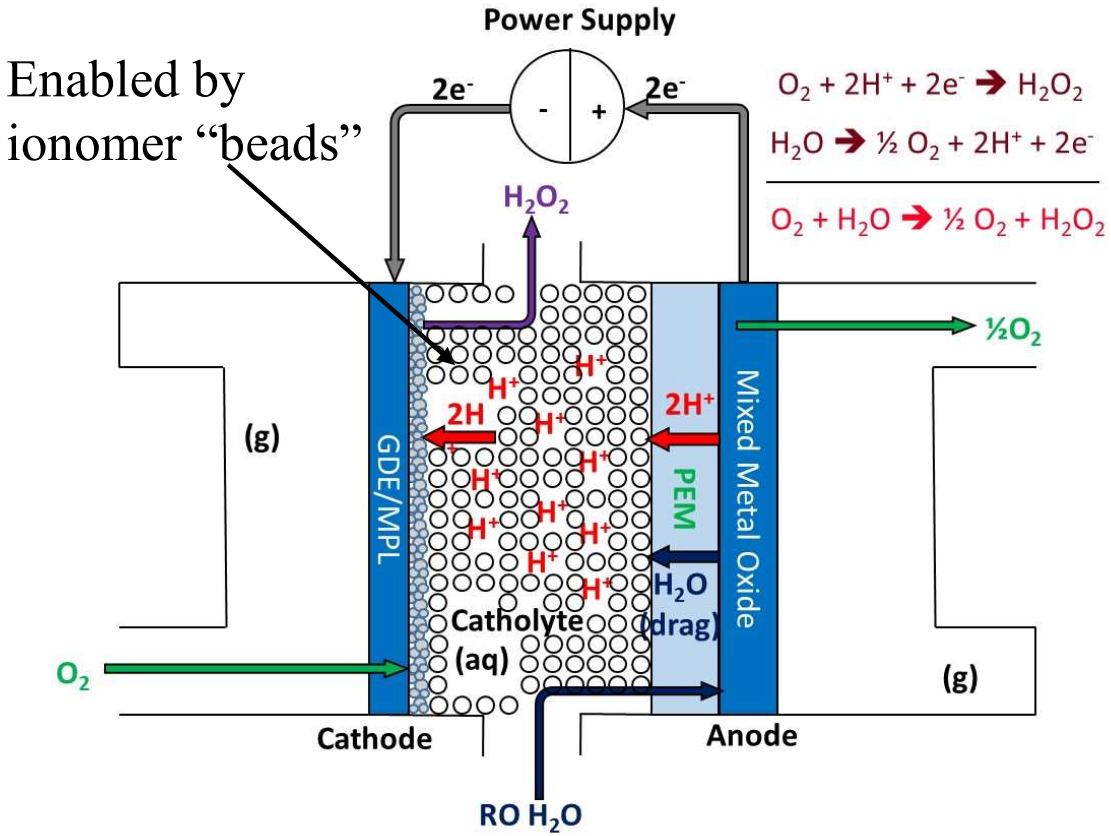
Available Resources on ISS

- Faraday Gen-1 system required electrolyte conductivity
- Water availability onboard ISS:
  - Conductivity, 2 – 3 μS/cm
  - pH 5.5 – 6.7
  - TOC - <0.18 – 2.5 mg/L.
- Pure Oxygen available onboard ISS but could use on board air supplies

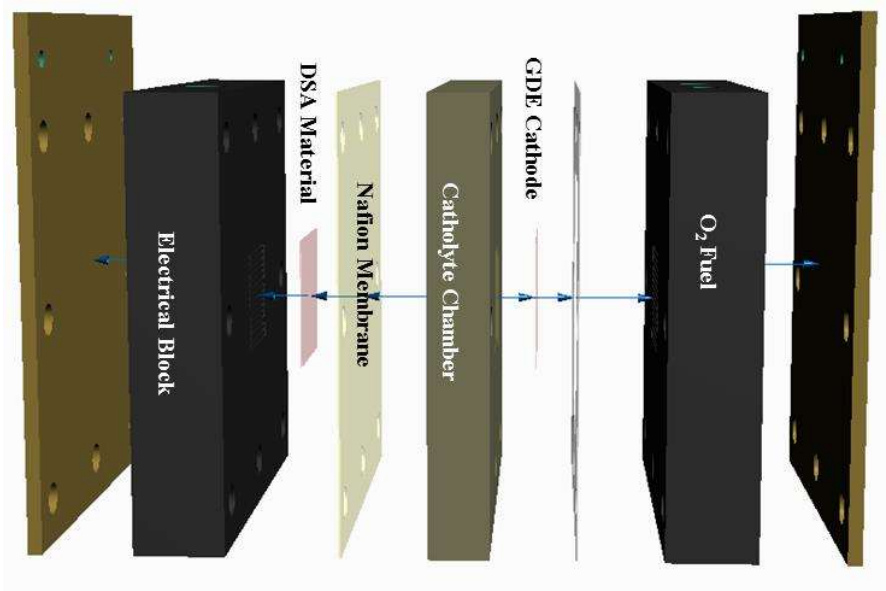
Potential water source for testing would be RO/DI water to mimic the ISS resource availability

Sweterlitsch, Jeffrey J., "RE: ISS water conductivity", Message to EJ Taylor. 14 May 2017

Peroxide Generation Unit



Peroxide Generation Unit (PGU)

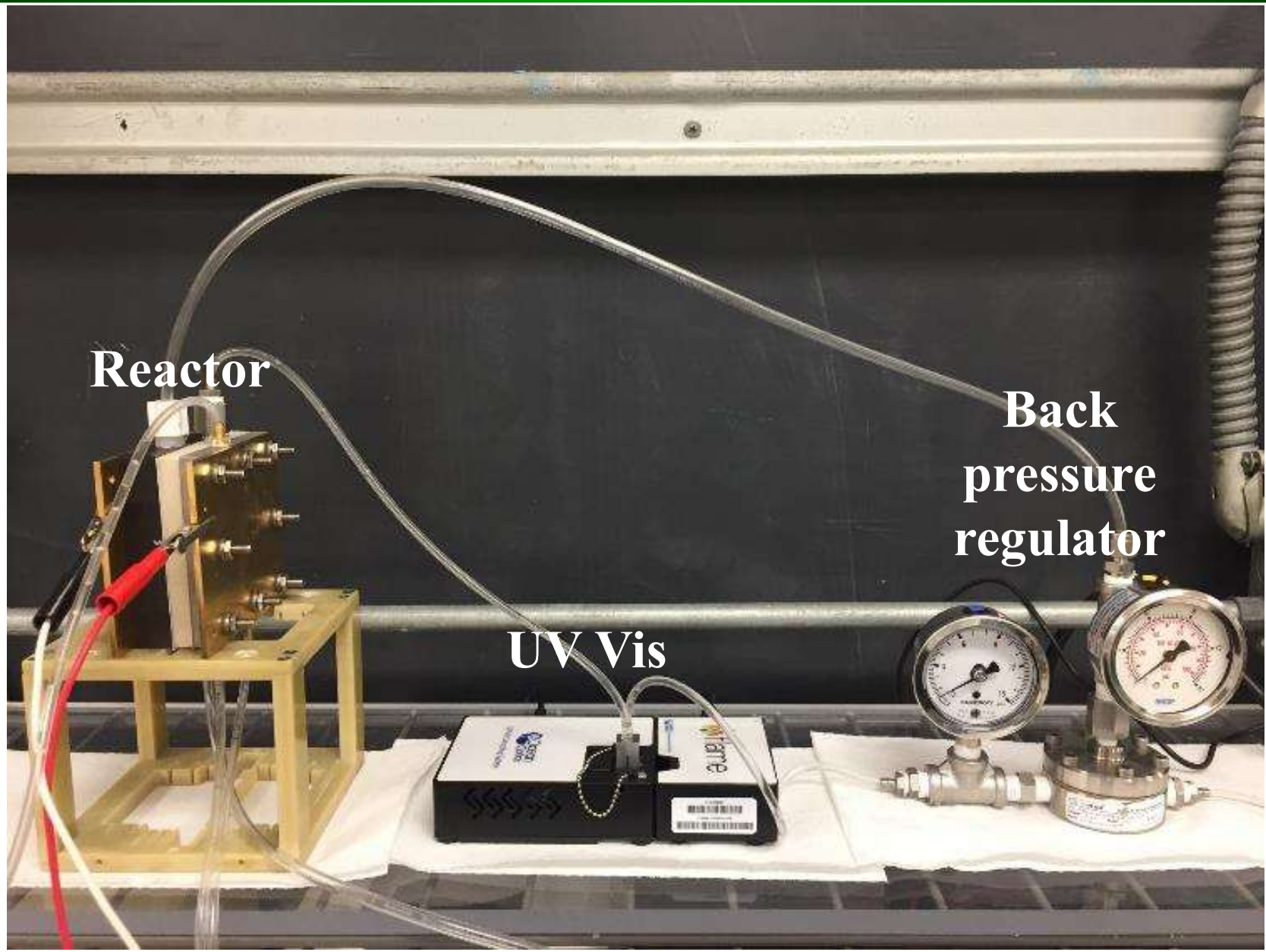


Ref: ICES-2019-38: Vijapur, Santosh, et al. "In-Situ Resource Utilization for Electrochemical Generation of Hydrogen Peroxide for Disinfection." 49th International Conference on Environmental Systems, 2019.

- Eliminates need for conductive electrolyte
- Peroxide generation with a low conductivity water input enabled by conductive ionomer "beads/resin"

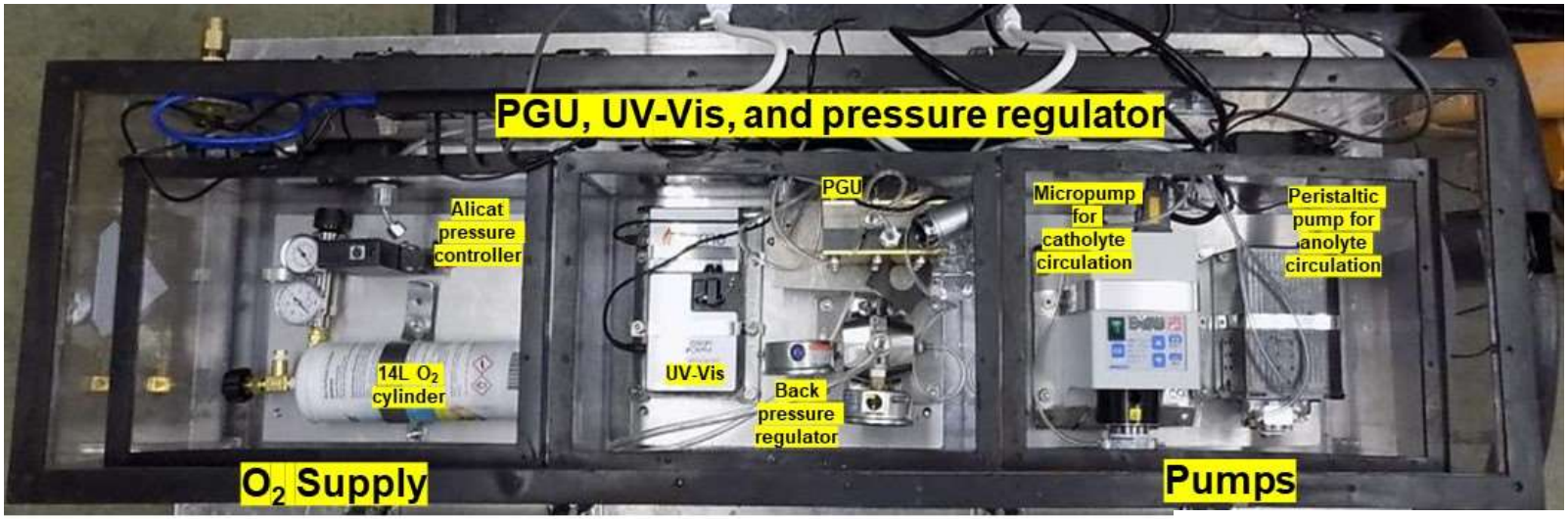
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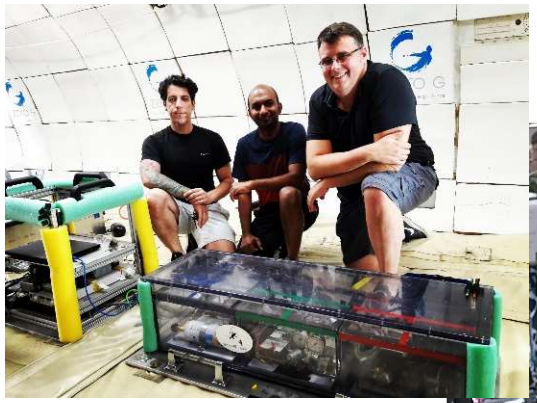
Peroxide Generation Laboratory Setup



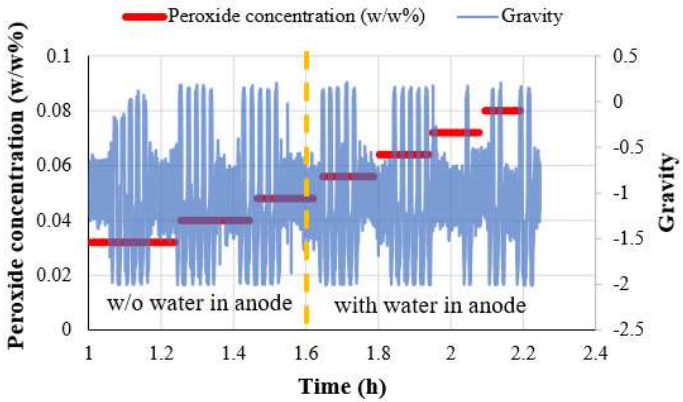
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Phase II:
Transition to Zero-Gravity Demonstration





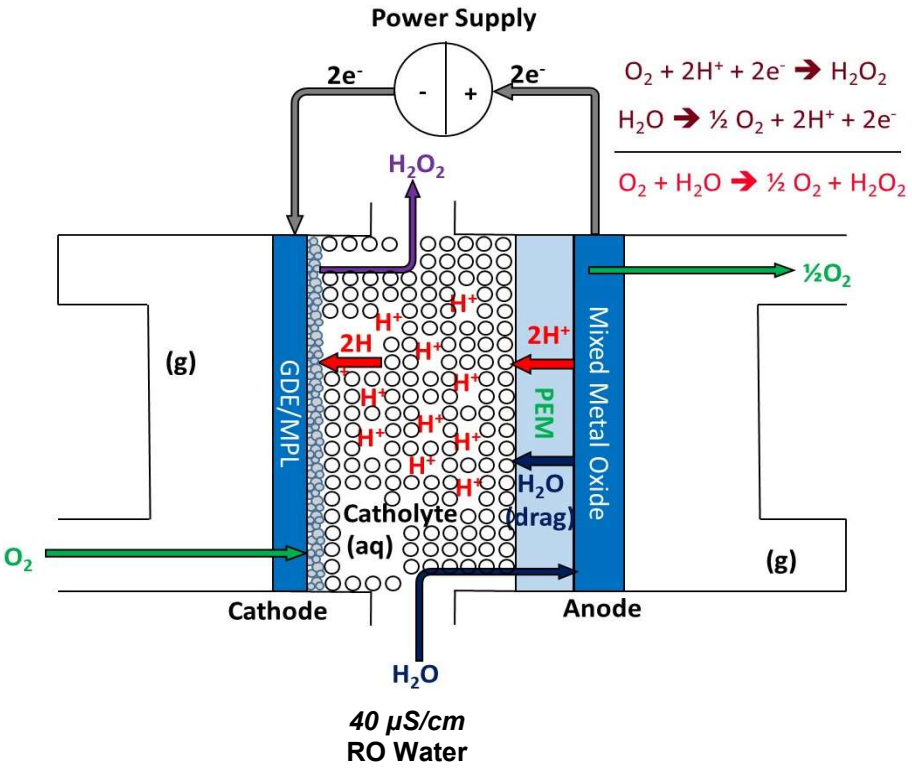




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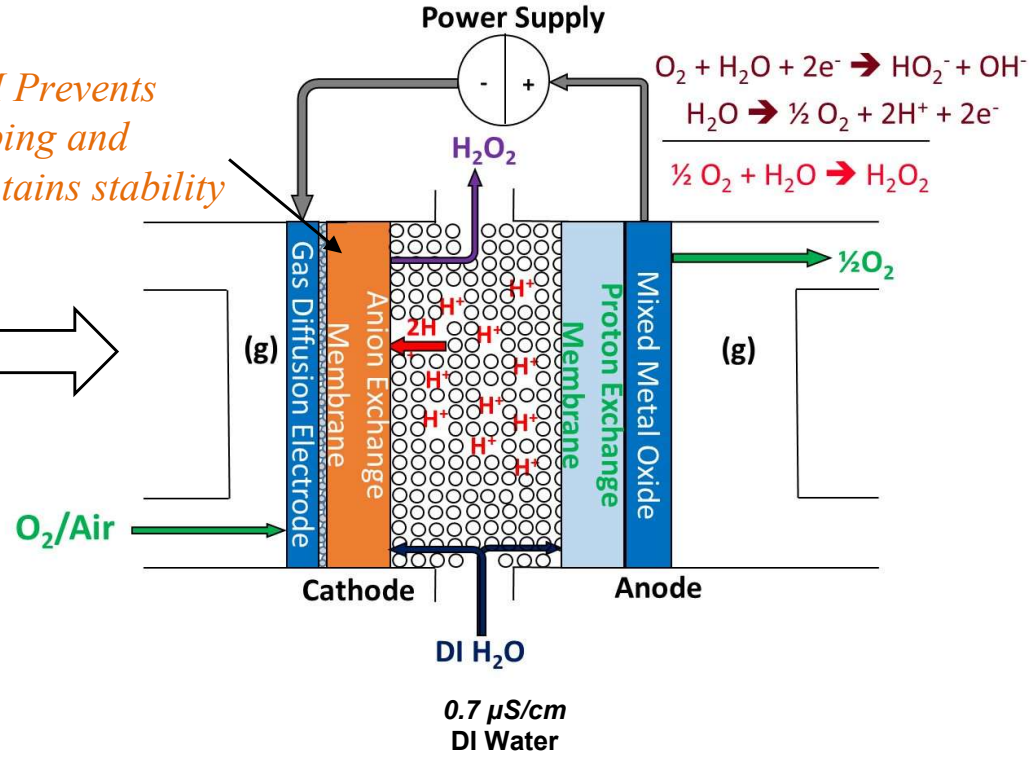
Phase IIE/III
Peroxide Generation Unit Transition

Phase II
Peroxide Generation Unit



Phase IIE/III
Peroxide Generation Unit

AEM Prevents weeping and maintains stability



Ref: ICES-2019-38: Vijapur, Santosh, et al. "In-Situ Resource Utilization for Electrochemical Generation of Hydrogen Peroxide for Disinfection." 49th International Conference on Environmental Systems, 2019.

Ref: ICES-2021-273: Vijapur, Santosh, et al. "In-Situ Resource Utilization for Electrochemical Generation of Hydrogen Peroxide for Disinfection." 50th International Conference on Environmental Systems, 2021.

Subscale Reactor:
Performance Overview

Electrolytes tested (50 mL per day)	Peroxide concentration (w/w%)			
	Oxygen		Air	
	0.5	6	0.5	6
DI water	✓ (3)		✓(4)	
DI water with 1 – 4 mg/L of iodine	✓(2)		✓(1)	
DI water with 200-400 ppb silver (from AgF)	✗		✗	
DI water with 200-400 ppb silver (from $AgNO_3$)	✗		✗	
0.2M Na_2SO_4	✓	✓ (6)	✓(2)	
RO water	✓(2)			
Tap water	✓ (3)			
Sodium chloride	✗			
0.05M Sodium pyrophosphate	✓ (3)			
0.2M Sodium pyrophosphate	✓ (3)			

(Maximum peroxide concentration observed)

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Subscale Reactor: Durability

- Demonstrated intermittent operation over one month to produce 50 mL/day of ~3 w/w% peroxide
- Two different reactor demonstration

Reactor 1

Day	Trial	Electrolyte	Trial length (h)	Peroxide Concentration w/w% by titration	Storage time before the trail
Day 1	1	0.05M $Na_4P_2O_7$	24	3.38	-
Day 3	2	0.05M $Na_4P_2O_7$	5	1.13	Overnight
Day 6	3	0.05M $Na_4P_2O_7$	5	1.05	Over weekend
Day 7	4	0.05M $Na_4P_2O_7$	5	1.29	Overnight
Day 8	5	0.05M $Na_4P_2O_7$	5	1.10	Overnight
Day 9	6	DI water	5	0.89	Overnight
Day 10	7	DI water	5	1.10	Overnight
Day 13	8	DI water	24	3.54	Over weekend
Day 21	9	DI water	5	0.87	Over a week
Day 22	10	DI water	24	3.21	Overnight
Day 29	11	DI water	5	1.1	Over a week
Day 30	12	DI water	24	2.4	Overnight

Reactor 2

Date	Trial	Electrolyte	Trial length (h)	Peroxide Concentration w/w% by titration	Storage time before the trail
Day 1	1	DI water	24	2.77	/
Day 2	2	DI water	24	2.74	/
Day 6	3	DI water	24	2.91	Over weekend
Day 7	4	DI water	24	2.77	/
Day 9	5	DI water	24	2.41	Overnight
Day 13	6	DI water	24	2.06	Over weekend
Day 14	7	DI water	24	1.82	/
Day 16	9	DI water	24	2.81	/
Day 20	10	DI water	24	1.79	Over weekend
Day 22	11	DI water	24	1.62	Overnight

Based on these results, we determined we were ready to move to alpha-scale reactor

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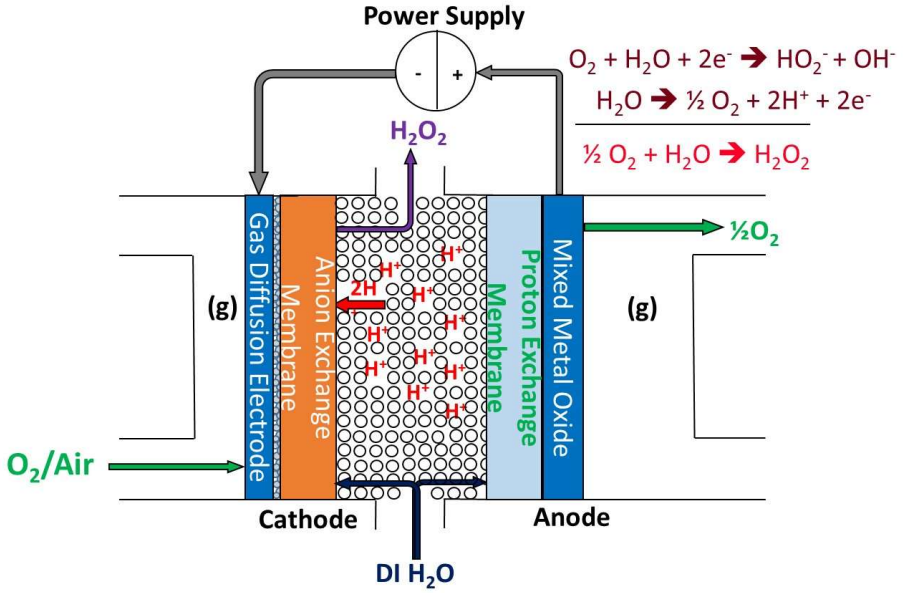
Phase IIE & III

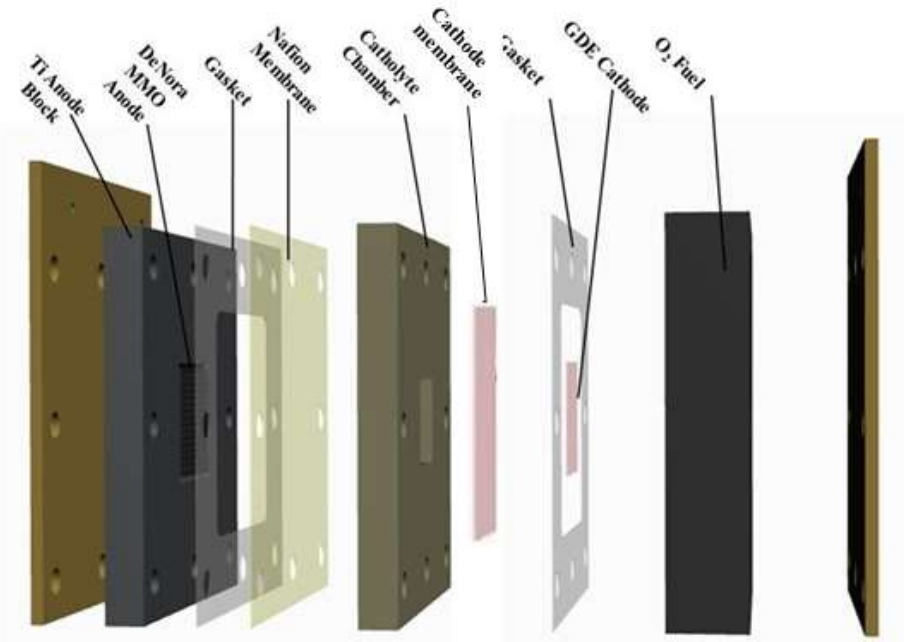
– Alpha Scale Reactor

Alpha Scale System: Design

- Goal of 1 L per day of 3 w/w% H_2O_2
  - **Assume:** Electrode area scales linearly

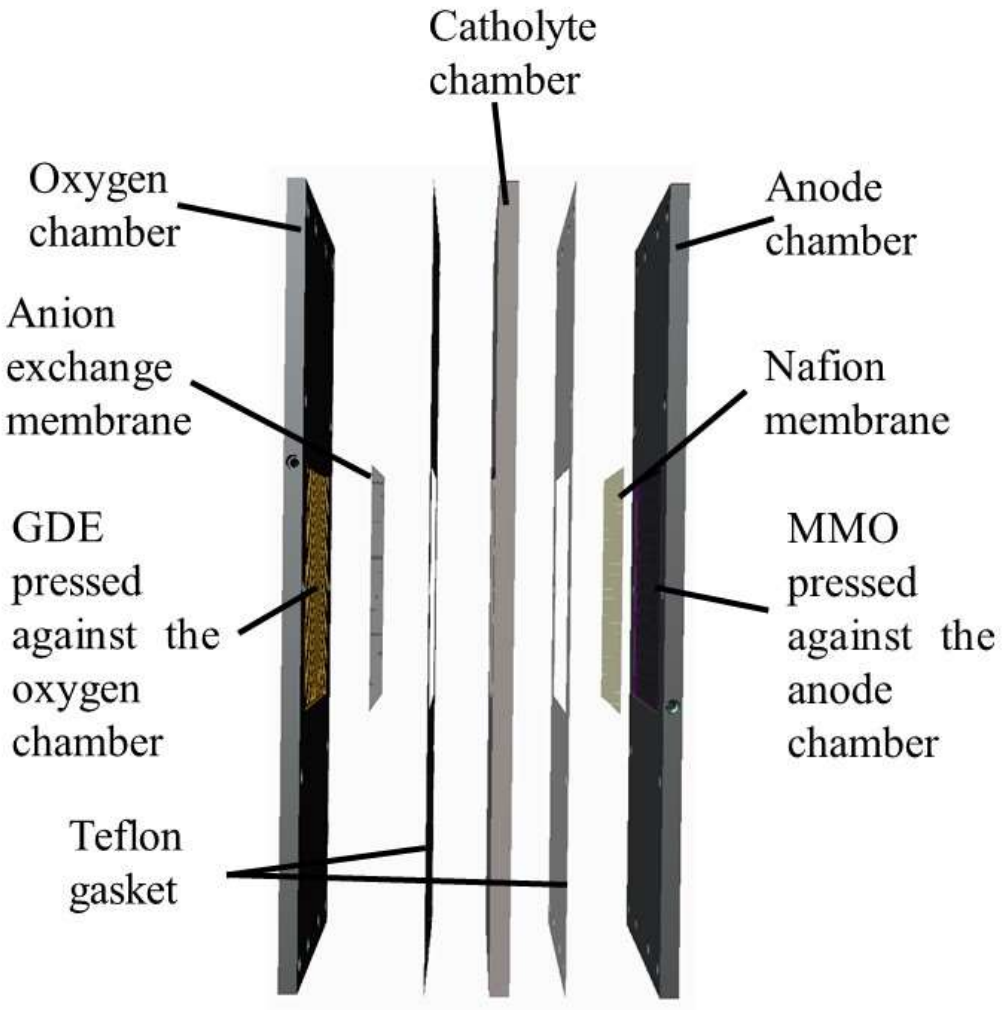
Reactor Scale	Peroxide generation capacity (mL of 3 w/w%)	Electrode Area (in^2)
Sub-Scale	50	1
Alpha-Scale	1000	25



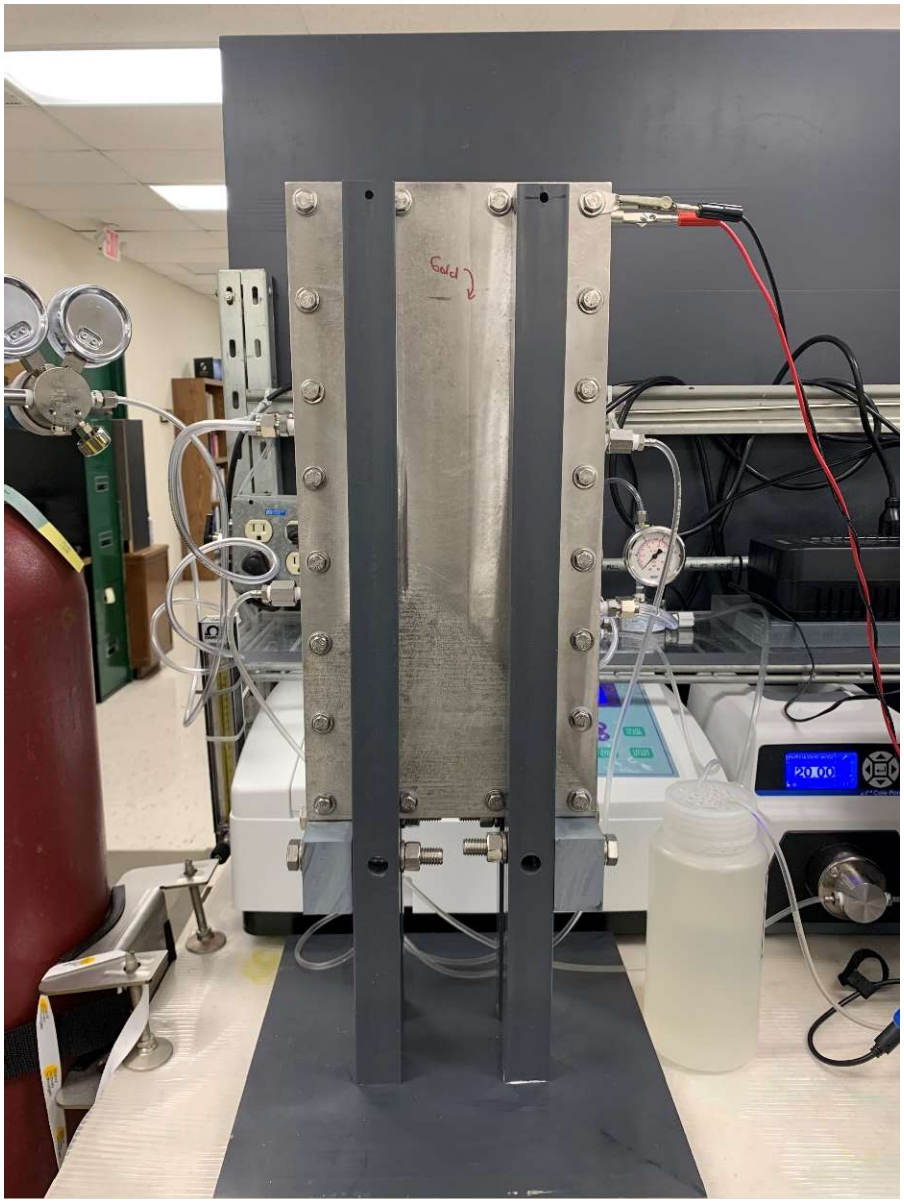


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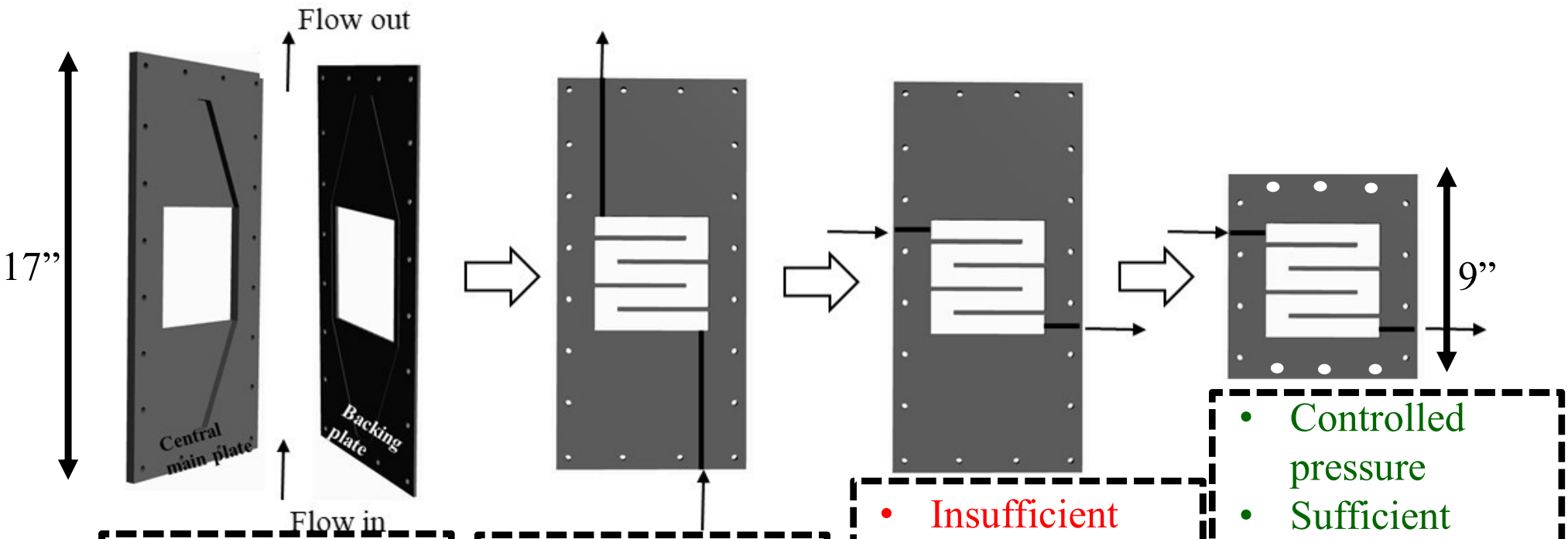
Alpha Scale System:
Build



Exploded view of 25 in^2 alpha-scale reactor



Alpha Scale System:
Design Modifications

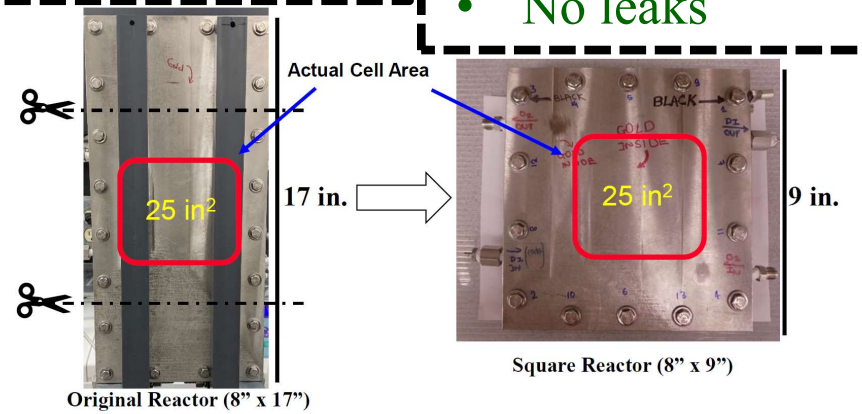


- High pressure head
- Insufficient compression
- Leaking

- High pressure head
- Insufficient compression
- Leaking

- Insufficient compression

- Controlled pressure
- Sufficient compression
- No leaks



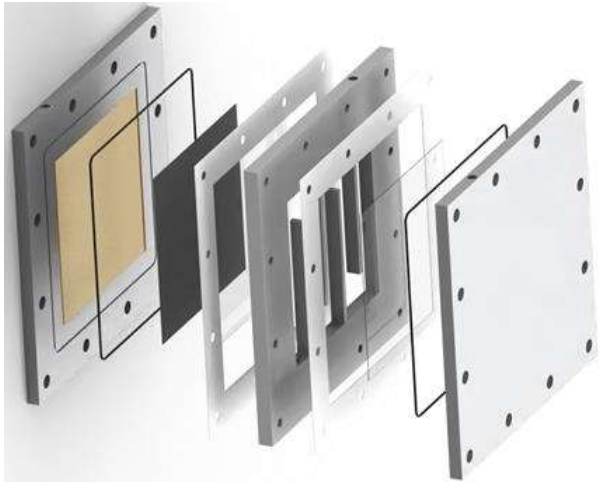
Alpha-scale reactor:
Performance and Durability 2 w/w%

Performance

Electrolytes tested	Peroxide concentration (w/w%)					
	Oxygen			Air		
	0.5	2	6	0.5	3	6
Alpha-scale reactor (25 in^2) with 1L per day						
DI water	✓	✓				

Durability (when generating H_2O_2 concentration lower than 2 w/w%)

Date	Trial	Electrolyte	Applied current (A)	Reaction time (h)	Peroxide Concentration w/w% by titration
Day 1	1	DI water	1	24	0.7
Day 2	2	DI water	2	24	1.2
Day 6	3	DI water	2.5	24	1.1
Day 15	4	DI water	1.4	24	1.7
Day 16	5	DI water	1.6	24	1.6

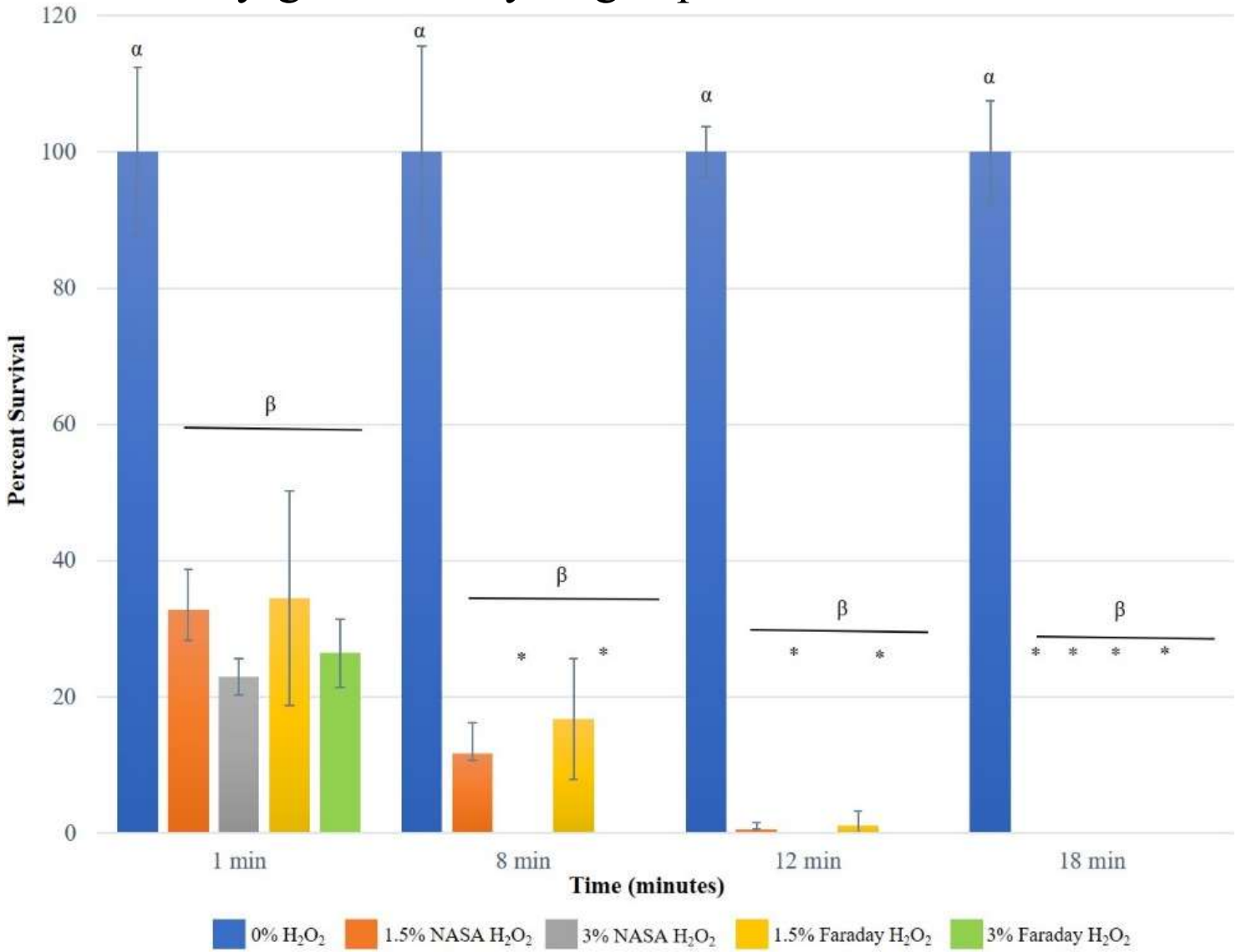


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Disinfection Demonstration

H_2O_2 Effectiveness at Disinfection

NASA evaluated Faraday-generated hydrogen peroxide as a disinfectant



Percentage survival of microbial consortium following hydrogen peroxide challenge

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Wipes Demonstration

- NASA supplied
  - zip-lock bag for demonstration
  - 10 dried commercial wipes

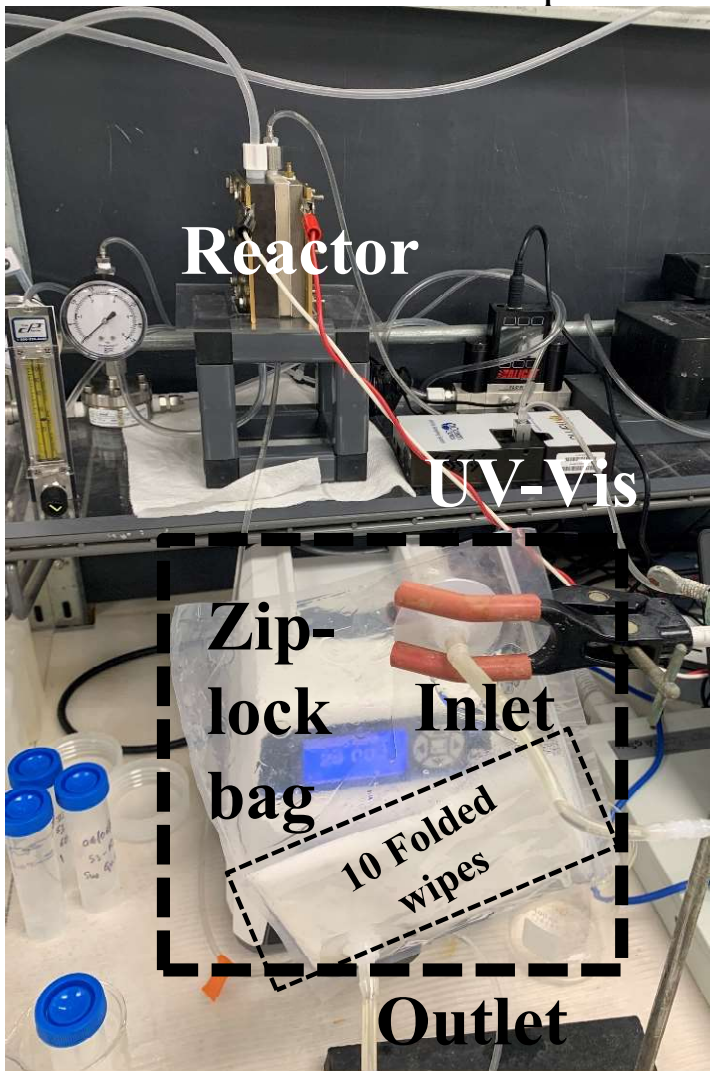
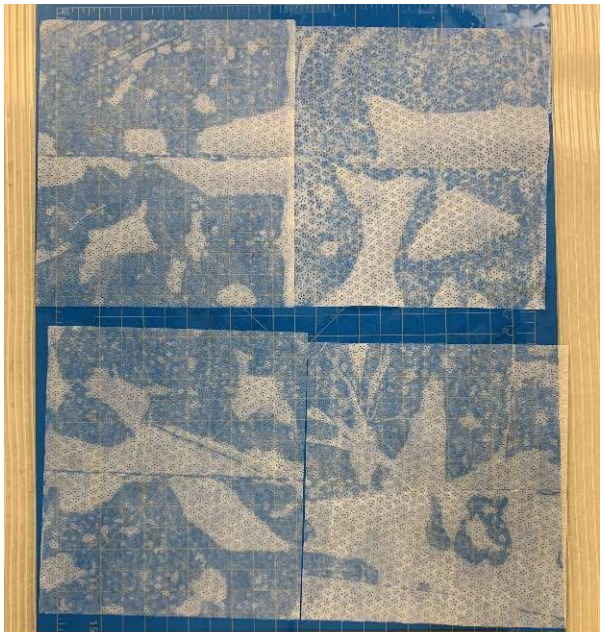


Image of wetted wipes



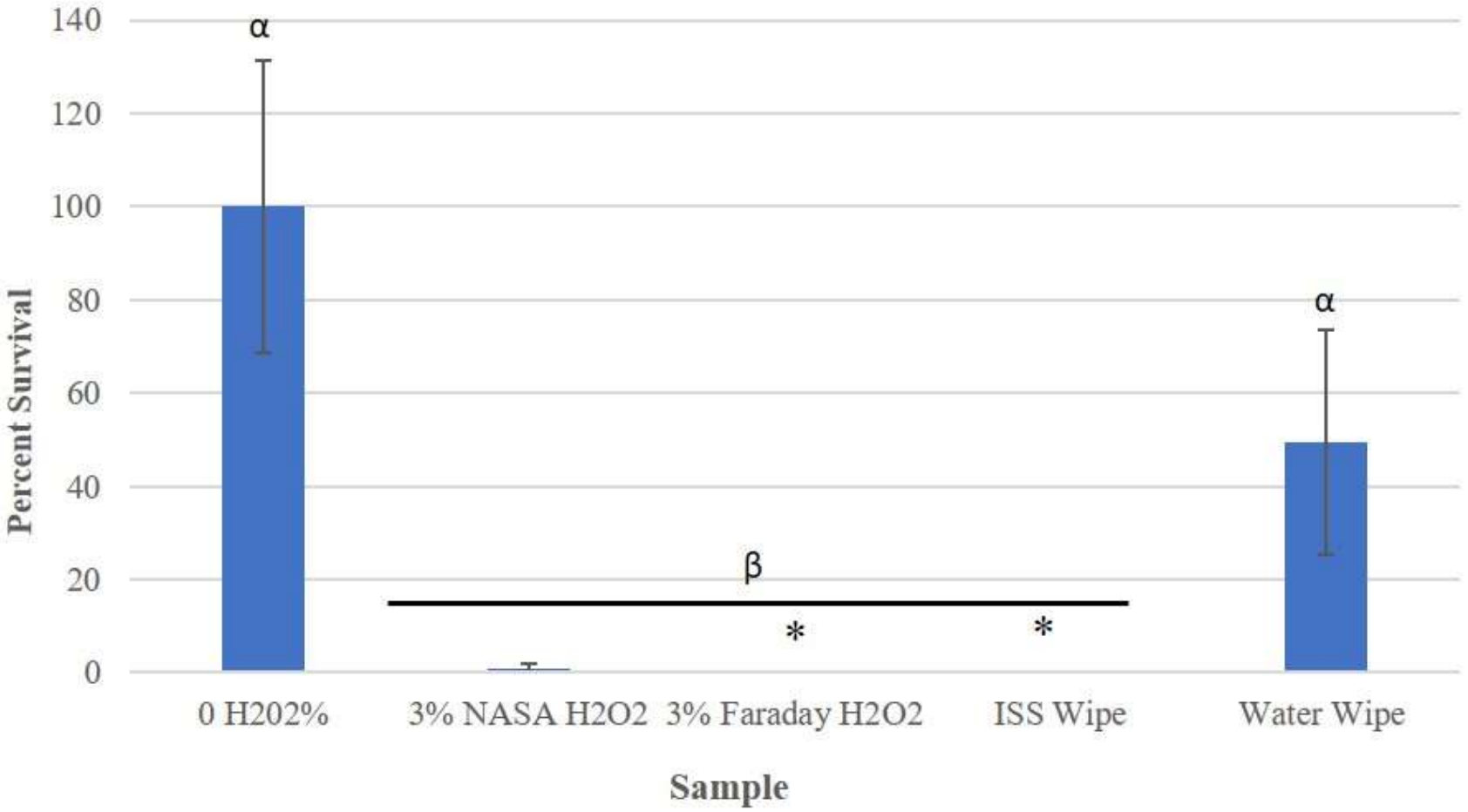
Solution from bag



- 1 h operation
- 80 mL DI water required
- ~0.1w/w% H_2O_2 generated
- All 10 wipes wetted
- Foaming observed during processing?
- Couldn't run longer due to foaming issues

Microbial Control Property Characterization

NASA evaluated Faraday-generated hydrogen peroxide as a disinfectant



Percentage survival of microbial consortium on coupons following wiping

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Microbial Control Property Characterization

CFU recovered following disinfection of environmental surfaces

	ISS Wipe		Faraday 3% Wipe	
	Bacteria Recovered (CFU/25 cm^2)	Fungi Recovered (CFU/25 cm^2)	Bacteria Recovered (CFU/25 cm^2)	Fungi Recovered (CFU/25 cm^2)
Toilet Seat	0	0	0	0
Lunch Table	0	0	0	0
Lab Bench space	0	0	0	0
Restroom Counter	0	0	0	0
Cubicle 1112D	0	0	0	0
Huddle Room 1116	0	0	0	0
Breakroom Counter	0	0	0	0

"Faraday generated hydrogen peroxide would be an efficient alternative for disinfection of ISS surfaces"

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Summary

- Designed system to generate H_2O_2 with available life support supplies
- Built sub-scale peroxide generation unit
  - 50 mL/day up to ~3 w/w% H_2O_2
  - Demonstrated 30 day system operational stability
- Built alpha-scale peroxide generation unit
  - ½ L/day up to ~3 w/w% H_2O_2
  - 1 L/day up to ~2 w/w% H_2O_2
  - Demonstrated 16 day system operational stability
- Faraday's H_2O_2 efficient alternative for disinfection on ISS
  - 1 min: 74% killing efficacy
  - 12 min: 99% killing efficacy
- Sub-scale (qty. 1) and alpha-scale (qty. 2) systems delivered to Johnson Space Center

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The financial support of NASA Contract No. NNX16CA43P, NNX17CJ12C, and 80NSSC20C0070 is acknowledged.

Special thanks to all our team members for their support

THANK YOU FOR YOUR ATTENTION!
QUESTIONS?

Contact Information:
Santosh Vijapur, Tim Hall, or Maria Inman
Ph: 937-836-7749

Email: santoshvijapur@faradaytechnology.com
timhall@faradaytechnology.com
mariainman@faradaytechnology.com