OUTLINE

• Path to IUCRC CEPS-the first unique center in US
• Conventional batteries vs. solid-state batteries
• Global challenge of energy storage (examples)
• CEPS mission and benefits for the state
• CEPS University sites: mission and goals
• CEPS membership benefits
• Examples of the NSF IUCRC funded centers
• Can we stay on top of the game and solve the global challenge?
• Potential CEPS members
A PATH TO CEPS: BATTERY RESEARCH IN SOUTH DAKOTA

- NASA EPSCoR Initiation Grant ($50K)
  - Summer 2013-2015 NASA Glenn Scholarships
  - Presentation at NASA Glenn
  - ACS PRF SOFC $60K
- 2014-2018 NASA EPSCoR Initiation Grant ($750K)
  - Summer 2013-2015 NASA Glenn Scholarships
  - Presentation at NASA Glenn
  - ACS PRF SOFC $60K
  - DOD NAVAIR SBIR NCI-SDSMT Phase I base and option ($150K)
  - DOD NAVAIR SBIR NCI-SDSMT (~$1M total)
  - SDSMT Track I
  - SDSMT IUCRC Planning Grant Preproposal
  - NSF IUCRC Planning Grant SDSMT USD SDSU NEU
- DOD NAVAIR SBIR NCI-SDSMT Phase I base and option ($150K)
- SDSMT Track I
- SDSMT IUCRC Planning Grant Preproposal
- NSF IUCRC Planning Grant SDSMT USD SDSU NEU

- Unsuccessful attempts
ALL-SOLID STATE ENERGY STORAGE: A NEW DIRECTION in SD ECONOMIC DEVELOPMENT

BATTERIES with LIQUID ELECTROLYTES

- Boeing
- Samsung Galaxy 7

HP Lithium-Ion Laptop
50,000 Li-ion Batteries recalled

ALL-SOLID-STATE ENERGY STORAGE

- Flammable
- Temperature sensitive
- Limited charge/discharge
- Bad chemicals/recycling
- Poor performance
- Not reliable

GAME-CHANGING SOLID-STATE BATTERY TECHNOLOGY

QUALITATIVELY NEW APPROACH

- Non-flammable
- Broad temperature range
- Unlimited charge/discharge
- High voltage & power
- Eco-friendly recycling
- Lower risks at larger scales

Lithium metal
100 micron thick

Solid-state electrolyte
20 micron thick

Cathode challenge requires fundamental studies
Example 1: LITHIUM METAL BATTERY MARKET DISRUPTIVE APPROACH

MUCH LONGER DISTANCE ON SINGLE CHARGE

SAFE ONLY WITH SOLID-STATE ELECTROLYTES

LONGER RANGE

Example 2: ELECTRIC POWER GRIDS

US LITHIUM-ION STORAGE CAPACITY: 295MW (2018) to 2.5GW (2023)
US LITHIUM-ION BATTERY MARKET: 17% growth per year; $90B by 2025

CONVENTIONAL BATTERIES ARE NOT RELIABLE
NSF IUCRC CEPS MISSION and BENEFITS for the STATE

NSF-competitive research:
- New classes of solid-state materials
- In-situ/operando analysis at atomic/subatomic scale
- Safe, reliable, and economically feasible technology products

CEPS will diversify SD economy:
- High tech – engineering product management and manufacturing jobs
- Improved SD status as a high-tech state
- Support existing AG, industrial power market, and advanced product development for any products that needs battery storage
- Create technology core in Western SD

CEPS UNIVERSITY SITES GOALS

- Each site is independent (first 5yrs.)
- Goals can be changed based on requests from the full CEPS members
- Planning Grant Meeting in Rapid City (September 2019)

CAN WE STAY on TOP of this GAME and SOLVE the GLOBAL CHALLENGE?
STRONG SD and INDUSTRIAL SUPPORT: COMPANIES COMMITED to IUCRC CEPS PROJECT

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<th>SDSU Site</th>
<th>USD Site</th>
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<td>Idaho National Lab</td>
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EXAMPLES of the NSF IUCRC CENTERS CLOSELY REATED to CEPS

- Colorado State University
- Texas A&M University
- Texas A&M University-Central Texas
- University of Texas at Austin

WEBSITE: http://www.iucrc.org/center/next-generation-photovoltaics

- Virginia Tech
- Columbia University

http://www.cehms.com/
CEPS BENEFITS: UNMATCHED JURISDICTIONAL IMPACTS for SD

➢ In the past: no investments in high-tech energy storage in SD

EDUCATION
• New faculty lines
• Post docs
• GR and UG students
• New GR courses and programs

HEALTHCARE
➢ PACEMAKERS
• Small size
• No replacement
• No skin erosion
• Less invasive
• Life-long deployment

SOLID-STATE ENERGY STORAGE TECHNOLOGY

SOCIETAL
➢ Longer time of operation
➢ Lower cost

TRANSPORTATION
➢ TESLA $250K
• Longer time of operation
• Lower cost

CEPS MEMBERSHIP BENEFITS

• Industry
  (selling points)
  • Investment leveraging ($50K vs. $500K)
  • Sector networking (no violations of anti-trust laws) (e.g. Ford vs. GM)
  • Shared center/industry facilities
  • Workforce development/ access to talented students
  • Elimination of the gaps in supply chains
  • New research and education programs
  • Student/staff recruitment
  • Leverage proof-of-concept results for new funding

• Academia

  • Trusted relationships with industry
  • Ready partners for translation of discoveries
  • New industry sector relationships
  • Funding directly from the governmental agencies
POTENTIAL IUCRC CEPS MEMBERS for GREEN ENERGY TECHNOLOGY INITIATIVE

- Battery companies
- Automotive companies
- Lithium, cobalt, and nickel mining companies
- Electrical (e.g. Black Hills Energy)
- Manufacturers of wind and solar systems
- State and governmental agencies (DOE, NASA, DOD, etc.)
- National laboratories
- Big corporations, e.g. Google, Facebook, etc.

SOLID-STATE GREEN TECHNOLOGY RACE in AUTOMOTIVE INDUSTRY

Top Green Energy Financiers: $1 Trillion Investment in US

Volkswagen invest $100M in California startup QuantumScape (Stanford University spinoff)
https://www.greentechmedia.com/articles/read/wv-quantumscape-investment

Toyota, Nissan, Honda, Panasonic partner to develop solid-state technology

Tesla/ Fisker Emotion: Thin-film solid-state technology

Ford

GM and Honda are partnering for ASS-LIB development
https://electrek.co/2018/06/07/gm-honda-partner-next-gen-batteries-electric-vehicles/

Shell in the US and Australia: $70.23M

Battery market reports: https://www.sdle.co.il/services/market-research-reports/
Lithium Nitride Protective Layer via Plasma Activation for Highly Stable Lithium Metal Anodes

- Lithium chips were transferred from Ar-glove box into a quartz tube using a tightly sealed vessel.
- A radio frequency power of 125W was applied with 200 sccm continuously N\textsubscript{2} flow.
- N\textsubscript{2} plasma was created in quartz tube.
- After certain plasma treatment time, lithium chips were then quickly transferred back into glovebox for battery assembling and further characterization.

Energy Storage Materials, 18, 389-396, 2019

SEM images and XRD Diffraction of flower shape Li\textsubscript{3}N under different plasma nitriding time

* Scale bar 10 um

Energy Storage Materials, 18, 389-396, 2019
Cycling profiles of symmetric cells

Bare Li and Li/Li$_3$N (2 min) after 10 cycles

Energy Storage Materials, 18, 389-396, 2019
Electrochemical characterization of Li/LCO full cell

Energy Storage Materials, 18, 389-396, 2019

Ultrathin Bilayer of Graphite/SiO$_2$ as Solid Interface for Reviving Li Metal Anode

Abstract
Lithium metal anodes are expected to drive practical applications that require high energy density storage. However, the direct use of metallic lithium causes safety concerns, low rate capabilities, and poor cycling performance due to unstable solid electrolyte interphase (SEI) and undesired lithium dendrite growth. To address these issues, a radio frequency sputtered graphite SiO$_2$ ultrathin bilayer on a Li metal chip is demonstrated, for the first time, as an effective SEI layer. This leads to a dendrite-free uniform Li deposition to achieve a stable voltage profile and outstanding long hours plating/stripping compared to the bare Li. Compared to a bare Li anode, the graphite-SiO$_2$ bilayer modified Li anode coupled with lithium nickel cobalt manganese oxide cathode (NMC111) and lithium titanate shows improved capacity retention, higher capacity at higher rates, longer cycling stability, and lower voltage hysteresis. Graphite acts as an electrical bridge between the plated Li and Li Electrolyte, which lowers the impedance and buffers the volume expansion during Li plating/stripping. Adding an ultrathin SiO$_2$ layer facilitates Li ion diffusion and lithiation/delithiation, provides higher electrolyte affinity, higher chemical stability, and higher Young's modulus to suppress the Li dendrite growth.
Nyquist plots as a function of days a) bare Li, b) graphite-SiO$_2$ Li symmetrical cells, c) Nyquist plot after 10 cycles of plating stripping and Long-term cycling and voltage hysteresis of symmetrical cells at (d, e)0.5 mAcm$^{-2}$ and (f, g) at 1 mAcm$^{-2}$ respectively.

Advanced Energy Materials, 1901486, 2019

SEM images of (a, b) bare Li and (c, d) graphite-SiO$_2$ Li after 1$^{st}$ and 100$^{th}$ plating, respectively.

Advanced Energy Materials, 1901486, 2019
(a, b) Cycling performance and (c, d) Voltage profiles of NMC and LTO with bare Li and graphite-SiO₂ Li as an anode at the 0.1C rate for first 5 cycles followed by 1C rate respectively.

Advanced Energy Materials, 1901486, 2019

https://www.greenceps.com/
1899, Belgium
Car with a lead-acid battery
Speed: 67 mph

2016, USA, Tesla
Fully electrical car with lithium-ion battery and liquid electrolyte

NEEDS an URGENT REPLACEMENT