Redesigning electrode architectures for next-generation electrochemical power sources

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Research Focus for Electrochemical Power

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"No Power = No Mission"*

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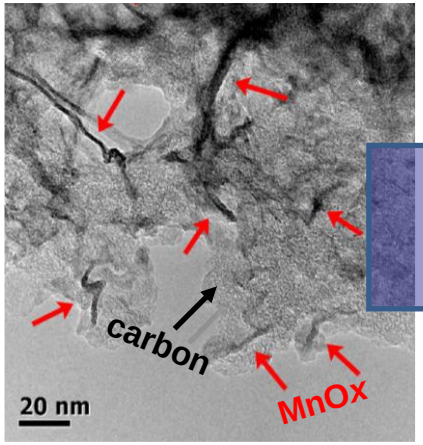
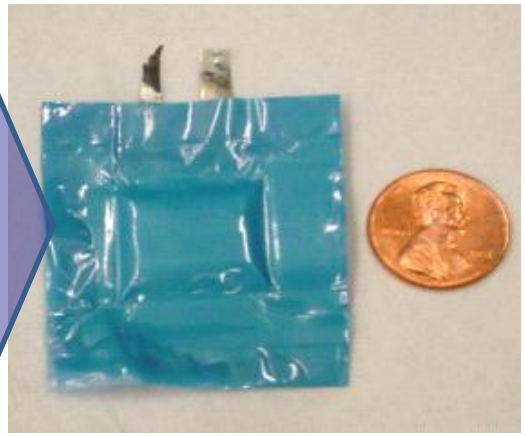
Fundamental

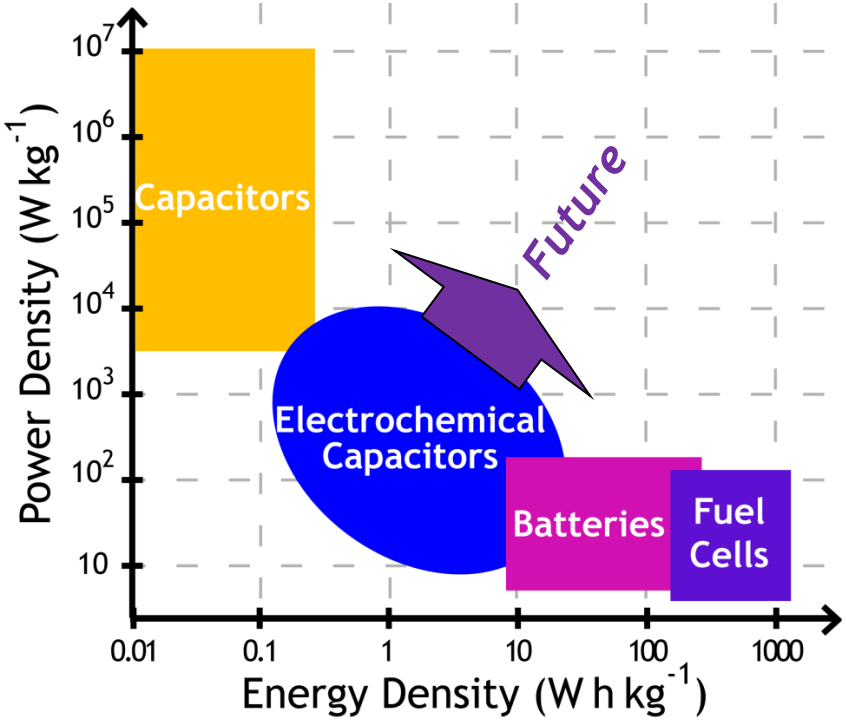


Mechanisms, synthesis, electrode design

Practical



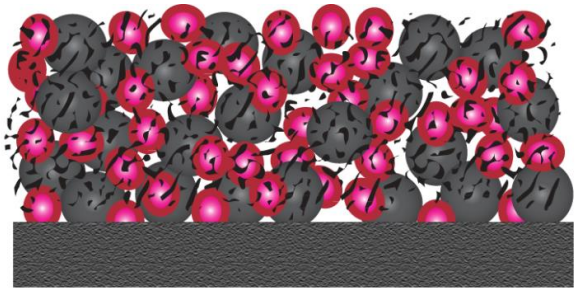
Prototype cells, "real-world" testing



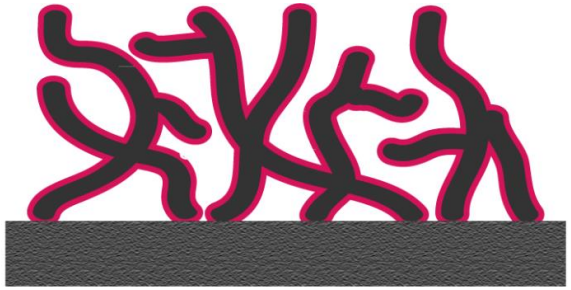
How do we achieve high power and high energy in a single power source?

Basic Concepts

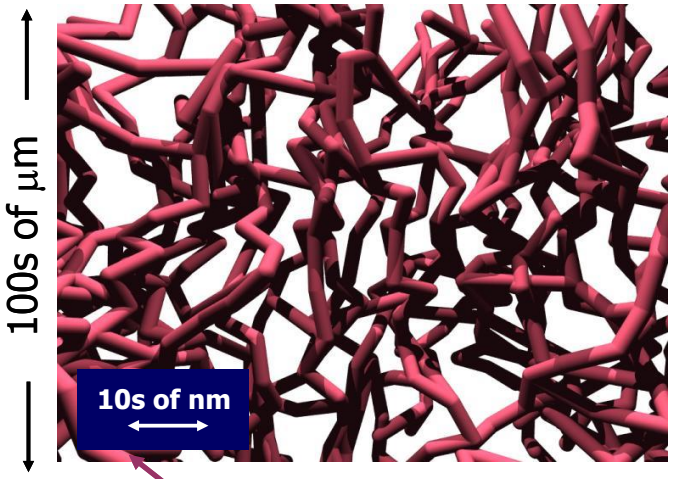
Thin Film
✓ High Power
x Low Energy



Powder Composite
x Low Power
✓ High Energy



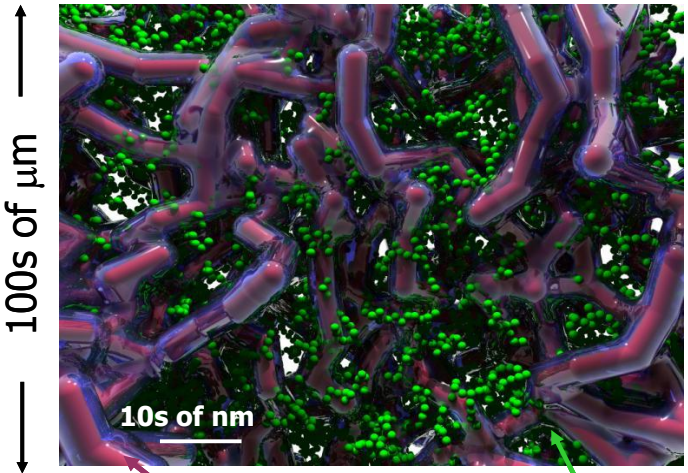
NRL's 3D Nanoarchitecture
✓ High Power
✓ High Energy



Ultraporous electrode architecture
$\sigma > 10$ S cm^{-1}

Nanoscale functionalization

Wired ion/electron transport in 3D



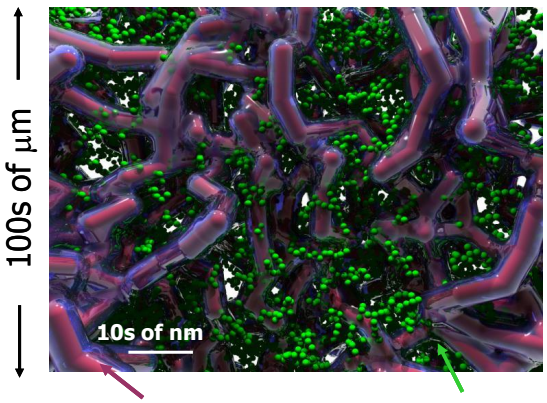
Ultraporous electrode architecture
$\sigma > 10$ S cm^{-1}

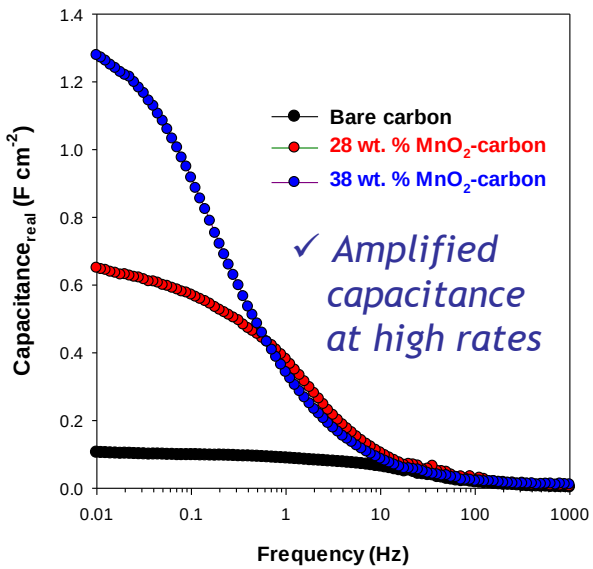
Functional oxide
~10-nm thick

Rolison, Long, Lytle, Fischer, Rhodes, McEvoy, Bourg, Lubers, *Chem. Soc. Rev.*, **38** (2009) 226–252

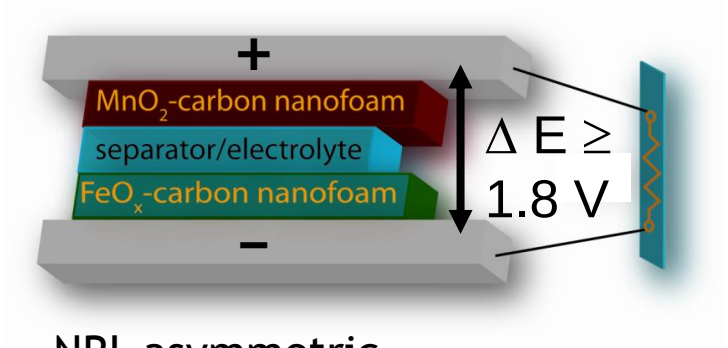
Origins in Basic Research

Materials design



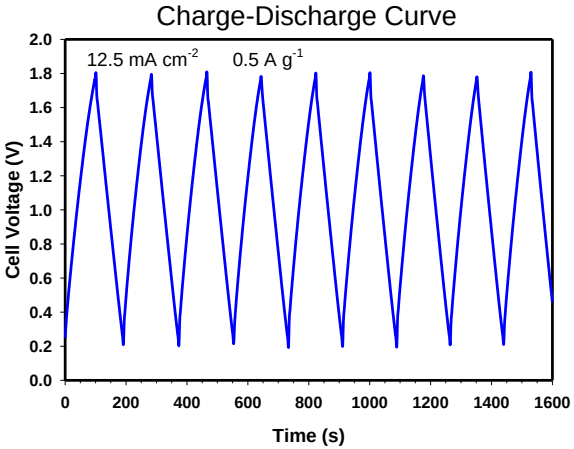


Device-level performance



NRL asymmetric *aqueous* electrochemical capacitors:

- ✓ Safety & cost advantages of water-based system
- ✓ Full charge–discharge in 10s of seconds
- ✓ 2–3 × greater specific energy (10–20 W h kg^{-1}) than carbon–carbon supercapacitors

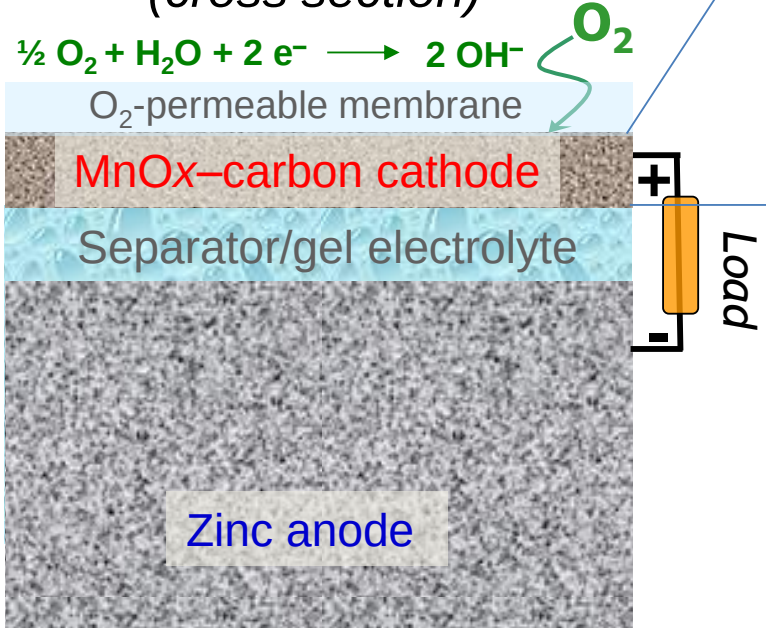


Long, Bélanger, Brousse, Sassin, Crosnier *MRS Bulletin* **7** (2011) 513–522

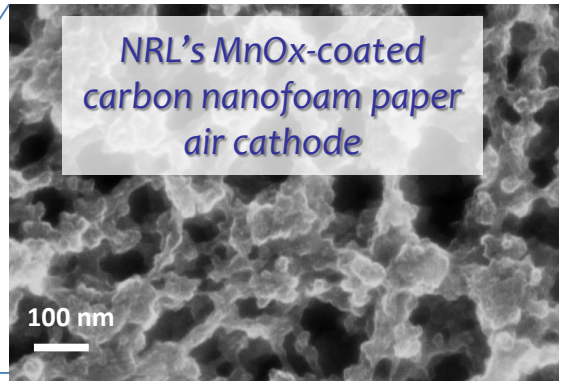
Applied Research: Logistics Trust Program

NRL Zn–air cell schematic (cross section)

$\frac{1}{2} O_2 + H_2O + 2e^- \longrightarrow 2 OH^-$



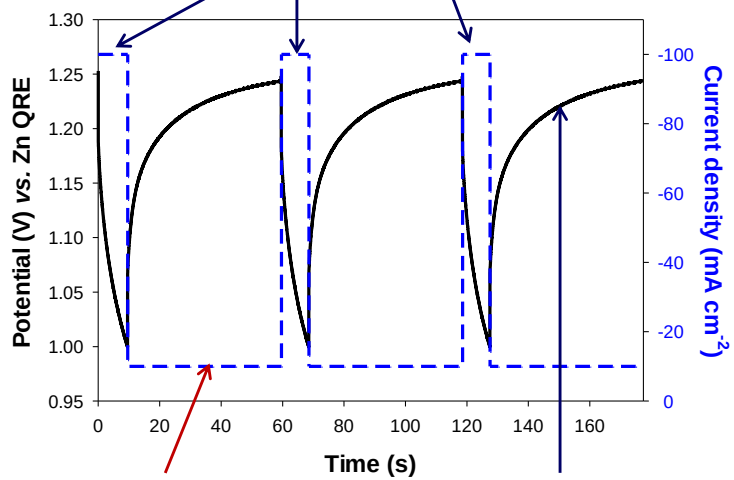
$Zn + 2 OH^- \longrightarrow ZnO + 2e^- + H_2O$



NRL "dual function" air cathode

1. O_2 reduction (long-term delivery)
2. "Pseudocapacitance" (intermittent pulses)

For intermittent high-current demands MnO*x* pseudocapacitance sustains load



At low loads, O_2 reduction (from air intake) provides long-term energy delivery

while

MnO*x* spontaneously recharged by O_2 to be available for subsequent pulse cycles

<u>Goal</u>: Overcome pulse-power limitations of present Zn–air batteries

Long, Chervin, Kucko, Nelson, and Rolison, *Adv. Energy Mater.*, **3** (2013) 584–588

Impacts/Benefits to Warfighting Capability

Impact: Leverage basic science findings to develop next-generation power sources that address military-specific needs:

- Wide range of platforms
  soldier/marine, aircraft, warships
- Challenging operating environments
  desert, polar, maritime, space
- Performance, safe operation, low signature
- Domestic/U.S.-friendly supply & technology base

Combining energy (endurance) & power (rate) functionality in a single device:

- ✓ "Lightens the load"
- ✓ Reduces system complexity
- ✓ Yields previously unattainable capabilities

"Opportunities for Electrochemical Capacitors as Energy-Storage Solutions in Present and Future Navy and Marine Corps Missions." J.W. Long, *NRL Memorandum Report 6170—09-0227*, 29 October 2009

Questions?

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