MARYLAND ENERGY INNOVATION INSTITUTE

ANNUAL REPORT FY2024

Left to Right: MD Delegate David Fraser-Hidalgo, US Rep. Glenn Ivey, MD Senator James Rosapepe, MD Governor Wes Moore, ION CEO Ricky Hanna, ARPA-e Director Evelyn Wang, ION CTO Greg Hitz, MEI^2 Director Eric Wachsman, and UMD President Darryll Pines

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The Maryland Energy Innovation Institute brings together science, industry, government and economic leaders to develop new energy technologies and facilitate the transfer of technology ideas into a reality.

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MARYLAND ENERGY INNOVATION INSTITUTE

MESSAGE FROM THE DIRECTOR

FY2024 was another excellent year for energy innovation in the state of Maryland based on the continued and growing success of the Maryland Energy Innovation Institute (MEI^2) since its inception in 2017. The University of Maryland (UMD) received another 7 US Department of Energy (DOE), Advanced Project Agency-Energy (ARPA-E) awards for $34.8M bringing our total to 50 awards and $160M in total research funding since ARPA-E's inception in 2009, more than any other academic institution in the nation other than MIT and Georgia Tech.

This is in addition to numerous other federal energy research awards received this year. Since its inception, MEI^2 has helped obtain over $253M in federal energy research awards a ~50X return on investment for the State of Maryland based on federal research funding alone.

Through coordination of the MEI^2 Seed Grant program and the Maryland Clean Energy Center's (MCEC's) Maryland Energy Innovation Accelerator (MEIA) program 8 new energy innovation companies were formed in Maryland during FY2024 bringing the total to 58 formed or advanced in Maryland to date. From a survey of these Maryland innovation companies, 42 new full-time jobs were created in FY2024 bringing the total to 134, 78 new patents were filed bringing the total to 124 patents, $9.2M in new private investment bringing the total to $70M, and $34.9M in new federal grant funding bringing the total to $142M for these companies.

Maryland continues to have tremendous potential for economic development from home grown, innovative clean energy technologies, and should consider this when setting R&D investment priorities.

Dr. Eric D. Wachsman
Director, Maryland Energy Innovation Institute
William L. Crentz Centennial Chair in Energy Research
Distinguished University Professor
University of Maryland

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EXECUTIVE SUMMARY

MEI^2 is actively engaged in helping the State attain its climate change goals as codified by the Climate Solutions Now Act (CSNA) through investing in and coordinating interdisciplinary energy research and innovation across all academic institutions within the State. These MEI^2 early-stage innovation investments have paid off in terms of a tremendous increase in federally funded energy research. For example, since the inception of the Advanced Research Projects Agency – Energy (ARPA-e) in 2009 as the US Department of Energy's (DOE) agency focused on energy innovation, UMD has participated in 50 ARPA-e awards for almost $160M leading the nation (with MIT and Georgia Tech) among all academic institutions for ARPA-e awards.

Since its establishment in 2017, MEI^2 has helped obtain over $253M in federal funding, including $110M from ARPA-e and multiple other large awards such as $40M from the US Department of Defense (DoD) for the Center for Extreme Battery Research (CREB) in partnership with the Army Research Lab in Adelphi, MD, with most of this funding directly benefiting the state economy. Thus, based on the MEI^2 share of the Strategic Energy Investment Fund (SEIF) that supports its activities (~$5.1M over the past 7 years), MEI^2 has demonstrated ~**50X return to the State economy based on federal research funding alone**.

MEI^2 also continues to develop international and domestic research partnerships to pursue advances in scientific understanding and technical innovation that will lead to commercialization for a wide range of societally relevant applications including renewable energy generation and storage and the effective use of energy. MEI^2 is leading the U.S. - Israel Bilateral Industrial Research and Development (BIRD) Foundation Energy Storage Consortium, a center with multiple academic and industry partners in Maryland and Israel. The MEI^2 director is also Thrust Lead in a major U.S. - German collaboration on energy storage which includes multiple U.S. and German national laboratories and universities.

More recently, MEI^2 has established a Master Research Agreement with Constellation, the nation's largest producer of carbon-free energy who provides sustainable solutions to homes and businesses across the US. MEI^2 also signed a cooperative agreement with the Korean Energy Technology Evaluation and Planning (KETEP). The signing launches the Korea - US Energy Cooperation Center at MEI^2/UMD to coordinate cooperation between US and Korea researchers.

Furthermore, MEI^2 is actively engaged across campus, the state, and the nation in educational and outreach efforts. MEI^2 hosted an NSF Research Experience for Undergraduates in the summers of 2022, 2023, and 2024 which provided students with recruitment opportunities from government and private industry.

Moreover, since 2017 MEI^2 has used the bulk of its share of the SEIF to award $3.3M in Energy Seed Grants to academic institutions and their associated energy spin-off companies throughout the State. As a result of the MEI^2 Energy Seed Grant program, in partnership with the Maryland Energy Innovation Accelerator (MEIA), 58 companies have been founded and/or advanced in Maryland creating 225 full and part-time jobs and bringing in $79M in private investments and over $111M in grant funding for those companies a ~**33X return to the State economy from companies assisted through this MEI^2 and MEIA partnership**.

INTRODUCTION

The state of Maryland has enacted legislation and made numerous major investments in the deployment of energy efficiency and renewable energy over the last several years creating a strong *market pull* for a wide range of energy technologies. Due to the inextricable link between energy and environment, most of this energy investment has come from proceeds from Maryland's portion (≥$100M annually) of the Regional Greenhouse Gas Initiative (RGGI) that was created as a market incentive to protect the environment by reducing CO_2 emissions. However, to capitalize on these investments, an energy innovation *technology push* is necessary to make sure the resultant high paying manufacturing jobs remain in the State. In order to ensure that Maryland continues to lead the charge in protecting the environment while growing the clean energy economy, Maryland SB313, "*Economic Development – Maryland Energy Innovation Institute*", was signed into law on May 4, 2017, creating MEI^2 to attract and develop private clean energy innovation in Maryland, with the legislative purpose to:

- Collaborate with academic institutions in the state to participate in clean energy programs.
- Develop and attract private investment in clean energy innovation and commercialization in the state.

The passage of SB460/HB419, "*Economic Development – Advanced Clean Energy and Clean Energy Innovation Investments and Initiatives*" in January 2022, ensured the continuation of MEI^2 to both grow the Maryland economy and address the grand challenges of climate change. The bills identified energy as an economic opportunity while broadening the definition of included technologies. It also removed the sunset date of MEI^2 funding and increased the budget with a specific focus on innovation.

In addition to overall promotion and coordination of energy and environmental research across all state academic institutions MEI^2 provides the critical infrastructure to enable clean energy technology breakthroughs to become commercially viable companies thereby stimulating economic growth and improving millions of lives across the State of Maryland.

The legislation also formalized a partnership between MEI^2 and the Maryland Clean Energy Center (MCEC). MCEC is a corporate instrumentality of the state created by the General Assembly with a statute-directed mission to advance clean energy and energy efficiency products, services, and technologies as part of a specific economic development strategy. MCEC's economic development mission is to advance the adoption of clean energy, and energy efficiency products, services and technologies with focus on three areas of effort:

- Access to capital.
- Educational outreach.
- Innovation advancement.

And now with the passage in FY2024 of SB960/HB1220, the Climate Technology Founder's Fund, additional funding will be available to support early-stage businesses and startups that are developing innovative climate and clean energy technologies.

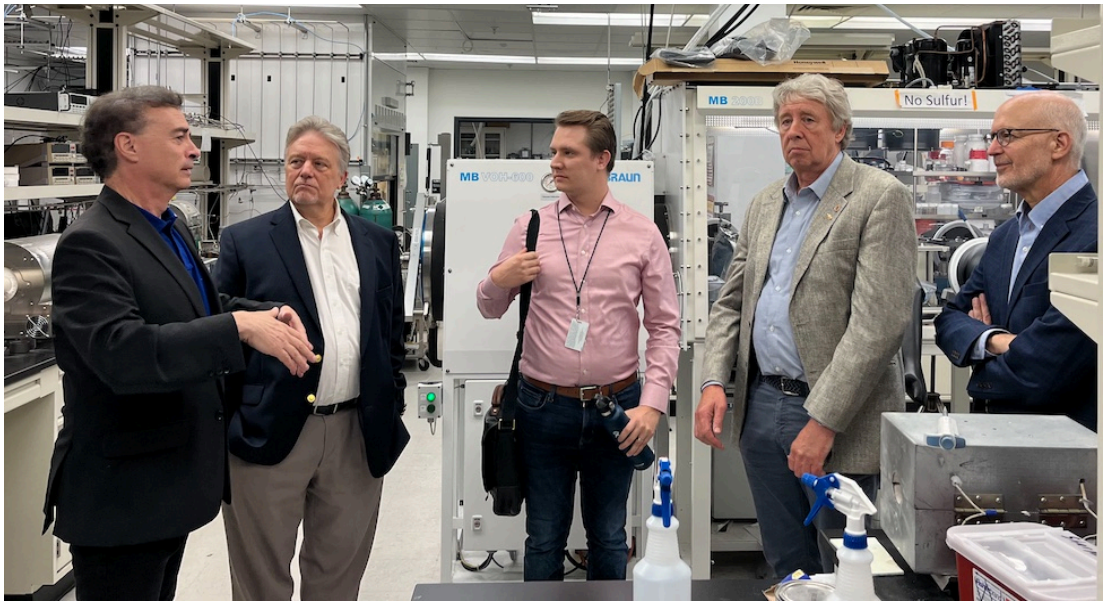
MEI^2 drives energy technology innovations across the state academic institutions in conjunction with Mtech and the Maryland Department of Commerce. In contrast, MCEC as a green bank investment vehicle, facilitates capital to support technology commercialization and project development, as well as provide a needed link to energy sector stakeholders and industry partners.

Recently as part of this partnership and its innovation advancement focus, MCEC stood up the Maryland Energy Innovation Accelerator (MEIA) that focuses on the business side of innovation, providing business, legal, and entrepreneurial training programs that directly complement the technology innovation focus of MEI^2 to create an integrated energy innovation ecosystem.

IMPORTANT FY2024 LEGISLATION

The clean energy industry generates hundreds of billions of dollars in economic activity and offers the US and Maryland a tremendous economic opportunity to invent, manufacture and export clean energy technology. The State of Maryland is committed to addressing carbon emission reduction, energy innovation and efficiency, and the electrification of transportation and workforce development as demonstrated by several legislative actions that took place in FY2024.

Prior to the legislative session in January 2024, Maryland Senator Brian Feldman and Delegate David Fraser-Hidalgo toured the MEI^2 labs at UMD and discussed key impediments to the advancement of clean technologies, specifically in the areas of battery commercialization and energy storage. Both legislators noted that investing in battery R&D can supercharge the Maryland economy and aid in the fight against climate change. These fruitful discussions helped lead to the creation of SB0960 (discussed below) that was introduced by Senator Feldman.



Left to Right: Senator Feldman, Dr. Eric Wachsman, Evan Chiarelli, Dr. Robert Briber (Associate Dean for Research), Ross Stern (Executive Director for Government Relations)

Additional funds from the bill will allow MEI^2 and MEIA to provide expanded support services for prototype development and manufacturing through their energy seed grant program and MEIA's accelerator/launchpad programs. This dedicated funding is critical to sustaining the impact and future growth for MEI^2 to facilitate early-stage technology commercialization in partnership with Maryland-based businesses, universities, and labs to support the State's clean energy and climate goals. The program helps startups at the early innovation stage create investible businesses focused on solar, wind, batteries, energy efficiency, grid modernization, carbon capture

utilization and storage (CCUS), and any other technology that reduces greenhouse gas emissions or provides negative emissions benefits in the electric, oil and gas, residential, commercial, or industrial sectors.

In addition, Governor Moore announced the transfer of $90M from the Strategic Energy Investment Fund (SEIF) in the FY2025 budget to support the administration's climate agenda. The funding includes at least 50% to uplift communities historically overburdened and underserved and will be used for three initiatives:

- **$17M** to purchase and lease electric school buses for the state's public-school systems
- **$23M** to install electric vehicle charging infrastructure in low and moderate-income communities
- **$50M** to electrify hospitals, schools, multi-family housing and community buildings

Building on this, several bills were passed that reflect Maryland's commitment to advancing renewable energy technologies and reducing its carbon footprint by promoting innovative solutions in waste management (anaerobic digestion) and supporting climate-focused startups.

- **SB0960 / HB1220** - Maryland Clean Energy Center - Climate Technology Founder's Fund - This bill establishes the Climate Technology Founder's Fund within the MCEC. The goal of the fund is to support early-stage businesses and startups that are developing innovative climate and clean energy technologies. The fund provides capital investments, seed funding, and other financial resources to help these companies grow, with a focus on those that can advance Maryland's clean energy and climate goals. This bill is designed to stimulate economic growth in the clean energy sector, foster innovation, and drive the development of new technologies that contribute to the state's efforts to combat climate change.
- **SB0808 / HB1466** – Anaerobic Digestion Technology – Coordination and Guidance - This bill focuses on promoting anaerobic digestion technology in Maryland, which is a process that breaks down organic materials (such as food waste and manure) to produce biogas and nutrient-rich byproducts. The legislation seeks to establish statewide coordination and guidance to encourage the development and deployment of anaerobic digestion facilities. The bill likely includes provisions for technical assistance, regulatory streamlining, and fostering public-private partnerships to facilitate this technology. It aims to reduce waste sent to landfills, generate renewable energy, and create valuable agricultural products while reducing greenhouse gas emissions.

Regarding the electrification of transportation in the coming years, the Maryland state legislature passed three key bills that work toward Maryland's goal of advancing electric vehicle adoption and renewable energy infrastructure to support a more sustainable and electrified future.

- **SB0465 / HB0159** - Common Ownership Communities - Electric Vehicle Recharging Equipment (Electric Vehicle Recharging Equipment Act of 2024) - This bill aims to make it easier for residents in common ownership communities (such as condominiums, homeowner associations, and cooperatives) to install electric vehicle (EV) recharging equipment. It ensures that these communities cannot unreasonably restrict or prevent the installation of EV charging stations. The legislation outlines the rights and responsibilities of both the property owners and

the common ownership community in relation to installing and maintaining EV charging equipment.

- **SB0951 / HB1028** - Electric Vehicle Supply Equipment Workgroup - This bill establishes an Electric Vehicle Supply Equipment (EVSE) Workgroup tasked with examining and making recommendations about the deployment of EV charging infrastructure in Maryland. The workgroup will likely explore issues such as the availability, accessibility, and equitable distribution of charging stations. They will also consider strategies to improve the deployment process, address technical challenges, and align infrastructure with EV growth.
- **SB0959 / HB1256** - Electricity - Tariffs, Distributed Energy Resources, and Electric Distribution System Support Services (Distributed Renewable Integration and Vehicle Electrification (DRIVE) Act) - This legislation focuses on integrating distributed energy resources (such as solar panels, energy storage, and electric vehicles) with the state's electric distribution system. It includes provisions for tariffs, support services, and incentives aimed at promoting the adoption of distributed renewable energy and EV infrastructure. The bill seeks to ensure that the electric grid can support an increased number of EVs and distributed energy sources while promoting renewable energy use and grid modernization.

Likewise, the MCEC Climate Catalytic Capital Fund (C3 Fund) continues to promote geographical impact remedies and to leverage increased private capital investment in technology development and deployment. An allocation of $15M over three fiscal years was committed to the C3 Fund beginning in FY2024. The C3 Fund is intended to be leveraged further with additional investments of private capital for projects and programs. A minimum of 40% of C3 Fund investments are to be targeted to assist low-income households and communities across the state to access decarbonization solutions and strategies.

In addition to state funding, at the federal level the US government is engaged in a number of new programs to combat the climate crisis by building a clean energy economy and lowering energy costs that provide tremendous opportunity for the State of Maryland in terms of greater support for energy R&D, innovation, deployment, and financing, all areas of focus for MEI[2] and its partner MCEC.

The DOE's FY2024 budget invested nearly $2 billion to support clean energy workforce and infrastructure projects across the Nation, including $425 million to weatherize and retrofit low-income homes, $83 million to electrify tribal homes and transition tribal colleges and universities to renewable energy, and $107 million for the Grid Deployment Office to support utilities and State and local governments in building a grid that is more reliable and resilient and that integrates accelerating levels of renewable energy. The newly established Office of State and Community Energy Programs launched a new Energy Burden Reduction Pilot with $50 million to retrofit low-income homes with efficient electrical appliances and systems.

To support US preeminence in developing innovative technologies that accelerate the transition to a clean energy economy, the Budget invested $9.4 billion, an increase of more than 19.7% percent over the FY2023 enacted level of $7.8 billion in DOE clean energy research, development, and demonstration. These investments will improve clean power technologies, strengthen clean energy-enabling transmission and distribution systems, decarbonize transportation, advance carbon management technologies, and improve energy efficiency in industry and buildings. This funding also leverages the tremendous innovation capacity of the National Laboratories,

universities, and entrepreneurs to transform America's power, transportation, buildings, and industrial sectors.[1]

And in February 2024, DOE announced a new $24 million funding opportunity for workforce training programs with a focus on training in clean energy jobs that do not require a four-degree. This funding, from the Bipartisan Infrastructure Law, will further expand the existing Industrial Assessment Centers (IAC) network to include more union training programs, community colleges, and trade schools. These IACs support US goals of growing our clean energy workforce and boosting the economy by helping small and midsized manufacturers (SMMs) identify opportunities to save costs and increase productivity. Programs will also offer training and upskilling opportunities for current manufacturing and building energy workers. Participants will exit these programs prepared for high-quality, in demand roles as building energy managers, insulators and heating, air conditioning, and refrigeration professionals, and as advanced manufacturing technicians for growing clean energy sectors like batteries and solar manufacturing.

FY2024 Advisory Board

Victor Der, Board Chair
Assistant Secretary of Fossil Energy, U.S.DOE (retired)
Mallikarjun Angalakudati
Sr. Vice-President Strategy & Innovation Utilities, Washington Gas
Steven Freilich
Dupont Central Research and Development
Thomas Greszler
Cell Development Manager, Saft America
Michael Gill
Acting Chair of the board for MCEC
Portfolio Manager, Cornerstone Advisory
Patrick McGrath
Program Director, Schmidt Family Foundation
David Rapaport
Siemens Corporate Technology
Paul Pinsky
Director, Maryland Energy Administration
Colleen Wright
Vice-President Corporate Strategy, Constellation

ADVANCING THE MARYLAND ENERGY INNOVATION ECOSYSTEM

MEI^2 Advisory Board

As per the enabling legislation there is an MEI^2 Advisory Board to provide advice to the Director on the management of the Institute. The MEI^2 Advisory Board consists of the following: 1) the chair of the board of directors of the Maryland Clean Energy Center; 2) the director of the Maryland Energy Administration; and 3) seven members selected by the Director based on expertise in energy technology commercialization, the clean energy industry, venture capital financing, and energy research. The Advisory Board welcomed two new members this year: Colleen Wright, vice-president of corporate strategy at Constellation, and Pat McGrath, program director of climate technology at the Schmidt Family Foundation. At Constellation, Wright advances new technologies, policies, and business model transformations through partnerships, grants and research and development. McGrath was previously the Deputy Director for Technology at ARPA-e, where he led a diverse staff of technical and commercialization experts to develop and deploy next-generation energy technologies.

The MEI^2 Advisory Board meets annually to provide advice, review progress on previous goals, and provide follow-on recommendations. The Advisory Board confirmed in their letter (Appendix

[1] Department of Energy FY 2024 Budget in Brief, March 2023, http://energy.gov/doe-fy2024-budget-in-brief.

FY2024 Investment Committee

Robert Briber (Chair)
Associate Dean for Research, UMD A. James Clark School of Engineering
Eric Chapman
UMD Assistant Vice-President for Research and Development
Ken Porter
Director of UM Ventures
Ryan Powell
Energy Program Manager, MD Department of Commerce
Tammi Thomas
Chief Development and Marketing Officer, (TEDCO)
Colleen Wright
Vice-President Corporate Strategy, Constellation

2) that MEI^2 has been achieving its goals catalyzing significant advancement in research and innovation of advanced clean energy technology toward greater economic growth in the state of Maryland.

MEI^2 continues to drive Maryland energy innovation in partnership with MCEC, Mtech, TEDCO, UM Ventures, and the Maryland Department of Commerce. Since its inception it has focused on advancing Maryland university energy research activity and translating the results of that energy research through a Seed Grant Program to prototype/process demonstrations of sufficient technology readiness level (TRL) to attract private, VC type, investment. Over the past six years, MEI^2 has used its share of the SEIF to award in Energy Innovation Seed Grants to academic institutions and their associated energy spin-off companies throughout the State.

MEI^2 Energy Innovation Seed Grant Program

Since its inception MEI^2 has focused on advancing Maryland's energy research and translating this research to economic growth. As such MEI^2 initiated a seed grant program to bridge the gap between academic transformative laboratory research results and the prototype demonstrations necessary to obtain investor interest. It is expected that projects should advance energy technology and economic growth in Maryland. At the end of one year, a report that describes work done and includes a plan for the next steps toward commercialization will be the final deliverable for the project. The plan should include: 1) clear assessment of technical readiness (including ultimate cost and scalability) of the product; 2) a survey of potential customers for the product; and 3) a strategy for next steps in financing the plan.

An MEI^2 call for seed grant proposals is issued annually and open to all academic institutions in Maryland. Annual seed grants are awarded at two levels: Phase I grants up to $100k, and Phase II up to $200k for projects that received prior seed funding. The project should advance energy technology and economic growth in Maryland. The device or process should have appropriate intellectual property protection (invention disclosure, patent application, or patent) filed with the applicant institution. Applicants are expected to address the following in their proposals: 1) innovation and technical merit, 2) the likelihood of attracting follow-on funding, and 3) the potential for commercialization. The MEI^2 Investment Committee was created to independently oversee the solicitation and review of the Energy Innovation Seed Grants and other activities that support the Energy Investment Fund.

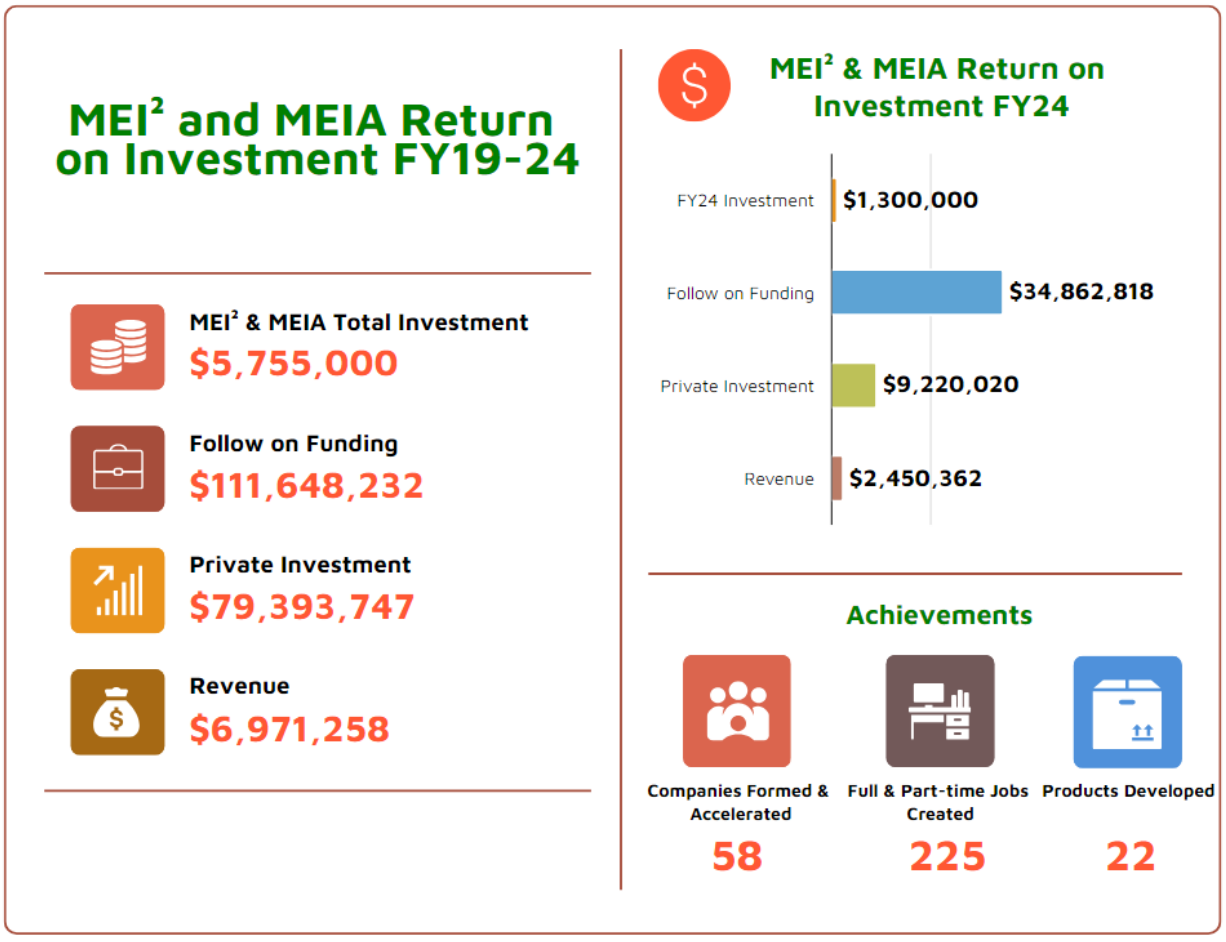
Since its 2017 inception, 34 companies and/or university researchers have received a total of $3.3M in funding from the MEI^2 Seed Grant program including the University of Maryland Baltimore County (UMBC), the University of Maryland Eastern Shore (UMES), Morgan State University (MSU), Johns Hopkins University (JHU), and the UMD. Twenty-seven total grants (27 Phase I and 7 Phase II) have been awarded. Additional funding

beginning in FY2023, allowed MEI^2 to expand the Energy Seed Grant funding from $400k to $650k annually.

Maryland Energy Innovation Accelerator

The Maryland Energy Innovation Accelerator (MEIA), created in 2019 as a program of the MCEC, is committed to rapidly bringing new solutions and innovations to market to help mitigate and adapt to climate change. Advancing these technologies is essential to achieving Maryland's ambitious climate goals. MEIA focuses on commercializing advanced energy and climate technologies developed by Maryland-based businesses, universities, and laboratories. By providing climate tech ventures with access to domain experts, experienced executives, co-founders, investors, strategic partners, professional services, and project management, MEIA supports and accelerates the achievement of commercialization milestones. As an integral part of the MCEC, the organizations play a pivotal role in bringing technologies to market and driving growth in the clean energy economy.

As such the MEI^2/MEIA collaboration provides traditional academic research a pathway into commercialization through a more comprehensive energy innovation ecosystem. To date, 58 Maryland based companies have been formed and/or received support from MEI^2, MEIA or in some cases both organizations.



In FY24, MEIA and MEI^2, in collaboration with UM Ventures, conducted a joint economic development survey of their accelerator and seed grant programs. Results from the economic survey are shown in the figure shown above.

Through Maryland Senate Bill 960, which benefits Small, Minority, and Women-Owned ventures and provides additional research resources. MEIA facilitated a Climate Tech Exchange to encourage collaboration among startups, service providers, and ecosystem programs. Additionally, MEIA and MEI^2 supported the first Maryland Climate Tech Meet Up at the University of Maryland College Park, and the Baltimore Climate Tech Meet Up. Through its commitment to fostering early-stage growth and cultivating long-term success, MEIA and MEI^2 not only accelerate the development of breakthrough solutions but also helps build a more sustainable and resilient future for all.

MEI^2 ENERGY INNOVATION AWARDEES

MEI^2 has been extremely active advancing the Maryland innovation ecosystem with a particular focus on advancing and mentoring Maryland university energy award winners in technology commercialization from proposal stage to post award results including the launch of several Maryland energy companies. A few of these are highlighted here.

ION Storage Systems

Founded in 2015, Ion Storage Systems (ION) has developed a groundbreaking 3D ceramic electrolyte architecture that enables solid-state batteries to charge faster and provide greater range. Spun out of UMD's MEI^2, ION's core technology is the brainchild of the UMD Distinguished University Professor, Dr. Eric Wachsman, who founded the company along with chief technology officer Dr. Greg Hitz (UMD, PhD '16). On April 29, 2024, ION began operating one of the largest US factories for solid-state batteries (SSBs) with over 75 employees in a 33,000 ft^2 Beltsville Maryland manufacturing facility, giving a boost to the adoption of green technologies. The plant will produce batteries that charge faster and store more power than lithium-ion batteries and will first be used in Department of Defense (DoD) applications.

ION is commercializing next-generation, high power-density, solid-state lithium metal batteries, based on ceramic electrolyte manufacturing for large-scale, low-cost battery production. The battery's 3D ceramic solid-state electrolyte architecture is nonflammable, making it intrinsically safer to use and store and works with a multitude of cathode chemistries and cell configurations. A key feature is there is no change in volume during cycling, resulting in simpler module packaging and higher pack level density. ION will mature the design and manufacturing processes toward deployment in the electric vehicle (EV) market with expansion opportunities into consumer electronics and defense applications. ION's approach has the potential to reduce battery manufacturing greenhouse gas emissions by 50% per kilowatt-hour. ION has been working with the DoD to rigorously test its SSB battery before expanding into other markets including electric vehicles, consumer electronics, and grid storage and recently announced that its anode-less and compression-less SSB achieved key customer *and industry* threshold for market deployment.

ION's SSB successfully achieved and exceeded 800 cycles with no capacity degradation in performance offering the potential to achieve automotive market requirements.

Left to Right: Founder Eric Wachsman (UMD), Todd Crescenzo (Clear Creek Investments), US Senator Chris Van Hollen, CEO Ricky Hanna (ION), US Rep. Glenn Ivey, Mark Fields (Alsop Louie), CTO Greg Hitz (ION)

In June 2024, ION received a $20M SCALEUP award from the DOE ARPA-e program. The SCALEUP program provides major new funding to previous ARPA-e awardees that have successfully de-risked their technology and established a viable route to commercial deployment. In addition, ION has received a $1M award from the Maryland Department of Commerce's Build our Future program, a $1.5M investment from TEDCO (Maryland's venture capital investors), and $200K from Prince Georges County Economic Development Fund (EDI). Federal and State officials gathered in August to celebrate ION's achievements. (*photo on cover*)

Materic

Based in Baltimore, Maryland, Materic custom designs and manufactures advanced materials. They apply expertise in electrospinning, nanoparticle separation, textile treatments, 3D printing materials, specialty inks and microencapsulation to their own product lines as well as taking on custom manufacturing projects for customers. Dr. Susanna Thon, JHU professor, in collaboration with NanoDirect LLC, a materials science company using proprietary separation technologies to manufacture high purity nanoparticles and silver nanowire inks, received a Phase I (2018) and Phase II (2021) energy seed grant to build transparent conductors for quantum dot solar cells that

can be used for building-integrated photovoltaics (BIPV). These allow for light-weight systems that can be incorporated into building facades, providing a solution to limited real estate for generating solar energy in high power consumption areas. Key advances due to the seed grant award include improved lab-scale-are colloidal quantum dot (CQD) solar cell device performance, demonstration of large-area CQD solar cell performance, construction and optimization of a scalable spray-cast deposition for large-area devices, and formulation of a silver nanowire electrode material necessary for high-performing, flexible devices. The group has identified over 100 potential customers for the materials, established a new laboratory and manufacturing site in Baltimore, liaised with corporate customers (LG, DuPont Microcircuit Electronics, SunChemical and VFP Ink) in preparation for shipping test materials, and produced a business plan specific to the silver nanowire and transparent conductor development.

In May 2021, NanoDirect joined with five other advanced materials companies to create Materic, LLC. NanoDirect and the other companies shared a common co-founder in Early Charm. By coming together under Materic, the group now have sales into the aerospace, healthcare, biotechnology, electronics, automotive, athletic, energy and military industries, giving them contacts into each of the key sectors for advanced materials. Materic's Baltimore-based scientists, engineers and designers are integrated into all customer collaboration phases – from ideation to prototyping to manufacturing – to turn advanced materials concepts into scalable products.

In March 2024, Materic announced the launch of its new product line, Koyla Web™. The Koyla Web line of carbon nanofibers includes three currently available types of mats, or products can also be custom ordered. This product line that will have a big impact in the clean energy industry and others. Carbon nanofibers have strong electrical and thermal conductivity and are corrosion resistant. These properties, paired with the high surface area characteristics of their web-like structure, make carbon nanofibers ideal for a variety of applications in the energy, automotive, aviation, and medical industries.

The Koyla Web launch coincided with Materic's selection to receive $10 million from the US DOE Department of Energy Office of Energy Efficiency & Renewable Energy (EERE), under the funding opportunity DE-FOA-0002922: "Clean Hydrogen Electrolysis, Manufacturing, and Recycling Activities under the Bipartisan Infrastructure Law." Materic's project, "SPIN into Power: Scaled Production of Integrated Nonwoven Gas Diffusion Layers for Fuel Cells," will focus on creating a new supply chain pathway for key components of hydrogen fuel cells with improved performance. Specifically, Materic and its project partners will work to strengthen the domestic supply chain for gas diffusion layers for low-cost fuel cells. The carbon nanofiber membranes will help improve the performance of hydrogen fuel cells today and in the future. Because the production process is highly tunable, Materic will be able to adapt the Koyla Web product line to meet the needs of fuel cell manufacturers even as industry technologies continue to evolve. Koyla Web carbon nanofiber mats are now available for purchase through Materic's website.

InventWood

Since their founding in 2016, InventWood has been developing high-performance, cost-effective, carbon-sequestering wood and cellulose materials to replace unsustainable alternatives that are currently used in building and other industries. In 2018, InventWood received $4M in federal funding through the ARPA-e OPEN grant for the development of MettleWood, which received its first patent in 2021. Since then, the company has been awarded 10 additional patents. In 2022, InventWood received a $20M ARPA-e SCALEUP award to utilize building MettleWood's pilot facility.

InventWood's manufacturing facility in Frederick, MD.

The company recently moved into an 89,000 square-foot industrial facility in Frederick, Maryland and will house a production line and new product development laboratory. InventWood plans to launch their commercial manufacturing in 2025. This expansion will allow the company to bring on more operational, technical, and scientific research staff. The company recently announced $8M in new funding. Joining existing investor Grantham Foundation, are new investors including Builders Vision, Echelon and John Rockwell, four-time CEO of successful clean technology companies and partner in multiple private investment firms.

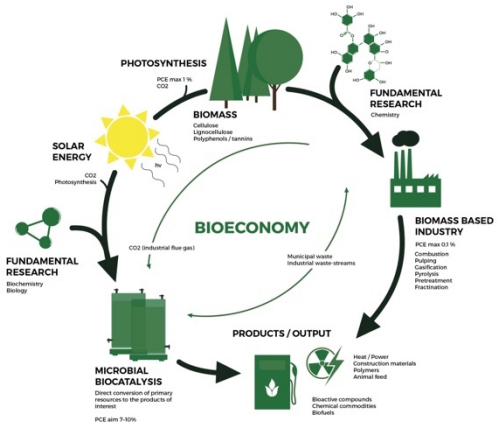
MettleWood is a biomaterial of unprecedented strength and durability that can replace 80% of all steel and concrete used currently. It is 50% stronger and 6 times lighter than steel. It consists of 100% wood and offers high performance while reducing climate-changing emissions. Because it is lighter than steel, it will greatly reduce transportation and construction costs, allow for easier handling and installation and faster building construction.


The InventWood team with founder Liangbing Hu (2nd from left), and Jonathan Scott of Property Brothers fame (3rd from left) at the 2024 ARPA-e summit.

Atlantic Biomass

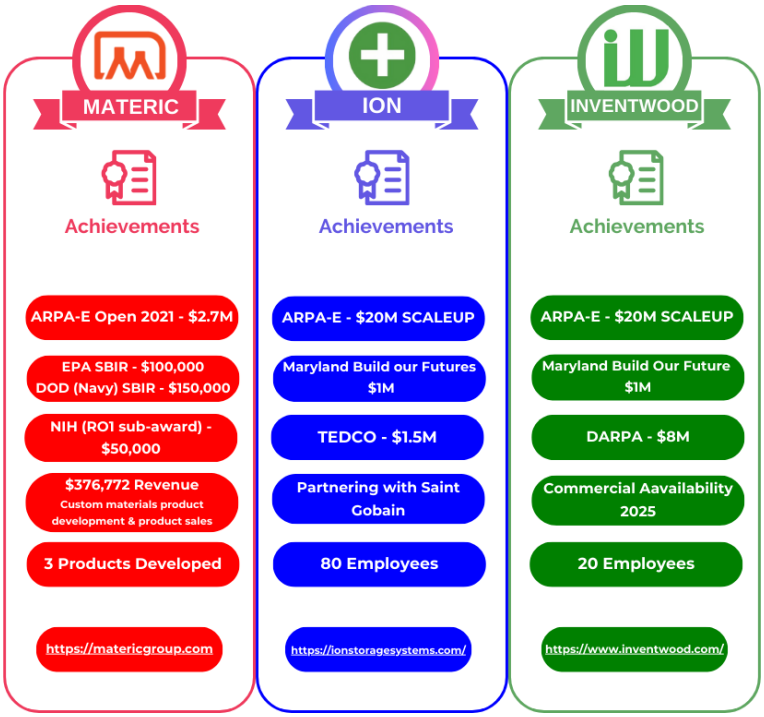
Atlantic Biomass, LLC, a small business located in Frederick, Maryland is focused on the development and commercialization of proprietary enzymatic-based biomass "deconstruction" processes. These processes allow the use of low-cost, non-food biomass as feedstocks for renewable sustainable biofuels and bioproducts. Processes developed convert hemp biomass, sugar beet pulp and grasses into the building blocks for biofuels and other bioproducts, as well as

dandelions for rubber. Atlantic Biomass is also a recipient of a Phase I (2020) and Phase II (2022) MEI^2 Energy Seed Grant, which enabled the company to scale up their technology. The company recently secured a Bioenergy Technologies Office Small Business Innovation Research (SBIR) award working to accelerate bioenergy R&D. Atlantic Biomass will be funded for its project: "Low-Cost Production of Sustainable Aviation Fuels (SAF) from Perennial Feedstocks using Simultaneous Ball Milling and Enzyme Hydrolysis".



Work on this project will be performed by Atlantic Biomass with their STTR Institutional Partner, The Ohio State University (OSU) Department of Food, Agricultural and Biological Engineering located in Wooster, Ohio. Dr. Fred Michel, OSU, has been working with Atlantic Biomass on the development of this system which began with the MEI^2 energy seed grant program. Dr. Kim Daehwan of the Biology Department of Hood College in Frederick, Maryland will be performing biomass structural analysis for the project. In addition, growers from the Association of Warm Season Grass Producers will provide samples of switchgrass and miscanthus from their commercial crops for testing and analysis. The purpose-grown herbaceous energy crops have the potential to provide 535 million dry tons of new biomass to the U.S. bioeconomy according to the latest DOE Billion Ton Study. These perennial grass energy crops, however, as DOE references in that report, need SAF-based processing breakthroughs to make them commercially viable.

This grant was awarded by US DOE under the *Alternative Uses of Commercial Equipment (ACE*) topic. Instead of developing new equipment from scratch, the intent of ACE is to use the expertise of cutting-edge small companies to modify and improve available equipment, to improve the processing of biomass and waste feedstocks. Atlantic Biomass optimized simultaneous ball milling/enzymatic hydrolysis process will make the production of fermentable sugars from biomass more cost efficient by eliminating pretreatment steps of current technologies. These biomass sugars will then be fermented into ethanol using the Atlantic Biomass combined fermentation and distillation system developed with MEI^2 seed grant funding. Bacteria that convert glucose and other biomass sugars will be utilized. This increases ethanol production by about 20% over conventional glucose-based systems. The ethanol would then be used as feedstock for sustainable aviation fuel or other chemical products.



FY2023 Energy Innovation Seed Grant Results

After one year, MEI[2] Seed Grant projects are expected to: 1) Provide a summary of expenses and a scientific progress report describing the work done and include a commercialization plan as a final deliverable for the project including clear market assessment and strategy, a viable revenue model, and a strategy for financing the plan; and 2) Submit a proposal to at least one external funding agency within 18 months of receiving the seed funding, and provide information on the outcomes of the seed funding (e.g., grant funds, publications, conferences) annually. In April 2023, six seed grant projects were awarded for a total of $650K. Follow on efforts and successes from these FY2023 seed grants are discussed below.

Natural Gas to Value-Added Chemicals Without Greenhouse Gas Emissions; Lead PI: Eric Wachsman, University of Maryland College Park; Partnering Company: Alchemity (Phase II)

Alchemity fully transitioned into incubator space, the facility has been fully commissioned, and equipment and test stands have been qualified and commissioned, reactor housing design developed along with seals, completing Milestones 1, 2 and 3. The standard operating procedures (SOPs), process controls, and documentation have been developed. Fully commissioned facility status includes all gas and electrical upgrades, test stands, and equipment. Reproducible membrane reactor fabrication and testing was demonstrated. The fabricated reactor tubes are made at a size necessary for the prototype demonstrations. With the successful completion of the prototype design, tests are expected to begin this Summer/Fall.

Reactor operation was successfully demonstrated for >300-hour test with no yield loss. Selectivity analysis demonstrated absence of CO_2 formation with this technology. Furthermore, stable selectivity was achieved for ethylene and benzene for the duration of the test. A small CO quantity formed to prevent coking can be captured in the outlet (liquids vs. gaseous products with absorbents) and/or recycled for multi-pass conversion. Additionally, CO and H_2 byproduct mixture

(syngas) could also be used as a feedstock for synthetic fuel and chemical production. A secondary reproducibility test yielded reproducible results with no measurable yield loss using Shell specified fuel composition, completing both Milestones 4 and the Shell Game Changer Award milestone.

Alchemity is currently closing a $2M pre-Seed funding round, with participation by the Maryland Discovery Fund, the Maryland Momentum Fund, the C3 fund and private investment firms. In addition, $1.2M ARPA-e in funding was secured for 2024-2025. The MEI^2 investment accelerated the technology transfer from the UMD and the progress towards demonstration of a minimum viable prototype through reactor vessel design and ceramic-to-ceramic and ceramic-to-metal seals. Three full-time employees were brought on in mid-February and will be joined by an additional two employees in Fall. Three interns, from UMD-College Park and UM Baltimore County, also joined the team in summer, bringing the total team to eight without the C-suite.

Facility progress status showing multiple commissioned test stands and finalized facility upgrades (gas, electrical, ventilation).

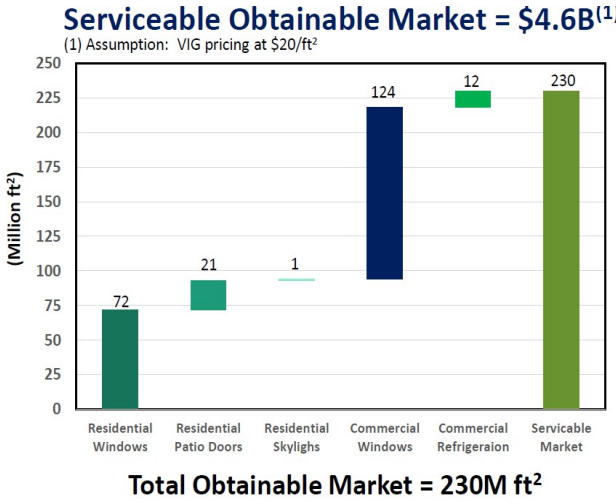
Low-cost Vacuum Insulated Glass; Lead PI: Ratenesh Tiwari, University of Maryland College Park; Partnering Company: NextGlass, LLC (Phase II)

The purpose of the project was to develop a weather resistant secondary seal, investigate a new high-capacity getter and perform thermal cyclic durability testing of the VIG prototypes. Thus far, we have completed the first two milestones and partially completed the third milestone.
Milestones and Deliverables:

1. Secondary seal was successfully developed, and severe durability tests showed that seal provides enough protection.
2. Similarly, typical VIG getters must withstand high processing temperatures and have very low absorption capacity. We worked with a third-party getter expert to develop low-temperature getter material that has at least two orders of magnitude higher gettering capacity.
3. The third task was to subject at least four 12” x 12” VIG prototypes under accelerated thermal cyclic testing as per industry standard ASTM E2190 to prove long term durability. Samples were sent to National Renewable Energy Laboratory (NREL) for testing. Two out of three prototypes passed full thermal cyclic testing to prove long term durability. With the help of the

DOE, a thermal cycling chamber was developed at the UMD that can test about 10 samples simultaneously. More than two samples during the remainder of the project will be tested.

Product: Vacuum Insulated Glass (VIG) windows with thermal insulation comparable to that of the surrounding walls are being developed. Such a glass will reduce the energy required for cooling/heating. The product sold will be a bare VIG that can be integrated into a third-party frame. We have established a Maryland company, NextGlass LLC, that will be used for commercialization purposes. Initial target customers will be manufacturers of freezer display doors for convenience and grocery stores. Such manufacturers are having difficulty meeting strict DOE energy efficiency standards with their current glass doors but will easily meet them using our VIGs. VIG for freezer doors has a much shorter payback time of 3 years since the door is exposed to subzero temperatures 24 hours a day, seven days a week. The overall market for such display doors is more than $500 million per year. Furthermore, new product adoption in the freezer door market is much easier than in buildings where the certification process can take years.



Residential Windows	**72**
Wood & Fiberglass Windows	62
Triple Pane Glazing	10
Residential Patio Doors	**21**
Wood & Fiberglass Windows	13
Multi-Unit Doors	8
Residential Skylights	**1**
Wood & Fiberglass Windows	0.4
Venting – Motorized Operable	0.6
Commercial Windows & Facade	**124**
Shop Fabricated Windows	62
Curtain Wall	62
Commercial Refrigeration	**12**
25% Normal Temperature	3
Low Temperature	8
Open Case Retrofit	1

Large-Scale Biofuel Production Using a Novel Cyanobaterium; Lead PI: Viji Sitther, Morgan State University; Partnering Company: HaloCyTech LLC

Among potential biofuel sources, cyanobacteria have demonstrated distinctive environmental applications in the synthesis of third-generation biofuels, due to their rapid generation time and enhanced net energy conversion from biomass to fuel. Nonetheless, the realization of large-scale biodiesel production from cyanobacteria requires the establishment of efficient lipid extraction methodologies. Until such alternatives are developed, the widespread commercial viability of cyanobacteria-based biofuel remains constrained. MSU has successfully scaled up production capacity using brackish waters, achieving a yield of 800 liters per week. Our results revealed using MiracleGro as a nutrient source at concentrations as low as 0.074 g/L led to comparable growth of F. diplosiphon relative to current media, while reducing cost by over 99%. Comparison of conventional lipid extraction and osmotic pressure extraction methods indicated salt shock disruption to be an efficient, cost-effective and more scalable alternative. Total lipid content in the osmotic method (32.0±2.08%) was found to be significantly higher than both homogenization (21.0±1.73%) and heat disruption methods (15.33±1.20%). In addition, photosynthetic pigments, which are high-value co-products have been identified to be released simultaneously with lipids, indicating added revenue streams to commercial biofuel production. Results also revealed that

production of one pigment, phycocyanin, can be significantly increased by covering the culture vessel with a red filter (5.44±0.001 vs. 2.29 ±0.001), leading to over a two-fold increase in yield. Our findings pave the way for a more sustainable and economically viable future for cyanobacteria-based biodiesel production. Further research will delve into the mechanistic aspects underlying the effects of different extraction methods to explore opportunities for optimizing the yield of lipids and co-products.

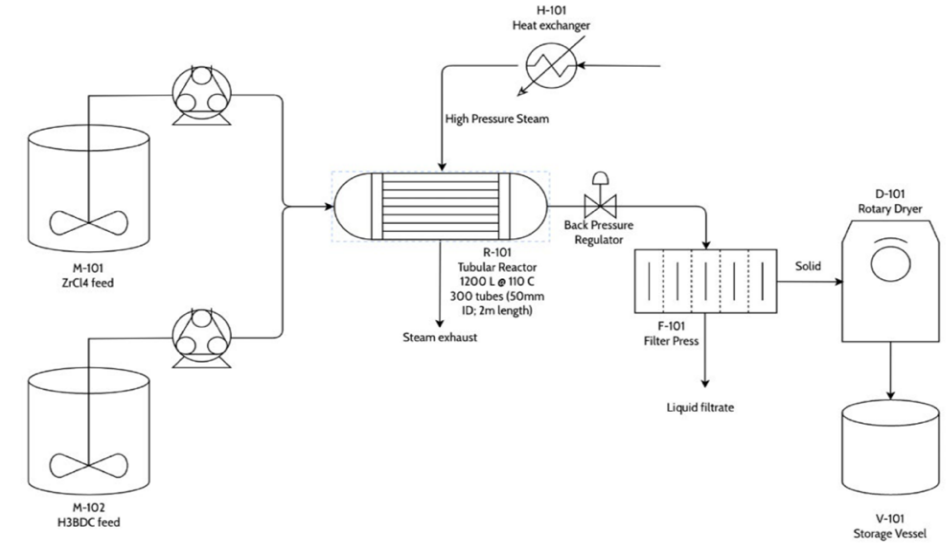
Milestones and Deliverables

- Intellectual Property Disclosed: An Intellectual Property Disclosure has been filed on work done during Phase I of the project, with the aim of publishing a US Patent. Sitther, V., Gichuki, S., Tabatabai, B., and Yalcin, Y. 2023. Biocrude production from cyanobacteria via hydrothermal liquefaction. IPD 193/2023.
- The PI and the University lead presented a poster and display table at the MEI^2 seed grant poster session on April 29th, 2023, at the advisory board meeting. The presentation was titled "Scale-up Cyanobacterial Cultivation and Biofuel Production". HaloCyTech LLC also presented posters at the board meeting.
- Conference Proceeding: Abstract submitted for a conference proceeding to the International Conference on Sustainable Transportation (ICTA, 2024) titled 'Cyanobacteria-based biofuels: Comparison of lipids from heat and osmotic shock to conventional extraction methods', which is currently under review. Abstract was previously accepted to be presented at ICTA 2024 Conference on July 29th-31st, 2024.
- Federal Grant Submission: HaloCytech LLC in partnership with Morgan State University has submitted a Small Business Technology Transfer (STTR) grant proposal titled "A Cost-effective Organic Feed Supplement for Aquaculture using Rapidly Grown Cyanobacteria" to USDA-NIFA for approximately $170k.
- First Private Funding: Secured $2k private seed funding from an individual for 200L growth tanks (picture below) to increase cultivation capacity at Morgan State University to over 500L. There is also the potential for additional future donations.

SulAnchor Cathodes for Solid-State Lithium Sulfur Batteries; Lead PI: Sara Thoi, Johns Hopkins University, Partnering Company: Lithinity, LLC

A major goal of this project is to translate SulAnchor technologies into solid-state Li-S batteries, which is challenged by poor ion transport, high internal resistance, and unstable cathode-electrolyte interfaces. To this end, we have (1) identified a series of promising metal-organic frameworks (MOFs) that can be used as a sulfur cathode additive under electrolyte-lean cycling conditions in liquid cells, (2) incorporated MOFs into sulfur cathodes for polyethylene oxide-based lithium sulfur batteries, and (3) devised a manufacturing plan for scale-up of metal-organic materials. The project has illustrated the utility of MOFs as a cathode additive in both liquid and solid-state lithium-sulfur batteries. They have identified a series of MOFs for integration into PEO-based Li-S batteries and demonstrated improved areal capacities. However, the heterogeneity of the resulting cathode led to poor coulombic efficiency and cycle life. A manufacturing plan has been developed for scaling from benchtop synthesis to a 100 ton/year and 1 kton/year pilot scale and the associated cost has been estimated. A manuscript is in preparation describing the application of MOFs as a sulfur cathode additive for electrolyte-lean battery cycling and an invention disclosure is filed to JHU for the use of MOFs in solid-state Li-S batteries, which we expect will move forward with a provisional patent application. In anticipation of future funding,

next steps include reformulating the MOFs cathodes, developing a charge/discharge profile that can extend cell lifetime, and testing optimized cathodes in pouch cell prototypes. The group will pursue future funding through an MEI^2 Phase II Award as well as DOE and NSF SBIR programs.



Process Flow Diagram of large-scale production of MOF1, based on established lab-scale tests

Development and Commercialization of Rechargeable Zn-ion Batteries from Crab Shell; Lead PI: Xin Zhang, University of Maryland College Park; Partnering Company: WH-Power, Inc

A low-cost chitosan-based zinc battery, referred to as "Crab Battery" was developed by the research groups of Professors Liangbing Hu and Robert M. Briber at UMD and published in the high impact journal *Matter*. The preliminary performance data on Crab Batteries reveal its ability to stabilize the Zn anode, passivating interphase side-reactions and the potential for commercialization.

The following milestones were achieved with the Phase I MEI^2 seed grant:

1. Applied and awarded DOE ARPA-e SBIR CREATE grant directly related with the ME^{12} project ($500,000 for 2 years) Title: Low Cost All Temperature Zinc-pulp Battery for Stationary Storage
2. Applied and awarded DOE ARPA-e PROPEL-1k grant as subcontractor of UMD together with SAFT as a team indirectly related with the MEI^2 project ($1.5M total, $450,000 in WHP for 1.5 years) Title: *High-energy, rechargeable, low-cost batteries for train and ship electrification*
3. DOE ARPA-e OPEN 2021 project passed Go/NoGo and continued to year 2 (Indirectly related with MEI^2, ~$400,000 for 3 years)
4. Received $1.3M in private investment.
5. Added 6 new employees (including accepted offers) that are Maryland residents, 4 in technical roles and 2 in business/management roles
6. Full lab established

7. Established collaboration with Vibrantz of Baltimore, Maryland (MnO_2, cathode material), EverZinc of Houston, Texas (zinc, anode material), and Tidal Vision of Seattle, Washington (Chitosan, separator-electrolyte material)
8. Attended Zinc Battery Workshop, organized by DOE/University of West Virginia. Attended by Sandia National Lab – Long Duration Energy Storage Consortium, Office of Electricity, Office of Energy Efficiency and Renewable Energy, Advanced Material and Manufacturing Technology Office, Pacific Northwest National Lab, major zinc battery raw material supplier, major zinc battery manufacturers, and potential customers.
9. Achieved high performance electrolyte-separator design and testing.
10. Potentially successfully suppressed the MnO_2 capacity decay, further test at a larger scale is still needed. Invited to ARPA-e summit (Dallas, May 21), major event to demonstrate technology and meet customers.

Inside of WHP's lab facility, showing (1) glovebox and pouch cell sealer, (2) vacuum over, (3) heated calendaring, (4) fume hood, (5) constant temperature storage for battery testing, (6) pouch cell electrode stacker, (7) ultrasound welder, (8) Arbin doctor's blade coater, Landt batter testersm electrode die cutter, pouch former.

FY2024 Energy Innovation Seed Grant Awardees

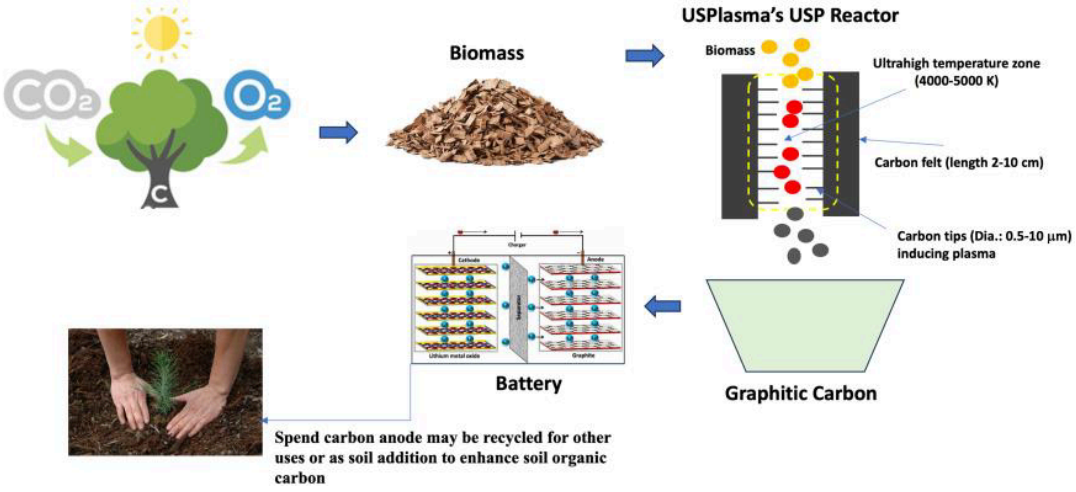
In early June 2024, seven Energy Seed Grants were awarded to the following academic institutions/companies, two of which were follow on Phase II awards. A short synopsis of each is given below.

Renewable Electricity-based Ultrahigh Temperature Plasma Heating to Rapid, Continuous Manufacturing of Battery Anode from Biomass; Lead PI: Hamideh Soltani-Ahmadi, USPlasma, Inc

Dr. Ji-Cheng Zhao and Dr. Liangbing Hu, UMD, have recently invented a disruptive and impactful platform technology that overcomes the shortcomings of past plasma processes, and is featured in a *Nature* video, and *Nature* paper. This uniform ultrahigh-temperature, stable plasma (USP) heating method can address the market need to produce green and clean graphitic carbon from

biomass for energy and battery applications with high throughput, negative carbon emission, and no adverse environmental impacts. Hu and Zhao co-founded USPlasma Inc., a spin-out from UMD. The startup already has an exclusive all-fields worldwide license to further develop this USP platform technology and produce graphitic carbon for battery applications. A PCT patent application has already been filed. USPlasma Inc. will use this momentum to launch a seed investment round to fund further development and commercialization activities.

There is a need in the global marketplace for a low-cost, secure, and environmentally friendly graphite manufacturing process to meet the growing demand. The global graphite market is highly attractive and is expected to grow at 7.3% CAGR, from $17.5 billion in 2022 to $25.0 billion in 2027. Due to its unique properties, high thermal and electrical conductivity, thermal stability, lubricity, and inertness, it is widely useful in the areas of energy, such as batteries, refractories, metallurgy, lubricants, and other industrial applications. However, graphite application in batteries and other conductive materials segment is expected to grow at a highest growth rate of 14.2% CAGR, $2.4 billion in 2022 to $4.7 billion in 2027.

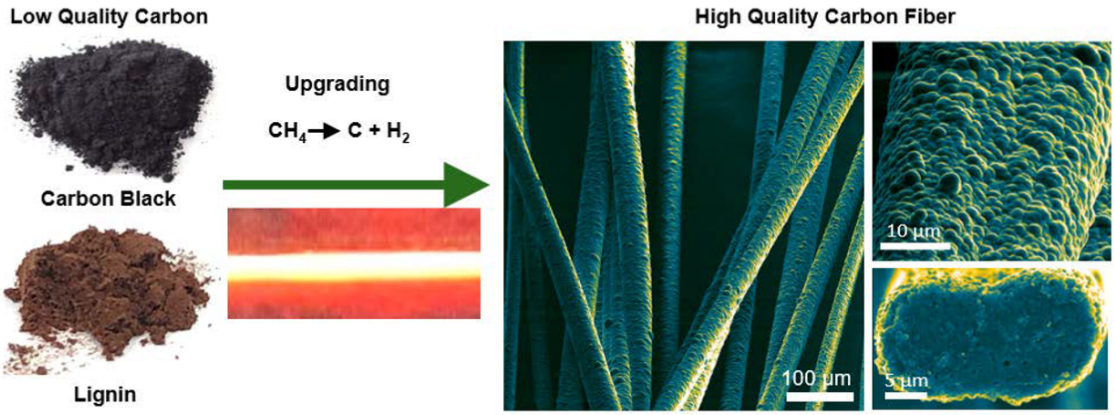


USPlasma's Graphitic Carbon Production Process with Negative Carbon Emission and No Adverse Environmental Impact

USPlasma Inc.'s proposed graphitic carbon manufacturing process addresses key environmental concerns such as global warming and resource depletion. Economically, converting biomass into graphitic carbon is an astute move, turning what would typically be low-value waste into a high-value product. This process diverts waste from landfills and provides a cost-effective alternative to more expensive, non-renewable carbon sources. Moreover, biomass's inherently porous structure endows the resulting carbon with desirable properties for various applications, particularly in energy storage, where high surface areas are crucial. This intersection of economic viability, environmental responsibility, and technological innovation is why synthesizing graphitic carbon from biomass is not just an option but a forward-thinking solution for a range of contemporary challenges.

Roll-to-roll Joule Heating Device for Electrothermal Upgrading of Carbon Fibers; Lead PI: Canhui Wang, Johns Hopkins University; Partnering Company: Carbon Plus, Inc

Carbon Plus Inc. is actively commercializing a low-cost carbon fiber production technology jointly owned by the UMD. This innovative technology effectively addresses the market demand for environmentally sustainable and economically viable carbon fibers as a lightweight and strong structure material. The technology facilitates low-cost production of carbon fibers with the potential for minimal environmental impact, making it a prime solution for industries such as automotive and clean energy, where strong, lightweight materials and affordability are crucial. Co-founded by JHU and UMD faculties, Carbon Plus Inc. currently has an exclusive all-fields worldwide license to further develop this technology. The project aims to design and construct a roll-to-roll Joule heating device tailored for the continuous upgrading of carbon fibers. This device will integrate innovative technology to optimize the conversion of low-quality carbon into high-value graphitized carbon fibers, supporting scalable production and enabling widespread commercial application.



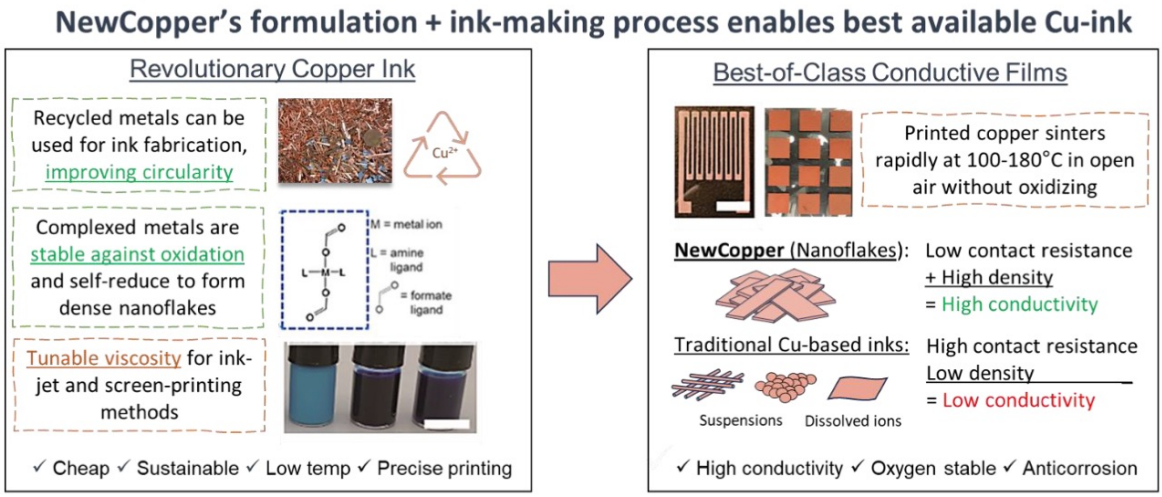
Schematic of the methane-enhanced energy-efficient electrified carbon fiber fabrication method and SEM images of the carbon black based carbon fibers.

Carbon Plus's eco-friendly, cost-effective carbon fiber is a game-changer in industries where performance and affordability are paramount. Carbon Plus carbon fiber is designed to achieve a strength-to-weight ratio that surpasses aluminum by 30 times, aluminum alloy by ~9 times, with a comparable cost to aluminum alloy and an environmental impact on par with that of aluminum or aluminum alloy. This exceptional balance of performance, affordability and sustainability makes it an ideal choice across various sectors. The aluminum industry is known for its significant carbon footprint, producing more than one gigaton of CO_2 emissions annually. By substituting aluminum with Carbon Plus's carbon fiber, industries can achieve more than just cost savings and enhanced material strength; they can also significantly cut down on $_{CO2}$ emissions (by more than 80%). This shift not only supports global carbon reduction targets but also aligns with growing environmental sustainability mandates across industries.

Printed Ultra-Conductive Copper from Recycled Feedstock; Lead PI: Colin Preston and Shenqiang Ren, University of Maryland College Park; Partnering Company: NewCopper LLC

The goal of NewCopper LLC is to achieve highly conductive, oxidation- and corrosion-resistant Cu conductors. The recyclable ultra-Cu conductors are all of great commercial interest to meet sustainability goal. Given the rising demand in energy sectors, the development of low-cost ultra-Cu with oxidation and corrosion resistance will be on a fast track to commercial success.

Printed electronics provides a cost-effective and materials efficient method to create new age devices that are smaller, flexible, wearable, and lighter. The ability to manufacture these devices relies on conductive inks, which currently have a lot of problems. Most conductive inks rely on silver, which is expensive, scarce, and toxic to the environment. Copper is orders of magnitude cheaper than silver, but it is too challenging to integrate into devices because of how quickly it degrades from oxidation and corrosion. Methods to make silver inks less expensive or copper inks more stable cause them to be less conductive and harder to manufacture. This offset of cost versus performance for conductive inks holds back the entire printed electronics industry and must be eliminated. Moreover, electronics waste (e-waste) is a hot topic for impending regulatory oversight, creating a need for scalable circular materials in conductive inks.



Summary of NewCopper conductive copper ink technology advantages.

NewCopper aims at producing Ultra-Cu that exhibits 50% greater electrical conductivity than that of bulk copper at high temperatures (150ºC) with optimum gravimetric power densities (5 times increase of the current density ampacity, 2×107 A/cm2). The proposed advancements in Ultra-Cu technology offer a trifecta of benefits for the field of printed electronics:

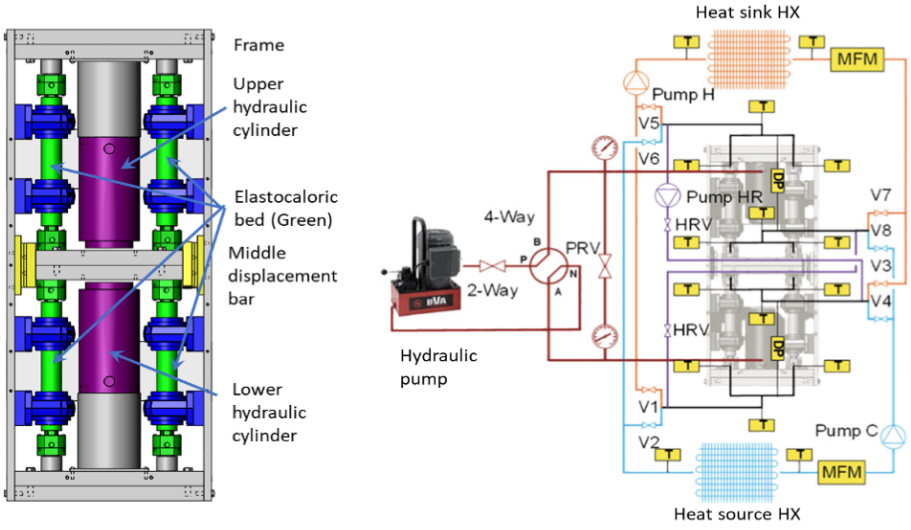
1. The enhanced stability of printable oxidation-resistant copper not only reduces processing and manufacturing limitations but also contributes to a lower overall cost. This increased stability lifts constraints, paving the way for more flexible and cost-effective ambient production processes.
2. The improved conductivity of printed copper, coupled with greater temperature stability, promises superior performance for electronic devices relying on current silver or carbon inks. This upgraded functionality comes at a lower cost compared to traditionally used silver or gold, making it a more economically viable solution.
3. The introduction of recirculated metal feedstocks brings a sustainability dimension to printed electronics, allowing for reduced environmental impact and further cost reductions in device manufacturing.

Altogether, these advancements position copper as a versatile and cost-efficient material, poised to drive innovation and sustainability for printed electronics. NewCopper's environmentally friendly approach, minimizing waste and energy consumption, aligns with sustainability goals in

electronic manufacturing. As this technology evolves, it holds the potential to reshape industries by providing a versatile, sustainable, and high-performance solution for the creation of electronic components.

Elastocaloric High Temperature Heat Pump; Lead PI: Abimael Santos and Ichiro Takeuchi, University of Maryland College Park; Partnering Company: Maryland Energy and Sensor Technologies, LLC

The proposed project will increase the technology TRL from 2 to 4 to attract industry's interest in adoption of high efficiency residential and industrial heat pumps with zero-GHG emission. The dangerous effects of climate change continue to escalate, posing significant threats to communities worldwide. While the demand for low carbon cooling solutions is vital, the need for low carbon heating has recently emerged as another major global challenge. The need to wean off fossil-fuels based heating (e.g. natural gas) has been made particularly acute with the war in Ukraine. The incentives to increase the adoption of heat pumps to electrify heating is a crucial immediate step toward reducing CO_2 emissions, but regular heat pumps still rely on the same high global warming potentials (GWP) refrigerants used in cooling systems, and they suffer from the same challenges from leaks: the current refrigerants have GWPs over 1,000 times that of CO_2.



Elastocaloric HTHP system design and test facility

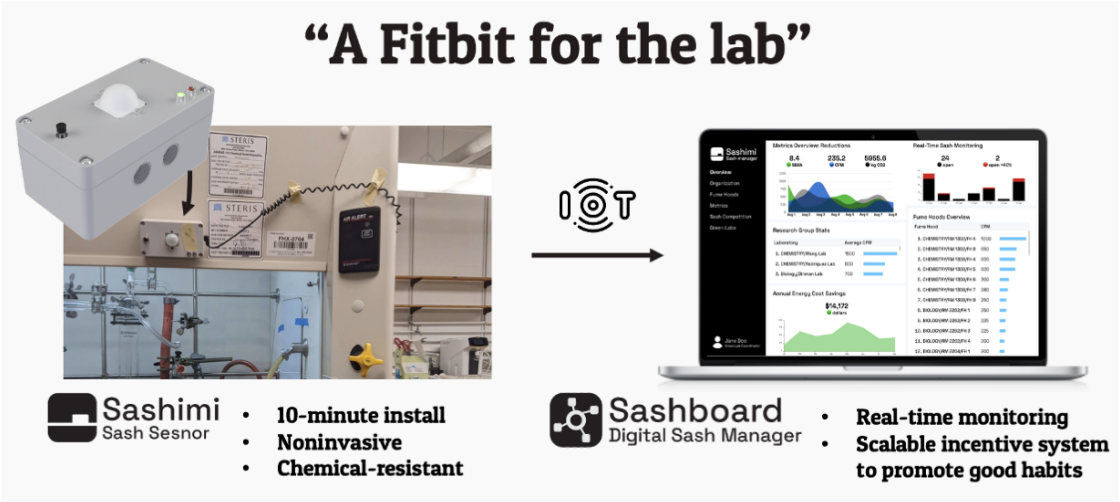
Thus, there is an urgent need for sustainable heating solutions that move beyond the tradeoffs imposed by refrigerants while meeting the growing demand for heating in a more extreme world. Thermoelastic/elastocaloric heat pumps is a promising alternative first invented at the UMD in 2012 and spun-off into the company Maryland Energy and Sensor Technologies, LLC (MEST) the same year to commercialized elastocaloric "refrigeration cores" to replace traditional compressors in cooling systems. This effort to commercialize elastocaloric systems is on the cusp of commercial viability thanks in part to prior support from ARPA-e, DOE, the Maryland Technology Development Corporation (TEDCO), and a major HVAC manufacturer. Elastocaloric cooling has been demonstrated as a prototype laboratory system with sufficient performance, efficiency, and reliability to replace existing systems that use chemical refrigerants. However, ongoing support is needed to make the technology cost competitive with existing systems that have over 100 years of development and that can externalize much of the environmental costs of

refrigerants. If successful, elastocaloric systems have the potential to replace conventional vapor compression systems in a variety of HVAC-R applications directly lowering the global warming impact from refrigerant leakage.

Reducing laboratory energy waste with a fume hood monitoring and incentive system; Lead PI: Kevin Tu, University of Maryland School of Medicine; Partnering Company: Sustainabli

This project is built upon research in building energy efficiency. The research has resulted in an easy-to-deploy, scalable monitoring and incentive system to reduce energy waste in the lab ("Fitbit for the Lab"). This product has achieved small-scale validation; we are now seeking funding to beta-test our product in a large, multicenter pilot study across North America. The results of such a study would enable private investment and commercialization.

Fume hoods, workstations for handling volatile chemicals used in laboratory and industrial workplaces, consume as much energy as 3-4 houses when their user-facing windows (sash) are open. In the US, their total electricity usage is upwards of 26 TWh a year resulting in annual costs upwards of $4.2 billion with and contributes 11 megatons of CO_2 a year (1). Best practices advise that the fume hood sash only be open as much as necessary to complete work and be closed when unattended. However, fume hoods are, on average, left open to 30-50% of their height even when not in use. In the US, this contributes an estimated 6-8.5 TWh of energy waste annually, costing $1-1.4B per year.



Sustainabli has developed "a Fitbit for research labs" with its first product Sashimi^{TM}, an easy-to-deploy IoT device that monitors and incentivizes energy efficient and safe fume hood use. Our solution can be installed within 10 minutes, features a user-friendly interface the Sashboard^{TM} for monitoring, and is effective at producing energy-efficient fume hood habits in the long-term.

This seed grant will go towards assessing technical readiness for high-volume commercialization through beta testing as well as setting up our manufacturing pipeline. Customer demand for the product exists. The beta-testing would assess feasibility, energy savings, user-friendliness, and scalability of the platform. Following the pilots, Sustainabli looks to scale pilots to the rest of each organization, generating recurring revenue. Sustainabli was recently accepted into the 2024

CleanTech Open Accelerator (CTO), which will provide mentorship in setting up manufacturing pipelines to allow us to meet demand at scale. Follow on investment through CTO angel investors or a SBIR allows us to meet demand, refine manufacturing, and find more sales leads.

Low-cost Vacuum Insulated Glass; Lead PI: Ratenesh Tiwari, University of Maryland College Park; Partnering Company: NextGlass, LLC (Phase II)

Buildings account for 35% of US CO_2 emissions of which ~35% is used for space heating and cooling. Windows are responsible for ~$40 billion/year in energy losses and 7% of US $_{CO2}$ emissions. We are developing Vacuum Insulated Glazings (VIGs) that can cut the energy loss through windows by 75% by reducing conduction and radiation through the window. Although VIGs have been under development for more than 30 years, they have not had significant market penetration due to their high cost and durability concerns. Typical production time of double pane Insulated Glass Units (aka IGUs) is 20-30 seconds. In contrast, VIGs are sealed at high temperature (about 350-450°C) and require 30-60 minutes to complete the process, making them 10 times more expensive to produce.

Vacuum Insulated Glass (VIG) can achieve 5 times more insulation than typical Argon filled double pane window, making it almost as good as wall itself. However, currently developed VIGs cost 10 times more than double pane windows, presenting a large market barrier. UMD is developing a VIG manufacturing process that will bring its cost similar to double pane glass. Such development has potential to replace all double pane windows to VIGs.

The project will conduct a technology validation for UMD's room temperature sealed VIG, which can be produced at a cost similar to IGUs. Such VIG technology has the potential to disrupt the estimated $25 billion/year VIG market. As a part of Department Of Energy (DOE) funded project, Next Glass developed a unique metal sealing process that can be performed at room temperature, without need of any heating. This saves hours of heating and cooling time. Currently we are sealing the glasses manually, however, creating meters of long seals manually is not always consistent. Thus, we cannot prove what will be the yield of sealing process that will be performed using an automated process. Thus, the group proposes to develop an automated sealing process that is repeatable and hence increases investor's confidence.

As a part of a DOE project and MEI^2 Phase 1 project, we developed 12" x 12" and 14" x 20" fully tempered window samples that can retain long term vacuum. These windows were tested using a special Spinning Rotor Gauge to determine the long-term vacuum level in the stand alone VIGs. Finally, these window samples were tested and passed long term durability test.
Milestones for the Phase II award include:

- Build automated glass edge metallization proof of concept.
- Demonstrate automated VIG bonding on a 12" x 12" prototype. A machine shall be built based on the outcomes of the Milestone 1 tasks.
- Automated process testing and iterations.

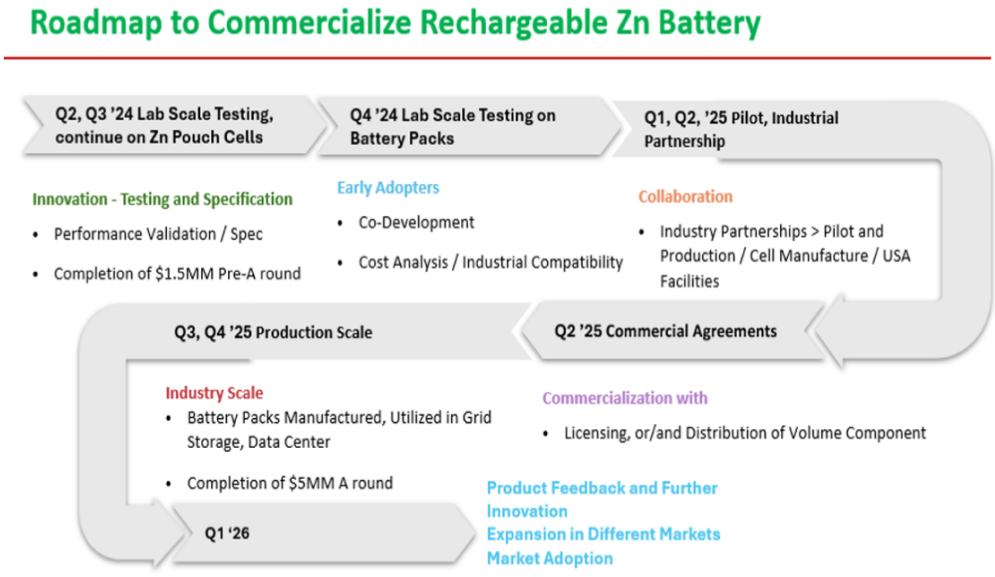
Development and Commercialization of Rechargeable Zn-ion Batteries from Crab Shell; Lead PI: Xin Zhang, University of Maryland College Park; Partnering Company: WH-Power, Inc (Phase II)

Increasing electric energy consumption as well as demands for decarburization and sustainable technologies highlights the need for rechargeable batteries from renewable sources for large-scale

grid storage systems. Aqueous Zn-metal batteries are an attractive candidate to fulfill this energy storage requirement due to their fast charge/discharge kinetics, high theoretical capacity, significant global reserves of Zn, intrinsic safety due to the use of a nonflammable aqueous electrolyte, eco-friendliness and low cost. However there has been limited commercialization of Zn batteries for grid storage due to problems associated with the Zn anode during operation, including Zn dendrite formation, corrosion, and hydrogen generation. This leads to decreased cycling efficiency and finally battery failure. A new type of rechargeable battery made from crustacean shell derived material (chitosan) and zinc metal has been reported and patented by the research groups Hu and Briber at UMD. The battery shows exceptional Coulombic efficiency, high- rate performance, long-term cycling stability (>400 cycles at 2C) and is attractive in terms of safety and sustainability. At the same time, Wang's group at UMD has developed a high-entropy aqueous electrolyte which enables wide temperature Zn-metal batteries with high columbic efficiency and capacity retention with a temperature range of -60 °C to +80 °C. The combination of the 2 technologies enables Zinc batteries with excellent performance that exceeds what is currently available in terms of cycling stability, safety, operating temperature range and sustainability. WH-Power (WHP) plans to commercialize this technology for grid storage. WHP has an exclusive licensing agreement with UM Ventures for the IP.

With MEI[2] Phase I funding, WHP has achieved impressive results on Chitosan-Zn electrolyte and $LiVPO_4F$ cathode development (details presented earlier). With Phase II funding, the group will accomplish the following tasks:

- Modify the $LiVPO_4F$ cathode to achieve better cycling performance and higher capacity loading.
- Develop an MnO_2 cathode with stable mechanical and electrochemical properties.
- Fine tune the Chitosan-Zn electrolyte for lower cost and wider operating temperature range for both $LiVPO_4F$ and MnO_2 cathodes.
- Perform customer studies, market assessment and revenue/cost modeling of the Crab Battery system for grid and residential markets. Implement technical and commercial collaboration with leading material suppliers and battery manufacturers.



RESEARCH AWARD HIGHLIGHTS

Significant financial support of research into new energy technologies was obtained in FY24. Examples of these are six DOE ARPA-e awards bringing the UMD total award amount to ~$160M since the inception of ARPA-e in 2009. Additionally, the UMD Center for Environmental Energy Engineering (CEEE) secured $5M in funding through the DOE's Buildings Energy Efficiency Frontiers & Innovation Technologies (BENEFIT) program for revolutionary efficiency projects.

ARPA-e Awards

In June 2024, ION was a recipient of a $20M ARPA-e SCALEUP (Seeding Critical Advances for Leading Energy Technologies with Untapped Potential) award. The SCALEUP program provides major new funding to previous ARPA-e recipients that have successfully de-risked their technology and established a viable route to commercial deployment. Moreover, since the SCALEUP program started in 2019 only UMD, MIT, and Stanford related teams have received multiple SCALEUP awards with ION and UMD start-up InventWood being the only 2 companies to receive the maximum $20M award.

Maryland Governor Wes Moore congratulates ION's CTO, Dr. Greg Hitz.

ARPA-e's RANGE program initiated the development of this technology in 2013. Now, ION will collaborate with Saint-Gobain, one of the world's largest ceramics, glass and material suppliers and KLA, a leader in semiconductor process and quality control, to dramatically accelerate the commercialization of ION's high-performance anode-less SSB. The ARPA-e SCALEUP program will contribute $20 million that will be matched by another $20 million in private funds, bringing the total program size to $40 million. The project will include sustainability-focused cell design and manufacturing milestones, with planned innovations offering the opportunity for the mitigation of greenhouse gas emissions on the order of tens of thousands of metric tons of CO_2 per GWh relative to Li-ion. Federal and state officials gathered at ION over the summer to celebrate the UMD based company on its recent achievements and its leading role in establishing the state of Maryland as a clean energy innovation hub. Maryland Governor Wes Moore and DOE ARPA-e Director, Evelyn Wang, both praised the company's achievements. Dr. Wang noted, "ION's impact will be felt across America's energy landscape. This technology can fundamentally change the way we use, generate and store energy. And we are so proud to be a part of this journey."

UMD received four COOLERCHIPS awards from ARPA-e. The target for COOLERCHIPS is to reduce total cooling energy expenditure to less than 5% of a typical data center's IT load at any time and any US location for a high-density compute system. A data center's total cooling energy is the energy needed to ensure that all heat generated from its IT and non-IT loads is rejected. Reducing data center cooling energy will reduce the operational CO_2 footprint of data center operations. COOLERCHIPS technologies will achieve these goals by dramatically reducing the

thermal resistance of heat rejection, which will allow for coolants to exist at temperatures much closer to operating temperatures of the latest generation of chips (targeting <10°C difference between chip and coolant). This will result in more efficient heat removal from the facility. The program will develop solutions for high volumetric compute density systems of >80kW/m^3, equivalent to about >3kW per server. COOLERCHIPS aims to be commercially competitive with current state-of-the-art solutions by offering a lower total cost of ownership without compromising data center reliability and availability.

Dr. Patrick McCluskey, Mechanical Engineering professor, is leading the project entitled *Multi-Objective Optimization Software for COOLERCHIPS*. This project will develop an integrated decision support software tool for the design of next-generation data centers that seamlessly links the existing open-source software for modeling reliability, energy, carbon footprint, and cost with an innovative co-simulation framework. This tool will permit data center designers to develop transformational and disruptive design advances compared to existing state-of-the-art technologies. He is also a partner on the project, *Hyperefficient Data Centers for Deep Decarbonization of Large-scale Computing* with the University of Florida.

Dr. Michael Ohadi, Mechanical Engineering, is working with Flexnode, a data center in Bethesda, Maryland, on a prefab modular liquid-cooled micro data center. They will develop a prefabricated, modularly designed EDGE data center that will leverage four key component and system-level technology advancements: a novel manifold microchannel heatsink, a chassis-based hybrid immersion cooling approach, a cost-effective additive manufacturing-enabled dry cooling heat exchanger system, and a topology optimized container housing the entire system.

UMD Professor Chunsheng Wang and Assistant Professor Paul Albertus, both in the Department of Chemical and Biomolecular Engineering, are developing next-generation energy solutions to advance batteries for electric maritime and rail vehicles—an effort that could revolutionize modern transportation and curtail millions of tons of yearly greenhouse gas emissions. They received $1.5M from ARPA-e through the Pioneering Railroad, Oceanic and Plane Electrification with 1K Energy Storage Systems (PROPEL-1K) program. PROPEL-1K, named after the 1,000 watt-hour per kilogram and per liter energy requirement to propel large vehicles, seeks to more than quadruple energy storage capabilities that current electric vehicles batteries present, which limits its use to cars and SUVs. Wang and Albertus will leverage their chemistry and modeling expertise to develop a rechargeable battery for ships and rail cars that meets program requirements, while minimizing changes to infrastructure.

WH-Power, another UMD start-up company, received an ARPA-e Exploratory award for their research on Low Cost All Temperature Zinc-pulp Battery for Stationary Storage. The group will develop a high-entropy electrolyte and pulp-based zinc battery that could operate in temperature ranges from -80°C to 80°C and can be used for both residential and grid-scale energy storage applications. WHP's battery would be inherently safer and lower cost than existing batteries and could be produced from abundant materials that are readily available domestically.

The annual ARPA-e Summit was held May 22-24, 2024 in Dallas, Texas. The Summit and ARPA-e program are aimed at moving transformational energy technologies out of the lab and into the market. ARPA-e advances high-potential, high-impact energy technologies that are too early for private-sector investment. ARPA-e awardees are unique because they are developing entirely new ways to generate, store, and use energy. Fifteen UMD companies/technologies were present at the Summit's technology showcase this year (figure below).

Buildings Energy Efficiency Frontiers & Innovation Technologies

In FY2024, UMD's CEEE secured $5M in funding through the DOE's Buildings Energy Efficiency Frontiers & Innovation Technologies (BENEFIT) program for revolutionary efficiency projects. DOE awarded $46 million for 29 projects across 15 states to develop advanced building technologies and retrofit practices that enable healthier households and communities and reduce energy waste. BENEFIT funding will help advance cost-effective solutions to successfully electrify buildings across the nation while also improving their energy efficiency and demand flexibility. CEE secured three of the 29 awards. The three projects include:

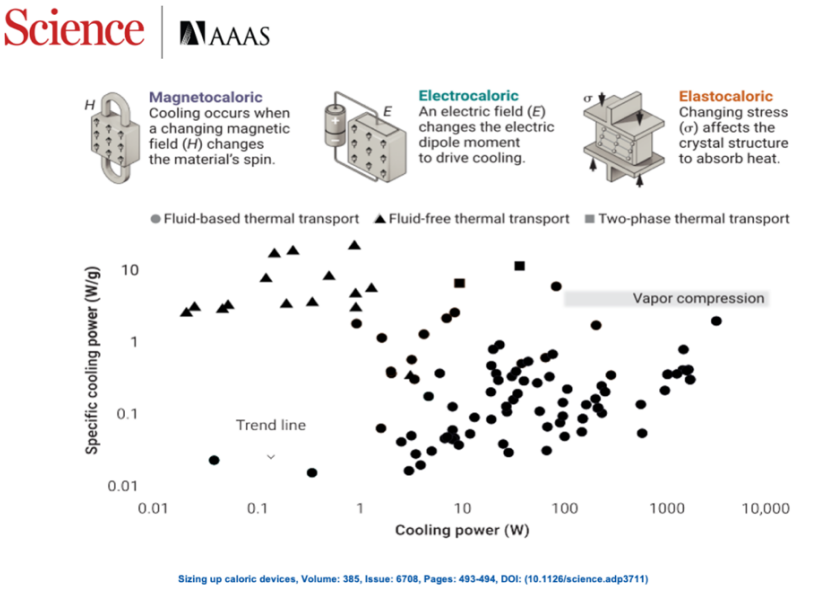
- Next-Generation Liquid-to-Refrigerant Heat Exchangers for Heat Pumps, Water Heaters, and Refrigeration Systems (NG-LRHX) – The University of Maryland will improve the thermal performance of small heat exchanger packages using liquid-to-refrigerant heat exchangers to address operational issues, reducing energy consumption by 10-15%. (Award amount: $1.4 million)
- Smart Cold Climate Rooftop Heat Pump with Low-GWP Refrigerant – The University of Maryland will design a cold climate heat pump rooftop unit that uses low-GWP refrigerants and advanced compression techniques to enable low temperature heating capacity, furthering CCHPRTU availability. (Award amount: $2.3 million)
- Low Cost and High Performance Modular Thermal Energy Storage for Building Equipment – The University of Maryland will design a heat pump-integrated cross-media thermal energy storage system that uses an innovative 3D-printed polymer heat exchanger to overcome low thermal conductivity, allowing for load shifting during peak demand periods and reducing heating and cooling demand. (Award amount: $1.3 million)

INVENTIONS AND PUBLICATIONS

Significant and impactful research progress was made in FY2024 through inventions and publications. Multiple papers were published in high profile journals such as Nature (ranked first in impact internationally) and Science (ranked 3rd in impact internationally). Not only have many papers appeared in these journals this last fiscal year, but they have graced the cover of these journals as well. Several notable FY2024 research publications are discussed below.

Top 10 Emerging Technologies of 2024

The World Economic Forum's latest Top 10 emerging Technologies of 2024 report recently unveiled a future teeming with possibilities. A wider lens was employed for this year's report, now in its 12th edition, leveraging the expertise of over 300 world-leading academics and experts from the Forum's Global Future Councils, the University & Researcher Network and the Top 10 Emerging Technologies Steering Group members. Their insights, combined with data analysis, ensure a robust understanding of each technology's potential impact in addressing multiple global challenges: from advancements in materials science to transformative technologies in healthcare. The green and highly efficient solid-state cooling developed at UMD has been named one of the top 10 of these breakthrough technologies of 2024.



The relentless onslaught of the scorching summer days is perhaps a reminder of the peril of global warming and climate change. Elastocaloric cooling belongs to the family of energy-efficient solid-state cooling techniques called calorics. Unlike the

ubiquitous vapor compression technology, which derives cooling from pressure-induced liquid to vapor phase transition of environmentally harmful hydrofluorocarbons (or alternatively flammable fluids), calorics utilize solid to solid phase transitions of functional materials. Because these techniques directly tap into the first order transition of solids, they are entirely green and naturally highly efficient. The elastocaloric cooling effect is observed in materials such as superelastic shape memory alloys, which undergo a structural phase transition upon application of mechanical stress. A major discovery which helped to kickstart the worldwide activities in the field was the experimental observation of the large elastocaloric effect in NiTi wires at the UMD in 2012, where the temperature lift as large as 17K was recorded.
The team at the UMD is led by Ichiro Takeuchi (Materials Science and Engineering), Reinhard Radermacher (Mechanical Engineering), and Yunho Hwang (Mechanical Engineering) in the A. James Clark School. The UMD effort funded by DOE has recently led to a successful demonstration of a full elastocaloric system with a record delivered cooling power of 260W. Research associated with this award can be found here: Suxin Qian, Ichiro Takeuchi, Sizing up caloric devices. *Science* 385, 493-494 (2024). DOI:10.1126/science.adp371

Physical Sciences Invention of the Year/Overall Winner: Stable Plasma for Extreme Materials

In a mesmerizing display, a kaleidoscope of tiny lightning strikes gives way to a brilliant glow hotter than the surface of the sun. That miniature lightning is electric arcs passing between two "hairy"-looking blocks made up of carbon fibers; the glow is a plasma that reaches 8,000 degrees Celsius—nearly twice as hot as the highest melting point of any metal. But it isn't just ultra-hot; it's also stable enough to revolutionize high-temperature materials engineering.

Professor Liangbing Hu (second from left) is honored at the Innovate Maryland Invention of the Year award event. Also pictured (from left), Professor Robert Briber, MSE Chair Ji-Cheng (JC) Zhao, UM Ventures Associate Director Felicia Metz, UM Ventures Executive Director Ken Porter. (Photo courtesy of Stephanie S. Cordle.)

The new method for creating stable plasma, developed by UMD Distinguished University Professor Liangbing Hu, can be used in extreme materials. The protocol works by applying a voltage between two blocks made of thin carbon fibers. The fibers act as a tip through which electrons can flow, resulting in all the gas between the blocks being turned into a highly stable and ultra-high-temperature plasma. The process, is simple, scalable, and powered by renewable energy, allowing for reduced cost and a lower carbon footprint to make extreme materials. The method took home the top prize on April 29, 2024 at the UMD's annual Invention of the Year competition.

Along with winners in three other categories, the award was announced as part of Innovate Maryland—an annual celebration of UMD researchers' creativity in translating cutting-edge research into practical, impactful solutions to address global challenges. In addition to the

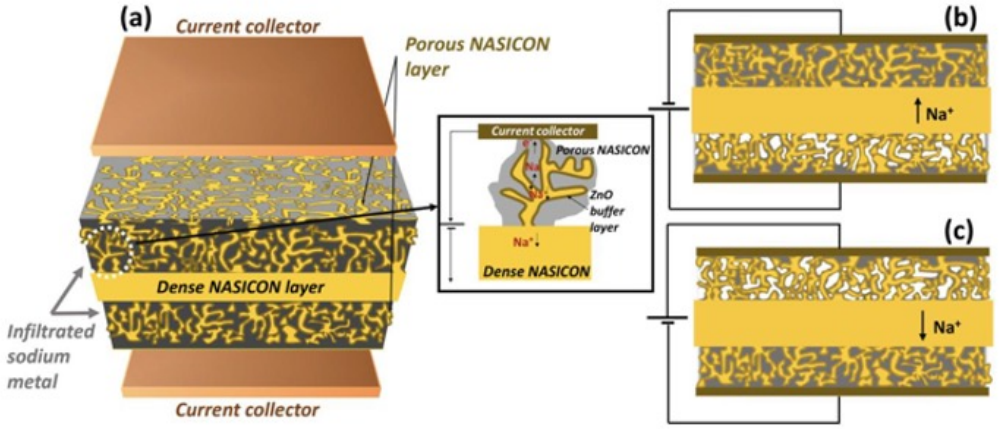
Invention of the Year awards, Dr. Hu received a special recognition award presented by UMD President Darryll J. Pines. Hu has submitted 134 invention disclosures, making him the second-most prolific inventor in the university's history—a feat he accomplished in only 11 years. He also co-founded the highest number of university IP-based startups, with a record four this fiscal year alone.

Battery Technology

High-rate cycling in 3D dual-doped NASICON architectures toward room-temperature sodium-metal-anode solid-state batteries. P.W. Jaschin, C.R Tang, and E.D. Wachsman, *Energy & Environmental Science*, 17, 727737 (2024) DOI: 10.1039/D3EE03879C

While lithium-ion batteries currently dominate the industry, serious concern remains about the limited availability of lithium used in these batteries. Conversely, sodium-ion batteries provide a more sustainable alternative due to the tremendous abundance of salt in our oceans, thereby potentially providing a lower-cost alternative to the rapidly growing demand for energy storage.

Currently most sodium-ion batteries contain a liquid electrolyte, which has a fundamental flammability risk. In contrast, Sodium (Na) Super Ionic Conductor (NASICON) materials are non-flammable solid-state electrolytes with high ionic conductivity and superior chemical and electrochemical stability. To achieve safety, sustainability and economic feasibility, all solid-state sodium batteries are the most promising next generation batteries that are touted to yield a high energy density of 200 W h kg−1. Since the solid electrolyte synthesis process involves a pragmatic tape-casting technique, this unique 3D electrolyte architecture provides promise of high energy density and commercially viable solid-state sodium batteries.



Schematic of a trilayer-based symmetric cell assembly (inset shows an enlarged region of (a) depicting the flow of sodium ions during process of stripping). Stripping and plating mechanisms of sodium metal across the pores of trilayer under an external current is shown in (b) and (c).

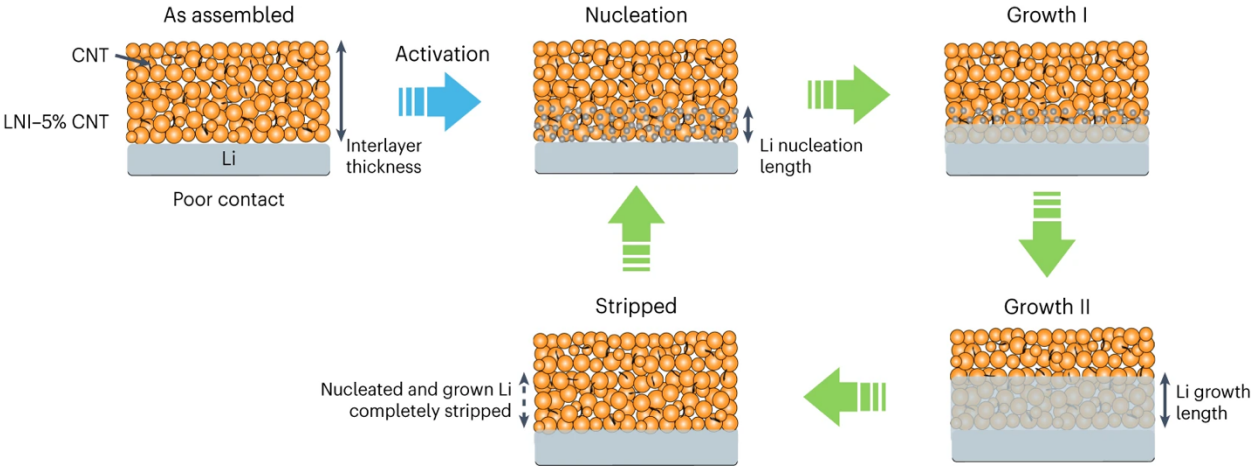
The unique 3D electrolyte architecture was recently published in *Energy & Environmental Science* and provides the promise of high energy density and commercially viable solid-state sodium batteries. The successful demonstration of both stable sodium cycling at high current densities and full cell cycling with thin 3D structured ion-conducting NASICON solid-electrolytes are a significant advancement towards sustainable and more economical energy storage technology.

Lithium anode interlayer design for all-solid-state lithium-metal batteries. Wang, Z., Xia, J., Ji, X., Liu, Y., Zhang, J., He, X., Zhang, W., Wan, H. and Wang, C., *Nature Energy*, 9, 251–262 (2024). https://doi.org/10.1038/s41560-023-01426-1

UMD researchers uncovered the failure mechanisms of solid-state batteries to develop a new technology that could spark a next generation of safer, high-energy electric vehicles. The new technology, published in the journal Nature Energy, involves a method that suppresses the formation of lithium dendrites—crystalline structures often linked as the cause for short circuits, which hold back the commercialization of solid-state batteries. The study presented a novel design that used battery modeling to observe and tackle dendrite formation, a turning point for solid-state battery research.

With a higher energy density, longer life cycle and enhanced safety capabilities, solid-state batteries hold a promising future for electric vehicles—standing at the forefront of scientific exploration. Unlike conventional lithium-ion batteries, which have a liquid electrolyte more prone to ignition, the emerging devices boast complete solidity, which are less flammable under high temperatures. The main obstacle blocking the adoption of solid-state batteries is the formation of lithium dendrites.

Several components make up a battery's interface: a negative conductor, known as the anode; and a positive conductor—the cathode. Somewhere in between lies the electrolyte, which transports lithium ion between the two ends, and protects the battery from overheating. Dendrite formation at the interface level is usually attributed with causing battery short circuits.



The grey rectangle is the Li anode. The yellow spheres are LNI electrolyte particles. The small grey spheres are nucleated Li. The black sticks are CNT. The Li/LNI–5% CNT interface has poor contact in an assembled Li/LNI/Li cell. After activation, Li can nucleate on the Li/LNI–CNT interface (rather than the SSE/LNI–CNT interface) and then reversibly penetrate into/extract from the porous LNI–CNT interlayer during Li plating/stripping. If the Li growth length is larger than the Li nucleation length, the nucleus was merged during Li plating and was completely extracted during Li stripping.

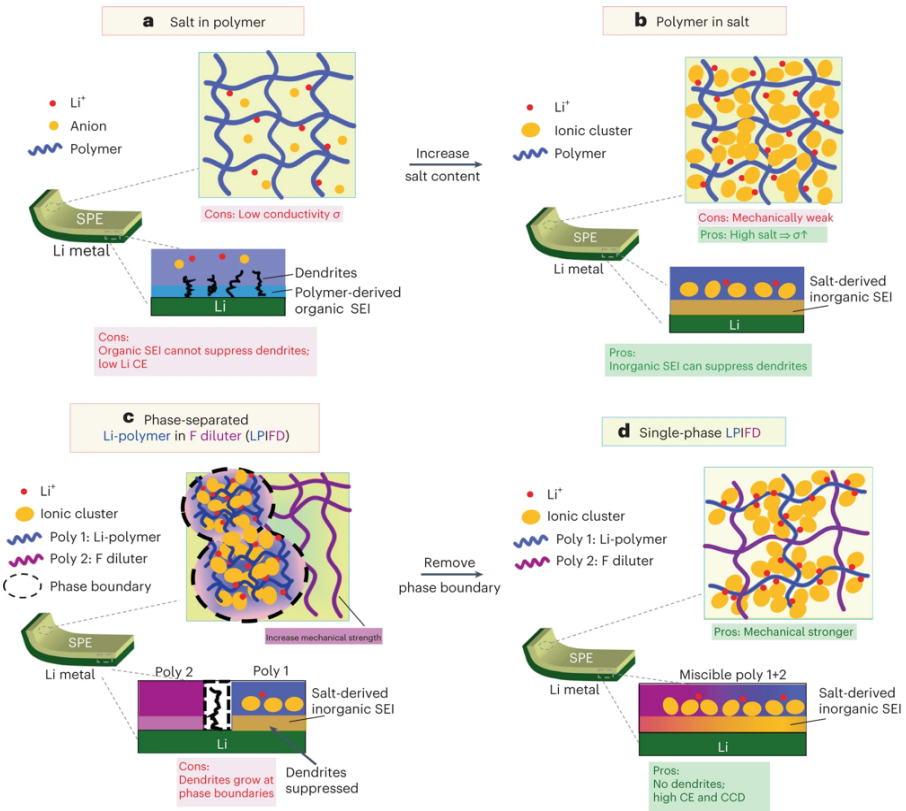
The team has developed a new method that can be used as a model for new predictions. Previous efforts aimed at suppressing lithium dendrite growth relied only on conventional experimental processes. In using battery modeling systems, the researchers presented a new design principle

that could guide others in developing the ultimate solid-state battery. The contribution led to the development of an interlayer that effectively prevents lithium dendrites from growing into the solid electrolyte, the battery's heat-protecting layer. Early laboratory tests showed that the new technology exhibited an above-average discharge capacity of 82% after 350 cycles. Following this breakthrough, researchers will shift their focus to study interlayer materials, scale up manufacturing processes and ultimately test the device on vehicles.

Single-phase local-high-concentration solid polymer electrolytes for lithium-metal batteries. Zhang, W., Koverga, V., Liu, S., Zhou, J., Wang, J., Bai, P., Tan, S., Dandu, N.K., Wang, Z., Chen, F. and Xia, J., 2024. *Nature Energy*, 9, pp.1-15.

Lighter and safer smartphone devices could swoop in the market following a recent breakthrough made by Department of Chemical Biomolecular Engineering (CHBE) researchers developing emerging battery technologies. The new technology addresses the main challenges slowing down the adoption of solid-state batteries: the formation of lithium dendrites—which lead to short circuits—and the instability of high-voltage cathodes, which reduces the cycle life and energy density of batteries. The study, led by UMD Professor Chunsheng Wang, aims to improve performance and reduce the size of consumer electronic batteries.

The study proposes an enhancement to the battery's key component, the polymer electrolyte. The technology would blend two chemical components: a lithium polymer-in-salt and a fluorine diluter, which effectively suppress lithium dendrites and stabilize high-voltage cathodes. Their work seeks to ultimately unleash a new generation of higher-energy, safer and smaller smart devices.



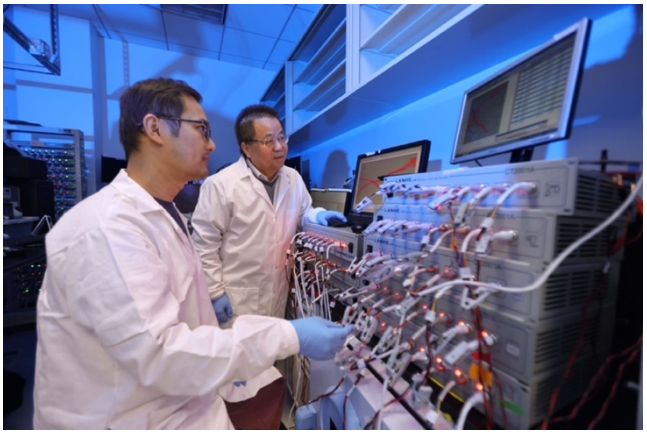
Each design element holds different functions. The polymer-in-salt acts as the dendrite suppressor: when activated, the component forms a protective layer—a barrier that blocks the lithium dendrites from causing a short cell circuit. It also facilitates the quick transport of lithium ions throughout the battery, a quality known as high ionic conductivity, which in turn generates a fast-charging device. In combination with the fluorine diluter, the electrolyte gains mechanical strength, making it flexible and

resistant to the dendrites. While these membranes go widely unnoticed by most electronics users, they hold an essential role in their device's performance. The electrolyte acts as a transportation medium for lithium ions throughout the battery's interface, which enables the charging and discharging cycles. It also separates the negative and positive conductors of the battery, maintaining the safety and stability of the device. It presents the first high-performing solid-state lithium battery that uses polymer electrolytes. In achieving these goals, researchers created a successful strategy that overcame the low ionic conductivity and instability challenges that comes with conventional polymer electrolytes. The group has conducted extensive research on solid-state batteries for electric vehicle applications, but this electrolyte is aimed at improving the performance of consumer electronics. The proposed battery electrolyte design could unveil a new generation of faster-charging, smaller batteries that would reduce the size of devices such as cellphones, laptop computers, smart watches and others.

Methylation enables the use of fluorine-free ether electrolytes in high-voltage lithium metal batteries. Li, AM., Borodin, O., Pollard, T.P. *et al.* *Nature Chemistry,* **16**, 922–929 (2024). https://doi.org/10.1038/s41557-024-01497-x

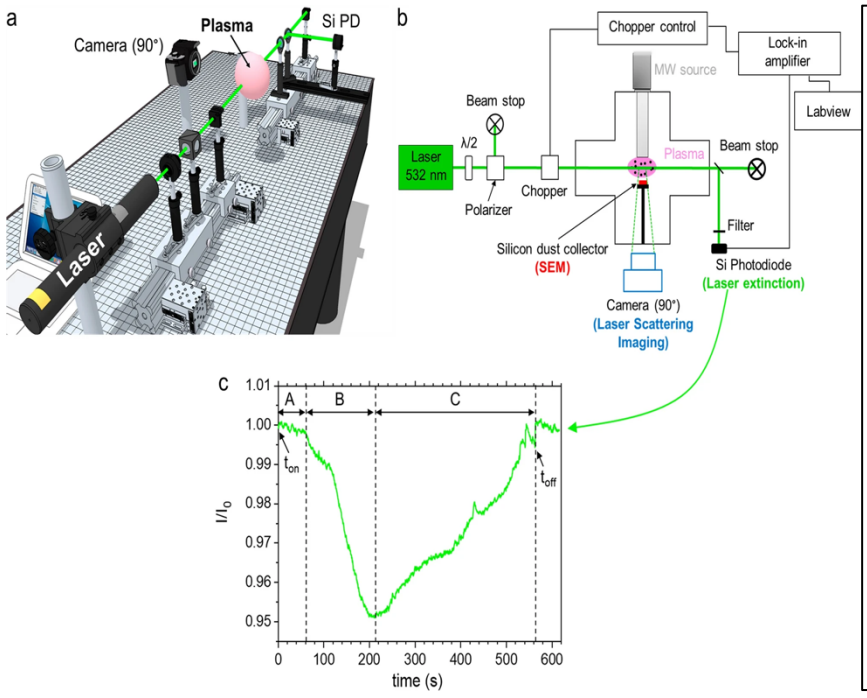
Researchers aiming to commercialize highly energic batteries for electric vehicles developed a new technology that involves cost-efficient manufacturing processes and a reduced environmental impact. Ongoing efforts to undercut the reliance on hydrocarbon fuels unfolded a new technology by UMD Professor Chunsheng Wang. His latest invention involves a high-energy lithium metal battery that deals with fewer manufacturing resources and a reduced environmental impact.
His invention seeks to replace conventional lithium-ion batteries with developing technologies that boast higher energy capabilities: enhancing consumer electronics as well as potentially enabling long-distance transportation. What stands in the way of lithium-metal battery commercialization lies in its key component, the electrolyte, which cannot stabilize the highly energetic system, causing it to fail.

Seeking to resolve this challenge, Wang's research team designed a new electrolyte that enables the successful operation of lithium-metal batteries with cost-effective components that are also less harmful to the environment. They accomplished this design without incorporating fluorinated solvents, largely employed chemicals in today's batteries that sometimes release toxic gases, which pose a threat to both human health and the environment. Their work enabled a recyclable technology that requires simpler and fewer manufacturing processes associated with fluorinated solvents, which allows for widespread adoption while removing some environmental concerns. Moving forward, the research team aims to patent their invention and commercialize it via Wang's venture, WH-Power, a battery manufacturing company that he co-founded with UMD Professors Robert Briber and Liangbing Hu.



Advanced Materials
A stable atmospheric-pressure plasma for extreme-temperature synthesis. Xie, H., Liu, N., Zhang, Q. *et al.* *Nature* **623**, 964–971 (2023). https://doi.org/10.1038/s41586-023-06694-1

Joint research from UMD and Princeton has developed a new plasma technology capable of reaching 8,000 Celsius. The new uniform, ultrahigh-temperature, stable plasma (USP) can be easily set up at a lab using relatively low electrical voltage such as 50 volts. The unique tip-enhanced electrodes comprise of long and short carbon fibers on the surface of carbon felts. Under an applied voltage, the Joule heat generated at contacts or defective regions of the longer fibers creates small gaps that pronouncedly reduce the plasma breakdown voltage to less than 50 volts in comparison with 1,500 volts at atmospheric pressure without the fiber tips—a 30-times reduction. Plasma is known as the fourth state of matter beyond the regular three states: solid, liquid and vapor (gas). It consists predominantly of positively charged particles known as ions and negatively charged electrons at approximately equal proportions. Plasma can be generated by splitting a gas with an intense spark as in the case of lightning bolts or subjecting a gas to an electromagnetic field. The unique tip-enhanced electrodes comprise of long and short carbon fibers on the surface of carbon felts. Under an applied voltage, the Joule heat generated at contacts or defective regions of the longer fibers creates small gaps that pronouncedly reduce the plasma breakdown voltage to less than 50 volts in comparison with 1,500 volts at atmospheric pressure without the fiber tips—a 30-times reduction. Meanwhile, the short, vertically aligned fiber bundles create a concentrated electric field that expands and coalesces the gas discharge, enabling a smooth transition to a volumetric plasma.



3D-view (**a**) and schematic side-view (**b**) of laser extinction/scattering experiments and (**c**) Time-resolved extinction signal recorded during dusty plasma experiment. The times at which plasma was switched on and off are indicated by the arrows. The extinction signal shows three typical regions: A = a slight decrease of the transmitted signal revealing NPs formation onset, few tens of seconds after the plasma ignition; B = a strong decrease of the transmitted signal revealing a large increase of the density and/or the size of NPs; C = an increase of the signal revealing a gradual disappearance of NPs from the laser beam path.

To demonstrate the broad applications, the team has used USP to synthesize various extreme materials, including various refractory metal alloys and ultrahigh-temperature ceramics. An example is hafnium carbonitride that was predicted from first principles calculations to have the highest melting point of all solids. The highly flexible carbon felt electrode can be shaped into various geometrical configurations to meet different manufacturing needs. For instance, a cylindrical design with coaxial electrodes can confine plasma in the channel, serving as a prototype for gas phase reactions, alloying of refractory metals, and various atomization processes. The team also demonstrated that a focused USP beam generated by a small carbon felt electrode can serve

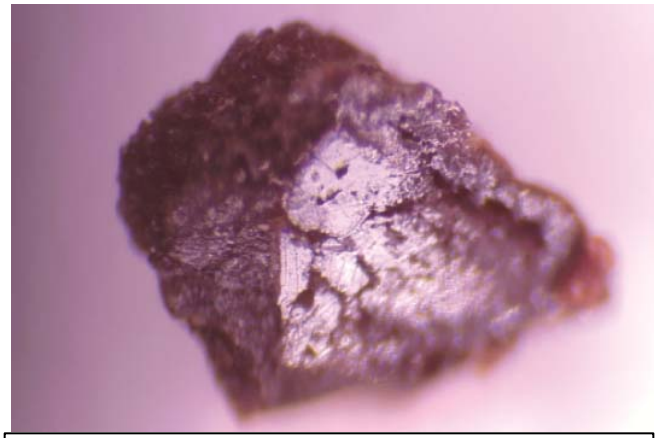
as an alternative 3D printing (also known as additive manufacturing) method for ultrahigh-temperature materials.

A solution-processed radiative cooling glass. Zhao, X., Li, T., Xie, H., Liu, H., Wang, L., Qu, Y., Li, S.C., Liu, S., Brozena, A.H., Yu, Z. and Srebric, J., 2023. *Science*, 382(6671), pp.684-691.

To combat rising global temperatures UMD researchers developed a new "cooling glass" that can turn down the heat indoors without electricity by drawing on the cold depths of space. The new technology, a microporous glass coating can lower the temperature of the material beneath it by 3.5 degrees Celsius at noon and has the potential to reduce a mid-rise apartment building's yearly carbon emissions by 10%. The coating works in two ways: First, it reflects up to 99% of solar radiation to stop buildings from absorbing heat. More intriguingly, it emits heat in the form of longwave infrared radiation into the icy universe, where the temperature is generally around -270 degrees Celsius, or just a few degrees above absolute zero. Unlike previous attempts at cooling coatings, the new UMD-developed glass is environmentally stable—able to withstand exposure to water, ultraviolet radiation, dirt and even flames, enduring temperatures of up to 1,000 degrees Celsius. The glass can be applied to a variety of surfaces like tile, brick and metal, making the technology highly scalable and adoptable for wide use. The team is now focusing on further testing and practical applications of their cooling glass. They are optimistic about its commercialization prospects and have created the startup company CeraCool to scale up and commercialize it.

Magnet-in-ferroelectric crystals exhibiting photomultiferroicity. Wang, Zhongxuan and Wang, Qian and Gong, Weiyi and Chen, Amy and Islam, Abdullah and Quan, Lina and Woehl, Taylor J. and Yan, Qimin and Ren, Shenqiang, *Proceedings of the National Academy of Sciences*, (2024)121 (17) e2322361121, https://doi.org/10.1073/pnas.2322361121

A new blend of naturally-occurring components used in responsive materials could spur low-power wearable sensor and memory devices that can respond to light stimuli. A recent discovery by UMD Professor Shenqiang Ren's research team could unveil low-power sensors and semiconductors that can be altered using light. Powerful materials that respond to electric and magnetic forces, known as "multiferroic," are used in sensors and memories due to their ability to process external stimuli. Building on conventional technologies, Ren's team designed new materials that can also respond to light—holding easy-to-make prospects for electronic devices with low energy requirements. The process is simple: organic ingredients, such as carbon, hydrogen and nitrogen, are assembled in low-temperature environments and crystallized in solution. These slightly dense, synthetically rich, flexible and relatively affordable materials are attractive candidates for wearable sensors and biomedical electronics. Their invention, named "photo-induced multiferroic materials," comes as the first material of its kind to respond to photo-induced stimuli. The team merged light-matter interaction with multiferroicity to open up a brand-new field: photo-induced

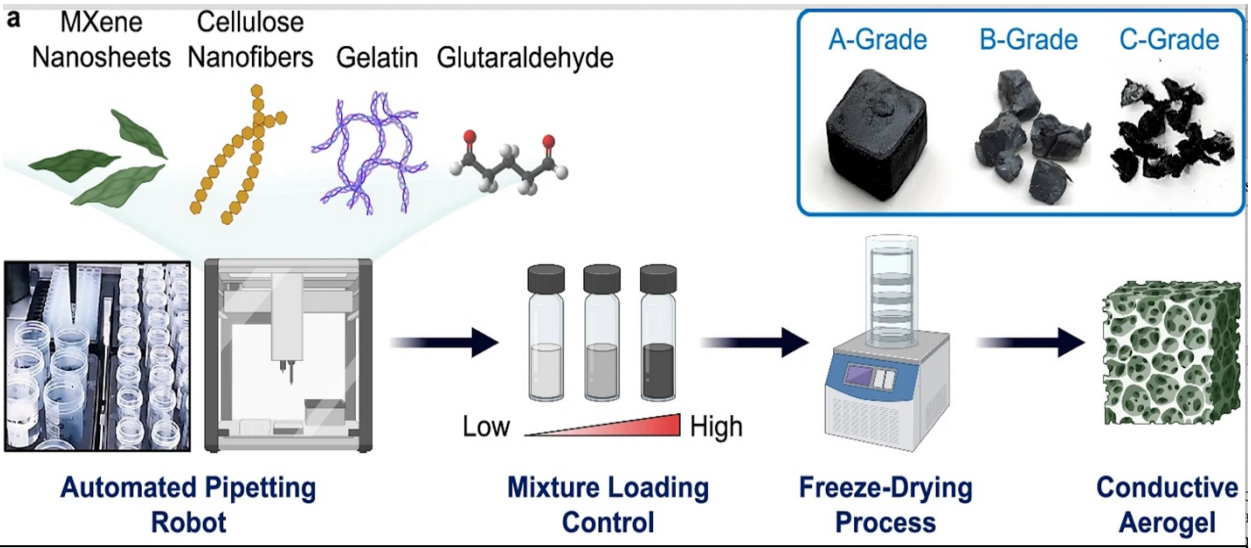


Optical photograph of $ImClO_4$

multiferroicity. This discovery could unleash a next generation of ultra-low-power sensor electronics.

Machine intelligence accelerated design of conductive MXene aerogels with programmable properties. Shrestha, S., Barvenik, K.J., Chen, T. *et al.* *Nature Communications* **15**, 4685 (2024). https://doi.org/10.1038/s41467-024-49011-8

Defying engineering challenges in record time, researchers at UMD developed a machine learning model that eliminates hassles in materials design to yield green technologies used in wearable heaters. Push-back associated with trial-and-error experimental processes often delays innovations. To solve this challenge, Po-Yen Chen, an assistant professor in the Department of Chemical and Biomolecular Engineering, proposed an accelerated method to create materials used in wearable heating applications. His model, published in *Nature Communications*, could automate design processes by leveraging machine learning and collaborative robotics. Similar to water-based gels, but instead made using air, aerogels are lightweight and porous materials used in thermal insulation and wearable technologies for their mechanical strength and flexibility. But despite their seemingly simplistic nature, their assembly line is quite complex. Researchers rely on endless experiments and experience-based approaches to explore the vast design space and design these materials. To solve these issues, Chen's team combined robotics, machine-learning algorithms, and material science expertise to enable aerogel design with programmable mechanical and electrical properties—breaking through scientific barriers at full speed. His prediction model is built to generate sustainable products with a 95% accuracy rate.



Schematic illustration of the fabrication process of conductive aerogels accelerated by an automated pipetting robot (i.e., OT-2 robot). Four building blocks were incorporated, including MXene nanosheets, cellulose nanofibers (CNFs), gelatin, and glutaraldehyde (GA). By adjusting the MXene/CNF/gelatin/GA ratios and the mixture loadings (i.e., solid contents of aqueous mixtures), the mechanical and electrical properties of conductive aerogels were controlled.

Materials scientists often struggle to adopt machine learning design due to the scarcity of high-quality experimental data. The workflow, which combines robotics and machine learning, not only enhances data quality and collection rates, but also assists researchers in navigating the complex design space. This tool can be expanded to meet other applications in aerogel design. Green technologies used for oil spill cleaning, sustainable energy storage, and thermal energy products—

like insulating windows—could become more accessible sooner than expected with this fast-paced assembly process. The team foresees leveraging this new scaleup production platform to design aerogels with unique mechanical, thermal, and electrical properties for harsh working environments.

PARTNERSHIPS AND COLLABORATIONS

Throughout the fiscal year, MEI^2 has developed many local, national, and international partnerships and collaborations in support of the Institute's research and innovation foci.

Constellation Master Research Agreement

The UMD and Constellation reached a major new milestone in their strategic partnership by signing a Master Research Agreement (MRA) in early 2024. The new agreement will enable a streamlined process for initiating collaborative projects, as well as strengthening the partnership between UMD and Constellation. Collaborative efforts will focus on energy and climate solutions.

Following on the MRA, MEI^2 and Constellation facilitated the first UMD/Constellation Research Day in July 2024. Carbon capture and sequestration technical solutions and intended growth given climate policy adoptions were discussed. Constellation also requested UMD to spotlight on the funding submission for Conowingo dam, helping to give a tangible example of how these tech solutions can be applied and growth across the sector. Kathleen Kennedy from the School of Public Policy, Center for Global Sustainability highlighted some of the emerging overlaps in climate and energy policy research opportunities. She currently analyzes the impact of direct air capture with carbon storage (DACCS) on emissions reductions and examining ways to achieve a global 1.5°C future using rapid technological growth to reduce CO_2 emissions. Jay Li, Director of the UMD Industrial Artificial Intelligence Center, discussed the uses of artificial Intelligence (AI) in an industrial setting. His current research is focused on developing non-traditional machine learning including transfer learning, domain adaptation, similarity-based machine learning, stream-of-x machine learning, as well as industrial large knowledge model (ILKM), etc. In addition, he is leading Data Foundry which consists of over 100 diversified industrial datasets including semiconductor manufacturing, jet engines, wind turbine, EVs, high speed train, machine tools, robots, medical TBI, etc. for machine learning research. These datasets are used to rapidly develop and validate Industrial AI system with scalable and systematic approaches.

The Master Research Agreement supports an agenda of broader and closer research partnerships between the two institutions. The MRA provides a framework for current and future cooperation that leverages the resources, talent and ideas of both institutions to produce innovative solutions for global and national energy and climate solutions. The framework includes work in these key areas: decarbonization forecasting; artificial intelligence as it relates to dispatch optimization, maintenance and power flow; nuclear energy; battery technology for storage; and other areas. MEI^2 has been interacting with Constellation for several years and have already collaborated through federally funded projects. Constellation has a strong footprint in Maryland and an interest in energy innovation, and the partnership will expand the portfolio of energy research and innovation topics.

This Strategic Partnership reflects recent collaboration between MEI^2 and Constellation. Collaboration began with various Constellation executives serving on the MEI^2 Advisory Board and Investment Committee. Theresa Christian, former Director of Technology and Innovation

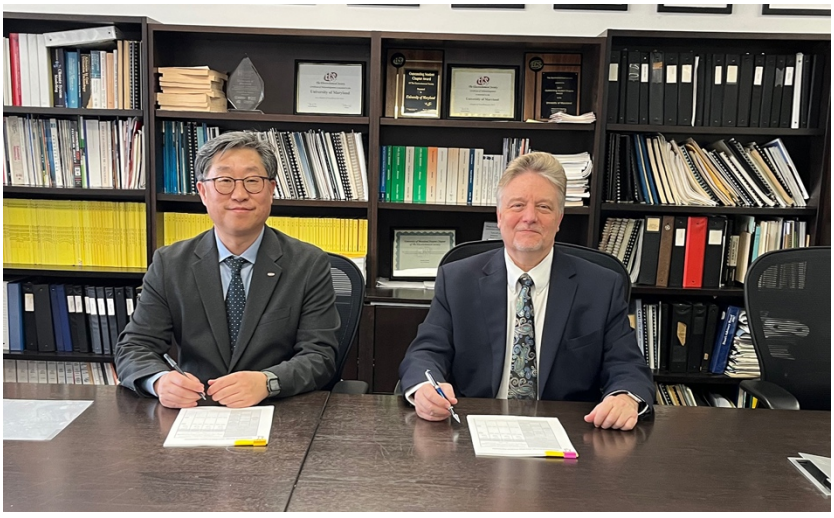
served on both boards in 2022 and 2023. Currently Collen Wright, Vice-President of Corporate Strategy at Constellation serves on both the advisory board and investment committee.

Korean Energy Technology Evaluation and Planning (KETEP)

During the inaugural United States – Korean Critical and Emerging Technologies (CET) Dialogue in December 2023, the United States (US) and the Republic of Korea (ROK) welcomed enhanced cooperation between the governments, industry, and academia across many technology domains including policies and planning; technologies and research; and commercialization and deployment, all to support economy-wide decarbonization in the US and the ROK. Specific domains included supply chains and technology; biotechnology and biomanufacturing; batteries and clean energy technology; and quantum.

U.S. Energy Secretary Granholm and Korean Minister Lee discussed ways that the US and the ROK may cooperate to strengthen clean energy technology supply chains and collaborate on clean energy technology demonstrations and deployment. The two affirmed the need to promote clean energy partnerships through people-to-people exchanges, investments, and R&D cooperation between experts on areas of mutual agreement.

In follow up to the two governments' discussion, Dr. Eric Wachsman, Director of the Maryland Energy Innovation Institute (MEI^2) and UMD Distinguished University Professor, and Dr. Sang Bok Lee, UMD Professor, Department of Chemistry & Biochemistry and Director of the Maryland NanoCenter, have worked together with Office of Energy Policy of the Korean Energy Technology Evaluation and Planning (KETEP) for a cooperative agreement to establish the Korea - US Energy Cooperation Center at MEI^2/UMD.



Sung Joo Lee (KETEP) and Dr. Eric Wachsman (UMD) sign agreement, March 2024

As a direct result, on Wednesday, March 14, 2024, Dr. Eric Wachsman, signed the cooperative agreement with Sung Joo Lee, Executive Director of Office of Energy Policy and Principal Investigator of Korea-US Energy Cooperation Center. The signing launches the Korea - US Energy Cooperation Center at MEI^2/UMD to coordinate cooperation between US and Korea researchers. Other work force contributors from KETEP for the agreement include Sang Joo Baek, Team Manager of International Cooperation Division and Jeongyong Kim, Director of Finance, Accounting and Contract Division.

Both governments, as well as UMD and KETEP, are committed to spurring research, innovation, and technology deployment; promoting joint demonstration projects; and expanding clean energy jobs to advance clean energy and decarbonization efforts.

US – Israel Solid Energy Consortium (UISEC)

In 2020, the US DOE in partnership with the Israel Ministry of Energy and Israel Innovation Authority, decided that the U.S.-Israel Energy Center (managed by the BIRD Foundation) would oversee joint projects to accelerate development and deployment of critical and innovative technologies in the areas of (1) Fossil Fuels; (2) Energy Storage; (3) Cyber Security for Energy Infrastructure; (4) Energy-Water Nexus, while facilitating cooperation among consortia of US and Israeli companies, research institutes, and universities. From this call, the US – Israel Solid Energy Consortium (UISEC) was established for the purpose of advancing the science and development of solid-state batteries, including work on advanced coatings, cell components, cells, and materials informatics software, for both Na and Li metal batteries. Led by UMD's Dr. Paul Albertus in the US and by Bar-Ilan University's Professor Malachi Noked in Israel along with their respective teams of co-PIs and graduate students, the consortium also includes the participation of Saft, Forge Nano, Inc. and Ion Storage Systems from the US and 3DBattery, Materials Zone and Tel Aviv University from Israel.

Key technical highlights in the past four years include:

- 26 publications were either published or submitted for publication. In addition, a joint publication of Israeli academic (Bar Ilan Univ, BIU) and US industrial (Forge Nano) authors has been published in Nature Nanotechnology.
- The US company Forge Nano (based on Colorado) and Bar Ilan University (through BIRAD Research & Development Company), directly building on their UISEC collaboration over the past three years, were awarded a proposal to BIRD Energy titled "Advanced Flexible Thin Films Coating by Molecular Layer Deposition for Improved High-Capacity Anodes." This is a direct example of collaboration through the US-Israel Energy Center moving to a more commercially focused collaboration.

Collaborations continue to play a key role in the UISEC consortium. The development of cold- and hot-pressed (densified) pelletizing process for Argyrodite (Li6PS5X, X=Cl, Br, I) solid-state electrolyte and operando-pressure dependent ionic conductivity study between the Lee-Rubloff-Albertus (UMD) and Zitoun (BIU) group yielded two manuscripts that are in preparation. The Lee/Rubloff group is also in discussion with Forge Nano for large scale ALD process on 3D nanostructured anodized aluminum oxide (AAO) film. Additionally, the Lee-Rubloff group has started a new company called Ionic Devices, Inc. based on 3D nanostructured battery research.

Materials Zone continues to work with the Albertus (UMD) group, Golodnitsky Lab (TAU), Forge Nano and the Noked (BIU) Lab to build a solid state battery database. The results from 120 SSB cells from the literature were collected, with composition and preparation data, and uploaded to the platform in an accessible way for all contributors. The database enables easy, concurrent visualization of the relationships between battery chemistry/assembly and their Cycle and Rate testing results; and will help researchers discover trends, gaps and potential solutions from a wide range of literature sources.

The Aurbach (BIU) and Wachsman (UMD) groups have been working on improving the electrochemical properties of a polymer matrix-based electrolyte at a temperature lower than Tm of the SPE. Characterization of symmetric cells with non-blocking electrodes. Likewise, Golodnitsky's group (TAU) is collaborating with the Wachsman group (UMD). Mg/Zn dual doped $Na_3Zr_2Si_2PO_{12}$ (NZSP) NASICON ion-conducting ceramics, synthesized by the Wachsman

research group was supplied to TAU and tested as protective coatings prepared by electrophoretic deposition method.

3DB continues to work with Forge Nano. They received raw materials from Forge Nano for testing (pristine and ALD-coated NMC811 powders); have started evaluation of the pristine and coated NMC811; and have received coated Li metal foils for evaluation (pristine and ALD-coated Li metal). Similarly, 3DB was working with Ion Storage Systems on cathode testing. 3DB has sent high-load NMC811 cathode sheets and TDS to Ion-Storage for testing. However, Ion-Storage evaluated cathode and found inferior performance than the one they are currently using.

UMD's Dr. Paul Albertus in the US and by Bar-Ilan University's Professor Malachi Noked at US DOE, March 2024.

Forge Nano, together with the Lee/Rubloff groups at UMD and the Noked group successfully implemented a SSB full-cell assembly training activity at the UMD campus. The training allowed each partner to observe a complete demonstration of a solid-state full cell assembly. The technique and associated instrumentation was outlined fully by the Noked group at and the associated documentation was provided to each partner institution with emphasis on operational and technical details. The activity aligned all partners with the best technique. Forge Nano is now implementing changes to their SSB testing procedures and updating some instrumentation to enable new/improved/more reliable testing capabilities that will further advancement of the grant objectives. The UISEC team presented these results in March 2024 to the US-IL Energy Center Executive Committee at the US DOE.

Center for Research in Extreme Batteries (CREB)

The Center for Research in Extreme Batteries (CREB) is the Only US battery center focused on extreme performance, safety, and environmental needs of the Department of Defense. It was initiated through strong existing collaborations between Chunsheng Wang (UMD) and Kang Xu (Army Research Laboratory). It is the first ARL open-campus initiative and has since created a model for future open-campus initiatives. In FY2024, the US Congress appropriated an additional $10M to CREB, bringing the total federal appropriated funds to more than $40M. The spring bi-annual meeting focused on progress in the three main thrusts of the CREB consortium.

Thrust 1: Advanced Safe Electrolytes

Advanced safe electrolytes in battery technology are crucial for enabling enhanced performance and safety in modern energy storage systems, especially under extreme conditions. Solid-state electrolytes (SSEs) represent a significant leap forward by offering higher thermal and electrochemical stability compared to traditional liquid electrolytes, making them suitable for low-temperature operations. Water-in-salt electrolytes (WISE) are also a promising innovation due to their ability to extend the electrochemical stability window of aqueous systems, which helps

facilitate battery performance in cold climates. To improve manufacturability and performance, advancing the processing and structural integrity of SSEs is key. This involves refining methods to produce materials with enhanced ionic conductivity and reduced interface resistance, critical for scaling solid-state batteries (SSBs). Additionally, improving the ruggedness and durability of SSBs through better mechanical and chemical resilience will lead to more robust battery systems capable of withstanding diverse environmental stresses. These innovations collectively support the development of safer, high-performance batteries for a range of applications.

Thrust 2: Advanced Cathodes

Advanced cathodes are pivotal in enhancing the energy density, longevity, and safety of next-generation batteries. One prominent development is in advanced Nickel Manganese Cobalt (NMC) cathodes for Li-ion batteries, which offer high energy density and improved cycle life. These NMC cathodes have seen increasing nickel content to boost capacity, while reducing cobalt for cost-effectiveness and ethical sourcing. This composition enables better performance in electric vehicles (EVs) and consumer electronics. Alternative cathodes for nonaqueous Li-ion and aqueous Zn-air batteries are also emerging as promising solutions. In nonaqueous systems, cathodes made from materials like sulfur, phosphates, or even organics are being explored to overcome the limitations of traditional cathode materials, offering higher capacities or increased stability. For aqueous Zn-air batteries, oxygen reduction catalysts are critical for efficient operation, where research is focusing on using non-precious metals or metal oxides to enhance performance and reduce costs. These advances in cathode technology are essential for creating safer, longer-lasting, and more sustainable energy storage solutions across different battery chemistries.

Thrust 3: Silicon Anodes

Silicon anode technology has made significant strides in advancing battery performance, particularly for high-energy applications. The development of a 100% porous silicon anode-based pouch cell marks a major breakthrough, offering extreme high energy density while maintaining fast charging capabilities and enhanced safety. This porous structure allows for better accommodation of silicon's expansion during charge-discharge cycles, improving battery longevity. To further optimize performance, adjusting the NP (negative to positive) ratio and employing chemical doping are crucial strategies. These approaches enhance fast charging capabilities and safety by mitigating issues like lithium plating and uneven charge distribution. Insights into the reactivity of silicon anodes from isothermal microcalorimetry have revealed key information about thermal behavior and side reactions during cycling, helping researchers design safer and more stable silicon anodes. In addition, the development of fast charging protocols and specialized fast chargers for silicon anode-based lithium-ion batteries has further unlocked their potential for applications that demand quick recharge times, such as electric vehicles. These advances collectively push the boundaries of energy storage technology, offering solutions with higher performance, faster charging, and greater safety.

OUTREACH and EDUCATION

International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE)

As the world looks towards reducing greenhouse gas emissions and impacts from climate change, clean hydrogen will be instrumental in several "hard-to-decarbonize" sectors, including heavy-duty transportation, industrial and chemical processes, synthetic fuels, and long-duration energy storage. Hydrogen is already used in light duty transportation and in industrial and chemical applications such as petroleum refining and fertilizer production, food procession and cosmetics – all important processes that are essential to our quality of life.

Top to Bottom: Eric Wachsman, Rebecca Maserumule, and Sunita Satyapal

Therefore, the Maryland Energy Innovation Institute (MEI^2) welcomed U.S. Department of Energy (US DOE) partners, dignitaries from nearly 20 countries within the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE), and academic researchers and students from across Maryland and the District of Columbia for a day of education and outreach. The meeting focused on education, research, and workforce development through discussions on current skills gaps; challenges faced by underrepresented groups; and ways to strengthen recruitment, retention, and advancement of clean hydrogen professionals globally.

By partnering with MEI^2 and showcasing current student research (at all levels - undergraduate, graduate and post-doctoral), the University of Maryland (UMD) and other regional academic institutions such as Johns Hopkins, George Washington University and Morgan State University, hope to empower the next generation of employees to enable a sustainable clean hydrogen economy. The event was a great precursor to the start of Hydrogen Week (October 8 as the date 10/08 shares the same sequence of numbers as the atomic weight of hydrogen: 1.008) and an opportunity to celebrate ***clean*** hydrogen and the crucial role this element plays in supporting a robust, equitable clean energy future globally.

IPHE Chair, Rebecca Maserumule from the National Department of Science and Innovation (DSI) in South Africa, Sunita Satyapal, IPHE Vice-Chair and Director at the DOE Hydrogen and Fuel Cell Technologies Office (HFTO), and Dr. Eric Wachman, MEI^2 director, opened the event noting the large number of students in attendance and emphasizing the importance of bringing new talent and new ideas to hydrogen and fuel cell research and deployment.

During the meeting, Maserumule announced the recent launch of the Hydrogen Diversity Equity Inclusion and Accesibility (H_2-DEIA) platform. One of the first steps for H_2-DEIA is a pilot mentor-mentee program that will guide early career

professionals and students by identifying skill gaps; addressing challenges faced by underrepresented groups; and strengthening the recruitment, retention, and advancement of clean hydrogen professionals. H_2-DEIA serves a global purpose—uniting governments, industry, academia, non-profit organizations, research institutes, capital investors, and the broader stakeholder community to help shape a skilled, diverse workforce for the clean hydrogen industry.

Research Experience for Undergraduates

MEI^2 in conjunction with the UMD Department of Materials Science and Engineering hosted a summer research experience for undergraduates (REU) and research experience for high school teachers (RET) funded through the National Science Foundation (NSF). The program is entitled Renewable and Sustainability Energy Technologies (ReSET). The research projects for the REU/RET Programs represent state-of-the-art research at MEI^2 and the UMD in renewable energy technology and sustainable generation, use and storage. The range and depth of the student/teacher research experiences will help train the next-generation workforce in energy systems, development of sustainable alternatives materials and approaches, nanomanufacturing, and more. All the projects contribute to the mentors' research program so intellectual merit arises from publications and presentations with participants and publications the participants helped to enable. Future intellectual merit will result from students who go on to careers in energy related technology and research. While student persistence in STEM has a broader impact, the future publications, patents and inventions of these students will contribute to intellectual merit.

The objectives of this REU program are to:

- Offer an engaging research experience for 8 undergraduates and 2 high school teachers to explore how engineering and science advance technology for renewable and sustainable energy generation, use and/or storage;
- Offer research opportunities to students with little or no research experience including community college students (at least 50%) as well as rising sophomore and juniors, and encourage participation from historically underrepresented groups (economically disadvantaged students, underrepresented minorities, veterans, etc.) from a mix of colleges and universities with 75% of students from institutions other than the UMD;
- Recruit teachers who teach underrepresented and economically disadvantaged students; and work with them to integrate their research experience into their classroom to enhance their students' understanding of subject matter and the context of STEM concepts and encourage students to pursue STEM majors and careers;
- Provide professional development to both REU and RET participants through expert lectures and discussions, tours, presentation and writing opportunities, and development of experimental and analytical skills; also provide a welcoming, inclusive environment where participants form a cohesive cohort and mentors encourage development of research, engineering and critical thinking skills as well as self-efficacy;
- Provide opportunities for students to present and publish their research; and
- Offer REU cohort opportunities to explore STEM career options to help them determine which types of STEM careers best suit them.

This year's cohort participated in the UMD campus wide Summer Undergraduate Research Conference, visited local start-up companies, and attended career development seminars on ethics, career pathways, and entrepreneurship.

Upon completion of the summer program, one student submitted a research paper to the *Journal of Power Sources* with her mentor. This paper examines the problem of estimating the states, including state of charge, of battery cells connected in parallel. The simulation results highlight the computational benefits of both the clustering strategy and inverse dynamics approach for state estimation ("State Estimation for Parallel-Connected Batteries via Inverse Dynamic Modeling", Hannah Lee, Casey Casten, and Hosam K. Fathy (2024). Submitted to *Journal of Power Sources*).

Graduate Energy Fellowships

MEI[2] awarded one Harry K. Wells graduate energy fellowship and one Barbara Hulka graduate energy fellowship in March 2024. Bothe fellowships come with a $20k stipend for research and a $4k award for conference travel and materials.

Since 2008, Ms. Barbara Hulka has provided funding for the Hulka Energy Research Fellowship to support graduate student research in selected alternative energy fields at the UMD. This announcement serves as a request for proposals for engineering graduate student(s) and their faculty advisor(s) to seek funding to pursue new research in one of the following research areas**:**

- advanced solar energy conversion
- fuels and power from sustainable biological processes,
- renewable wind energy,
- ocean thermal or wave energy or geothermal energy conversion

This year's recipient of the Hulka Fellowship is Shanchuan Liang, Department of Electrical and Computer Engineering. His research is titled: *Advancing Renewable Wind Energy through the Development of Strong Two-Dimensional (2D) Magnets*.

This proposal aims to advance renewable wind energy technology by developing strong two-dimensional (2D) magnets1 with large coercivity and magnetization, offering a compelling approach to enhance the efficiency and durability of wind turbines. By leveraging the unique properties of novel 2D magnets, this proposal seeks to develop 2D magnets that are lighter, stronger, and more resistant to demagnetization than their traditional counterparts. These advancements are expected to lead to the design of wind turbines that are more efficient, capable of operating in a wider range of environmental conditions, and more cost-effective in the long term. The project will encompass the characterization of these innovative 2D materials and comprehensive evaluation of their performance. Achieving success in developing these 2D magnets for use in wind turbines could significantly lower wind energy costs and expedite the transition to sustainable energy sources.

Mr. Harry K. Wells established an endowment to support engineering graduate student research in energy at the UMD. This announcement serves as a request for proposals for engineering graduate

student(s) and their faculty advisor(s) to seek funding to pursue new research in the field of sustainable energy generation and/or storage**.**

The Wells Fellowship recipient for 2024-2025 is Aniqa Anjum, Chemical and Biomolecular Engineering. Her project is titled: *Development and Optimization of Cobalt-Free Cathodes for High-Performance Solid Oxide Cells*. Solid oxide fuel cells (SOFCs) offer promising prospects for clean and efficient energy solutions, but challenges persist, particularly regarding the reliance on cobalt in cathode materials. This research aims to address this issue by exploring cobalt-free cathodes for enhanced sustainability, and reduced geopolitical sensitivity. The preliminary work shows promising results with Pr-Sr-Ni (PSN) based cobalt-free electrocatalyst. The proposed research plan outlines Phase 1, focusing on isolating individual phases of the PSN cathode to assess their electrochemical performance, and evaluating the impact of substitution with other lanthanide elements, such as Nd and La. The expected outcomes include enhanced understanding of cathode capabilities, selection of optimal candidates, and achieving benchmark full cell performance. The project outlines a plan to foster collaborations, and attract potential funders for Phase 2. In Phase 2, the project aims to operate cells in electrolysis mode with an ultimate goal to develop a regenerative solid oxide cell (SOC) integrated system for energy conversion and storage.

APPENDIX 1. Maryland Energy Innovation Institute FY24 Budget

FY24 Budget Expenditures and FY25 Proposed Budget
As there was a $32K carryover from FY23, and in anticipation of additional funding being received through the Founders Fund, the Investment Committee opted to fund an additional Energy Seed Grant in FY24.

	FY24 Budget	Actual	Difference	FY25 Budget
Salary/Fringe	$238,127	$217,599	$20,528	$301,181
Seed Grants	$650,000	$710,500	-$60,500	$650,000 (+$1M or $375k)*
Communication/Reporting	$2,500	$1575	$925	$2500
Events/Outreach	$13,000	$6836	$6164	$6,000
Supplies/Materials	$25,000	$9888	$15,112	$8,000
Travel	$10,000	$2984	$7016	$8,000
Subtotal	$938,627	$949,382	-10,755	$975,681
MCEC	$1.2M	$1.2M	$0	$1.2M
Total	**$2,138,627**	$2,149,382	-$10,755	$2,175,681*

*There are two scenarios of funding for SB960. MEI^2 will either receive a minimum additional $375K or could receive as much as $1M in additional seed grant funding.

APPENDIX 2. Letter from the MEI^2 Advisory Board

UNIVERSITY OF MARYLAND

GLENN L. MARTIN INSTITUTE OF TECHNOLOGY
A. JAMES CLARK SCHOOL OF ENGINEERING

Maryland Energy Innovation Institute

June 10, 2024

Dr. Eric Wachsman
Director, Maryland Energy Innovation Institute
University of Maryland
1202 Engineering Lab Building
College Park, MD 20742

Dear Dr. Wachsman,

The Maryland Energy Innovation Institute (MEI^2) Advisory Board has prepared this guidance letter reflecting its observations and recommendations based on perspectives and inputs from the May 10, 2024 meeting.

The Advisory Board welcomes its newest members, Mike Gill of Cornerstone Advisory, Colleen Wright of Constellation, and Pat McGrath of the Schmidt Family Foundation.
The Advisory Board also extends its appreciation to Ellen Williams, Distinguished University Professor upon her retirement from the University of Maryland, for her exceptional service as Advisory Board Vice-Chair and Chair of the Investment Committee.
Also, Geoff Oxnam of American Microgrid Solutions is leaving the Advisory Board and we thank him for his extended service and contributions.

The Advisory Board also welcomes Ryan Powell of the Maryland Department of Commerce, Tammi Thomas, of TEDCO, and Colleen Wright of Constellation as new members of its Investment Committee.

Observations

Need for Increased Funding Support
As MEI^2 is now in its seventh year of operations, the Advisory Board notes its continued impressive advances in clean energy research and technology development. As in prior years the Advisory Board once again notes that much more could be accomplished if funding resources were significantly increased. MEI^2 continues to demonstrate its ability to greatly leverage private sector funding and investments in collaboration and coordination with the Maryland Clean Energy Center (MCEC) and the Maryland Energy Innovation Accelerator (MEIA).

MEI^2, MCEC and MEIA continue to coordinate well along the value chain of concept innovation,

through launch of startups and early operations, all of which are necessary in competing for investments and contracts to commercial viability and growth. The Advisory Board notes that such successes could not be realized without the support from the Maryland Governor's and Legislature's continued commitment to invest in energy innovation to address climate change. The enactment and signing into law the provision for the Maryland Clean Energy Center - Climate Technology Founders Fund is a prime example of their support. Special acknowledgment and thanks also go to Senator Feldman and Delegate Vogel for sponsoring the bill. The Founders Fund will help startup companies gain access to resources essential in assisting more in-state startups to successfully transition to sustainable enterprises.

The Advisory Board commends the premiere faculty associated with MEI^2 who continue to receive recognition and distinguished awards from various widely respected organizations in addition to the numerous patents arising out of its clean energy research. The Advisory Board is impressed with MEI^2/UMD in its continued success in winning ARPA-e awards, as evidenced in the 7 new awards received since the last Advisory Board meeting in 2023. This is particularly noteworthy in light of the limited State research and development funding support in clean energy innovation (~$2 million in fiscal year 2022) relative to health/biotechnology (~ $26 million in fiscal year 2022) which continues to receive significantly more from the State.

Strategic Planning

- The Advisory Board notes that a strategic planning session held October 28, 2023 resulted in the formulation of a Strategic Plan identifying the vision for MEI^2 and the strategic goals and objectives aimed at addressing key SWOT areas. More in- depth discussion of the SWOT areas may be taken up at the next Advisory Board meeting.

- **MEI^2 mission:** To catalyze clean energy technology to address climate change, stimulate economic growth, and create a sustainable future in Maryland

- Key Performance Indicators – Implementation

  The ongoing implementation of the Strategic Plan is reflected in the progress against its Key Performance Indicators (KPIs). With a total of $6M in State funds invested in MEI^2 and MEIA, the KPI metrics to date indicated a yield of: over 36 Maryland based companies formed; over 134 full-time jobs created; more than 124 patents filed; $70.1 M in private investments; $76.7 M in grants awarded; and $4.5M in revenue generated by those companies. Moreover, this university- company partnership has helped bring to Maryland over $214 M in non-dilutive grant funding. This combined with the $70.1 M in private investment has resulted in an estimated 47 times return on investment (ROI).

Seed Grants Program in Coordination with MEIA

- The Seed Grant program supported by MEI^2 continues to be a resounding success within the limited funding provided. The research funded through this program along with support from MEIA continues to be game changing in the clean energy technology arena. To date 36 energy innovation companies were founded and advanced through the Seed Grants Program and/or in

partnership with MEIA, including 10 new companies since last year. Cumulatively, seed grant recipients also represent a broader program participation from other universities across the state with 61 total proposals received of which 28 were awarded (47% acceptance rate), including 9 submissions from Historically Black Colleges and Universities of which 5 were awarded (55% acceptance rate).

- With the additional resources enabled by the Climate Technology Founders Fund discussions were held regarding consideration of funding Phase-3 grants to support a follow-on phase for companies that have already launched. The Advisory Board's discussion was prompted by consideration of balancing grant funding to address the long-term health of companies created against funding to launching more startup companies.

- The Advisory Board supports a position of providing the Investment Committee flexibility in the seed grant selection/award process, subject to availability of overall Seed Grant Program funds. However, the Advisory Board recommends, given the limited available resources, that Phase-3 awards should focus on the required company cost share for federal proposals/awards. Secondary consideration should be for company operating funds after receiving an award during the time period between start of work and payment of first invoice as start- up companies may struggle to find cash resources to finance this gap. It is worth noting that tying Phase 3 to Federal awards would by definition be high leverage – bringing in two to four dollars in Federal funding for every dollar of state funding. This would also position companies well by bringing in more non- dilutive capital as they grow. Moreover, as Phase-3 awards would be tied to the timing of federal solicitations/awards, MEI^2 Seed Grant proposals for these types of awards be on an open basis rather than the annual or semi-annual timing of the Phase-1 and Phase-2 solicitations.

- The Advisory Board also notes that seed grant awards have led to several game- changing clean energy companies becoming success stories. Much of the success is also due in large part to the coordinated efforts and support from MCEC and MEIA. As just one prime example of the numerous startups formed, Ion Storage Systems, a Seed Grant recipient from 2019, has now progressed significantly towards commercialization with its launch of a 33,000 square-foot pilot manufacturing facility in Beltsville, Maryland, with 74 employees and $42 million in private investment.

- As mentioned in our previous letter to MEI^2, the University has extensive research and technology facilities, programs and expert capabilities, including those of MEI^2. Moreover, it is noted that there are currently no energy focused incubation facilities which are sorely needed to assist seed grant recipients towards viable startup. As such this should be a priority for the University and the State.

Research Partnerships

Research partnerships in specific areas of collaboration in clean energy research continue to be impressive. In particular, the Advisory Board notes the impressive progress from ongoing major advanced battery research collaborations including the BIRD Foundation Israel Solid Energy Consortium; the Center for Research in Extreme Batteries for defense, space and biomedical applications; and the US-Germany Cooperation on Energy Storage. In addition, the Advisory

Board notes an important agreement signed on March 14, 2024, establishing Korea-US Energy Cooperation Center headquartered at MEI^2/UMD with Korean Energy Technology Evaluation and Planning (KETEP) on collaborative energy research projects.

Outreach and Education

The Advisory Board recognizes the continued importance of MEI^2's coordinated outreach and education activities in clean hydrogen technology, fuel cells, and sustainable energy. It commends MEI^2 for its outreach activities with the US Department of Energy and the International Partnership for a Hydrogen Economy (IPHE) in fostering a foundation for a sustainable workforce and creating a network to explore early career paths in these areas.

In addition, the Advisory Board commends MEI^2 for continuing its extensive participation in Summer Research Experiences in Renewable and Sustainable Energy Technology (ReSET) engaging students, STEM teachers in a host of lectures, activities and tours.

Coordination with MCEC and MEIA

The focus of activities from MCEC and MEIA are essential to fostering the success of commercial startups arising from the Seed Grant Program and innovations stemming from MEI^2's in-house research. Both MCEC and MEIA continue to make significant progress toward program strategic goals and metrics against their Key Performance Indicators (KPIs).

In support of climate technology commercialization as part of Maryland's Climate Solutions Now Act, MCEC's programs continue to effectively facilitate access to capital and operate financing programs using leveraged or direct investment. It provides specialized procurement and technical support as well as equity outreach and community development to facilitate project implementation. The Advisory Board notes that under the MCEC-managed Climate Catalytic Capital (C3) Fund there were 8 technology innovation applications and encourages expanded participation. The Advisory Board also sees an opportunity for seed grants applicants to apply for that funding as well and encourages MEI^2 to inform them of that opportunity.

The Advisory Board acknowledges MEIA's continued significant progress on its three- tier program: Pre-Accelerator for customer discovery; the Launchpad to develop a business and financial model while creating a new company; and the Accelerator to legally launch the company and put management team into place. MEIA continues its funding partnership with the Maryland Technology Development Corporation (TEDCO) as well as its cost-shared partnership in the U.S. Economic DevelopmentAdministration's (EDA) Build to Scale Venture Challenge grant program.

This year's annual report to the governor and the state legislators will combine the collective progress status and achievements of both MEI^2 and MEIA.

Funding and Budget

The Advisory Board again advocates and supports continued funding increases to MEI^2. As the Advisory Board recognizes the importance of additional funding provided through the enactment of SB690, it strongly supports the higher funding scenario of SB690 to spur more successful launches of clean energy entities for the state.

For the state to realize its zero-emissions climate target, substantial increases are needed in clean energy funding at levels comparable to its investment in bio-tech and health. As noted in our previous letter, an increase in funding is needed to the statewide Green Bank at MCEC which currently remains much less than that of other states. The Advisory Board reiterates its position on the need to convene a "blue ribbon" panel to assess the
state's total landscape in clean energy technology innovation as was done in the bio-tech area. An important outcome of the panel would be to provide an assessment of the state's competitiveness in clean energy technology relative to that of other states and to make relevant recommendations.

STATUS OF PREVIOUS RECOMMENDATIONS FROM ADVISORY BOARD

The reported status of MEI^2's actions in response to the Advisory Board's recommendations arising from the prior meeting of April 28, 2023, are as follows:

- **Develop a Five-year MEI^2 strategic plan** with vision, goals, priorities and targeted metrics consistent with and supportive of Climate Solutions Now Act

Status: Strategic Planning meeting was held on October16, 2023 to develop a methodology and identification of MEI^2's strengths, weaknesses, opportunities and threats (SWOT analysis). A strategic plan along with an updated vision statement, detailed SWOT analysis, goals and objectives and Key Performance Indicators (KPIs) has been developed. The strategic plan is a living document and will be updated as needed to address future developments in the clean energy landscape including market and policy priorities relevant to MEI^2's strategic vision and mission.

- **Explore Private Sector Membership** to enhance value and broaden funding support to MEI^2: Devise a value proposition model that plays to the strengths of MEI^2 and considers priorities/motivations of potential donor members.

Status: This is an ongoing effort as new Advisory Board members from industry have joined can provide insights in pursuit of private sector membership and funding support. Engaged with private sector board for feedback on priorities resulting in establishment of Master Research Agreement with Constellation in areas of interest including where Artificial Intelligence can be impactful, and a proposed date for joint Research Day with Constellation to discuss potential focus areas for collaboration opportunities/proprieties.

- **Fill vacant Advisory Board** positions

Status: New Advisory Board members from industry have joined.

- **Outreach**: Continue to coordinate outreach materials development between MEI^2 and MEIA with new products by the next annual Advisory Board meeting.

Status: Coordination continues including integrated reporting and strategic outreach approaches, and potential engagement with Maryland Department of Commerce to provide assistance to startups with information materials and platforms. Engagement and information meetings continue with state legislators championing the introduction of Energy Innovation Legislation.

ADVISORY BOARD RECOMMENDATIONS TO MEI²

After discussions, inputs and deliberations, the Advisory Board makes the following actionable recommendations to MEI²:

Explore Additional Funding Avenues:

- In coordination with the Investment Committee members and in conjunction with Maryland Department of Commerce explore additional funding strategies such as enacting a tax equity provision for startups in clean energy.
- MEI² should encourage seed grants applicants to apply for C3 funding managed by MCEC. Possibly at the next Advisory Board meeting in conjunction with Sustainability Day, MEI² could invite the C3 grant recipients in addition to Energy Seed Grant recipients.
- Continue to explore funding partnerships/memberships that align with similar clean energy priorities**.** Examine partnership models from other universities.

- **Advocate for Maintaining and Expanding MEI² Core Capability:** Actively continue discussions with the University administration and key decision makers on the immediate importance of maintaining a core capability in light of the pending departure of a key faculty specifically appointed to MEI². Currently there are about 100 affiliated faculty across campus, but only 4 faculty hired specifically for MEI². The ties to Chemical Engineering and Materials Science make these areas of particular strength for MEI², but the University has a breadth and depth of talent in Mechanical Engineering, Computer Science, Biotech, and other energy- and climate-relevant disciplines. Stronger ties across departments would benefit the University to leverage the network, connections, and track record of success with Federal and private funding in MEI². The Advisory Board encourages MEI² to participate in search committees for new faculty and push for joint appointments. In addition, the Advisory Board recommends MEI² requests for expanding the number of faculty as direct appointments as this is essential to MEI² realizing its full potential in clean energy technology innovation and enhancing its ability to attract major funding partners.

- **Expand Advisory Board Membership:** Consider including representation from broader cross-section from private sector including corporate representatives from solar/wind and building energy efficiency industry, clean energy financial investment and other NGO clean energy trade groups.

As always, the Advisory Board is fully committed to advising MEI² on the strategic planning, development, implementation and alignment of its priorities with the University and the State of Maryland. The Advisory Board thanks all the meeting participants for their time and guidance through discussions with MEI² on its clean energy innovation efforts.

Sincerely,

Victor Der

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David Rapaport**
Head, Research Collaboration Management, Siemens Technology

Colleen Wright
Vice-President Corporate Strategy, Constellation
(*Unable to attend May 10 Meeting; ** remote attendance)