Lynntech

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Desalination Batteries for Microgrid Energy Storage and Potable Water Production

Project Overview 1/31/23

Contract No: N39430-22-C-2410
Contract Duration: May 30, 2022 – May 29, 2023
TPOC: Kyle Lawrence
PI: Jeff Parkey

About Lynntech

- **Mission:** Nurture and harvest scientific creativity to produce life changing technologies
- **Company**
  - Founded in 1987
  - 100 employees (30% PhDs)
  - 170,000 sq. ft facility in College Station, TX
- **Experience**
  - Material, device, systems-level research and development
  - Low rate initial production and scale-up
  - Working with prime contractors
- **Proven track record of moving technology to market**
  - Success in commercial ventures (sales, spin-offs, licensing)
- **2016 Tibbetts Award winner for outstanding contribution**
  - Of the 47,000 SBIR companies in US, only 37 received Tibbetts award for excellence

Recent Transition Successes

FBAT
Flight Breathing Awareness Trainer

ODS On-Demand™ Systems Inc.

TRIAD-MP™

Licensed Disinfection/Sterilization Technologies

Water Pik Aquia

Stryker Sterizone VP4

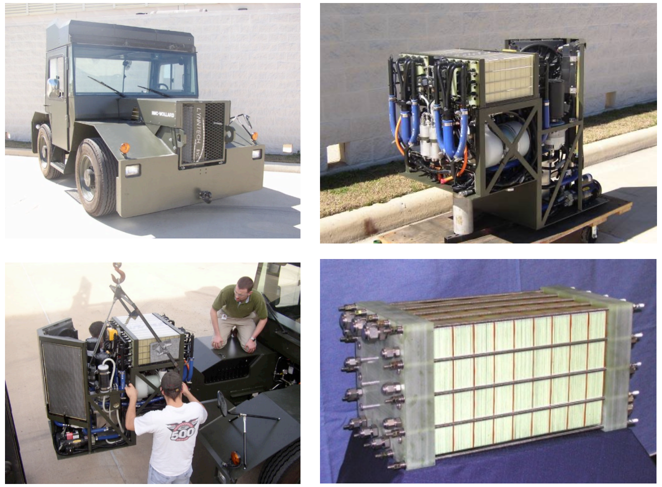
Electrochemical Systems Developed by Lynntech

Portable Soldier Power

Medical Applications – Drug Infusion Pump

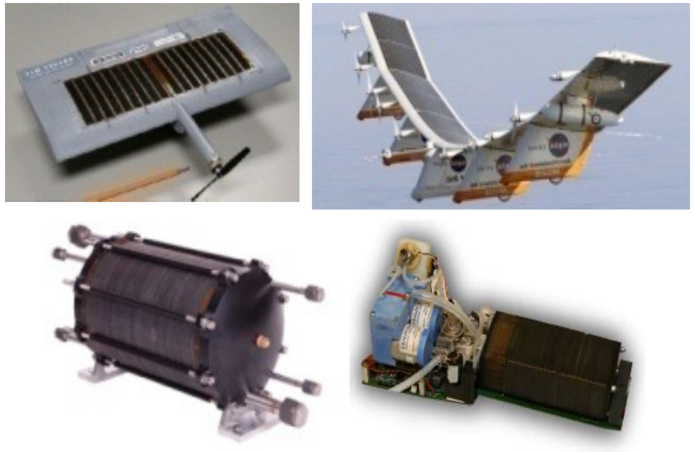
Fuel Cell Test Stations – Lynntech spin off

Fuel Cells - Tactical Vehicles



Unmanned Underwater Vehicle Power Systems

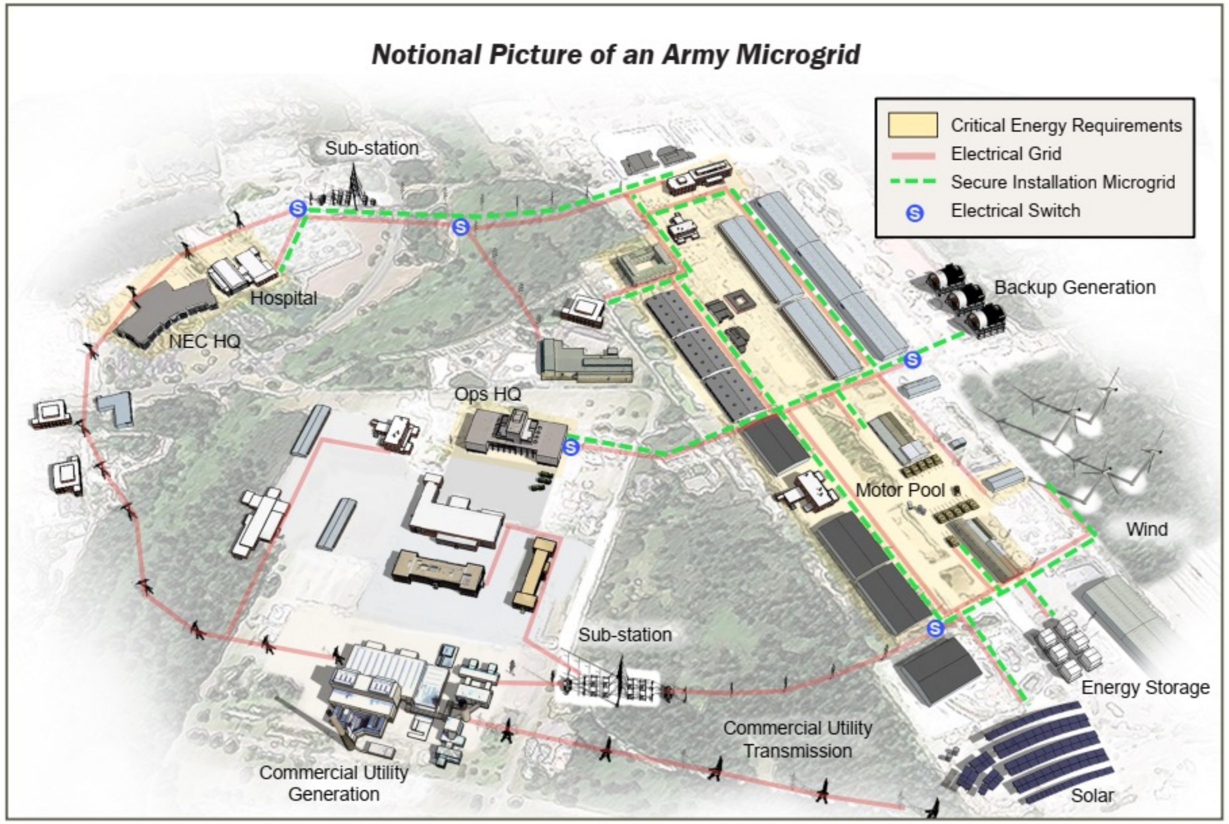
Aerospace Applications

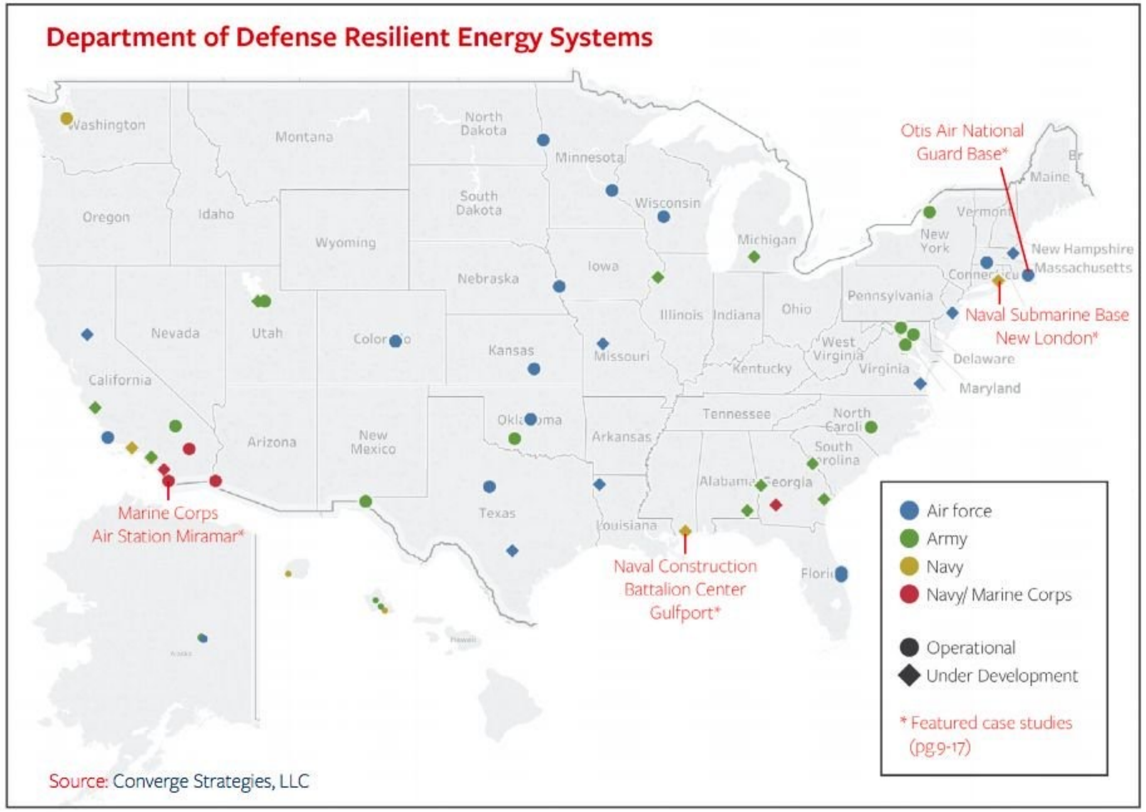


NASA Oxygen Concentrator

Fuel Cell Tailgate Genset

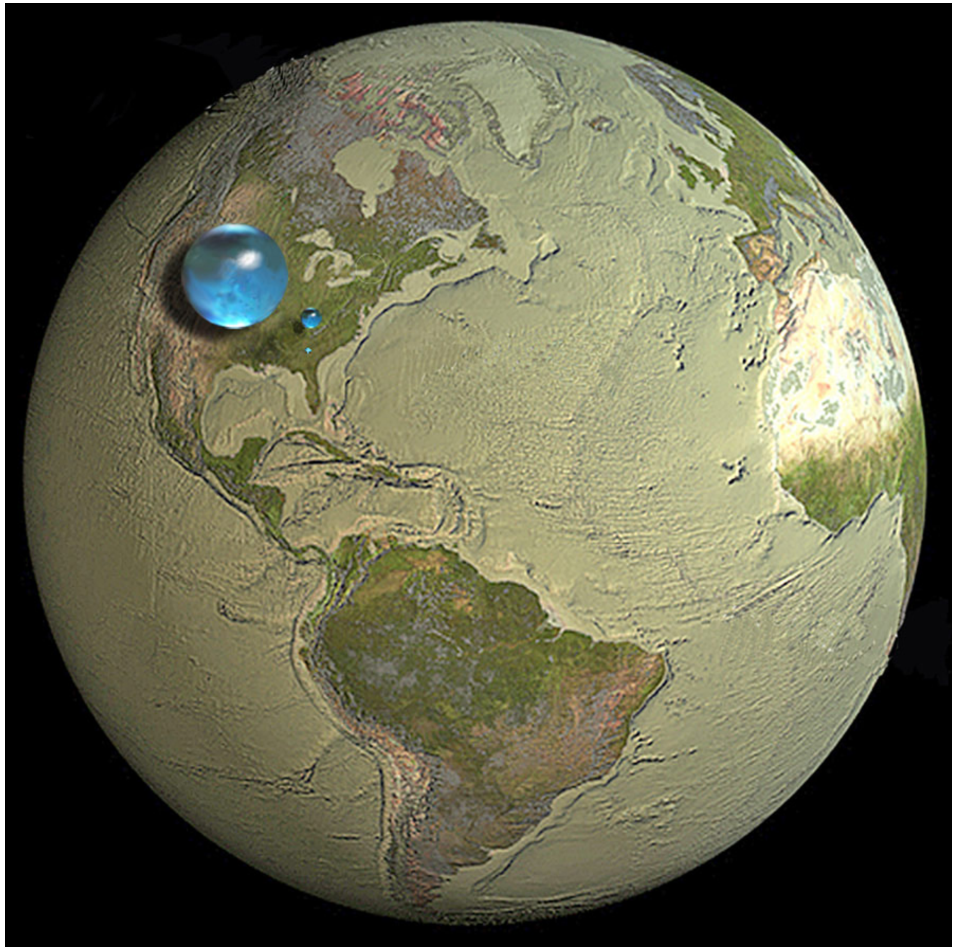
DoD Microgrids and Energy/Water Resiliency

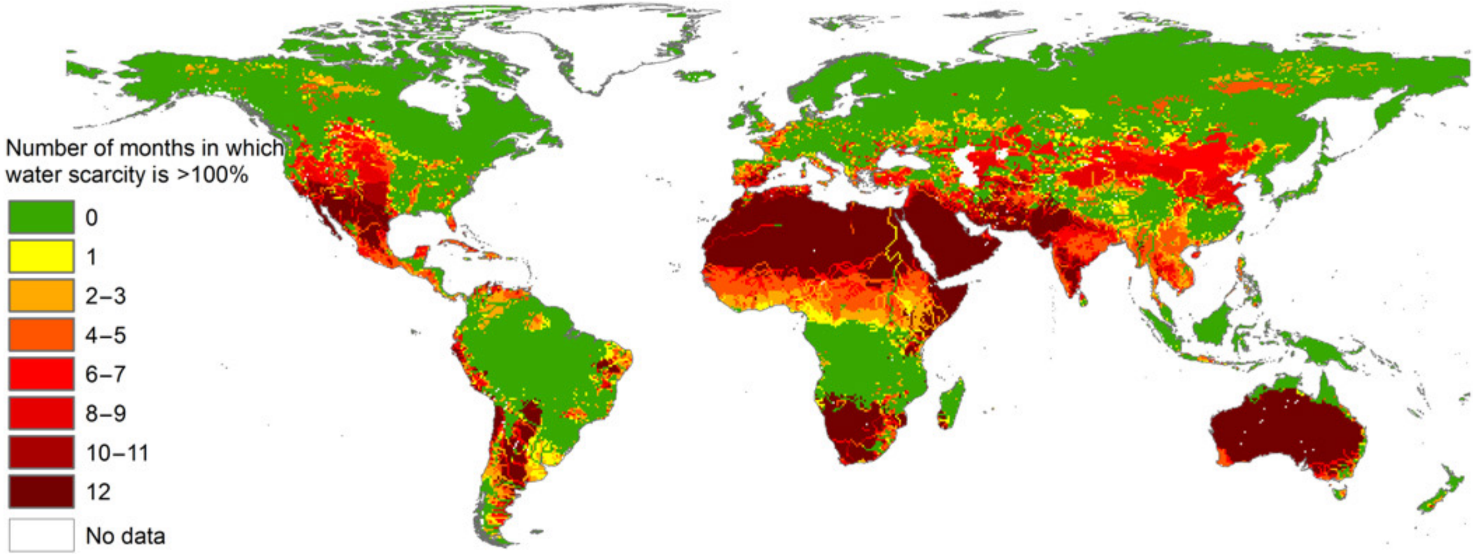




- Lot of focus on energy resiliency for the DoD using microgrids, renewable energy, etc
- Far less focus on water resiliency although energy/water are very interdependent
- Long-duration energy storage remains a key technical challenge

Need for Desalination





- Easily accessible freshwater (rivers, lakes, swamps)
  - <0.3% of world's freshwater supply
  - 0.014% of the world total water supply
- Most groundwater is saline (55%)

Current Desalination Technologies

- Reverse osmosis is the current gold standard process
- Energy intensive – 5 Wh/L at large scale (20% efficiency)
- Only viable when co-located with cheap energy source (typically hydrocarbon)
- Energy is ~50% of O&M costs
- Environmental
  - Brine discharge
  - CO_2 related to power production

Carlsbad Desalination Plant - California

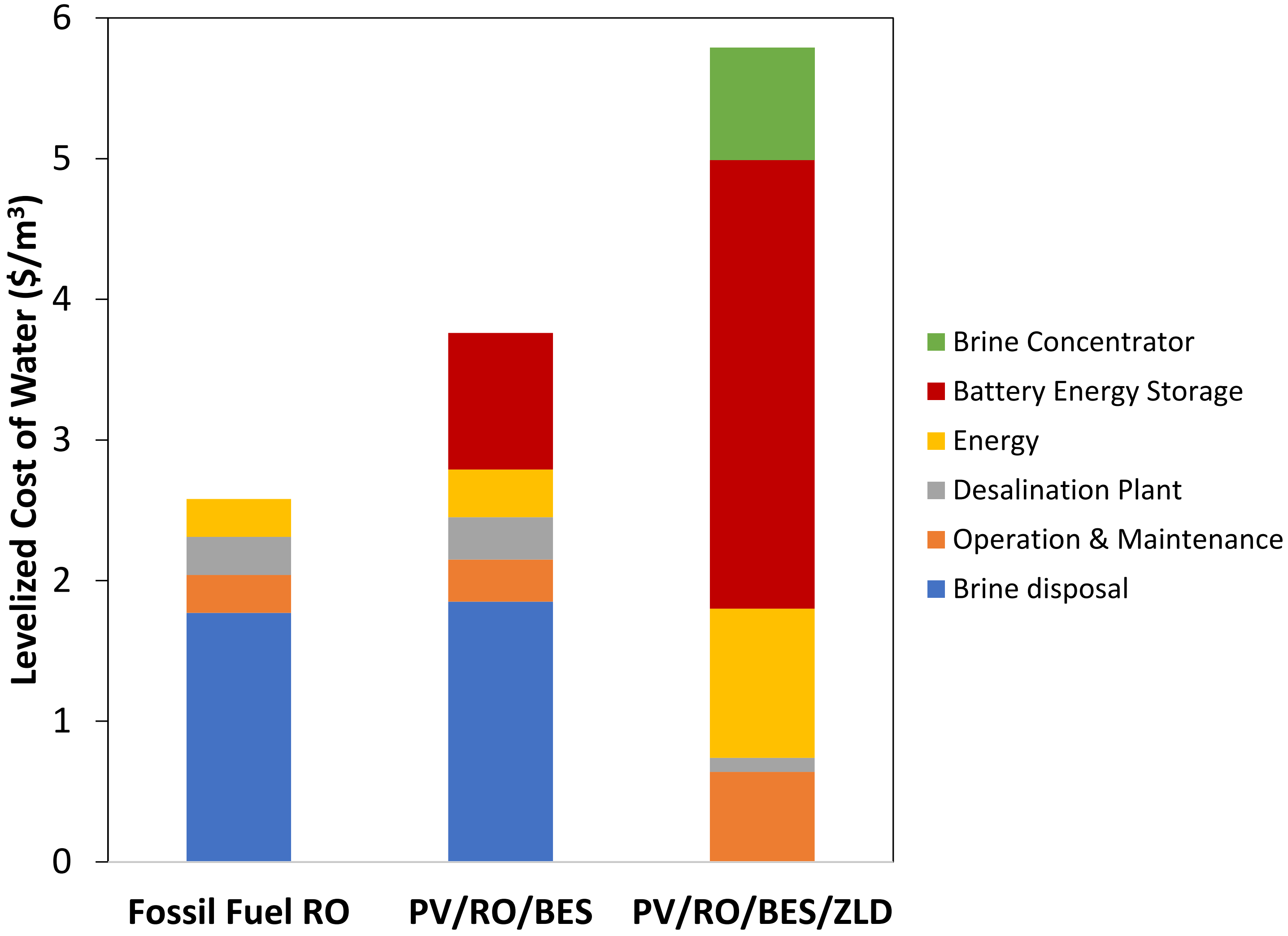
https://wcponline.com/2009/01/10/green-desalination-carlsbad/

Desalinating 1,000 m^3 consumes 37 barrels of crude oil → 10 tons of CO_2 emissions

Alkaisi, A.; Mossad, R.; Sharifian-Barforoush, A. A Review of the Water Desalination Systems Integrated with Renewable Energy. *Energy Procedia* **2017**, *110*, 268–274.

Current Costs for Renewable Energy Powered Desalination

- Recent study compared costs for multiple scenarios
  - Fossil fuel powered reverse osmosis plant (baseline)
  - PV-powered RO w/ Li-ion battery energy storage and brine disposal (PV/RO/BES)
  - PV/RO/BES w/ ZLD brine concentrator
- **BES is the major cost driver for RE powered desalination**



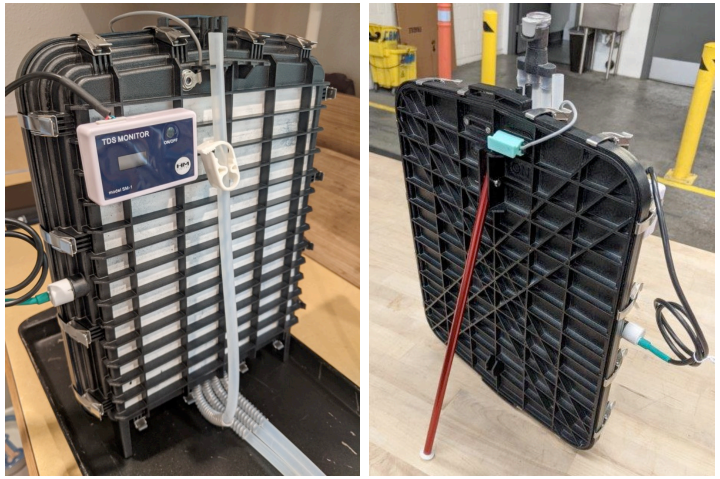
Data adapted from: A. K. Menon, M. Jia, S. Kaur, C. Dames, R. S. Prasher, Distributed Desalination using Solar Energy: A Technoeconomic Framework to Decarbonize Nontraditional Water Treatment. iScience, 105966 (2023).

Lynntech's Desalination Battery Technology

- Originally developed under DARPA project (2016-2019)
- Integrates electrodialysis into a battery to desalination during discharge
- Focus was on small, light systems for individuals/small groups
- Mg/Air battery chemistry
  - Non-rechargeable
  - High energy density → lightweight for man-portable applications

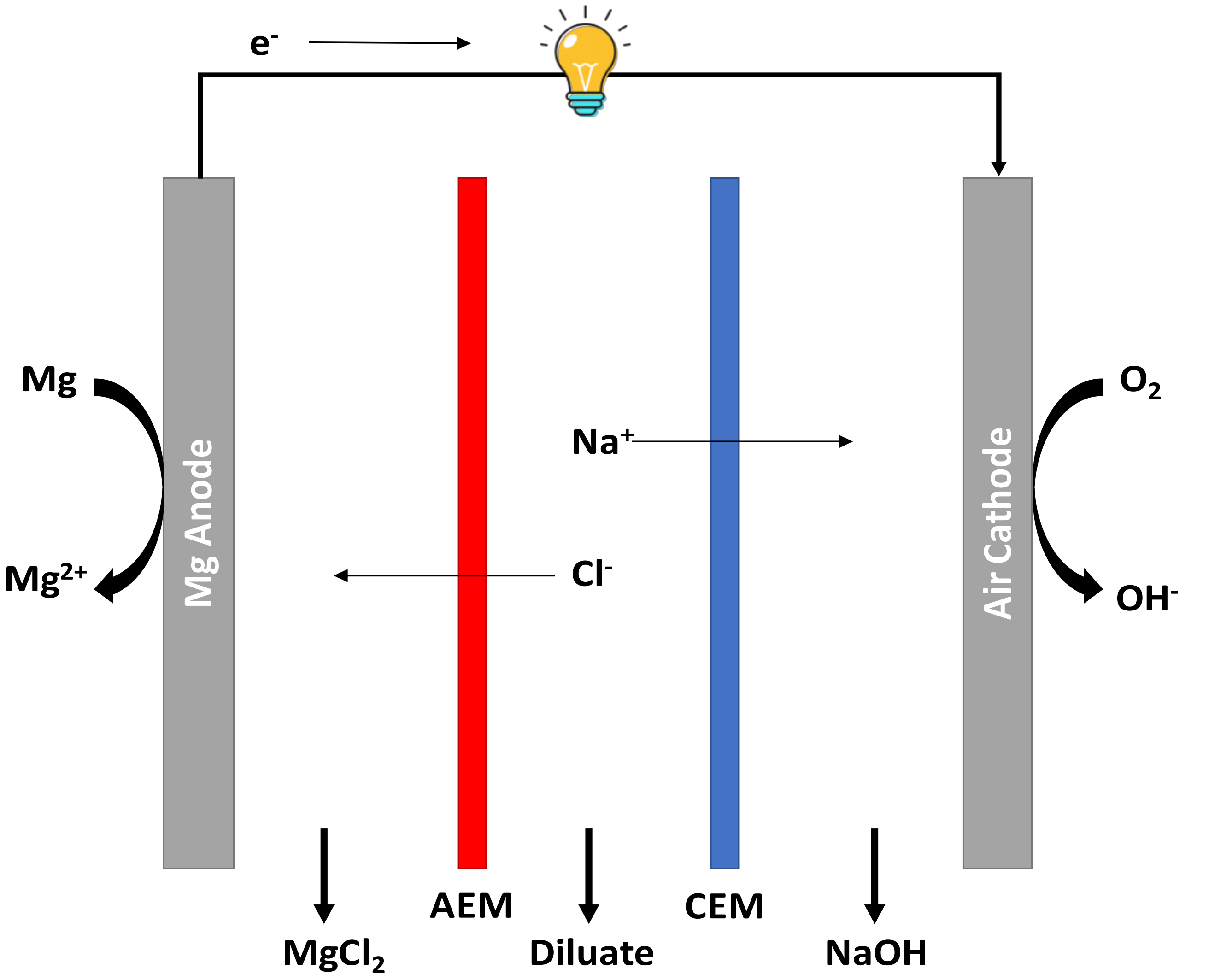
DARPA 5 L/hr System (Seawater)

Natick Individual Soldier 1 L/hr Desal Battery (Brackish)



Lynntech's Desalination Batteries – How They Work

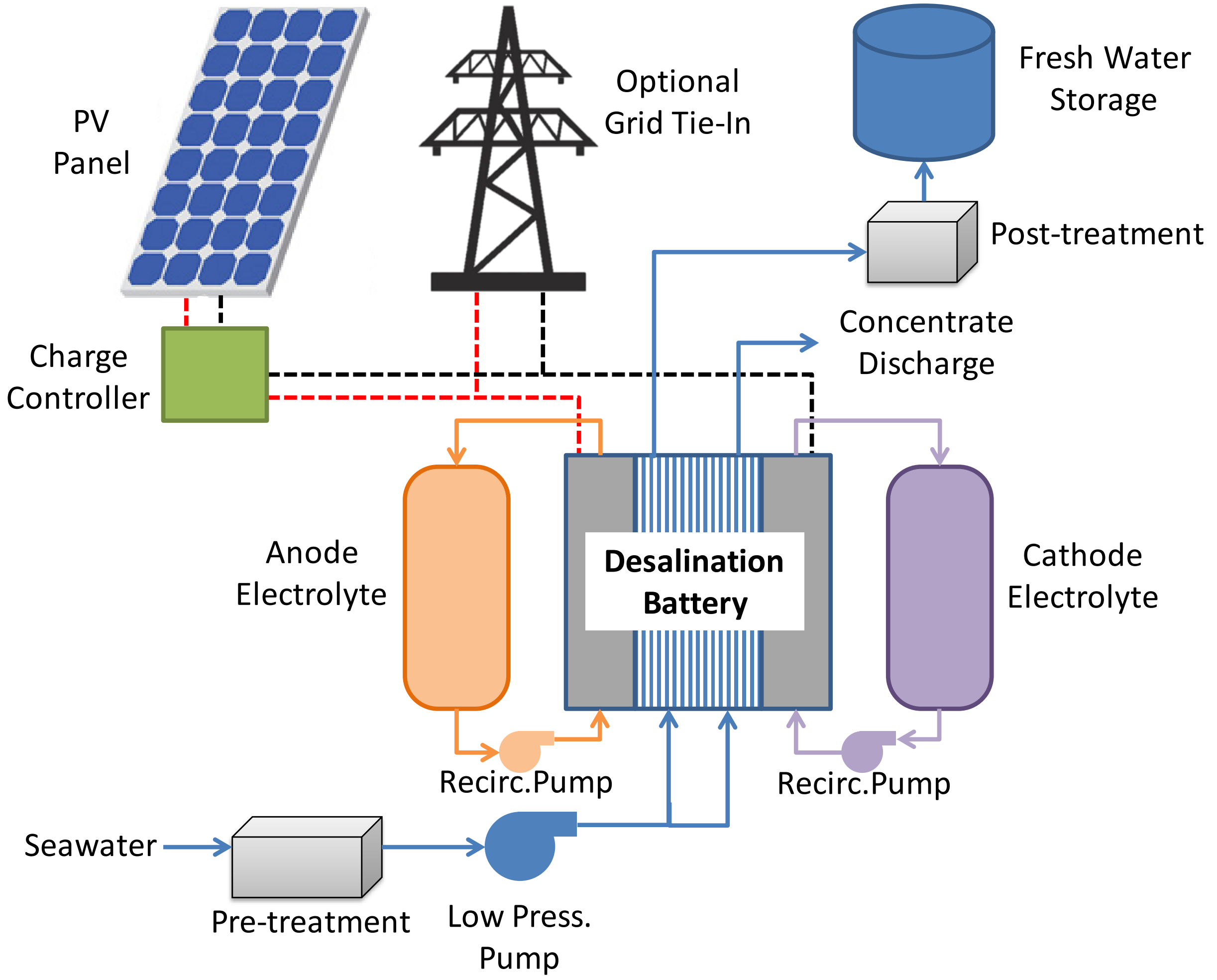
- Combines metal-air batteries and electrodialysis into a single device
- Stored dry, feed water acts as electrolyte
- Salts removed as battery is discharged
- Self-limiting, no discharge with deionized water
- Mechanically recharged by replacing Mg electrodes



AEM = anion exchange membrane CEM = cation exchange membrane

NSETTI Technical Approach

- Large scale desalination battery using redox flow chemistry
- Enables desalination for RE microgrids without need for separate battery energy storage
- Can be flexibly used for potable water production and/or energy storage
- Resiliency for both energy/water
- Potential for shore microgrids and expeditionary environments



Technical Objectives

Metric	Target	Importance
Desalination rate	>50 L/hr per m^2 electrode area	System size and capital cost
Desalination energy consumption	<3 kWh/m^3 (seawater)	Energy consumption + O&M costs
Roundtrip charge/discharge efficiency	>70%	Energy consumption + O&M costs
Charge/discharge cycle stability	>100 cycles, <0.01% degradation	System lifetime + O&M costs
Levelized cost of storage	<$100/kWh	Cost competitiveness with PV/RO/Battery storage
Levelized cost of water	<$4/$m^3$ (seawater)	Cost competitiveness with PV/RO/Battery storage

Work Plan Strategy

Paper Study – Identify candidate chemistries → Lab testing → Preliminary full scale system design → Techno-economic analysis

Paper Study – Identify candidate chemistries

Pre-screen chemistries based on desal battery requirements

Lab testing

Determine key performance metrics

- Desalination rate
- Cycle efficiency
- Energy consumption
- Cycle stability/lifetime

Preliminary full scale system design

Includes all critical balance of plant components

- Pumps
- Filtration
- Storage tanks

Techno-economic analysis

Estimate levelized cost of water including

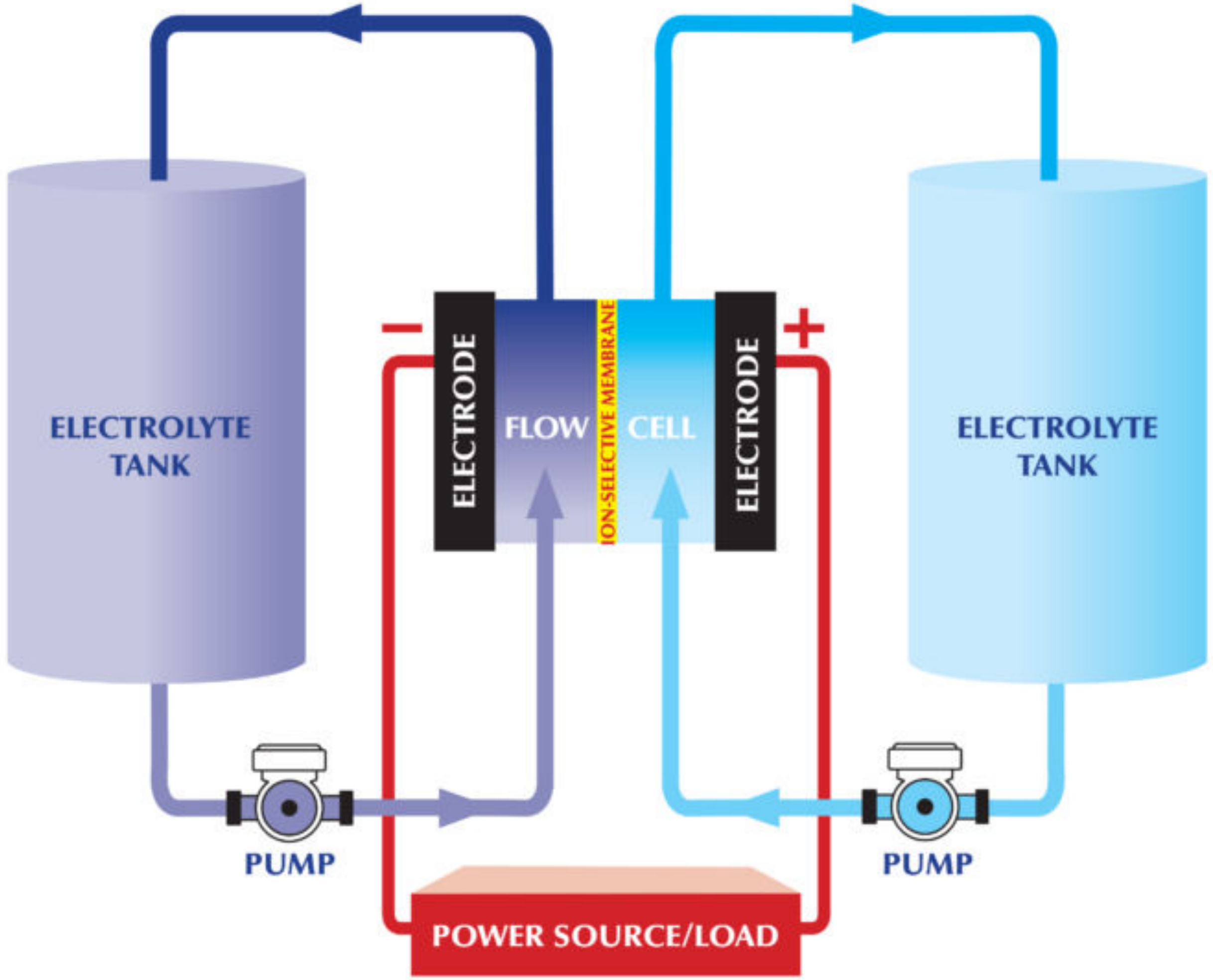
- Capital costs
- Operation and maintenance costs
- System lifetime

↓

Go/No Go for pilot scale development

Redox Flow Batteries

- Energy capacity of a lithium-ion battery limited by the thickness of the solid electrodes
- Redox flow batteries use liquid “electrodes” that can be stored in tanks
- Bigger tank = bigger energy storage capacity
- Potential for much lower cost and longer duration energy storage for microgrids

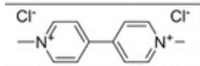
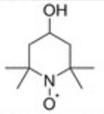
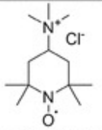
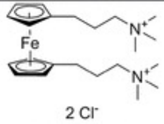


https://flowbatteryforum.com/what-is-a-flow-battery/

Candidate Chemistries for Desalination Batteries

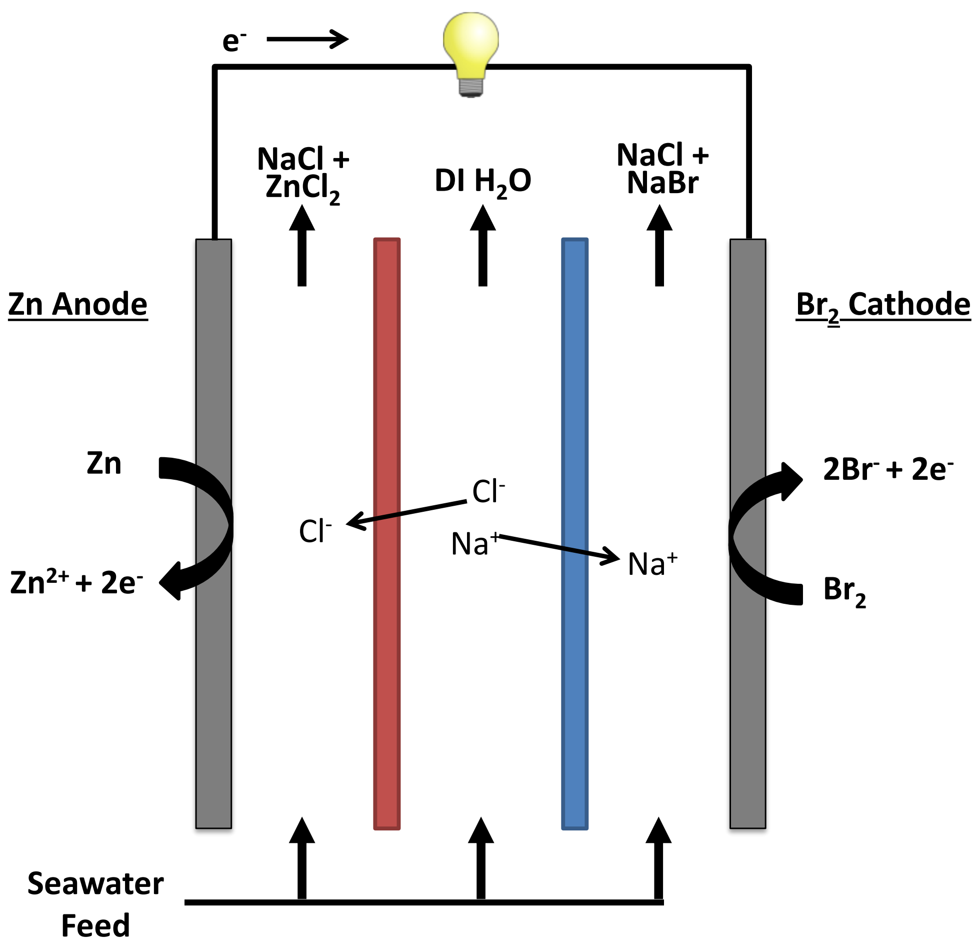
DOI: 10.1021/acssuschemeng.9b02720

- Numerous inorganic and organic compounds can be used for desalination batteries
- Key requirements
  - Stability and round-trip efficiency more important than energy density
  - Compatible with ions in natural waters other than Na^+ and Cl^- that can precipitate and form scale
  - Operation at near-neutral pH
  - Low cost and low toxicity
- Aqueous neutral pH organic redox compounds have potential for lower cost and safer operation than metal-based RFB

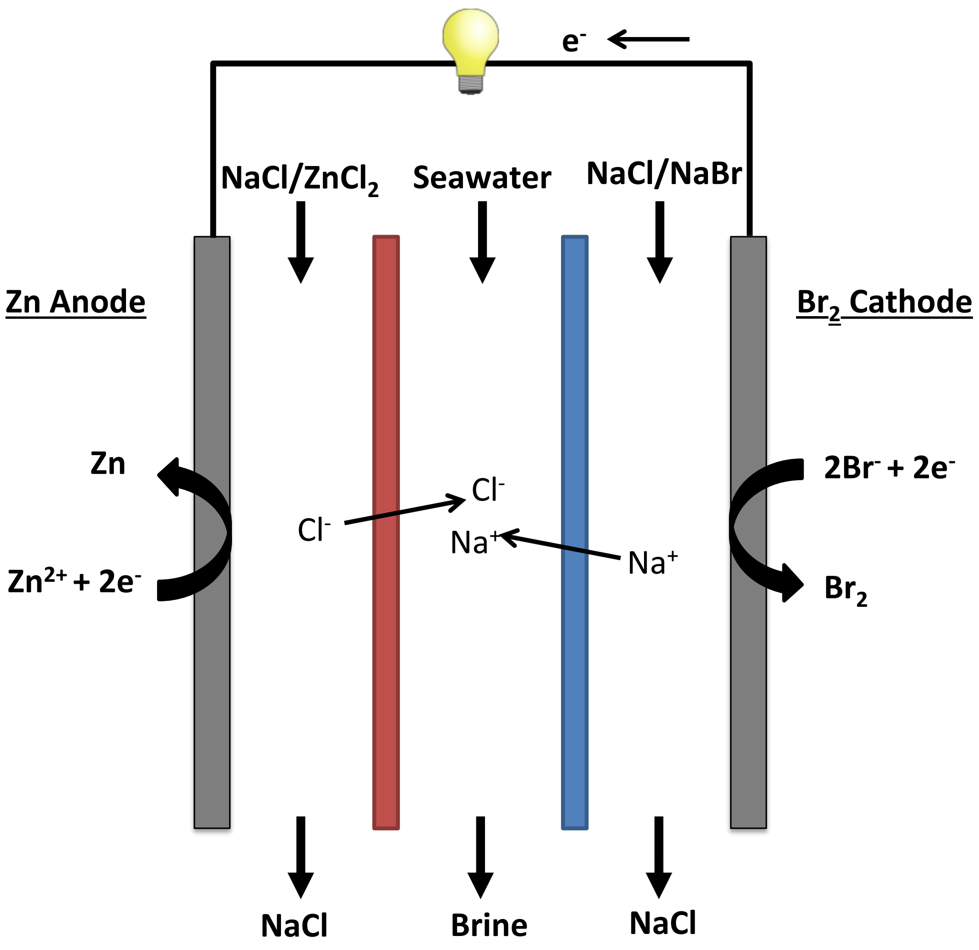
Reactant	Criterion							Remarks	Ref.
	(a) Neutral pH compatible	(b) Oxygen stability	(c) Overall solubility	(d) Not proton-coupled	(e) Fast kinetics	(f) Low membrane permeability	(g) Feedwater compatible		
V^{2+}/V^{3+} or VO^{2+}/VO_2^+	pH <2	V^{2+}			V(III)/ V(IV) is slow		pH <2 feedwaters only		12
Fe^{2+}/Fe^{3+}	pH <2	Fe^{2+}					pH <2 feedwaters only		14
Zn/Zn^{2+}	pH <6 at $[Zn^{2+}]$ >1 M						Forms precipitates with HCO_3^-	Dendrite formation; difficult to use solid Zn(0) as a shuttle	15
$[Fe(CN)_6]^{4-}$/ $[Fe(CN)_6]^{3-}$							Forms precipitates with Mg^{2+}, Ca^{2+}, Fe^{3+}, etc.		15
I^-/I_3^-		I^-						Volatility of free I_2	12
Quinone derivatives		Hydro-quinone	Varies				Unknown		21
 methyl viologen (MV^{2+}) and other viologen derivatives		$MV^{\bullet+}$					Unknown	Highly toxic	26-28
 4-HO-TEMPO							Unknown	Low chemical stability	26
 TEMPTMA							May oxidize Br^- and I^-	Strong oxidant Unproven chemical stability	28
 BTMAP-Fc									This work

Example: Zn/Br_2 Redox Flow Desalination Battery

Discharge/Desalination Cycle



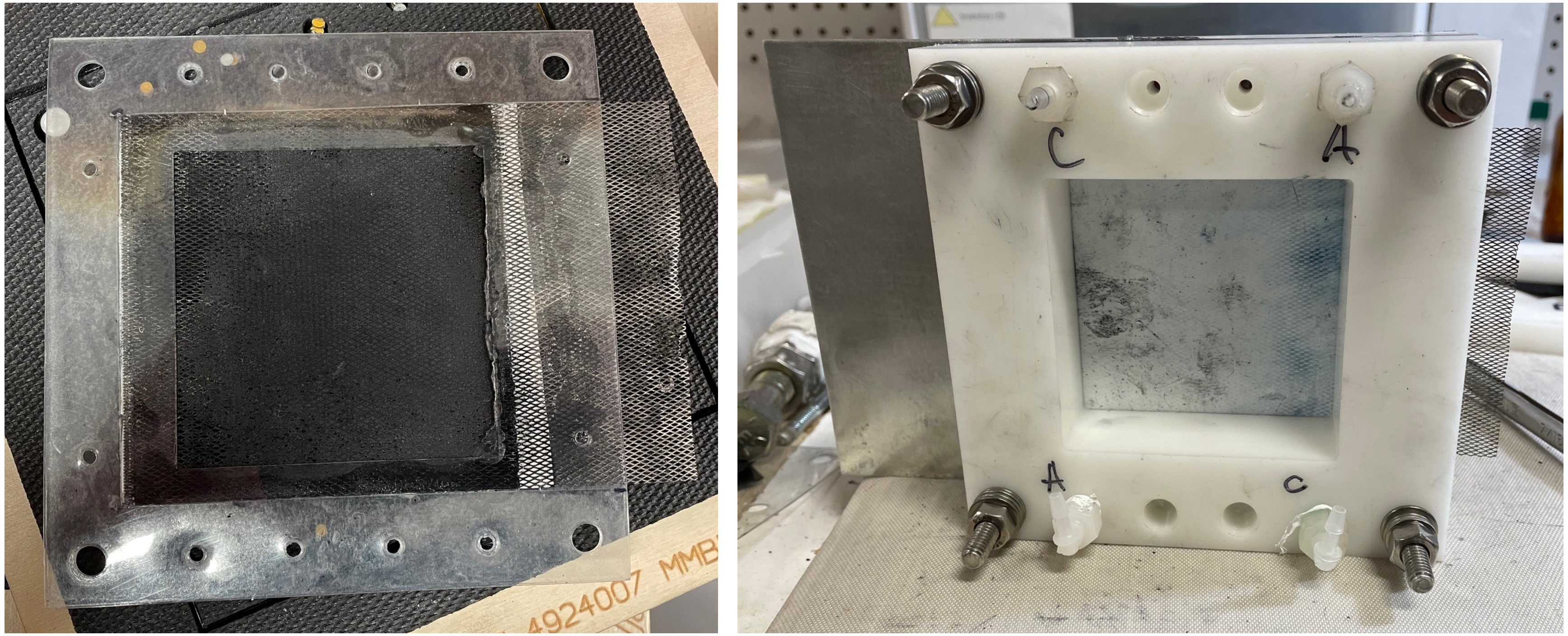
Charge/Salination Cycle



Lab-Scale Testing of Rechargeable Desalination Batteries

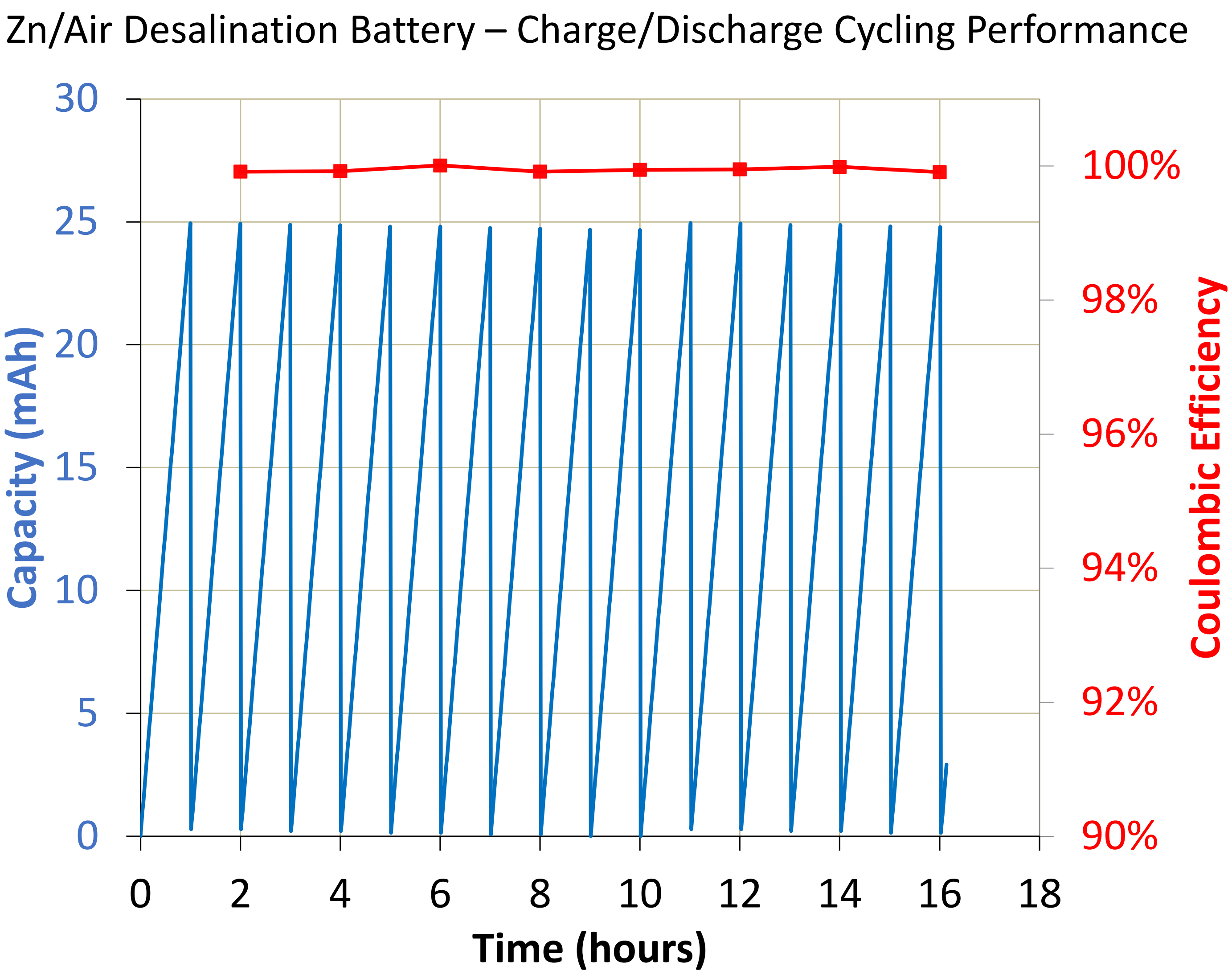
- Currently evaluating several chemistries at the lab scale
- Key metrics
  - Round trip efficiency
  - Desalination rate
  - Cycle stability

50 cm^2 test cell for rechargeable desalination batteries



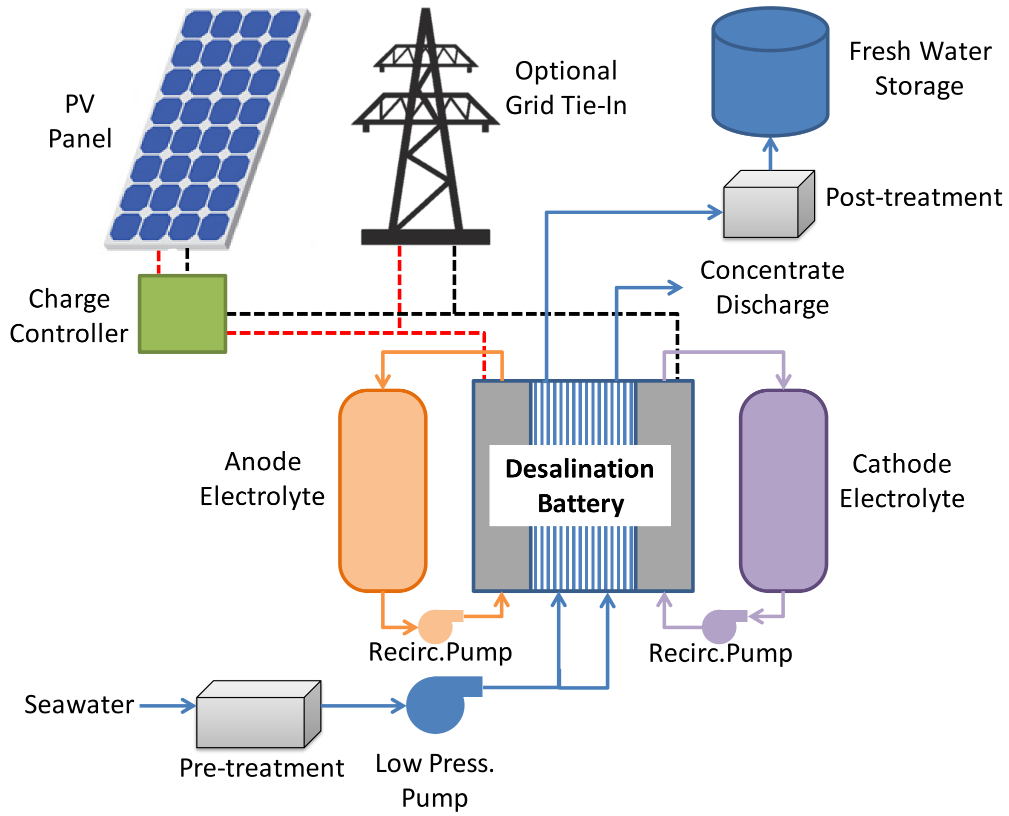
Current Progress

- Identified new cell configuration which eliminates issues with precipitation due to Mg^{2+} and Ca^{2+} ions in natural feedwaters
- Currently testing new configuration with Zn/Air battery chemistry
- Begun long-term cycling testing with promising initial results



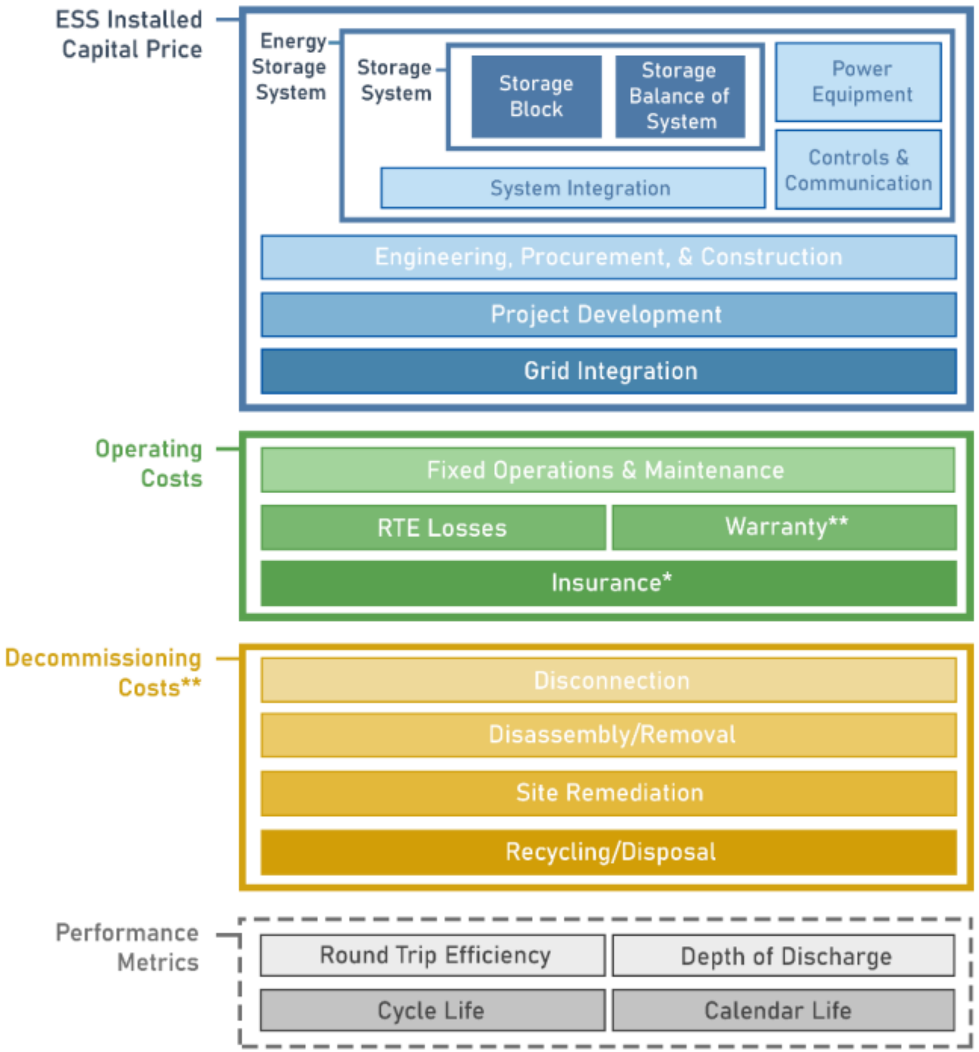
Preliminary Full Scale System Design

- Full scale containerized system will be designed based on single cell performance with all balance of plant components
- Target desalination rate of >1 m^3/day of product water
- Electrochemical stack
  - Sizing
  - Ion exchange membranes
  - Electrodes/current collectors
  - Endplates/manifolding
- Balance of plant
  - Pumps
  - Pre- and post-filtration
  - Electronics/controls including tie-ins with renewable energy
  - Storage tanks for reactants and product water



Techno-Economic Analysis

- Several models focused on desalination and energy storage will be used to assist in the analysis
- Will consider all CAPEX and OPEX costs to estimate a levelized cost of electricity (LCOE) and water (LCOW)
- To be competitive, targeting:
  - <$100/kWh for LCOE to compete with Li-ion battery storage
  - <$4/m^3 for LCOW to compete with PV/RO/Li-ion



Source: PNNL

Potential Benefits of Redox Flow Desalination Batteries

	Reverse Osmosis	Lynntech's Rechargeable Desalination Batteries
Energy Requirements	3-5 kWh/m^3	2-4 kWh/m^3
Capital Cost	\$500-\$1,500 per m^3/day	~\$500 per m^3/day
Fouling Resistance	Poor - High pressure operation - Extensive chemical cleaning of RO membranes required to remove fouling	Good - low pressure operation - electrodialysis reversal during charge/discharge cycle removes foulants - reduced cleaning/maintenance requirements
Water Production Cost	\$0.50-\$1 per m^3 (coal power) \$5-\$10 per m^3 (renewable energy)	\$0.30-\$0.70 per m^3 (coal power) \$1-\$5 per m^3 (renewable energy)
Integration with Renewable Energy	Poor - Energy storage system required for continuous operation - Oversized renewable energy system needed to account for electrical inefficiencies	Good - Continuous desalination without the need for an expensive energy storage system - Reduced renewable energy system size due to lower energy consumption and improved efficiency

These metrics are being updated throughout the project based on lab results with various battery chemistries.

Future Research and Development

- Fabricate and test pilot-scale system
  - Containerized system
  - 1-10 m^3/day capacity
  - Integrated with renewable energy and water storage
- Initial markets
  - Military/expeditionary
  - Emergency response
  - Developing countries
  - Island communities
- Not limited to seawater – other potential water sources
  - Brackish groundwater
  - Agricultural runoff
  - Industrial wastewater

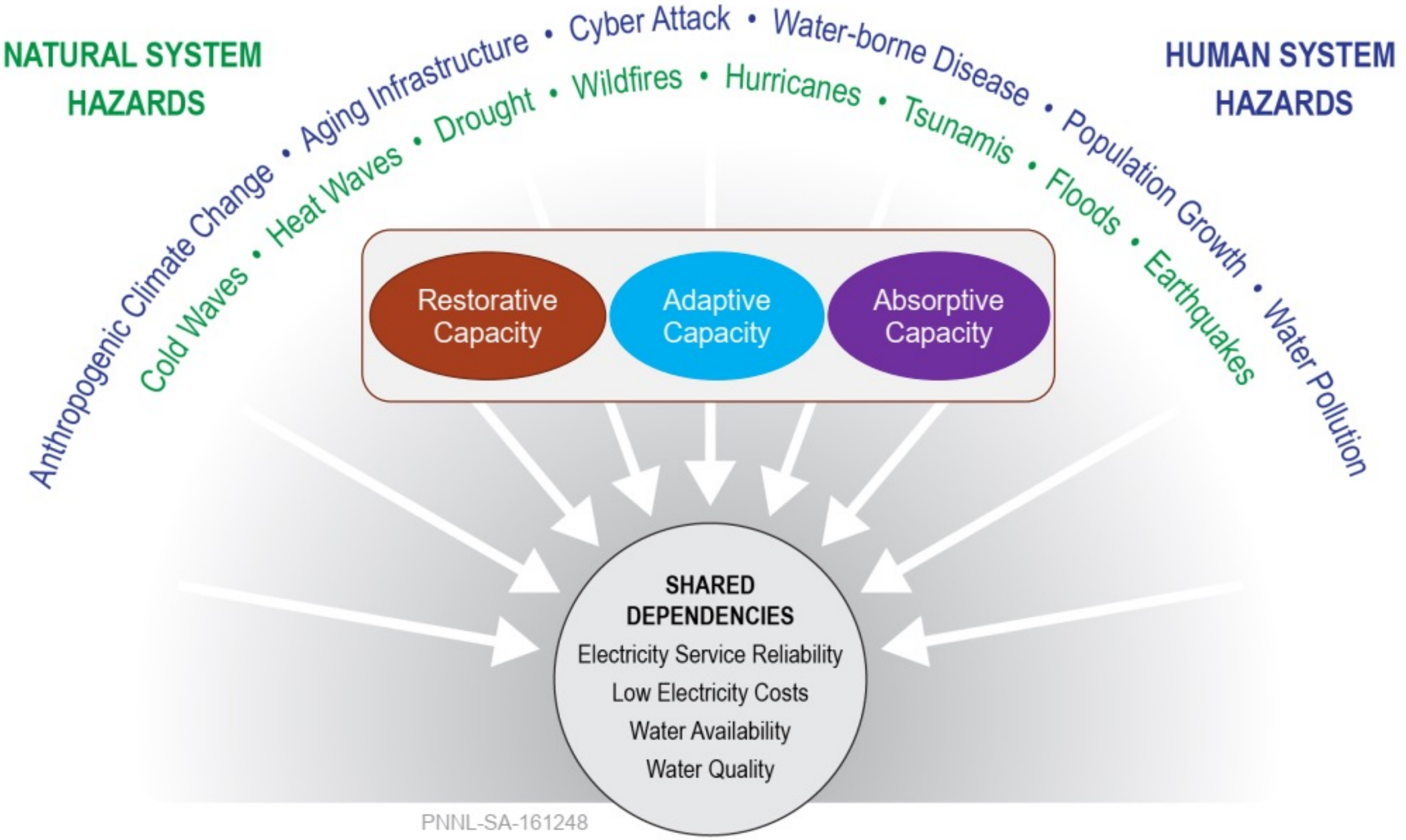
Example PV-powered RO Desalination Plant

https://givepower.org/

Overall objective: Integrate desalination batteries with renewable energy for the scalable production of low cost, carbon-neutral potable water.

Potential Synergy for Energy and Water Resiliency

- Energy and water resiliency strategies are mostly the same
  - Distributed generation
  - Site-specific requirements
  - Diverse sources
  - Improve efficiency and conservation
- Lots of potential benefit to coordinated energy/water resilience planning



https://www.pnnl.gov/projects/integrated-water-power-resilience-project

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- Big thanks to NAVFAC and Navy Shore Energy Program for supporting this effort!
  - Bill Varnava
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