

Physical Sciences

Technology Available for Licensing

DARTMOUTH

Technology Transfer

Handheld, Inexpensive, Side-by-side Transmission Probe

PRINCIPAL INVESTIGATOR: [Paul M. Meaney](#), Professor of Engineering, Dartmouth

CO-INVENTORS: [Timothy Reynolds](#), Lead Senior Systems Engineer, Dartmouth | [Dr. Robin Augustine](#), Associate Professor of Electrical Engineering, Uppsala University

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DESCRIPTION

- Critical to clinical diagnosis and monitoring of conditions such as lymphedema, edema and skin wound is an **accurate picture** of all the diseased and injured tissues.
- Current technologies such as commercial reflection-based dielectric probes include **inadequate penetration** for interrogating deeper tissues and **high sensitivity** to movement during measurements, rendering them less suitable for dynamic or point-of-care applications.
- This **handheld, inexpensive, side-by-side transmission dielectric probe** builds upon the principles of **oversized coaxial probes and transmission techniques**, combining deeper signal penetration with reduced susceptibility to artifacts and improved clinical usability.
- The probe operates using an “**open-circuit**” coaxial **interface**, where a signal fringes out from one open-circuit coax and is coupled to an adjacent receiving open-circuit coax, propagating through the intervening tissue for interrogation.

ADVANTAGES AND BENEFITS:

- **Enhanced penetration:** This technology achieves penetration depths of **several centimeters**, far surpassing the sub-millimeter range of existing probes.
- **Motion artifact reduction:** Its transmission-based design is far **less susceptible to cable motion artifacts** than current technologies.
- **Improved clinical applicability:** The **side-by-side layout mitigates multi-path signal corruption**, enhancing clinical versatility.
- **Broadband capability:** An “open-circuit” coaxial interface enables **very broad bandwidth** and rich spectral content for diagnosis at varying tissue depths.
- **Portability and cost:** The probe pairs with emerging **handheld Vector Network Analyzers (VNAs) operating up to 3 GHz for under \$500**.
- Prototypes have been fabricated using **advanced CAD and metal 3D metal printing**, showing strong early promise. The design has evolved from earlier concepts, now potentially using **elliptical coaxes** to better confine fields and focus the interrogation zone.

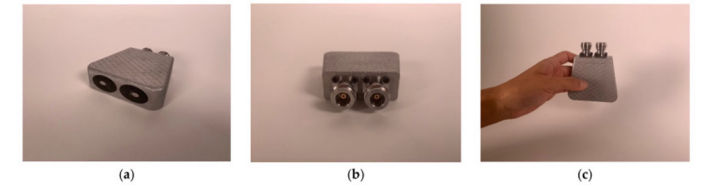


Figure 1: Preliminary design of the probe.

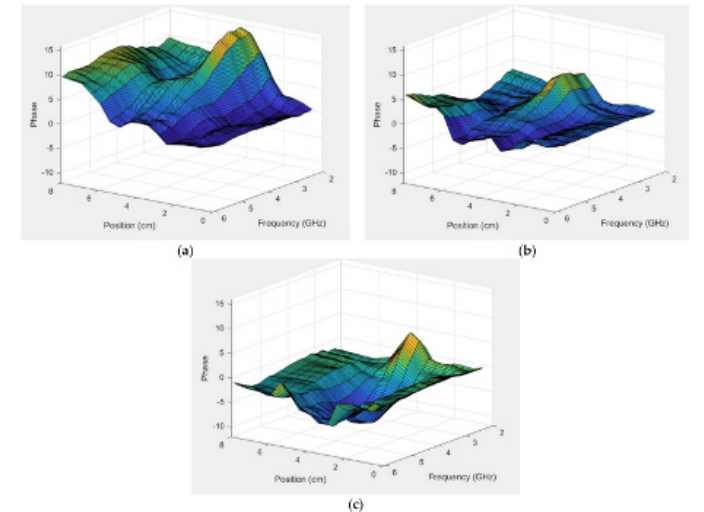


Figure 2: Normalized phase plots as a function of horizontal position above muscle phantom for all frequencies: (a) 4.32, (b) 2.54, and (c) 1.78 cm diameter. The fat rod was clearly visible for a relatively large frequency range (2-4 GHz).



Polyester-based solid polymer composite electrolyte for electro-chemically superior and high-performance sodium metal batteries

PRINCIPAL INVESTIGATOR: [Dr. Weiyang \(Fiona\) Li](#), Professor of Engineering



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INVENTION OVERVIEW

- Novel solid polymer composite electrolyte enabling the fabrication of **safe, electrochemically stable, high energy density, and high-performance** all-solid-state sodium metal batteries.
- Solid-state electrolytes, particularly ceramic ones, suffer from issues such as poor scalability, high manufacturing costs, and structural inflexibility, while conventional solid polymer composite electrolytes have issues with ionic conductivity and interfacial resistance between the electrolyte and electrode.
- Dr. Li's solid polymer composite electrolyte solves the challenges of both existing technologies.

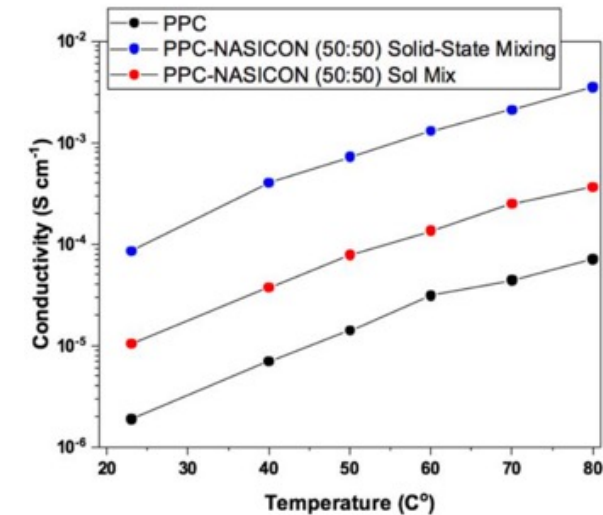
ADVANTAGES

- **Performance:** Significant improvement in ionic conductivity (**100x higher**) and interfacial impedance (**10-fold reduction**) compared to conventional solid polymer composite electrolytes. Better mechanical strength, scalability, environmental friendliness, and cost compared to conventional solid polymer composite electrolytes.
- **Better stability:** Addresses major issues in sodium metal battery commercialization, such as metallic dendrite formation, unstable solid-electrolyte interphase, and large volume expansion.

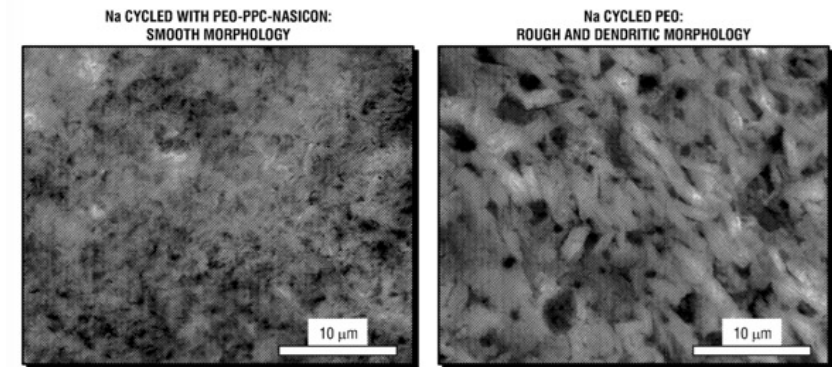
- **Enhanced Efficiency:** Allows for improved sodium metal plating/stripping behavior, with a significantly smaller voltage overpotential (**0.3 to 0.4 volts compared to 2 to 4 volts** with conventional electrolytes), and remarkably smoother post-cycling electrode morphology.
- **Cost Benefits:** The use of low-cost, environmentally friendly polyester and a scalable manufacturing process make this electrolyte commercially viable for next-generation, high-performance sodium metal batteries.

MORE DETAILS

- This innovative electrolyte is synthesized using a **solid-state mixing method** via high-energy ball milling, ensuring a homogenous mixture of polyester, polyether, and ceramic materials.
- The proposed solid polymer composite electrolyte has a high ionic conductivity of **1.5×10^{-4} S/cm**.



The proposed solid polymer composite electrolyte demonstrates ~100x higher ionic conductivity than conventional counterparts across various temperatures, showcasing superior performance in all conditions.



Left: Na metal electrode cycled with proposed solid polymer composite electrolyte exhibited very smooth and dendrite-free morphology.

Right: Na metal electrode cycled with conventional solid polymer composite electrolyte exhibited rough dendritic morphology.



Novel Cathode Material to Improve Capacity & Life Span of Li & Na Batteries

PRINCIPAL INVESTIGATOR: [Dr. Weiyang \(Fiona\) Li](#), Professor of Engineering



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INVENTION OVERVIEW

- The invention provides **a metal-sulfur battery, where the cathode/catholyte is a metal-phosphorothioate.**
- The melt phase can be used as a binder and ion-conducting buffer for battery electrodes.
- Synthesis is a simple two-step mixing process; forming a metal polysulfide followed by mixing with phosphorus pentasulfide to form the metal phosphorothioate. Compatible with both Li- and Na-Sulfur batteries.
- Cathode is formed from a combination of the metal phosphorothioate, electroconductive carbon black, and a salt.

ADVANTAGES

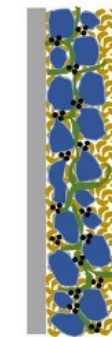
- Improved Performance:** Use of Li or Na Phosphorothioate improves energy density, diffusion rate and electrochemical kinetics by creating a continuous interphase and removing voids.

- Superior electrochemical performance:** 25% greater initial capacity with significantly greater Coulombic efficiency compared to conventional metal-sulfur battery.
- Cost-effective:** The raw materials of sodium phosphorothioates are inexpensive and the fabrication method uses a scalable and time-saving process.

MORE DETAILS

- The core innovation is a complexation-precipitation method to produce sodium/lithium phosphorothioates by reacting sodium/lithium sulfide, phosphorus pentasulfide, and sulfur powders in a solvent such as diglyme.
- The solid-state electrolyte ($P_2S_5-Na_2S_8$) exhibits an ionic conductivity of $3.04 \times 10^{-2} \text{ mS cm}^{-1}$, while its melt phase shows a conductivity of $5.70 \times 10^{-3} \text{ mS cm}^{-1}$ and maintains this conductivity even after cooling as measured using electrochemical impedance spectroscopy (EIS).
- Low temperature battery performance shown down to -60°C with long-term operability down to -40°C .

Traditional method



Current collector

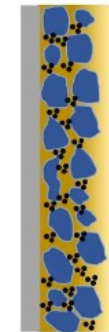


Voids
discontinuous interphase



Electrode particle

Proposed method



No voids
continuous interphase



Binder



Conductive additive

Comparison of electrode preparation for solid-state batteries in traditional method and proposed method. Note that the $P_2S_5-Na_2S_8$ melt works as binder and ion-conducting buffer. (patent no. 63/278,700)

Prototype test results and comparisons for NaS battery

	NaS catholyte w/ Na anode	Conventional NaS battery
Cyclic Retention	80% over 400 cycles	n/av
Coulombic Efficiency	> 95% over 200 cycles	< 50% over < 50 cycles
Initial Capacity	440 mAh/g active sulfur	350 mAh/g active sulfur



Acyclic/cyclic ether-based electrolyte that outstretches the low temperature limit of sodium metal anode

PRINCIPAL INVESTIGATOR: [Dr. Weiyang \(Fiona\) Li](#), Professor of Engineering



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INVENTION OVERVIEW

- Novel **low-temperature electrolytes** designed for sodium metal batteries using acyclic and cyclic ether solvents.
- Compatible with Na, Li and K based batteries.
- Customizable electrolyte composition for efficient operation at ranges between **-20°C and -150°C**.
- Lithium-ion batteries (LIBs) suffer from significant energy losses below 0°C, with commercial LIBs delivering only 5% of their energy density and 1 .25% of their power density at -40°C.
- There is a need for alternative battery technologies that can operate effectively at extreme low temperatures.

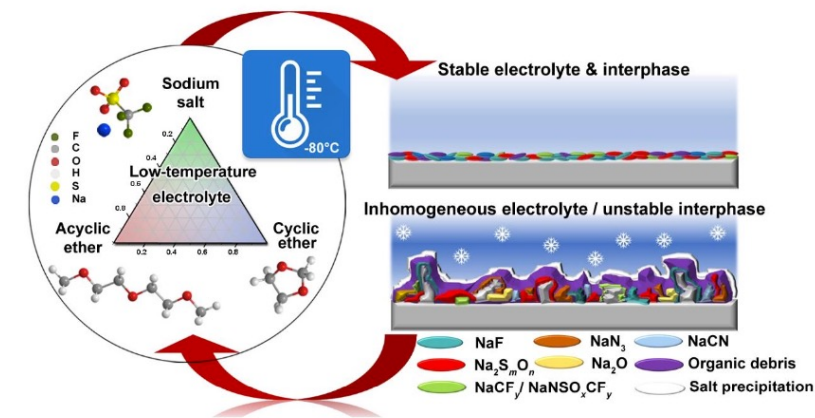
ADVANTAGES

- **Low temperature performance:** Stable operation of sodium metal batteries at temperatures below -80°C without salt precipitation or solvent freezing.
- **Enhanced stability:** Reduced dendrite formation = lower incidence of battery failure.

- **Improved efficiency:** Low electrolyte resistance and high ion transfer/migration at low temperatures, showing small overpotentials of less than 50 mV and stable cycling for more than 2000 hours in Na/Na symmetric cells.
- Broad applications: Applicable to portable devices, scientific tools in polar regions, or space exploration where temperatures can drop to -125°C.

MORE DETAILS

- The electrolytes consist of sodium conducting salts such as sodium trifluoromethanesulfonate (NaOTf) and/or sodium hexafluorophosphate (NaPF6) combined with organic ether-based solvents.
- The use of a binary solvent electrolyte consisting of 0.5M NaOTf in DEGDME/DOL (was shown to enable stable sodium plating and stripping with a low overpotential of 50mV even at a temperature of **-80°C** for over **2000** hours.



Low-temperature electrolytes consist of sodium conducting salts and unary/binary solvent including acyclic ethers and/or cyclic ethers in a range of mixing ratios. (patent no. PCT/US2021/045,949)

Comparisons between acyclic/cyclic ether-based electrolyte battery against existing battery solutions

	Acyclic/Cyclic ether-based	Standard Li-ion	Low-Temp Li-ion
Temp Range (°C)	-150 to -20	-40 to 0	-50 to -10
Capacity Retention	>95% @ -40°C	5% @ -40°C	80% @ -40°C
Low-Temp Efficiency	<50mV overpotential	>200mV polarization	100-150mV polarization
Dendrite Formation	Low	High	Low

Source: Benzo energy, Sunpower, UFine battery, Wang et al. (2022)



Optical time-of-flight imaging methods and systems for surgical guidance and fluorescence depth estimation in tissue

PRINCIPAL INVESTIGATORS: [Dr. Brian W. Pogue](#), Adjunct Professor of Engineering | [Dr. Petr Brůža](#), Assistant Professor of Engineering



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DESCRIPTION

- Critical information about the depth and shape of targets in fluorescence-guided surgery procedures is limited by the **one-millimeter visualization** barrier that hampers objectivity and utility.
- This invention introduces an **optical imaging system** that leverages time-of-flight data to precisely determine the depth and shape of fluorescence-tagged targets, such as tumor tissue, embedded within scattering media like healthy tissue.
- The technology addresses limitations in current surgical tumor guidance by **enabling subsurface imaging through diffuse radiation transport**.

ADVANTAGES AND BENEFITS:

- **Enhanced visualization:** The technology provides surgeons with crucial information about the depth and shape of fluorescent targets in vivo or ex vivo, offering guidance during procedures like fluorescence-guided surgery.
- **Improved accuracy:** By integrating multi-wavelength time-of-flight data, the invention calculates the target's surface topology, optical properties, and fluorophore depth, enhancing the precision of depth localization and shape evaluation.
- **Signal discrimination:** The technology reliably distinguishes the primary fluorescence signal from reflected secondary signals using time-of-flight information.

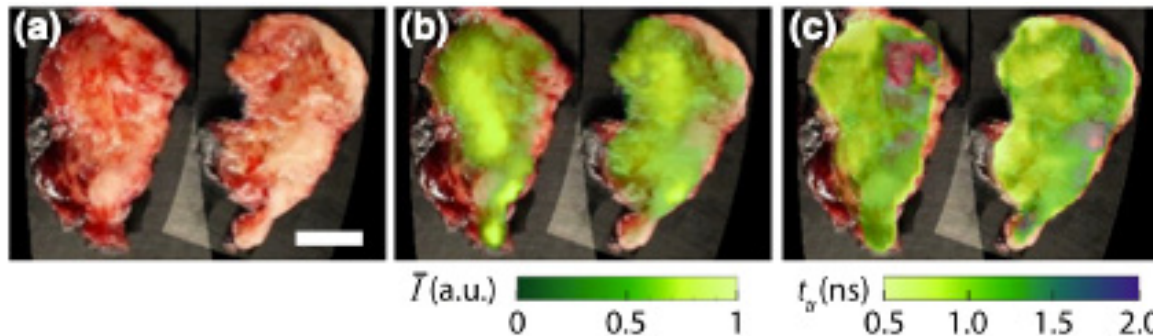


Figure 1: *In vivo* fluorescence LiDAR imaging of a resected head and neck tumour using time of flight data reveal picomolar ABY 029 fluorescence and map margins beneath the surface.

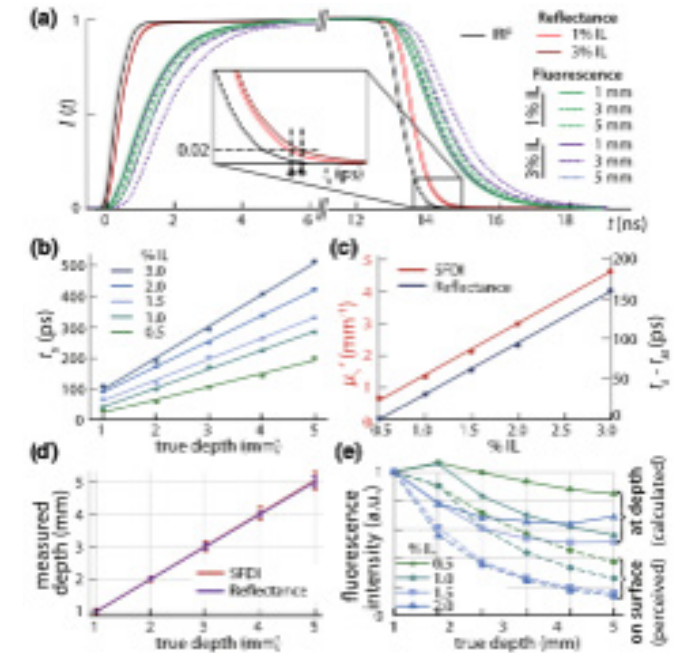


Figure 2: (a) shows depth dependent fluorescence/reflectance traces; (b) converts rising edge delay into a linear depth ruler; (c) retrieves tissue scattering and kernel width; (d) validates depth estimates within ≈ 0.3 mm across 1–5 mm; and (e) corrects surface measured intensity to the true subsurface fluorophore signal.



Clay Minerals to Sequester Carbon from the Ocean Surface

PRINCIPAL INVESTIGATOR: [Dr. Mukul Sharma](#), Professor of Earth Sciences



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INVENTION OVERVIEW

- Current atmospheric CO₂ removal technologies **lack the scale and cost-effectiveness** needed to accelerate transition to a low-carbon economy.
- The marine biological pump processes significant atmospheric carbon (25 Pg/year as DOM, 5-12 Pg as POM), but the majority oxidizes back to CO₂ in the upper ocean, limiting long-term sequestration potential.
- The invention proposes the use of clay minerals** to enhance natural carbon sequestration in the ocean by converting dissolved organic matter into sinking organoclay flocs, driving the efficiency of DOM to POM conversion.

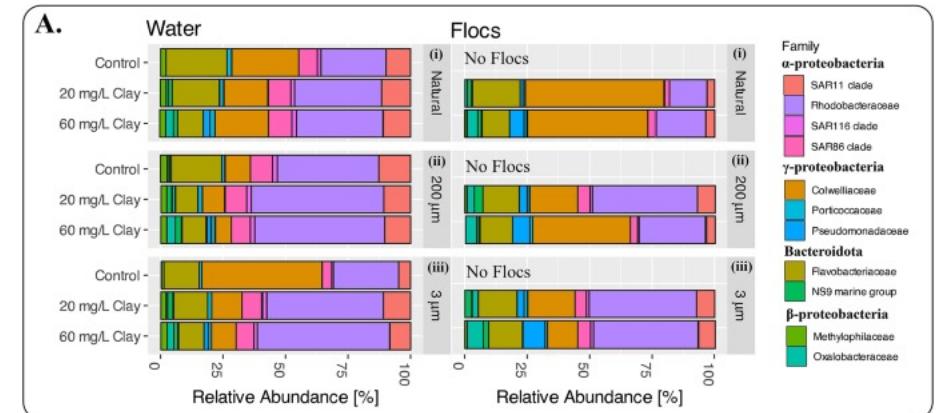
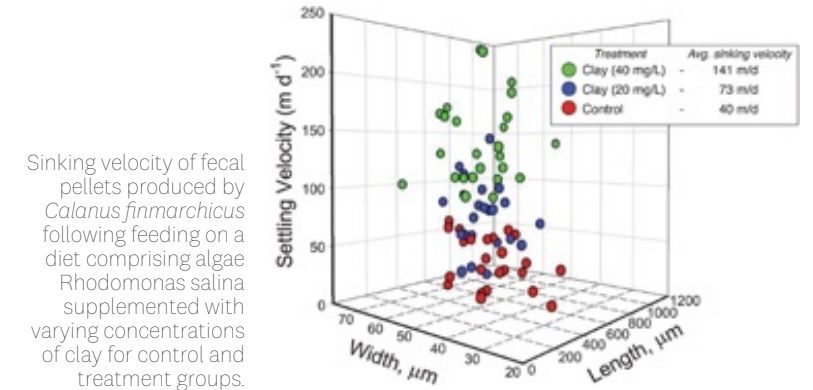
FEATURES AND OPERATING PRINCIPLES

- A mixture of clay minerals, specifically palygorskite, are applied to the surface of the ocean, where they act as a ballast, increasing the density and sinking velocity of organic matter.

- These organoclay flocs are then consumed by zooplankton, which package them into dense, rapidly-settling fecal pellets that enhance carbon transport to deeper waters, particularly during zooplankton diel vertical migration.
- This process enhances the biological pump, removing carbon from the surface waters and preventing its oxidation back to CO₂.

ADVANTAGES

- The invention has the potential to remove over **1 billion metric tons of atmospheric carbon per year** by sprinkling 10 million tons of clay, removing 10 g of carbon per 0.1g of clay.
- The method focuses on existing natural processes and present no adverse impact on the growth of marine bacteria and photosynthetic microalgae.
- Clay materials are inexpensive and readily available. They can also be derived from wasteful by-products of mining and phosphate processing, turning a liability into a potential resource.



Relative abundance and beta diversity from the 16s rRNA gene amplicon sequencing of bacterial communities in water and floc samples. Clay supplementation leads to floc formation with no change in bacterial population.



Nitrogen and Sulfur co-doped MXene compounds for improved hydrogen evolution reaction

PRINCIPAL INVESTIGATOR: [Dr. Will Scheideler](#), Assistant Professor of Engineering



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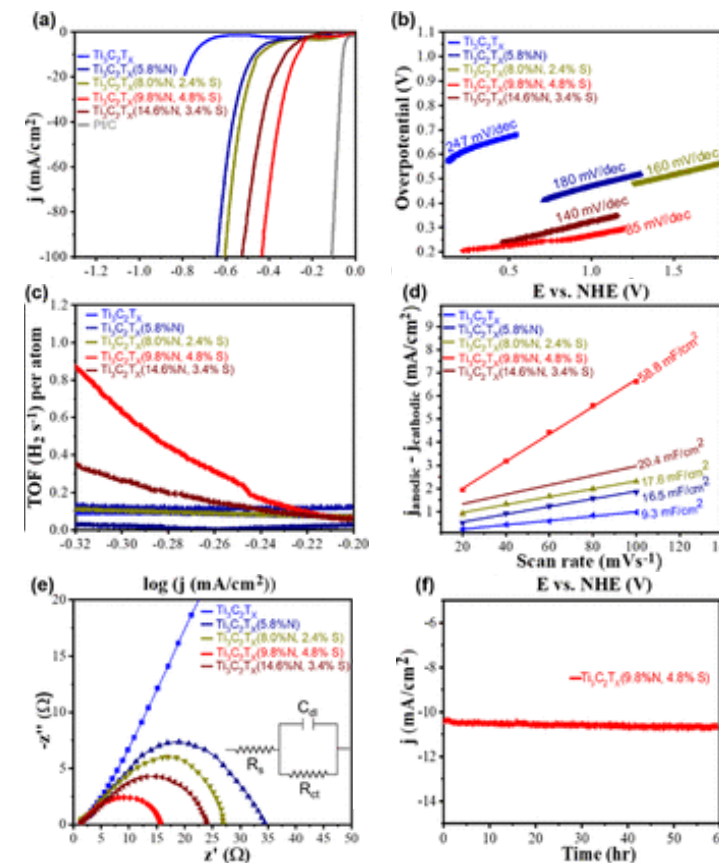
INVENTION OVERVIEW

- N- and S- co-doped MXene compounds offer improved performance and stability in hydrogen evolution reaction compared to existing MXene materials which are limited by poor intrinsic chemical activity and limited active site densities
- Simple thermal annealing process using solid thiourea at 300-700°C for 1-3 hours; allows for controlled surface modification of MXenes and the creation of new chemical bonds.

MXene	Standard Li-ion	Low-Temp Li-ion
Co-doped Ti ₃ C ₂ Tx	260mV	85mV/dec
Pristine Ti ₃ C ₂ Tx	~770mV	247mV/dec

ADVANTAGES AND SCOPE

- Enhanced performance:** This technology overcomes the limitations of poor intrinsic chemical activity and the limited active site densities of pristine MXenes by tuning the interfacial chemical co-doping with anions and is more stable than MXenes with metallic electron donors (Fe, Ni, and Co).
- Improved electrocatalytic activity:** The modified MXenes show significantly reduced overpotential for the hydrogen evolution reaction, achieving 260 mV at 10 mA/cm² which is three times lower than pristine Ti₃C₂Tx (-770 mV).
- Broad applicability:** The technology is generally applicable to electrocatalytically accelerating hydrogen evolution activity and could be extended to other MXenes and to enhance their performance in other electrochemical device applications such as supercapacitors and fuel cells.



Electrocatalytic performance of pristine and doped MXene



Novel Soil Amendment to Remove Atmospheric Carbon Dioxide

PRINCIPAL INVESTIGATOR: [Dr. Mukul Sharma](#), Professor of Earth Sciences



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INVENTION OVERVIEW

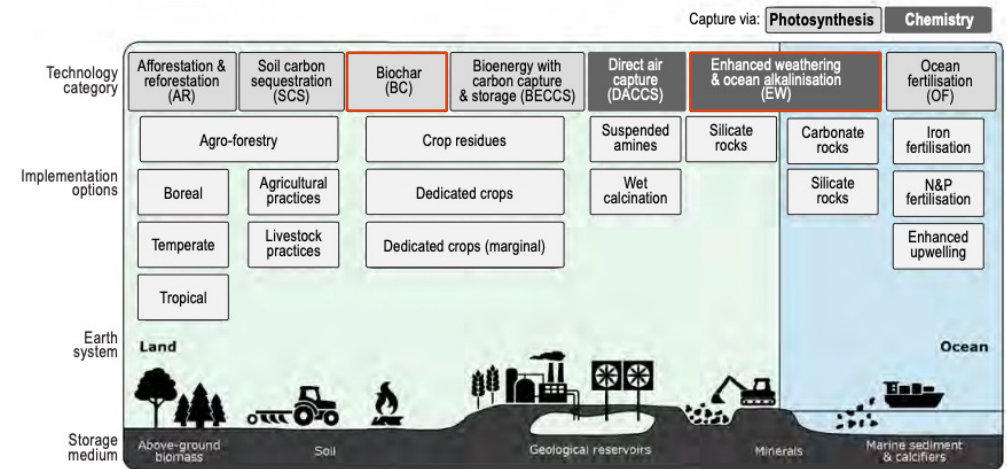
- Two current approaches to carbon dioxide removal (CDR) — enhanced silicate rock weathering (EW) and the application of biochar (BC) — **both have individual limitations.**
- A novel soil amendment**, Altered Basalt with Fortified Biochar (ABFB), is a composite material consisting of both biochar and basalt that can simultaneously **reduce atmospheric CO₂ and increase soil fertility.**
- This technology **addresses the limitations of EW** by accelerating basalt weathering kinetics and also **mitigates the drawbacks of BC** by minimizing the release of CO₂ during production and avoiding the synthesis of pollutants.

FEATURES / OPERATING PRINCIPALS

- ABFB consists of generating an altered basalt through heating and mixing it with BC, which can be derived from various biomass sources.
- This new material becomes a pool of recalcitrant carbon that can reduce atmospheric CO₂ and increase soil fertility by sequestering mineral bound refractory carbon in soil and producing soluble bicarbonate ion (HCO₃⁻) that has a mean residence time of 10,000 years in the environment.

ADVANTAGES / SCOPE

- Reduced Material Usage:** The invention requires about 100 times less basalt than traditional EW.
- Enhanced CO₂ Removal:** ABFB is projected to remove 0.3-0.5 tons of CO₂ per ton of ABFB per year.
- Soil Health:** ABFB improves soil fertility by providing nutrients, decreasing soil acidity, and increasing soil carbon and water content.
- Reduced Pollutants:** ABFB does not contain harmful organic pollutants that can be present in BC.
- Scalability:** The reduced material requirements and enhanced reaction rates make the technology more scalable than traditional EW.
- Cost Efficiency:** The technology is estimated to cost less than \$100 to remove a ton of CO₂.
- Resource Utilization:** The process utilizes waste heat and liquid from BC production, increasing efficiency.



Proposed technologies to get to net-zero. This invention proposes the combination of both Biochar (BC) and Enhanced Weathering (EW).

Figure credit: Baker S.E. et al., 2020, Lawrence Livermore National Lab.(LLNL), Livermore, CA (United States). Retrieved: https://gs.llnl.gov/sites/gs/files/2021-08/getting_to_neutral.pdf



Micro-lattice transition metal oxide materials and structures for efficient electrocatalysis

PRINCIPAL INVESTIGATOR: [Dr. Will Scheideler](#), Assistant Professor of Engineering

INVENTION OVERVIEW

- Novel materials, structures and fabrication processes for highly stable and efficient electrocatalysts for hydrogen evolution reaction (HER) and oxygen evolution reaction (OER) processes.
- Current nickel- and transition metal oxide-based electrocatalysts in alkaline media suffer from sluggish kinetics, stability issues, and low active site density, severely limiting their efficiency. Platinum group metal electrocatalysts are efficient and stable but expensive.

FEATURES

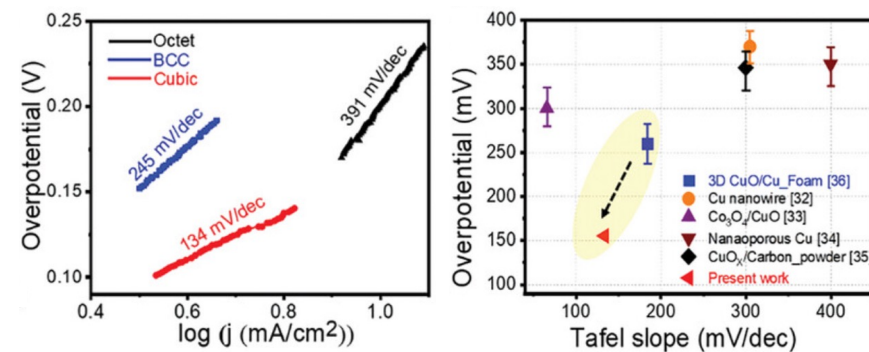
- The innovation uses 3D-printed, lattice-based mesoporous electrodes that provide a high density of electrochemically active sites, facilitate reactant transport, and enhance stability via efficient bubble evolution. The electrodes are fabricated using a polymer infusion additive manufacturing (PIAM) technique.
- The 3D electrodes showed promising performance metrics: an overpotential of **155 mV at 10 mA/cm² for HER** and **1.42 V at 10 mA/cm² for OER**.
- The electrodes also exhibit superior durability, with up to 240 hours of continuous hydrogen evolution without significant performance changes.

ADVANTAGES AND SCOPE

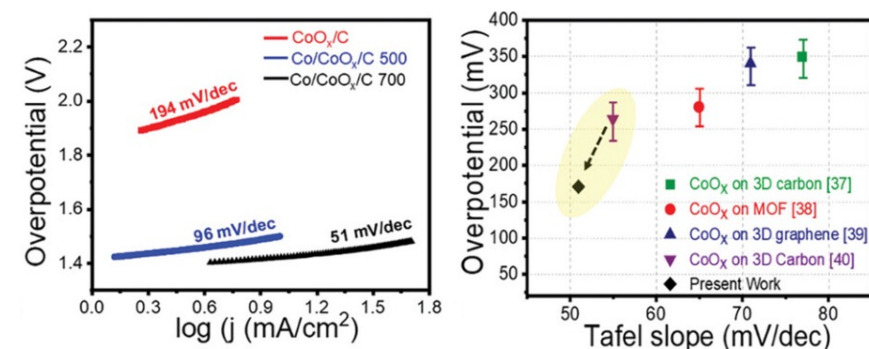
- **High stability:** This invention overcomes the limitations of low stability and activity of traditional earth-abundant electrocatalysts through 3D structuring and chemical modification via a simple heat treatment.
- **Scalability and cost:** 3-D printing manufacturing methods are low-cost and use earth-abundant materials, offering a significant cost advantage over precision metal catalysts.
- **Improved performance:** Superior overpotential for OER and HER compared to existing solutions and benchmark noble metal-based electrocatalysts; improved stability over 3D catalysts and powder electrocatalysts.
- **Design flexibility:** The process allows for greater design freedom in electrode architecture and the mixing of multiple transition metal precursors to form complex alloys for various catalytic reactions (HER, OER, CO₂ reduction, etc). The pore structure facilitates bubble release, preventing blockage of active sites.



VIEW PUBLICATION



Electrocatalytic performance for HER of different microlattices in 1.0 M KOH solution. Left: Tafel plots. Right: Comparison of overpotential at 10 mA cm⁻² and Tafel slopes between 3D microlattices of Cu/CuO_x/C and other 3D structured electrocatalysts



Electrocatalytic performance for OER of Co/CoO_x/C and CoO_x/C cubic microlattices catalysts in 1.0 M KOH solution. Left: Tafel plots. Right: Comparison of overpotential at 10 mA cm⁻² and Tafel slopes between 3D microlattices of Co/CoO_x/C and other 3D structured electrocatalysts.



Enhanced magnetic performance of Manganese Aluminum alloy via Titanium addition

PRINCIPAL INVESTIGATOR: [Dr. Ian Baker](#), Professor of Engineering



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INVENTION OVERVIEW

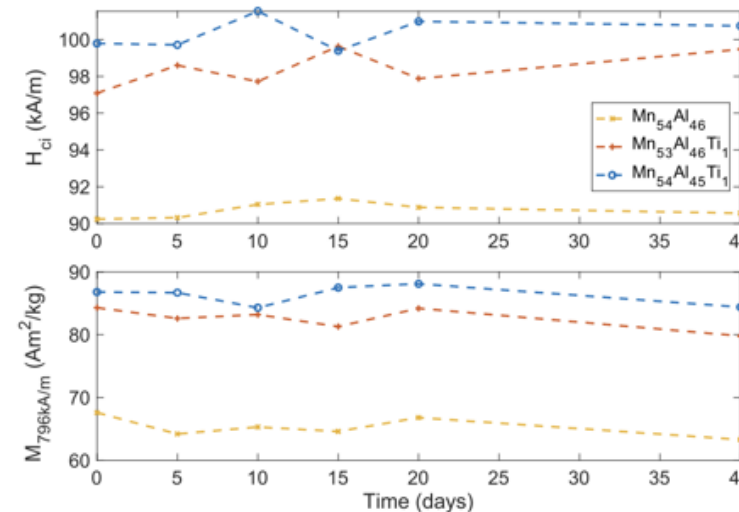
- This invention is a permanent magnet (PM) composed of a manganese-aluminum-titanium (**Mn-Al-Ti**) alloy, designed to improve upon existing magnet technology.
- Current permanent magnets with the highest performance are based on neodymium-iron-boron (Nd-Fe-B) and samarium-cobalt (Sm-Co), which have high raw material costs, scarcity, and require extractive mining.
- Manganese and aluminum are cheaper and more abundant, but current Mn-Al PMs do not perform as well as rare-earth magnets due to limitations in achieving both high coercivity and remanence, and issues with anti-phase boundary (APB) defects.

FEATURES AND OPERATING PRINCIPLES

- The core of the innovation is a Mn-Al-Ti alloy, with a targeted composition of about **1% of titanium**, which is found to preferentially sit on APBs to enable better ferromagnetic pairing across the APB.
- Experimental results demonstrate that a composition of $\text{Mn}_{54}\text{Al}_{45}\text{Ti}_1$ exhibits a **33% improvement** in the base magnetic performance factor (BHmax), as well as increased remanence and equivalent or greater coercivity compared to the standard $\text{Mn}_{54}\text{Al}_{46}$ alloy.

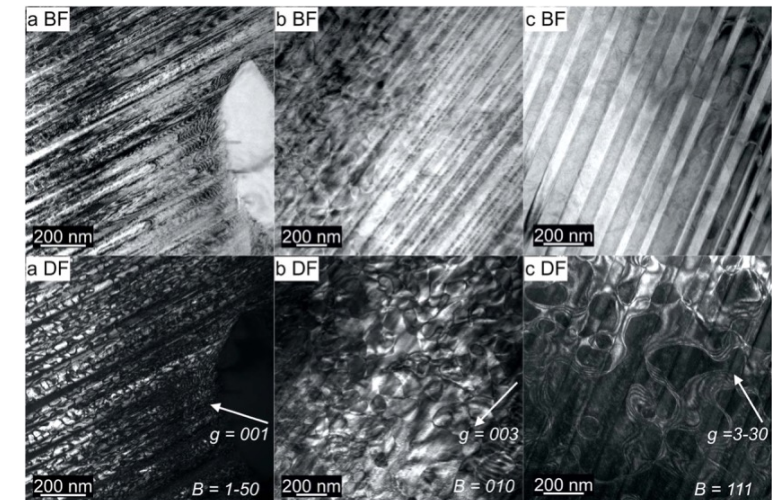
ADVANTAGES

- Improved performance:** The Mn-Al-Ti magnet exhibits higher magnetic remanence, equivalent or greater coercivity, and more stable coercivity at high temperatures compared to the standard Mn-Al alloy.
- Reduced defects:** The invention significantly lowers the density of APB defects and increases the size of anti-phase domains, leading to improved properties.



H_{ci} and M as a function of time at 250°C in air. Samples were not demagnetized corrected, so M values are relative and not absolute.

- Enhanced stability:** The titanium stabilizes the coercivity of the magnet at high temperatures and enables high temperature processing without losing coercivity.
- Cost-effective alternative:** The Mn-Al-Ti alloy provides a potential replacement for expensive rare-earth magnets by utilizing cheaper and more abundant materials such as manganese and aluminum.



TEM BF and DF images of Mn-Al-Ti alloys showing how the density of APBs decreases with Ti addition. (a) $\text{Mn}_{54}\text{Al}_{46}$ (b) $\text{Mn}_{54}\text{Al}_{46}\text{Ti}_1$ (c) $\text{Mn}_{54}\text{Al}_{45}\text{Ti}_1$. B is the beam direction and g is the diffraction vector.



A New Class of Stable and Earth-Abundant Thin Film PV Materials

PRINCIPAL INVESTIGATOR: [Dr. Geoffroy Hautier](#), Hodgson Family Professor of Engineering

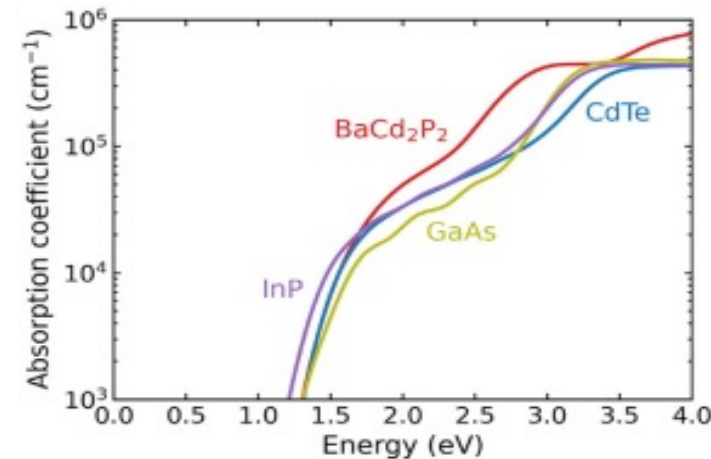
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INVENTION OVERVIEW

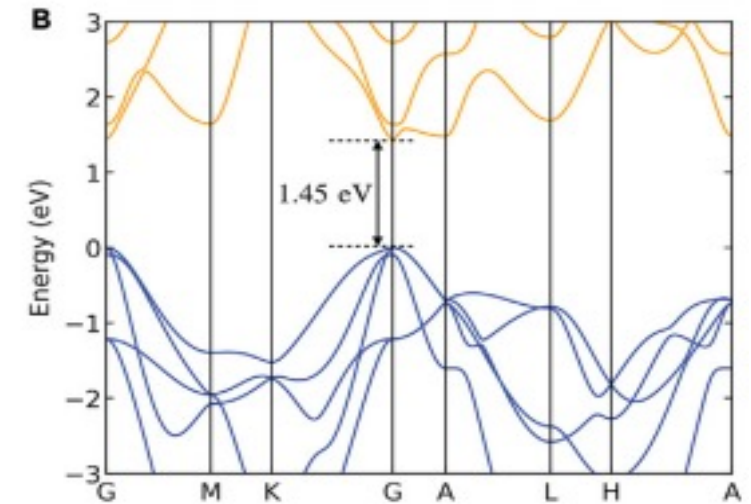
- The technology provides a **new class of materials, Zintl phosphides**, for thin-film solar applications; AM_2X_2 family where A & M are +2 ions and X is a pnictogen.
- A synthesized and tested example, **BaCd₂P₂**, exhibits an optimal band gap, favorable charge carrier properties, and high stability.
- Zintl phosphides offer **tunable electronic and optical properties**, earth-abundant compositions, and environmental stability providing new avenues for developing high-performance, stable, and cost-effective thin-film photovoltaic devices.
- Novel **computational screening process** predicts materials properties to support a highly-focused, efficient development effort.

FEATURES AND BENEFITS

- **Earth-Abundant and Low-Toxicity Elements:** Ba, Cd, P; potential for cadmium-free alternatives like $CaZn_2P_2$.
- **Experimental Verification:** Successful synthesis and empirical confirmation of $BaCd_2P_2$ properties including strong photoluminescence, long carrier lifetimes of up to 30 ns, and exceptional stability in air and water.
- **High-Efficiency Potential:** Optimal band gap ~1.45 eV; favorable carrier mobilities with effective masses for electrons: 0.11–0.74 m_0 , holes: 0.44–0.63 m_0 .



Improved optical absorption of $BaCd_2P_2$



Optimal Electronic band structure



A Dynamic Framework for Managing an Integrated Energy System Under Uncertainty

PRINCIPAL INVESTIGATOR: [Dr. James E. Smith](#), Professor in Decision Science



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INVENTION OVERVIEW

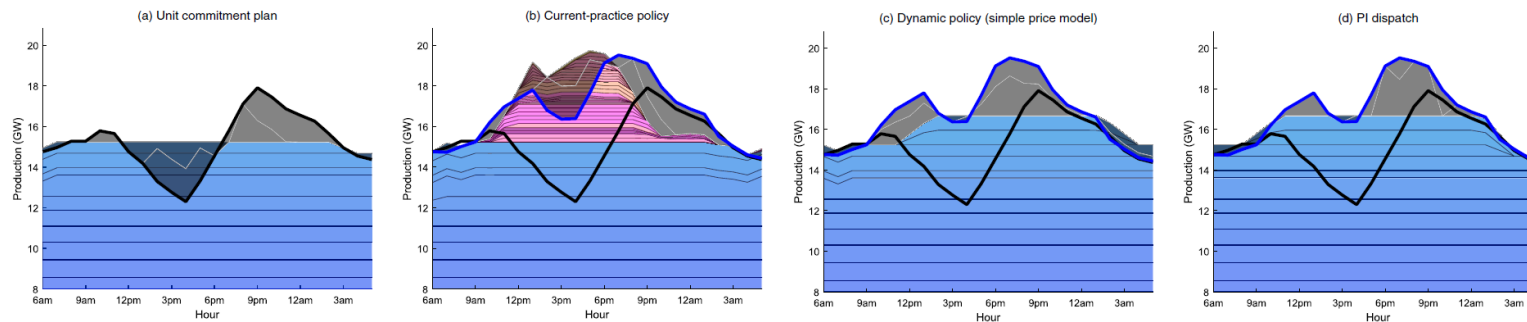
- This invention provides a **dynamic framework for managing an integrated energy system** using a novel approach based on weakly coupled stochastic dynamic programming.
- Current practices in energy management involve solving “unit commitment” and “economic dispatch” optimization problems, which, while complex, do not explicitly **incorporate uncertainty**.
- The increasing use of renewable energy sources has exacerbated issues related to variability and uncertainty in power systems, creating a need for better management techniques.

FEATURES AND OPERATING PRINCIPLES

- The model decomposes an integrated energy system across its various units, then uses a price model to describe the marginal value of energy production, allowing each unit to maximize its expected profit given uncertain prices.
- The system operator can start up or shut down slow-start units and deploy storage as desired, and the ramping constraints are fully respected in this dynamic approach. The unit-specific value functions from the dynamic program are used to incorporate longer-term effects in dispatch decisions.

ADVANTAGES

- Addresses uncertainty:** This dynamic programming method incorporates uncertainty in energy demand and renewable supply, enabling more efficient energy system operation.
- Improved efficiency:** The dynamic approach can reduce operational costs by ~2% on average in the present Duke Energy Carolinas system and can reduce costs by 4–5% on average in a future system with increased solar and storage capacity.
- Near-optimal performance:** The dynamic approach performs, on average, within 0.2–0.3% of production plans based on perfect foresight about future net demands.
- Scalability:** This method is computationally feasible at an industrial scale and can solve the Lagrangian dual problems on a desktop computer in seconds to minutes.



Unit commitment plan to meet deterministic demand forecast (shown with black line).

Given this plan, system response to higher than expected demand (shown with blue line); the unexpected peak is covered using peaking units. Costs are 12.4% more than with perfect information (PI).

Dynamic plan adjusts forecasts mid-morning and starts slow-start units and uses storage to cover unexpected peak. Costs are 0.3% more than PI.

With perfect information about demand. It is optimal to start slow-start units earlier and use less storage in the morning.

Key:

Blue = production from slow-start units
 Pink = production from fast-start units (peakers)
 Gray = into storage (dark gray) or from storage (light gray)

