MARYLAND ENERGY INNOVATION INSTITUTE

Annual Report FY2023

Dr. Greg Hitz (CTO) discusses Ion Storage Systems ground breaking solid-state battery technology on Capitol Hill in the Rayburn House Building during the Energy Innovation Showcase, July 2023

UNIVERSITY OF MARYLAND, 8136 PAINT BRANCH DRIVE,
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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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MESSAGE FROM THE DIRECTOR

FY2023 was an 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. Through coordination of the MEI^2 Seed Grant program and the Maryland Clean Energy Center's (MCEC's) Maryland Energy Innovation Accelerator (MEIA) program 28 new energy innovation companies have been formed in Maryland to date. From a survey of these Maryland innovation companies, they created 134 full time jobs, filed 124 patents, obtained a total of $142M in funding ($70M in private investment and $76M in federal/grant funding), and produced $4.5M in revenue over the past 6 years.

This is in addition to the growing university R&D base that feeds this energy innovation ecosystem. For example, the University of Maryland, College Park (UMD), continues its dominance in the U.S. Department of Energy (DOE), Advanced Project Agency-Energy (ARPA-E) awards receiving 41 awards for a total of $117M in total research funding since ARPA-E's inception in 2009. UMD's federal energy research awards **alone** since the 2017 inception of MEI^2 are $123M which constitutes a **30X return** on investment based on its share of the Strategic Energy Investment Fund (SEIF) that supports the MEI^2 programs. Adding the private investments acquired by the Energy Seed Grant Awardees, funding totals are $193M, a **45X return** on investment.

Maryland has 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. To date, UMD has participated in 41 U.S. Department of Energy (DOE) Advanced Research Projects Agency – Energy (ARPA-E) for over $117M, and an additional $7.5M from DOE's Industrial Efficiency and Decarbonization Office. MEI^2 is also leading the Center for Research in Extreme Batteries (CREB) in partnership with the Army Research Lab in Adelphi, MD. Since its establishment in 2017, MEI^2 has helped obtain over $123M in federal funding, with a significant fraction of that for the State of Maryland economy. Thus, based on the share of the Strategic Energy Investment Fund (SEIF) that supports its activities (~$4.2M over the past 6 years), MEI^2 has demonstrated a **30X return to the State 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, an $18M 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.

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 and 2023, and provided students with recruitment opportunities from government and private industry.

Moreover, since 2017 MEI^2 has used its share of the Strategic Energy Investment Fund (SEIF) to award $2.6M in Energy Seed Grants to academic institutions and their associated energy spin-off companies throughout the State. As a result of this MEI^2 Seed Grant Program, in partnership with the Maryland Clean Energy Center's (MCEC's) Maryland Energy Innovation Accelerator (MEIA) program, 28 new energy innovation companies have been formed in Maryland creating over 134 full-time jobs, 124 patents have been filed, over $70M in private investment and $76M in grant funding awarded, and $4.5M in revenue has been earned.

One seed grant recipient and Maryland start-up company, Ion Storage Systems, to date has received over $40M in private investment; $31M in follow on funding; created 70 jobs in Maryland; and has doubled their manufacturing space (all in Maryland) in the past year. This one $100K MEI^2 Energy Seed Grant award from 2019 has assisted in providing an **850X return to the State in private and federal funding**.

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, the majority 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.

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 FY2023 LEGISLATION

The clean energy industry generates hundreds of billions of dollars in economic activity and offers the U.S. 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 efficiency, and the electrification of transportation as demonstrated by several legislative actions that took place in FY2023.

Offshore wind is a renewable resource capable of providing U.S. coastal states with abundant amounts of energy. The National Renewable Energy Laboratory estimates U.S. offshore wind can provide more than 4,200 gigawatts of capacity. For comparison, the largest power plant in Maryland, the Calvert Cliffs Nuclear Plant in Maryland produces up to 1.79 gigawatts (1,790 megawatts). In March, Maryland Governor Wes Moore set an aggressive target of 8.5 GW of offshore wind (quadrupling current production numbers) for Maryland by 2035, which will require an array of social, economic, and technical aspects to be achieved. Not only will manufacturing and supply chain capabilities need to increase, but better technology needs to be developed and tested ahead of deployment. Researchers at the Universities of Maryland in Baltimore County (UMBC), College Park (UMD), and Eastern Shore (UMES); as well as Morgan State University (MSU), Johns Hopkins University (JHU), and others are developing various wind and wave harnessing energy technologies. MEI^2 is working to bring these researchers and institutions together to enable faster progress in technology development and testing while establishing new research collaborations and directions. In addition, the work on technology development needs to be integrated with the work in other academic disciplines and institutions focused on economic and social development and justice issues – a perfect opportunity for further engagement with MCEC.

For the next three years, MCEC will manage the Climate Catalytic Capital Fund to promote geographical impact remedies and to leverage increased private capital investment in technology development and deployment, including project planning, to:

- target the implementation of energy and weatherization measures for low- to moderate-income households;
- optimize the economic, health, social, and environmental value of community-scale infrastructure for resilience and energy equity;
- and allow for the deployment of advanced clean energy technology.

At least 40% of the funds are intended to focus on investments in projects to address underserved communities and facilitate environmental justice. As such it should be noted from the underlined section above that "*the purpose of the fund is to leverage increased private capital investment in technology development*" which is directly in line with the purpose and focus of the MEI^2.

Another key area of further collaboration and development is net-zero fuels and bioenergy which is vital to the agricultural industry in Maryland. Biomass is an important natural source used for conversion into renewable energy products in the form of biochar, fuel pellets, bioethanol, and hydrogen fuel, all which help the sustainable development of energy. In 2020, biomass generated one-tenth of Maryland's renewable energy. Biomass is organic matter, such as wood, crop and food waste, and sewage and manure, that is used as fuel. Maryland forests are a natural, renewable resource with untapped energy potential in the form of woody biomass, which could transform our local economy and create innumerable benefits to the health of our woodlands.

Agricultural and biological researchers at UMD and MSU, and UMES are working on microbial fuel cells, anaerobic digestion and biochemical methane production, sustainable products like biofuels and bioplastics from food waste, and genetic engineering of a model cyanobacterium to enhance value-added traits for sustainable energy applications. Meanwhile, atmospheric scientists at UMD are engaged in a Wood harvesting and Storage (WHS) project to manage intervention by tree harvesting or waste wood collection, followed by secure storage in engineered structures to prevent decomposition. Specific applications can have synergy with waste management, fire risk reduction, mine remediation, as well as extending the benefit of reforestation.

In addition, at the federal level the U.S. 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 FY23 Federal budget targeted strengthening domestic manufacturing, creating more resilient global supply chains, and supporting the deployment of clean energy infrastructure. The budget invested over $15 billion in discretionary funding for American clean energy innovation and infrastructure—$12 billion for clean energy innovation and $3 billion for deployment—and invested in quickly scaling-up domestic manufacturing of key climate and clean energy technologies; accelerating the deployment of carbon-free electricity, zero emission vehicles, and low-carbon industrial solutions; and creating good-paying American jobs. Investments included:

- $1 billion for a new mandatory Clean Energy Manufacturing program at DOE to build resilient supply chains for climate and clean energy equipment through engagement with allies, enabling an effective global response to the climate crisis while creating economic opportunities for U.S. businesses to increase their share of the global clean technology market.
- $200 million for a new Solar Manufacturing Accelerator at DOE that will help create a robust domestic manufacturing sector capable of meeting the Administration’s solar deployment goals without relying on imported components that were manufactured using unacceptable labor and environmental practices. It is imperative that the United States partners with our allies to create resilient clean energy supply chains.
- $150 million in new funding for DOE’s Office of Clean Energy Demonstrations to scale renewable and distributed energy resource technologies. This funding will augment the $21 billion in BIL funding for hydrogen hubs, energy storage, advanced nuclear reactors, carbon capture and storage, grid infrastructure, and other clean energy infrastructure projects.

  The Budget also advances the deployment of electric vehicle and its charging infrastructure through:

- $745 million for zero emission fleet vehicles and support for charging or fueling infrastructure in the individual budgets of 19 Federal agencies to provide an immediate, clear, and stable source of demand to help accelerate American industrial capacity to produce clean vehicles and components.

- $1 billion in formula grants and $400 million in competitive grants to build out a network of EV charging stations across key Alternative Fuel Corridors, particularly the Interstate Highway System, along with community chargers located in rural and underserved communities. These resources will be deployed in partnership with the newly formed Joint Office of Energy and Transportation, a collaborative effort of the Departments of Energy and Transportation.

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 is currently seeking a replacement for Dr. Theresa Christian, former Director of Technology and Innovation at Exelon, who recently left Exelon for the DOE Office of Clean Energy Demonstrations.

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 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.

FY2023 Advisory Board

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Director, Maryland Energy Administration

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

FY2022 Investment Committee

Ellen Williams, Chair *University of Maryland Distinguished University, Former Director, ARPA-E (DOE)*
Robert Briber
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
Arti Santhanam
Executive Director, Maryland Innovation Initiative, Maryland Technology Development Corporation (TEDCO)

necessary to obtain investor interest. An MEI² 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 MEI² 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.

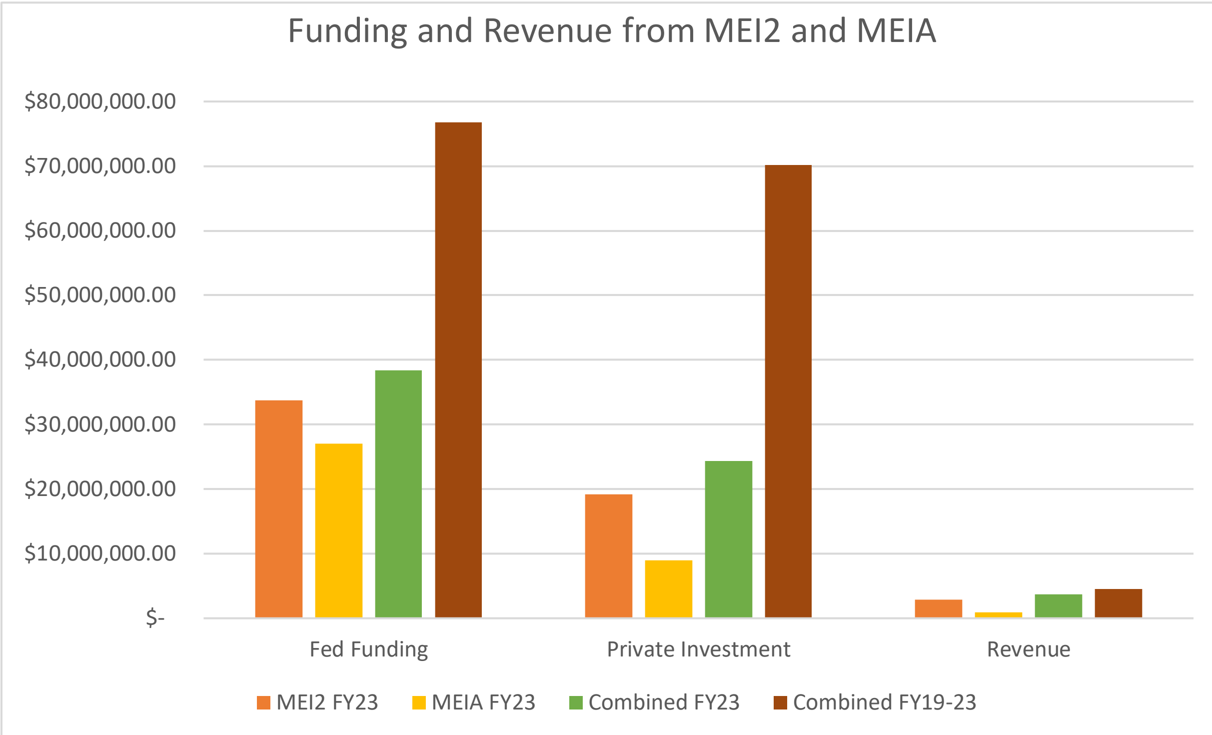
Since its 2017 inception, 22 companies and/or university researchers have received a total of $2.6M in funding from the MEI² Seed Grant program including the UMBC, UMD, UMES, MSU, and JHU. Twenty-seven total grants (22 Phase I and 5 Phase II) have been awarded. Additional funding beginning in FY2023, allowed MEI² to expand the Energy Seed Grant funding from $400K to $650K annually.

Maryland Energy Innovation Accelerator

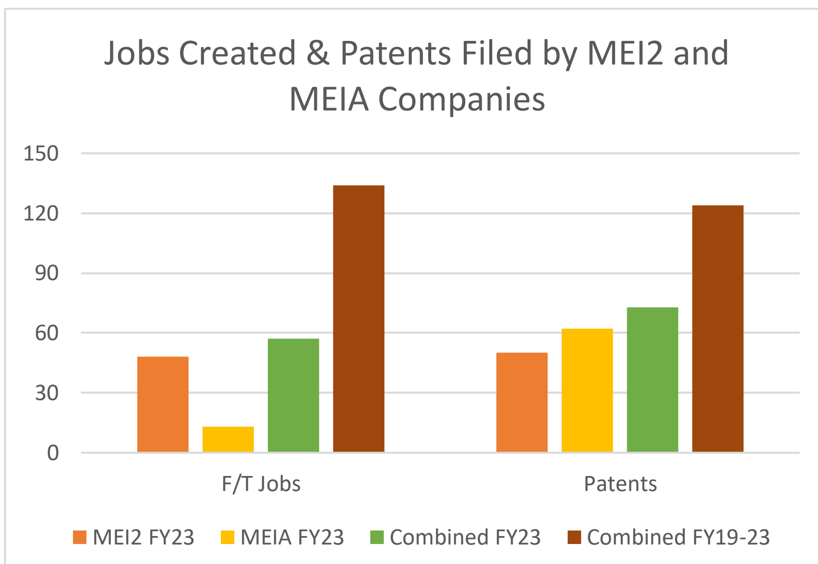
The Maryland Energy Innovation Accelerator (MEIA), launched in 2019 within the MCEC portion of MEI², takes a whole ecosystem-based approach to supporting future companies through a venture development program that complements the MEI² Seed Grant Program. MEI² inventors and scientists are matched with the business executives (Energy Executives in Residence) to support and mentor those teams in the accelerator while matching them with support from professional services sponsors, such as lawyers, accounts and marketing and branding firms. As such the MEI²/MEIA collaboration provides traditional academic research a pathway into commercialization through a more comprehensive energy innovation ecosystem. To date, 28 Maryland based companies have been formed and received support from MEI², MEIA or in some cases both organizations.

MEIA and MEI² conducted an economic development survey of their accelerator and seed grant programs. Results from the MEI² economic survey are shown for the energy seed grants that have concluded and are discussed in detail below. Six new grants were awarded in March 2023 and are just starting thus their results are not included.

It should be pointed out that numbers shown in the following tables are from the respective MEI² and MEIA surveys and reflected metrics for companies having received benefits from each of these individual programs. Whereas, "Combined" numbers are the sum of metrics for both programs but removing any double counting that would occur for companies that benefitted from



both MEI² seed grant and MEIA support (e.g., Alchemity, InventWood, WH Power). In FY23 alone, $38M in federal/grant funding was received; $24.5M in private investment funding; and $3.7M in generated revenue. Likewise, in FY23, from the Energy Seed Grant program, 57 jobs were created and 73 patents filed. Again, "combined" numbers account for companies benefitting from both programs.



To date, MEI² and MEIA programs have combined to create 134 jobs, bring in $76M in follow on funding; receive $70M in private investments; and generate $4.5M in revenue. This economic development survey has solidified the importance in continuing support for MEI².

MEIA Look Book

The Maryland Climate Tech Look Book is produced by MEIA as an MCEC program. The Look Book is focused on early-stage technology commercialization in partnership with Maryland-based Universities and labs to support the state's clean energy and climate goals. MEIA supports ventures in solar, wind, battery, energy efficiency, grid modernization, and carbon capture utilization and storage (CCUS) fields.

The Look Book presents an overview of diverse ventures building novel technologies that have the potential to help mitigate the effects of climate change. Maryland companies are finding ways to remove carbon from industries such as chemicals, natural gas, building materials, and concrete. They are developing imaginative ways to use new chemistry to build better batteries and other materials with cheaper and more abundant resources. Several Maryland companies are leveraging artificial intelligence, machine learning, and cloud-based technologies to prepare for severe weather or help lower energy usage in buildings. Many of these ventures have started in Maryland's universities, research labs, and entrepreneurs' garages. In addition, the Look Book highlights the growing ecosystem of organizations and programs supporting such ventures.

As this sector and the network of companies and organizations are constantly changing, this resource will be continually updated, with the latest version available online at www.mdeia.org.

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

ION Storage Systems (ION), founded in 2015 as a UMD spin-off company by MEI^2 Director Wachsman, has developed a groundbreaking 3D ceramic electrolyte architecture that addresses the key issues hindering the commercialization of solid-state batteries. ION's nonflammable technology offers safe operation, greater abuse tolerance, and both volume and weight reduction.

Left to Right: Ryan Naehr (ION Technology and IP Manager), Dr. Evelyn Wang (ARPA-E Director) and Dr. Greg Hitz (ION CTO) at the Energy Innovation Showcase

In the past year, they have received over \$3M in federal/grant funding (ARPA-E and SBIR awards) as well as an additional ~\$14M in venture/private funding (series A-2) bringing the total to over \$40M. Furthermore, they added 29 jobs bringing total to over 60 and expanded into a larger 33,000 ft^2 manufacturing facility in Beltsville, MD to scale-up production.

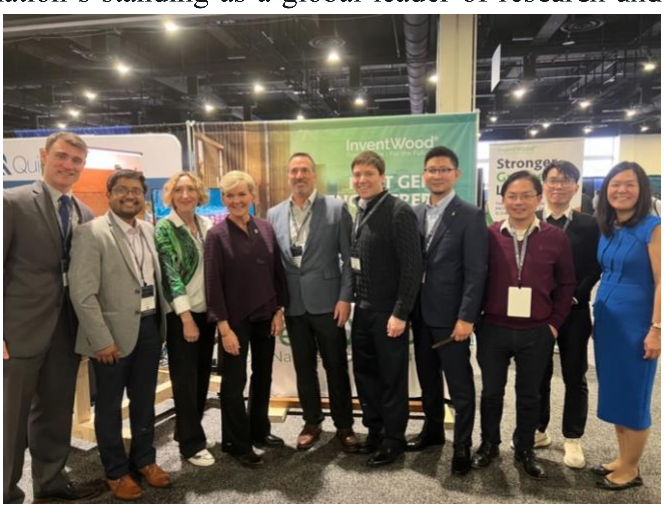
In July 2023, the U.S. House of Representative's Science, Space and Technology Committee's Subcommittee on Energy, Bipartisan Policy Center, and ClearPath hosted the ARPA-E Energy Innovation Showcase on Capitol

Hill in the Rayburn House Office Building. Six ARPA-E project teams including ION were selected to display their technology for Members of Congress, House and Senate staff, energy innovation leaders, members of the business community, and more. ARPA-E Director Evelyn Wang and Members of Congress addressed the audience and highlighted the importance of energy R&D (See photo on page 1) ION showcased their fast-charge, high-energy-density, solid-state battery being developed for a wide range of applications, including electric vehicles. Their technology meets the DOE's fast charge goals and has a lithium-metal anode formed on first charge, providing increased energy density for extended driving range in a cell format manufacturable at GWh scales. The team showcased calculators that are fully powered by this solid-state battery without heating or applied pressure necessary for operation. An ARPA-E video link from the event can be found here: https://www.youtube.com/watch?v=MSYxVSS_xrQ

By focusing on the design of the anode/electrolyte structure, ION has been able to meet next-generation performance metrics, including high-energy density, stable cycling performance, wide temperature range, and fast charging. The manufacturability of ION's technology also sets the company apart as it largely borrows from existing scaled ceramic processing. ION's first commercial application is soldier batteries, then rapidly expanding to EV and consumer electronic markets.

InventWood

InventWood is committed to transforming the world by developing cellulose-based materials that are high-quality, cost-effective, and environmentally sustainable. On November 22, 2022, the Secretary of Energy Jennifer Granholm announced the SCALEUP program of $100M to fund eight clean energy technology projects that support President Biden's goals to lower emissions through clean energy deployment, reduce dependence on imports of critical minerals, and secure the nation's standing as a global leader of research and innovation. Among the selected companies InventWood® will develop novel technologies that enhance existing clean energy infrastructure, such as aircraft electrification, rapid electric vehicle charging, and advanced floating offshore wind turbine technologies. InventWood® is founded by UMD Distinguished University Professor, Dr. Liangbing Hu.



Pictured: U.S. Department of Energy Secretary Jennifer Granholm (4th from left); InventWood CEO Josh Cable (6th from left); Founder Dr. Liangbing Hu (8th from left); ARPA-E Director Dr. Evelyn Wang (far right)

InventWood's $20M SCALEUP project will contribute to the decarbonization of buildings and enable them to store significantly greater amounts of carbon by scaling up a game-changing wood material, MettleWood®, that is 60% stronger than construction grade steel but 80% lighter, much less expensive, and far more sustainable. UMD professors Dr. Liangbing Hu and Dr. Ming Hu are co-PIs of this project.

MettleWood® is a high-value structural material invented by Dr. Liangbing Hu and his team at UMD. It is a highly suitable material for a range of purposes - from automotive to building construction to premium furniture. Specifically, MettleWood® offers numerous possibilities for deployment in the built environment including as a replacement for structural beams, columns, and connections that could ultimately result in reductions of 37.2 gigatons of greenhouse gas emissions over 30 years. It represents one of the few technologies with the potential to reduce steel and cement consumption and their associated carbon footprints.

Liatris, Inc.

Liatris, Inc. is delivering the cleanest and fastest energy savings for businesses and consumers by mass-producing high performance insulation that is easy-to-install, environmentally friendly, non-flammable, and non-toxic. Liatris insulation helps scale up advanced building construction to be easier and faster to produce as well as more affordable for owners. At the same time, this next generation insulation offers higher levels of comfort, quality and safety occupants. They are developing a proprietary nanocomposite using readily available inorganic materials (eliminating highly flammable organic plastics), as well as controlling the properties of our materials at a much smaller scale – micro and nano. The result: insulation that has higher performance, is non-flammable and better for the environment.

> "The MEI² Energy Seed Grant has notably strengthened the collaboration between my lab and Liatris. With the resources and financial support provided by the grant, our joint endeavors in research and development have positioned us for greater advancements in the thermal insulation domain."
> – Dr. Po-Yen Chen

Producing polymers and other composites with the desired mechanical and thermal properties is labor-intensive and iterative optimization experiments are often necessary to identify the optimal set of fabrication parameters. Working with Dr. Po-Yen Chen at the UMD, Liatris is creating a predictive model that can automatically recommend the ideal parameter set for a clay–cellulose–polymer aerogel with programmable properties would greatly expedite the development process. The collaborative endeavors have secured follow on funding from DOE and in Small Business Innovative Research (SBIR) awards for a total of $4.5M.

FY2022 Energy Innovation Seed Grant Awards

After one year, MEI² 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 2022, four seed grant projects were awarded for a total of $400K. Follow on efforts and successes from the 2022 seed grants are discussed below.

***Machine Learning-Accelerated Development of Non-Flammable Silica Aerogels for Building Thermal Insulation*;** Lead PI: Po-Yen Chen, UMD; Partnering Company: Liatris Inc

Traditional methods for the fabrication of clay–cellulose–polymer aerogels involve the preparation of aqueous mixtures of various building blocks, followed by a freeze-drying process. By adjusting the proportions of these building blocks, one can fine-tune the end properties of the clay–cellulose–polymer aerogels, such as thermal conductivities and compression resilience. However, the correlations between compositions, structures, and properties within clay–cellulose–polymer aerogels are complex and remain largely unexplored. Therefore, to produce a clay–cellulose–polymer aerogel with the desired mechanical and thermal properties, labor-intensive and iterative optimization experiments are often necessary to identify the optimal set of fabrication parameters. Therefore, this project created a predictive model that can automatically recommend the ideal parameter set for a clay–cellulose–polymer aerogel with programmable properties would greatly expedite the development process.

With regards to advancing scalable production methods for clay–cellulose–polymer aerogels, the lab has made significant headway in collaboration with Liatris. Working with Liatris, the group has successfully embarked on the design and fabrication of a cast-in-place molding prototype. This endeavor was informed by the data and insights from a machine learning model that was instrumental in determining the most suitable recipe and post-treatment conditions. Currently, this prototype is fully operational within Liatris's testing laboratory. Preliminary evaluations show promising results. The large-volume clay–cellulose–polymer aerogel samples, which are the direct output of the cast-in-place molding equipment, are currently undergoing rigorous testing. The group is actively assessing their structural, thermal, mechanical, and non-flammable properties.

Multiple follow on awards were received as a result of this project including a $1 million Phase II SBIR award and $1.2M award for the R-5+ Retrofit Cladding System featuring low-cost clay cellulose insulation, both from DOE. Three additional proposals have been submitted, two to the NSF and one to the NBMC R&D Funding Program.

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

The project focused on scaling up the design and cultivation of cyanobacteria in scaled up and pilot scale bioreactors using naturally available brackish water. During the scale up process, they

Carboy cultivation of *F. diplosiphon cultivation* in the greenhouse. (A) 5-liter carboy culture, (B) 10-liter carboy cultures.

successfully identified and addressed multiple challenges related to biomass cultivation and harvesting, as well as lipid and pigment extraction. Outcomes of this study have paved the way for production-level scale up and processing of Fremyella diplosiphon-derived biofuels and marketable bioproducts. Fuel produced using this technology will be eco-friendly and cost-effective and will make full use of the geographical location of regions with access to brackish waters.

Milestone 1: Optimization of cultivation reactor systems - The results of the project's cultivation studies provided critical insight in identifying that this cyanobacterial strain has the ability to be readily cultivated outdoors in closed systems, greatly increasing the potential cultivation capacity.

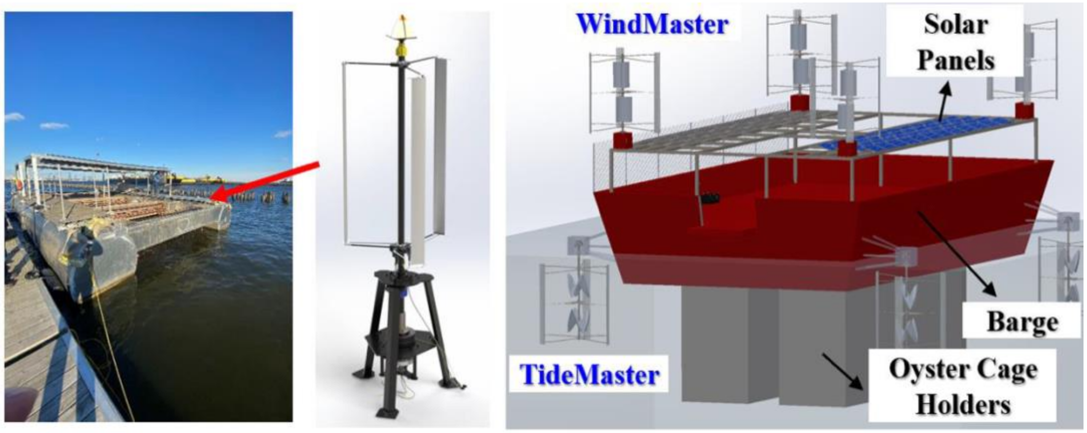
Milestone 2: Biomass harvesting and high-yield lipid extraction-conversion and transesterification - In addition to biocrude and biochar, other high value co-products were identified in the scale-up process, thus further increasing potential commercial opportunities that could provide revenue for future expansion of bioenergy operations. In particular, a significant increase in phycocyanin and chlorophyll a abundance over a 15-day period indicated that scaling up cultivation did not have a detrimental effect on photosynthetic pigment accumulation.

Milestone 3: *American Society for Testing and Materials (ASTM) testing of biomass* - The results obtained from the resultant biodiesel following transesterification of F. diplosiphon and compared to industry standards indicated that the prototype is already within acceptable industry standards for a number of parameters: lubricity and copper strip corrosion, as well as for phosphorus, sulfur, and metal content.

A manuscript on the scale-up studies (Milestone 1) and hydrothermal liquefaction (Milestone 2) performed has been written and published in the peer-reviewed journal Sustainability (https://www.mdpi.com/2071-1050/15/6/4878), which has an impact factor of ~4. In addition, a second manuscript on biofuel properties and ASTM testing is under preparation and will constitute a second publication from the MEI^2 Phase I energy seed grant. It will be submitted to a journal by November 2023.

Portable Hybrid Vertical-axis Turbine Technology for Efficient Aero-hydro Energy Harvesting**;** Lead PI: Meilin Yu, UMBC, Partnering Company: InoSonic LLC and Solar Oysters LLC

UMBC has been teaming up with Maryland's local companies to translate innovative renewable energy harvesting research into the "EnergyMaster" technology, including the "WindMaster" technology for distributed offshore wind energy harvesting and the "TideMaster" technology for low-speed tidal/wave energy harvesting. In this project, the "EnergyMaster" has been integrated into a solar-powered oyster farming barge developed by Solar Oysters LLC to improve the barge's energy production capability and resiliency. Note that the "EnergyMaster" can be integrated into any existing deep-sea floating platform to provide portable, efficient, and sustainable aero-hydro energy harvesting strategies for various applications, such as aquaculture and ocean clean-up. The team has optimized the "EnergyMaster" technology to ensure that the energy harvesting efficiency of the "EnergyMaster" can be reliably maintained about 80% of the Betz limit, the maximum efficiency that can be achieved by any turbine in an open fluid flow, at realistic wind speeds, such as 5~25 m/s, and at realistic tidal current speeds, such as 1~3 m/s. Lab tests of the "TideMaster" have been conducted in the water tunnel at the University of Iowa. To attract private investment, field tests of the “WindMaster” are currently being carried out on a pier at Baltimore owned by MAPC.



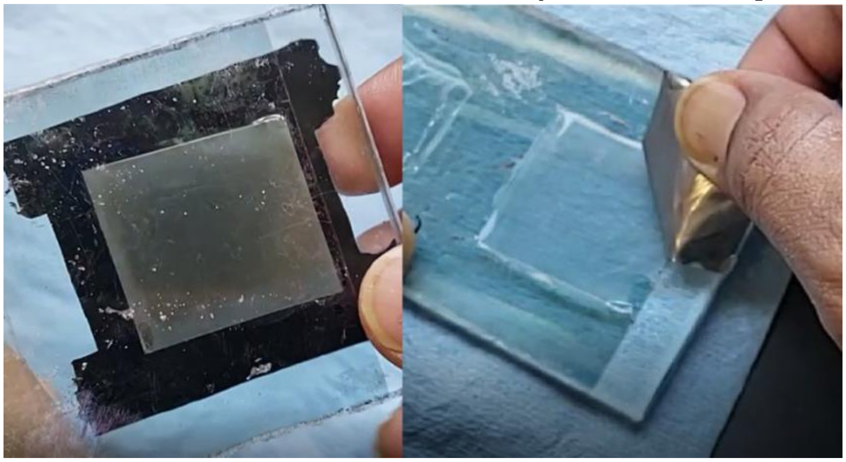
The 300 W “WindMaster” prototype that is currently being integrated into a barge at Baltimore.

The research team has been actively reaching out to potential customers, partners, and investors towards the commercialization of “EnergyMaster”, and exploring domestic and international markets. These include several domestic and multinational companies, such as Beach Wind Energy Group, Associated Energy Developers LLC, Aeronautica Windpower LLC, Ceres Pharms LLC, ModulMation LLC, Compassionate Care Company, Amelios Gmbh, and Frigitek Industrial Parks. A commercialization plan for the “EnergyMaster” technology in the distributed wind market has been developed for Blue and Green Energy Solutions LLC (BGE Solutions), a new university startup that will commercialize the “EnergyMaster” technology.

Low-cost Vacuum Insulated Glass (VIG); Lead PI: Junho Kim, UMD

The purpose of this 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.

Milestone 1: Develop a Secondary Seal - The current prototype is sealed with a low-temperature sealant with a strong bond. However, weather conditions such as humidity can have an impact on the long-term reliability of the seal. To improve window durability, traditional IGUs employ a secondary sealant such as PIB material. A suitable secondary sealant was investigated for the VIGs after discussions with the Department of Energy's Building Technology Office, window experts, and manufacturers such as Cardinal Glass. The chosen



moisture barrier method, h-dry, which has similar properties to a PIB sealant lasted for a longer test of over four months, showing no permeation of moisture or delamination leading to an increase in performance.

Milestone 2: Reducing vacuum pulling and bake-out time - Ca, Mg, and Ba based getters were tested for their gettering performance. A standalone vacuum chamber was created with known vacuum levels and activated the getters to test the vacuum pressure reduction capacity of the said getters.

Milestone 3: Thermal cyclic testing – Three fabricated 12” x 12” samples were created and sent to NREL for thermal cyclic and performance testing as per ASTM E2190. Two out of three units passed accelerated durability testing lasting full 66 days. The cause of the early failure in one unit was noted as being a manufacturing seal error near our pinch out port. The soldering seal was made too large causing the stainless steel to wrinkle on the surface and provide a pathway for air. This was facilitated by the handmade production and would not be an issue in machine manufacturing. Phase II seed grant funding will be proposed to continue testing and validation.

With the assistance of third-party VIG exerts, a thorough market research was conducted in addition to more than 50 interviews with freezer door users and manufacturers as a part of the TEDCO I-Corps program. According to the market research, the VIG market is expected to be around $25 billion per year (figure right), with an achievable market of around $4.6 billion per year. The commercial refrigeration door market is worth more than $500 million. Despite being a small portion of the overall VIG market, the refrigeration door market is large enough to pursue and is low-hanging fruit.

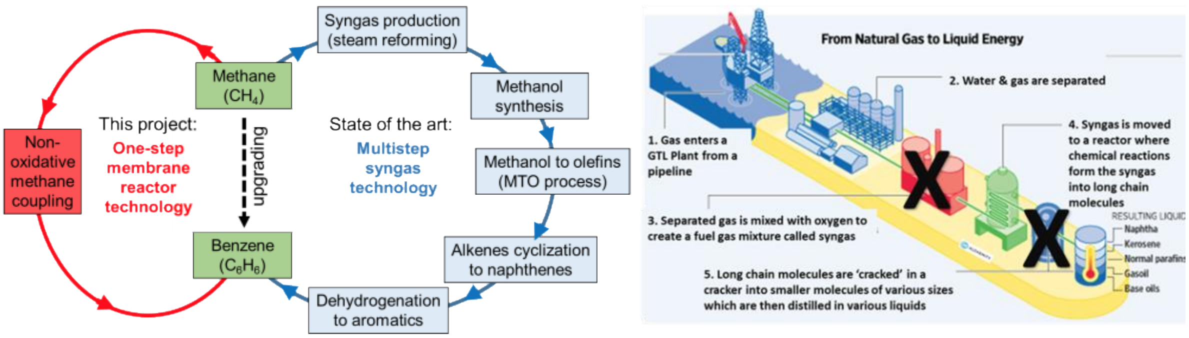
FY2023 Energy Innovation Seed Grant Awardees

In March 2023, six Energy Seed Grants were awarded to the following academic institutions/companies, three of which were follow on Phase II awards. Their six-month progress reports are forthcoming. A short synopsis of each is given below.

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

A single-step natural gas-to-chemicals (*GTChem*) membrane reactors was demonstrated under DOE and NSF sponsorship, augmented by an MEI^2 Phase 1 Seed Grant “*Prototype Study of One-Step Membrane Reactor for Stranded Natural Gas to Liquids*” in 2018, resulting in numerous publications and patents. This includes direct nonoxidative methane conversion in an autothermal hydrogen-permeable membrane reactor in which the ability to convert natural gas that would have otherwise been flared or vented (at 80X the GHG forcing factor of CO_2) into valuable chemicals such as ethylene and benzene was demonstrated. Moreover, this is the only *GTChem* technology ever demonstrated without greenhouse gas (GHG) emissions (the only byproduct is water).

Upon completion of a Phase 1 Energy Seed Grant, Dr. Wachsman entered the Maryland Energy Innovation Accelerator (MEIA) program, founded Alchemity LLC as a Maryland Company (https://alchemity.tech), recruited CEO Dr. Rodger McKain and CTO/CCO Dr. Emir Dogdibegovic and obtained exclusive licenses for the IP from UMD. During the MEI^2 Phase 1 Seed Grant, Shell was specifically identified as a potential partner/investor in this technology. Subsequently Alchemity was awarded an initial $260K Shell Game Changer award with a subcontract to UMD to demonstrate specific lab-scale technical milestones and potential for future funding and major (multi-$M) subsequent investment from Shell. Alchemity is also a recent recipient of a $300K Maryland Innovation Initiative (MII) grant from TEDCO to assist in transferring the technology from lab to market.

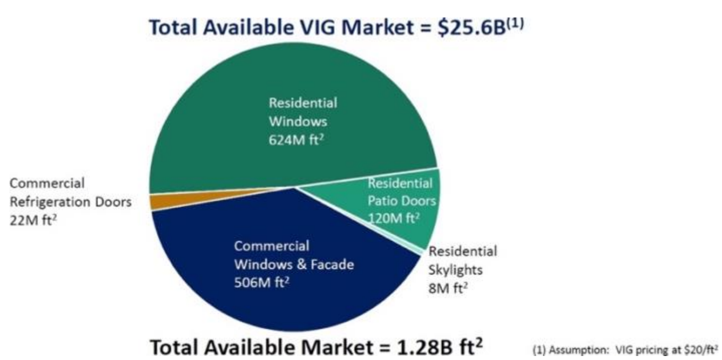


GTL processes for CH4 upgrading via our one-step DNMC membrane reactor vs. multistep syngas approach; left process flow and right example of capital equipment for conventional GTChem

For the Phase II award, the deliverable will be a bench-scale autothermal reactor unit. The project will first develop thermally stable ceramic-to-ceramic and ceramic-to-metal seals to enable prolonged reactor operation. The project will also design a prototype of a thermally integrated reactor. The preliminary model will incorporate developed brazing and reactor housing technologies, which will then be scaled with further investment. The preliminary design will be used to fabricate a bench-scale autothermal reactor for testing. The membrane tubes and catalyst will be fabricated at UMD under the existing Alchemity subcontract. The autothermal reactor will then be tested under various conditions to demonstrate a fully functioning prototype. The full-scale prototype reactor will be based on autothermal (H_2 permeate combustion) operation by using air sweep gas to avoid any additional heat input to drive CH_4 conversion process. The deliverable from this stage of the project will be a bench-scale process module unit. This proof-of-concept demonstration will attract additional industrial investment for scale-up to a pilot test and eventual commercialization.

Low-cost Vacuum Insulated Glass; Lead PI: Ratenesh Tiwari, UMD; Partnering Company: NextGlass, LLC (Phase II)

The project is conducting a technology validation for UMD's room temperature sealed vacuum insulated glass (VIG), which can be produced at a cost similar to insulated glass. Such VIG technology has the potential to disrupt the estimated $25 billion/year VIG market. As part of a DOE funded project, a unique metal sealing process that can be performed at room temperature without need of any heating has been developed. Currently, the glasses are sealed

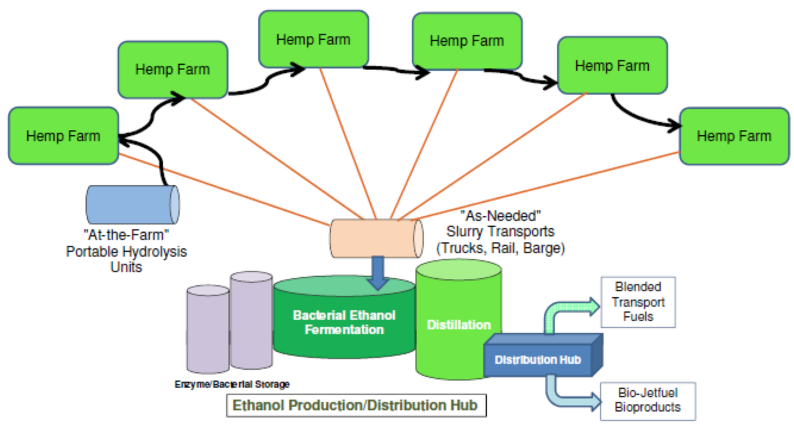


manually, however, the process is not always consistent. This project will develop and validate an automated sealing process that is repeatable and will thus increase investment confidence.

Proof on concept prototypes that achieved high thermal performance in the lab have been validated by thermal cycling testing standards. The goal of this phase II project is to de-risk the metal sealing technology. An automated glass sealing machine will be fabricated based on Phase I results. Extensive testing of the machine prototype will be performed to test the bond sealing. This follow on funding helps bridge the gap between lab technology and a commercially viable product. An extensive market assessment has shown that there are 3 major markets for VIGs: residential homes, commercial buildings, and freezer doors. For this project, the freezer door market is extremely attractive due to 1) small variation in size; 2) a constant 45ºC temperature difference resulting in relatively short payback times; 3) higher cost of freezer doors; 4) increasingly strict DOE energy codes for freezer doors; and 5) market is still very large (~$500M/year).

Advancing Technology for Commercialization of Sustainable Aviation Fuel (SAF) Production from Industrial Hemp Biomass; Lead PI: Sadanand Dhekney, UMES; Partnering Company: Atlantic Biomass (Phase II)

This Phase II energy seed grant project will build on Phase 1 results to develop a commercial system to produce Sustainable Aviation Fuels (SAF) for the market being created by provisions of the Inflation Reduction Act (H.R. 5376) as well as other international SAF programs such as the EU Emission Trading Scheme (ETS). Phase II is focused on translating Maryland developed enzyme optimization research into a suite of hydrolysis biofuel enzymes and process improvements that will greatly reduce the cost of converting residual hemp biomass into high-value Sustainable Aviation Fuels (SAF) required for international Green House Gas reductions. The first application of this resulting technology will be in the commercial joint venture between Atlantic Biomass, LLC and Bionoid, Inc for the production of SAF from industrial hemp.



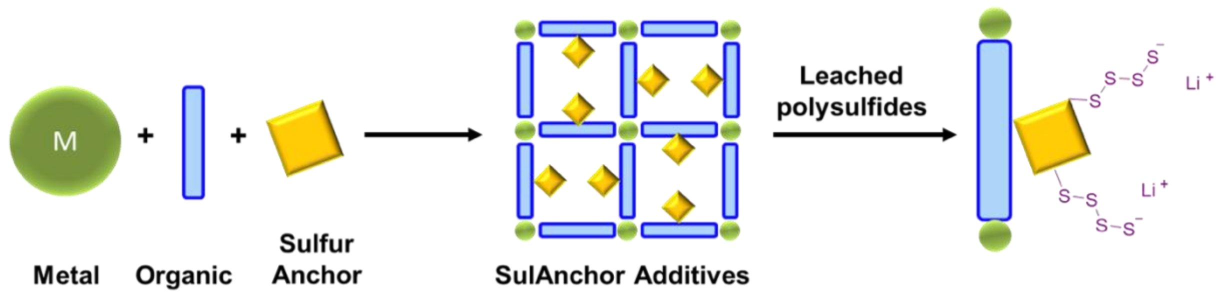
There are four specific objectives for this project:

1. Use Maryland-developed science to take the Atlantic Biomass residual hemp biomass to Sustainable Aviation Fuel (SAF) system to the commercial prototype stage.
2. Reduce enzyme costs, a key production challenge, by developing and owning optimized enzymes targeted for hemp biomass.
3. Build biomass-to-biofuel conversion science education and student employment opportunities at University of Maryland Eastern Shore (UMES).
4. Expand Maryland protein/enzyme development businesses into the emerging SAF enzyme hydrolysis and fermentation sectors.

Two key technical components, hydrolysis and fermentation, will be optimized and "ruggedized" for commercial application. This will be done by enhancing Phase 1 results and testing them under rigorous conditions so that the resulting Block 1 Commercial Unit (funded by later stage private investments) can be tested for end-to-end for overall cost and operational efficiencies after hydrolysis and fermentation processes have been worked out. This non-concurrent approach is being used to reduce overall development costs. Specifically, it recognizes the fact that the proposed new, unique features need to be worked out at a lower scale and cost before investments are made at the commercial scale.

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

This application describes a key enabling technology for solid-state lithium sulfur (Li-S) batteries to be competitive energy storage devices. SulAnchor technology targets the "polysulfide shuttle", that results in poor cycle life of the sulfur cathode. It has been demonstrated to be compatible within a solid-state device. Solving these key challenges dramatically improves the safety and commercial viability of LI-S batteries. Owing to the high specific capacity and low weight of sulfur, Li-S batteries can have as much as 2x the energy storage density as lithium-ion batteries (LIB). Sulfur also costs an order of magnitude less than typical lithium metal oxide used in LIB. While Li-S battery development has largely focused on liquid cells, solid-state Li-S batteries is extremely attractive due to their improved safety and higher energy densities. However, two critical challenges to solid-state Li-S battery adoption are short device lifetime and poor compatibility with a solid-state electrolyte.



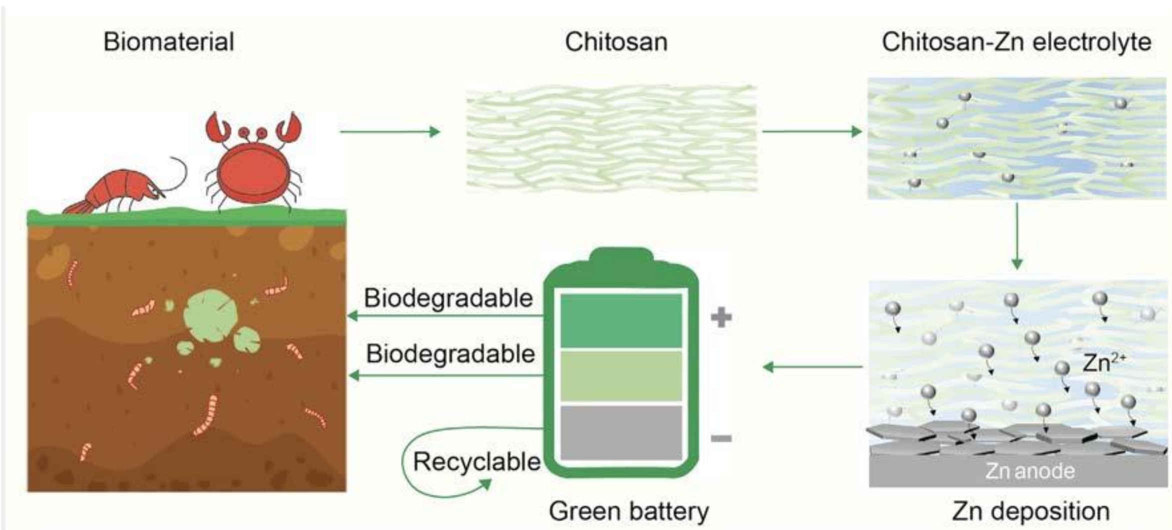
Schematic of SulAnchor Additives for polysulfide adsorption.

In addition to targeting the electrochemical process that results in poor cycle life of the sulfur cathode, SulAnchor has demonstrated that their cathodes are compatible with a solid-state electrolyte and enhance both the charge storage capacity and capacity retention. Improvements to the cyclability and safety of Li-S batteries drastically enhance their commercial relevance for applications in consumer electronics, aerospace and defense, transportation, and large-scale stationary energy storage. The enhanced safety of solid-state Li-S batteries also enables potential applications in wearable and implantable devices. The expected end products are optimized SulAnchor materials and cathodes that can be sold to solid-state battery manufacturers and technology licensing products (e.g., cell prototypes, synthetic and fabrication strategies, scaled processes).

The proposed work is focused on 1) materials optimization by incorporating high lithium and SulAnchor content for ion mobility and sulfur binding, 2) coin cell prototyping (e.g., solid electrolyte, cathode/anode composition) and testing, 3) development of a materials manufacturing and scale-up plan (with Lithinity), 4) optimization of solid electrolyte by varying polymeric and inorganic components, and 5) prototyping single-stack pouch cells. The last two tasks will be conducted in collaboration with subcontractor CIC energiGUNE.

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

A new type of rechargeable battery made from crab shell derived material (chitosan) and zinc metal has been reported and recently patented by the research groups of Professor Liangbing Hu and Professor Robert M. Briber at the University of Maryland. 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. WH-Power is negotiating an IP agreement with UM Ventures (the technology commercialization office for the University System of Maryland) to further develop and produce the battery.



This project will develop a low-cost rechargeable battery for grid and residential energy storage based on (1) electrolyte derived from crab shell containing chitosan and Zn (Chitosan-Zn), (2) low cost zinc metal anode, and (3) low cost manganese dioxide (MnO2) cathode. The proposed cathode is different from the previously published data of Crab Battery. In the publication, poly(benzoquinolyl sulfide) (PBQS), was selected for its biodegradability. In this proposal, MnO_2 is selected as the cathode material for commercialization due to its low cost and high scalability.

Specific milestones/deliverables include:

1. Develop MnO_2 cathode material.
2. Fine tune Chitosan-Zn electrolyte for MnO_2 cathode.
3. Assemble pouch cells with initial full cell specific energy of 40 Wh/kg, 70% capacity retention after 400 cycles with a working temperature range of -30 ℃ to 80℃ in phase I, and 50 Wh/kg, 90% capacity retention after 1000 cycles in phase II, same temperature range. The eventual

commercialization target is 60 Wh/kg, 90% capacity retention after 10000 cycles, over the same temperature range.

4. Perform customer studies, market assessments and revenue/cost modeling of Crab Battery for grid and residential markets.

Large-Scale Biofuel Production Using a Novel Cyanobaterium; Lead PI: Viji Sitther, MSU; Partnering Company: HaloCyTech LLC (Phase II)

In the Phase I seed energy grant described above, scalability studies and hydrothermal liquefaction were conducted at Morgan State University's Patuxent Environmental & Aquatic Research Laboratory (PEARL) which was successful. The second phase will position the project to fully transition to commercialization by 1) further scaling up and optimization of cultivation, harvesting, and lipid extraction; 2) developing product lines across various industries to increase potential revenue channels; and 3) business development, marketing, sales, and fundraising.

The proposed technology aims to develop a commercial scale production process for green products from the cyanobacterial strain HaloFd™. This technology will allow efficient biofuel production by utilizing brackish water, which is a rich source of different elements, and solar energy. In addition to reducing the cost of fuel generated by our technology, the project will take full advantage of Maryland's geography, which is located near the Chesapeake Bay and Eastern Seaboard. Full use of brackish waters to transform the energy industry will be employed. The biofuel produced by the endeavor will provide Marylanders and the nation with a clean, green source of energy, as well as create jobs and boost the economy.

Specific milestones include:

1. Increase biomass cultivation to the final pre-commercial pilot scale and optimize efficient lipid extraction
2. Maximize revenue generation by introducing reactor enhancements to further increase biomass yield, test cost-effective nutrient sources for growth and isolate co-products for additional revenue channels.
3. Develop the business through sales, investment, marketing, and networking. Increase sales across all applications to 1 kg biomass per month.

RESEARCH HIGHLIGHTS

Significant financial support of research into new energy technologies was obtained in FY23. Examples of these are five DOE ARPA-E awards including one $20M SCALEUP award; three from the Industrial Efficiency and Decarbonization Office (IDEO) totaling ~$7.6M; and one from the Designing Materials to Revolutionize and Engineer our Future (DMREF) which is part of NSF's Materials Genome Initiative.

ARPA-E Summit

The annual ARPA-E Summit was held March 22-24, 2023, at National Harbor in Maryland. 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.

Maryland Governor Wes Moore was one of the keynote speakers at the ARPA-E Summit and confirmed his commitment to energy innovation. While there he toured the technology showcase and met with MEI^2 and MEIA companies to discuss energy innovation as an economic driver in the State of Maryland as well as a way to address the global issue of climate change. UMD hosted **eleven** ARPA-E technology booths during the 2023 showcase.

MEI^2 startup InventWood participated in the SCALEUP Panel where it's Chief Manufacturing Officer Allan Bradshaw shared perspectives on the SCALEUP program (described previously) as well as the challenges and approaches of scaling up a cleantech hardware technology. Scaling up a start-up or small business presents multiple challenges. This is particularly true when commercializing hard engineering technologies due to the investment required to demonstrate cost and performance at commercial scale sufficient to address market adoptions risks. Through the SCALEUP program, first launched in 2019, ARPA-E has endeavored to help address these challenges and accelerate deployment of promising technologies previously funded by ARPA-E.

Dr. Eric Wachsman, MEA Director Paul Pinsky, and MD Governor Wes Moore discuss energy and climate

In the last fiscal year, UMD added five more ARPA-E awards bringing the total to 41 awards for over $117M since the agencies founding in 2009. UMD continues to be one of the top three academic institutions in the nation in terms of awards received.

ARPA-E EVs4ALL

In January 2023, UMD received 4 out of 12 awards from the Electric Vehicles for American Low-Carbon Living (EVs4ALL) program, which seeks to develop more affordable, convenient, efficient, and resilient electric vehicle (EV) batteries.

Distinguished University Professor, Dr. Eric Wachsman, is the lead PI of one of the awards entitled, *Fast-Charge, High-Energy-Density, Solid-State Battery*. The project will increase the charge/discharge-rate capability, energy density, and operating temperature window of solid-state lithium metal batteries. The team will use new mixed ionic-electronic conducting (MIEC) ceramics and processing techniques to fabricate thinner, higher porosity, and thus lower mass (porous/dense) "bilayer" and (porous/dense/porous) "trilayer" solid-state battery architectures. The patented 3D ceramic architecture has shown the highest Li-metal cycling rate for solid-state technology (100 mA/cm^2) at room temperature with no applied pressure, demonstrated numerous high energy density (~300Wh/kg) cells with multiple cathode chemistries and cell configurations, and is being commercialized by team member Ion Storage Systems. Finally, the team will integrate the MIEC ceramics in new advanced architectures with cobalt/nickel-free, high voltage cathodes to achieve higher gravimetric and volumetric energy densities while simultaneously enabling faster charging rates.

Dr. Paul Albertus, Associate Director for MEI^2 and Assistant Professor in the Chemical and Biomolecular Engineering (ChBE) department, is a co-investigator for two other awards: *Framework for Safety Evaluation of EVs4ALL Batteries*, led by Sandia National Laboratories and *Fast-Charging, Wide-Temperature, Low-Cost, Durable Batteries Enabled by Cobalt- and Nickel-Free Cathodes and Cell Engineering* led by Virginia Tech.

Dr. Chunsheng Wang, UMD ChBE Professor and Director of the Center for Research in Extreme Batteries is a co-investigator for the award: *High Energy Fast Charging All-Solid-State Batteries*. With Solid Power, they will develop a 3D-structured lithium (Li) metal anode and novel sulfur (S) composite cathode to enable high-energy and fast-charging electric vehicle battery cells. The advanced solid-state electrolyte will enable a three-dimensional Li metal anode and S cathode while overcoming the primary challenges for conventional lithium-sulfur chemistry.

DOE Industrial Efficiency and Decarbonization Office (IEDO)

The Industrial Efficiency and Decarbonization Office (IEDO) accelerates the innovation and adoption of cost-effective technologies that eliminate industrial greenhouse gas (GHG) emissions. With 30% of primary energy-related emissions attributable to the industrial sector, IEDO builds upon a foundation of energy efficiency as a decarbonization pathway to include process electrification, use of low carbon fuels and feedstocks, and carbon capture to meet industrial emissions reductions targets.

In June 2023, IEDO announced $135 million in funding for 40 projects that will reduce the carbon footprint of the industrial sector and move the U.S. towards a net-zero emissions economy by 2050. These 40 projects are expected to advance key transformational and innovative technologies toward these goals. Three of these awards were received by UMD and MEI^2 affiliated researchers.

In the area of *Cross-sector Decarbonization Technologies,* UMD received two awards. The first, entitled "Natural Refrigerant, Energy Efficient, Industrial High Temperature Heat Pump", will replace gas-fired industrial boilers with a supercritical CO_2 –based, high-temperature heat pump system designed to integrate into existing manufacturing infrastructure. The project plans to develop critical components of the high-temperature heat pump, including a high-temperature ionic liquid piston compressor, two energy recovery devices to recover thermal and compression energy, and compact heat exchanger design for superior thermal/hydraulic performance. This approach addresses critical technological barriers to achieving high efficiencies made possible by supercritical CO_2 working fluids. The project aims to achieve greater than 45% Carnot COP and more than 40% energy intensity reduction, using refrigerants with low global potential.

The second project "Efficient Saturation High-Temperature Heat Pump for Waste Heat Recovery" will advance the state of the art of high temperature heat pumps to enable continuous, zero-carbon heat for processes above 200C. To improve current heat pump technology, the team will adopt a novel injection system with isopropanol refrigerant, coupled with a highly efficient heat exchanger system to deliver the heat. The proposed approach of near-saturation cycle processes, with the help of multi-stage compression, aims to achieve 71% of Carnot efficiency at 200C with a temperature lift of 100K.

Under the topic of *Decarbonizing Paper and Forest Products*, the project, entitled "Highly-Efficient Multi-Effect Drying Systems Driven by Heat Pumps", will lead efforts to eliminate the use of fossil fuels or biomass waste for energy by developing a multi-effect drying system that creates a closed circuit in which the same energy can be used several times to heat the air for the drying process. This technology could allow the waste to be used as a feedstock for chemical production or a fuel source for other facilities, lowering the amount of primary energy needed and thus raising energy efficiency. The technology is driven by an electric heat pump using low global-warming potential (GWP) refrigerant expected to reduce energy consumption and CO_2 emissions by over 70% compared to fuel-burning kilns used in the wood products industry. When using a zero-carbon source of electricity, industrial heat pumps offer a pathway to eliminate fossil fuel combustion for heat across many industrial applications.

National Science Foundation

Professors Liangbing Hu and Yifei Mo received an award from NSF's Materials Genome Initiative (MGI) for Global Competitiveness. MGI aims to deploy advanced materials at least twice as fast as possible today, at a fraction of the cost for the well-being and advancement of society. The project leverages a novel ultra-high-temperature synthesis technique, previously developed by Mo and Hu's team at UMD, which can rapidly synthesize and sinter oxide materials in less than 10 seconds – conversely, conventional methods can take hundreds of hours, or more. The team will develop a new materials discovery framework to further integrate this new synthesis technique with computational modeling, machine learning and high-throughput measurements to greatly accelerate the discovery and design of novel oxide materials in a fraction of the time of conventional discovery. The framework will eliminate the current bottleneck in the discovery and development of these technological important materials. As a demonstration, the project will develop novel Na-ion conducting materials. These materials can be used for sodium batteries as economic, environmental-friendly and sustainable alternatives to lithium-ion batteries for renewable energy storage.

Publications

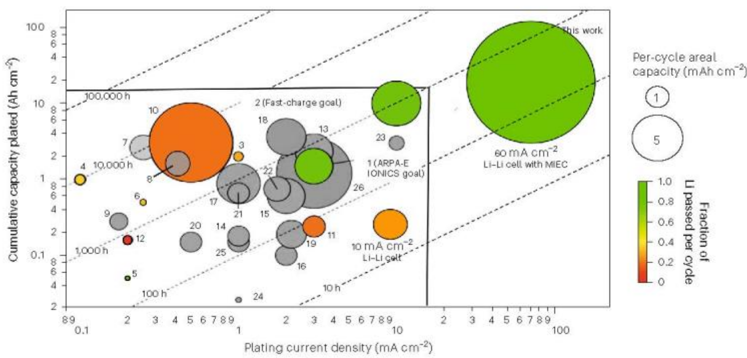
Significant and impactful research progress was also made in FY23. Multiple papers were published in high profile journals such as *Nature* (ranked first in impact internationally) and *Science* (ranked 3rd in impact internationally). Not only have many papers appeared in these journals this last fiscal year, but they have actually graced the cover of these journals. Several notable FY23 research publications are discussed below.

Battery Technology

"***Extreme Lithium-Metal Cycling Enabled by a Mixed-Ion-Electron-Conducting (MIEC) Garnet 3D-Architecture***," George Alexander, Changmin Shi, Jon O'Neill and Eric D. Wachsman, *Nature Materials (2023)*, https://doi.org/10.1038/s41563-023-01627-9

Current batteries are limited by their required charging time and achievable range. The DOE has proposed a Fast-Charge goal of 10 minutes to charge an electric vehicle (EV) battery. However, fast charging current Li-ion batteries can result in Li-metal plating of the carbon-anode and the potential formation of catastrophic (i.e. combustible) lithium dendrite shorts. Li-metal anodes have the potential to overcome these issues, as rather than plating Li-metal being a problem, it is in fact the anode, and moreover Li-metal anodes enable higher energy density batteries and thus EV range.

Dr. Eric Wachsman and his research team have developed a single-phase mixed ion- and electron-conducting (MIEC) garnet material which when integrated into their previously developed 3D architecture, not only achieved the DOE Fast-charge goal for Li cycling, but exceeded it by a factor of 10. The porous structure of the MIEC garnet helps relieve the stresses on the solid electrolytes (SE) during cycling by spreading the potential uniformly across the surface, thus preventing local hot spots that could induce the formation of dendrites. With this Li cycling capability EVs would be able to do 100% depth of discharge cycles every single day for 10 years, far beyond any anticipated EV lifetime/warranty requirements.



The large green circle on the upper right quantifies how much this breakthrough exceeds the US DOE goals, smaller green circles to left.

"***Critical interphase overpotential as a lithium dendrite-suppression criterion for all-solid-state lithium battery design***," Hongli Wan, Zeyi Wang, Sufu Liu, Bao Zhang, Xinzi He, Weiran Zhang and Chunsheng Wang, *Nature Energy (2023)* https://www.nature.com/articles/s41560-023-01231-w

All-solid-state lithium batteries (ASSLBs) can potentially achieve both high energy density and safety. However, the lithium dendrite growth and high interface resistance limit the cycle life of ASSLBs, especially at a high areal capacity, room temperature and low stack pressure. The solid–electrolyte interphase (SEI) from the reduction of solid-state electrolytes (SSEs) cannot block Li dendrite growth. Critical current density (CCD) is used to evaluate the lithium dendrite-suppression capability of SSE.

In this paper, UMD professor Chungsheng Wang and his research team evaluate lithium dendrite-suppression capability of several SSEs using critical interphase overpotential (CIOP), which is the intrinsic property of the interphase that depends on electronic/ionic conductivity, lithiophobicity and mechanical strength. Their creation of CIOP can be used to help design solid-state electrolytes for Li-dendrite suppression.

"***Electrolyte design for Li-ion batteries under extreme operating conditions***," Jijian Xu, Jiaxun Zhang, Travis Pollard, Qingdong Li, Sha Tan, Singyuk Hou, Hongli Wang, Fu Chen, Huixin He, Enyuan Hu, Kang Xu, Xiao-Qing Yang, Oleg Borodin and Chunsheng Wang, *Nature* (2023) https://doi.org/10.1038/s41586-022-05627-8

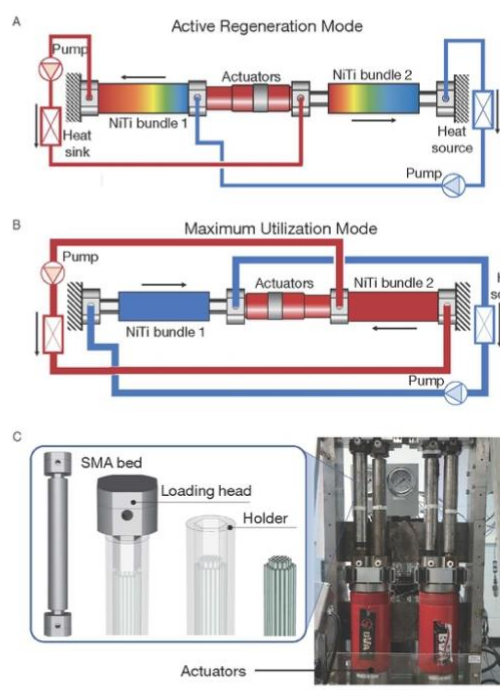
In addition to the CIOP mentioned above, the group has achieved a series of innovative results through the preliminary work proposing non-aqueous electrolytes. They have developed a class of soft solvating electrolytes that allows for fast recharging and operation of lithium batteries under a wide temperature variation, even in very extreme conditions. The finding provides a practical drop-in solution for Li-ion batteries towards next-generation EVs to meet the energy density, fast-charging, wide temperature operation (−60 °C to +60 °C), and safety requirements.

Advanced Materials

"***High-performance multimode elastocaloric cooling system***,' Suxin Qian, David Catalini, Jan Muehlbauer, Boyang Liu, Het Mevada, Huilong Hou, Yunho Hwang, Reinhard Radermacher and Ichiro Takeuchi, *Science*, **380**, 722-727, (2023) DOI:10.1126/science.adg7043

Air conditioning, refrigeration and other cooling technologies account for more than 20 percent of today's global energy consumption, and hydrofluorocarbons, used as refrigerants in vapor compression systems, have a global warming potential thousands of times greater than carbon dioxide. In the May 18 issue of *Science*, the team led by Materials Science and Engineering (MSE) Professor Ichiro Takeuchi and Mechanical Engineering (ME) Professors Reinhard Radermacher and Yunho Hwang introduce a high-performance elastocaloric cooling system that not only meets climate change concerns but could represent the next generation of cooling devices.

To capture the best aspects of the active regeneration cycle and the large utilization operation in a single practical prototype, the team developed a multimode elastocaloric cooling system leveraging the large temperature span of the active regeneration mode and the efficient cooling of the maximum utilization mode. In the prototype, the two modes can be easily switched from one to the other by controlling the operation sequences of valves in the heat exchange fluid network.



With the new technology, the materials remain in a solid state as compared to traditional refrigerants, like hydrofluorocarbons, that work by shifting gas and liquid phases. The new system has a cooling power of 260 watts of useful cooling power and a maximum temperature span of 22.5 Kelvin - among the highest reported for any caloric cooling system.

The team's calculations indicate that the system's overall efficiency could be improved by a factor of 6 by using more efficient actuators. Additionally, the researchers are hoping to improve efficiency by switching the NiTi with a known copper-based material that exhibits a similar elastocaloric temperature change under smaller stress. The team believes they can improve the performance of the system enough to make the technology commercially viable within several years. A current prototype can produce 200 watts of cooling capacity, enough to power a compact wine fridge, and team hopes to expand to window units, whole-house cooling systems, and commercial HVACs eventually.

"***A cellulose-derived supramolecule for fast ion transport***," Qi Dong, Xin Zhang, Ji Qianm Shuaiming He, Yimin Mao, Alexandra Brozena, Ye Zhang, Travis Pollard, Oleg Borodin, and Liangbing Hu, *Sci. Adv.* **8**, (2022) DOI:10.1126/sciadv.add2031

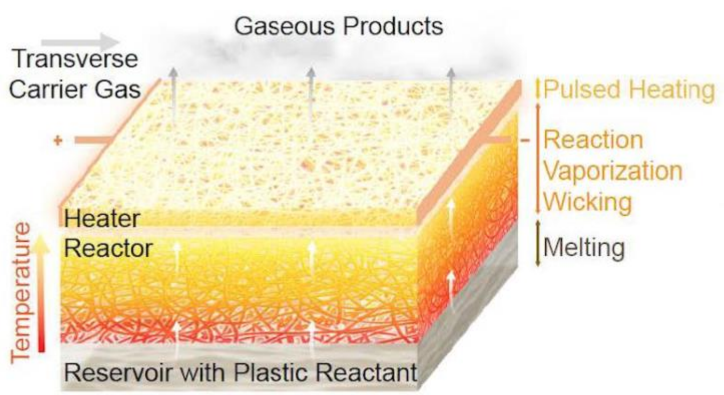
Cellulose, which usually serves as an important structural component in the cell walls of wood and other plants, is the most abundant natural material on Earth. The sustainable and multi-scale nature of cellulose makes it a promising candidate for many applications, especially at nanoscale. A research team led by UMD Distinguished University Professor, Liangbing Hu, has invented a scalable and cost-effective process to synthesize cellulose-derived supramolecules that features a three-dimensional, hierarchical, and crystalline structure composed of massively aligned, one-dimensional, and ångström-scale open channels. Using wood as a model cellulose material, the team for the first time demonstrated a wood-derived metal-organic framework (wood-MOF) for ion transport applications.

Using wood-based Na-CS as a model material, the group has achieved high ionic conductivities even with a highly dense microstructure, in stark contrast to conventional membranes that typically rely on large pores to obtain comparable ionic conductivities. This synthesis approach can be universally applied to a variety of cellulose materials beyond wood, including cotton textiles, fibers, paper, and ink. The high ionic conductivity of Na-CS makes it highly promising for biological (e.g., ionic cables, sensors, and diagnostics) and electrochemical applications (e.g., selective and ion-conductive membranes), where fast ion transport through a structured medium is desired.

"***Depolymerization of plastics by means of electrified spatiotemporal heating***," Qi Dong, Aditya Dilip Lele, Xinpeng Zhao, Shuke Li, Sichao Cheng, Yueqing Wang, Mingjin Cui, Miao Guo, Alexandra Brozena, Ying Lin, Tangyuan Li, Lin Xu, Aileen Qi, Dongxia Liu, Yiguang Ju and Liangbing Hu, *Nature* (2023) DOI: 10.1038/s41586-023-05845-8

Multi-billion metric tons of plastic products exist worldwide, many of which become waste, and if not properly handled will cause severe damage to the environment. As the heavy demand for plastics continues, it is imperative to develop efficient recycling methods to ensure a sustainable future. Currently, much of this waste is burned or landfilled, which is extremely environmentally unfriendly and economically disastrous. Recent development in thermochemical processing allows the plastics to be converted to useful chemicals through reactions.

A UMD led team has invented an electrified technique to conduct thermochemical plastic recycling, which can be used to produce green, value-added chemicals such as monomers via the pyrolysis of polyolefin and polyester plastics. This selective depolymerization process is realized by two features: (1) a spatial temperature gradient and (2) a temporal heating profile. The spatial temperature gradient is achieved using a bilayer structure of porous carbon felt, in which the top electrically heated layer generates and conducts heat down to the underlying reactor layer and plastic. The resulting temperature gradient promotes continuous melting, wicking, vaporization and reaction of the plastic as it encounters the increasing temperature traversing the bilayer, enabling a high degree of depolymerization. Meanwhile, pulsing the electrical current through the top heater layer generates a temporal heating profile that features periodic high peak temperatures (for example, about 600 °C) to enable depolymerization, yet the transient heating duration (for example, 0.11 s) can suppress unwanted side reactions.



The process opens up a new route towards efficient thermochemical plastic recycling with renewable electricity. Not only does the technique show great performance in plastic recycling, it offers a unique far-from-equilibrium platform for chemical synthesis. Using this technique, electrified heating could enable green manufacturing of value-added chemicals from a range of plastic wastes and other feedstocks with renewable electricity.

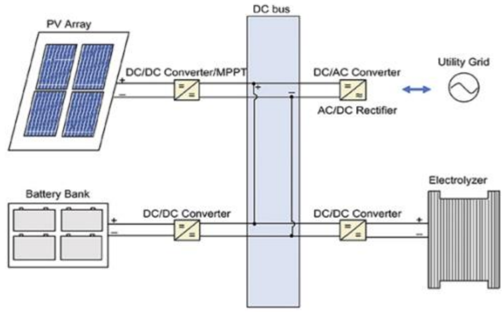
Renewable Energy

"***Optimal design of a coupled photovoltaic–electrolysis-battery system for hydrogen generation***," Aisha Alobaid and Raymond A. Adomaitis, *Sustainable Energy Fuels*,**7**, 1395-1414 (2023)

In a time of climate change, hydrogen-based energy is a possibility for a world looking to replace fossil fuels with more environmentally friendly sources. Currently, most hydrogen production relies on fossil fuels, but it is possible to produce hydrogen in greener ways. For example, hydrogen can be produced using a photovoltaic-electrolysis-battery system that uses renewable sources such as wind and solar to power water electrolysis. The researchers have developed a computational algorithm that models an integrated photovoltaic–electrolysis-battery system and can identify the optimal size a system should be. In testing, this algorithm evaluated more than 2 million possible sizing combinations. They found that optimizing the system's cost and hydrogen production rate implicitly ensured a minimized levelized cost of energy for the system.

Photovoltaic (PV) modules are connected solar cells that absorb energy from sunlight and convert it into electrical energy through semiconducting materials. In an integrated system, these modules provide the power that runs the electrolyzer, a sub-system that uses electricity to create hydrogen gas by breaking water into hydrogen and oxygen. Excess power generated by the PV modules charges the battery. At night, the battery provides the power necessary to ensure the electrolyzer's uninterrupted operation.

The analysis goal was to identify the optimal system configuration that could maximize hydrogen production rate, minimize levelized cost of energy and total system cost, and target a net-zero grid energy operation. The clear mathematical model developed can calculate the amount of energy



Above: Figure 1 from the paper. A schematic diagram of the coupled system.
Below: ReACTHouse, the University of Maryland's 2017 Solar Decathlon entry, on site in Colorado.

from sunlight falling on a PV module surface, given its orientation, location, and time of the day. Unlike research that uses only a 24-hour period to simulate and analyze the hybrid system, or assumes a fixed averaged value of global irradiance, this model uses hourly incremented calculations to simulate the coupled system for an entire year; including both diurnal and seasonal weather variations.

The flexible computational platform can be extended to more complex hybrid systems. For instance, wind power can be added to promote further sustainability and drive the system to off-grid limits. Additionally, the model could be modified to evaluate the influence of incorporating environmental measures in the optimization problem, such as minimizing carbon dioxide emissions. Another possibility is the inclusion of post-production stages in the simulation, such as hydrogen purification, storage, conditioning, and distribution to the end user, which offer a broader perspective and can be nicely integrated with the current study to form a hydrogen supply chain network design problem. The model can also accommodate reliability, environmental impact, and safety measures for assessment.

PARTNERSHIPS AND COLLABORATIONS

Throughout the past fiscal year, MEI^2 has developed many local, national and international partnerships and contracts in support of the Institute’s Research and Innovation foci.

U.S.-Israel Binational Industrial Research and Development Foundation Energy Center

The first Israel-based meeting of the U.S.-Israel Energy Center's battery storage consortium at Bar-Ilan University's Institute of Nanotechnology and Advanced Materials took place in January 2023. Marking the second time the U.S.-Israel Energy Consortium (UISEC) has convened in person following a June meeting in Maryland, the event brought together prominent academic researchers, cutting-edge entrepreneurs and key government representatives from the U.S. and Israel to accelerate the development of lithium and sodium metal solid-state batteries for advanced energy storage applications - a priority for both nations.

Led by UMD's Professor Paul Albertus in the U.S. and by Bar-Ilan University's Professor Malachi Noked in Israel along with their respective teams of co-PIs and dedicated graduate students, the consortium also includes the participation of Saft, Forge Nano, Inc. and Ion Storage Systems from the U.S. and 3DBattery, MaterialsZone and Tel Aviv University from Israel. The consortium members had the chance to discuss research milestones; engage with detailed poster presentations; tour the Bar-Ilan labs of Professors Noked, Lior Elbaz and David Zitoun; tour 3DBattery's impressive facilities in Rehovot and Tel Aviv labs of Professor Diana Golodnitsky and Professor

Emanuel Peled. The meeting was productive and infused momentum into the quest for the ultimate lithium and sodium metal solid-state batteries - a key to helping both countries meet ambitious zero-carbon goals.

In June 2023, the BIRD Foundation, along with the Embassy of Israel to the United States, co-hosted a dynamic reception in Washington, D.C., bringing together an exceptional community of U.S. and Israeli innovators, connectors, and key stakeholders who reaffirmed the power of collaboration and the limitless potential of joint industrial research and development. Keynote speakers, whose inspiring words set the tone for an evening filled with productive conversations and invaluable networking opportunities, included:

- Dr. Laurie Locascio, Director of the National Institute of Standards and Technology (NIST) and Undersecretary of Commerce
- Prof. Paul Albertus, Associate Director of the Maryland Energy Innovation Institute, Assistant Prof. at the University of Maryland, and U.S. Leader of the U.S.-Israel Energy Center's Storage Consortium (UISEC)

From left to right: Mojdeh Bahar (BIRD Foundation U.S. Co-chair), Jaron Lotan (BIRD Executive Director), Natalie Gutman-Chen, (Minister for Economic and Trade Affairs), Michael Herzog (Israeli Amabassador to the U.S.), Laurie Locascio (NIST), Paul Albertus (UMD)

Opening remarks by Israel's ambassador to the U.S., Michael Herzog, who reaffirmed the importance of cross-border R&D collaboration and our collective capacity to advance globally needed tech solutions. BIRD Executive Director Jaron Lotan and U.S. Co-Chair Mojdeh Bahar, Associate Director for Innovation and Industry Services at NIST, both shared valuable insights into the Foundation's mission and accomplishments, showcasing the impact that BIRD has had in facilitating fruitful partnerships between the U.S. and Israel.

Current achievements of the UISEC Consortium include:

- Three collaborative journal publications and one collaborative book chapter were published, along with several individual publications.
- A US-IL joint publication (based on work in BIU and FN) was submitted for publication in August and is under review at Nature Nanotechnology.
- Coatings development at several consortium members, and technical collaborations.
- Development of solid electrolyte powders (e.g. Li^+-conducting argyrodites and NaSICON) and cathode materials (e.g., Co-free Li insertion materials).
- New models for the study of metal plating stability and building of a new database and protocols for UISEC materials.
- Continued advances in the development of full battery cells at several consortium members, and for both Li-based and Na-based cells.
- Forge Nano techno-economic analysis of the BIU atomic layer deposition process.

Center for Research in Extreme Batteries

The Center for Research in Extreme Batteries (CREB) was created as a partnership between MEI[2] and the Army Research Lab (ARL) in Adelphi, MD, to develop advanced batteries for the extreme needs of defense, aerospace, and biomedical devices. In April 2022, CREB received a cooperative agreement (CA) providing an additional $9 million from the U.S. Department of Defense (DOD) - $8.55M to the University of Maryland (UMD) and $450K to Argonne and Brookhaven National Laboratories – to advance transformational army batteries. U.S. Army operations require that batteries not only have high energy density, but also be able to endure extreme temperatures, thermal and mechanical stresses during storage, transport and maneuvers, as well as high safety to bolster Warfighter operations. A targeted investment in battery research and development is one of the pivotal enablers to address the Army's need for rapid and resilient responses to future threats. CREB has assembled teams of scientists and engineers to conduct research in three closely aligned thrusts: (1) Advanced Safe Electrolytes; (2) High Energy Cathodes; and (3) Silicon Anodes.

The CREB Bi-annual meeting in December 2022 focused on focused on "Fast-Charging", specifically civilian and military adoption of battery power that can provide fast recharging to meet user demands. For military equipment, the concern extends to warfighter safety and mission success. Industry, government and academic researchers discussed Fast charging of lithium-ion batteries including methodologies to monitor electrode polarization, detect Li-plating, examine lithium concentration gradients in electrodes and investigate electrode materials changes, during and after exposure to high currents.

The key to the success of electric vehicles are reliable, inexpensive batteries that can charge fast and provide improved performance and range retention in cold weather compared to state-of-the-art commercial options. Several presentations focused on range anxiety and battery degradation from fast charging. Recent efforts jointly align electrochemical methods with targeted characterization and advanced analysis to detect failure modes. Specifically, machine learning and other advanced analysis approaches show promise to reduce the time and effort needed to predict life, delineate failure modes, and provide input to electrochemical models. This provides feedback information for the refinement of advanced charging protocols designed to minimize specific aging pathways.

Following the meeting, there was a student poster session and reception sponsored by the ECS National Capital Section. Mr. Shannon Reed, ECS Director of Community Engagement opened the reception and applauded the UMD ECS Student Chapter for their active participation in the community.

In June 2023, the CREB bi-annual meeting focused on the search for higher energy density cathode/catholyte architectures and systems in battery technology. Industry, government and academic researchers discussed next-generation cobalt-free cathodes, fluorinated catholytes to boost battery energy, as well as nickel rich cathodes to name a few. The mass adoption of solid-state batteries, due to recent achievement, was also forefront in the discussion. Solid-state batteries (SSBs) are considered the future of battery technology, offering improved safety, higher energy density, and greater durability compared to conventional lithium-ion batteries, but are constantly seen as ten years away from adoption. Several companies are developing unique process and cell structures/engineering in the lithium metal system to enable some > 500Wh/kg design cells, the DOE fast-charge goal.

Another key sector included advances in battery technologies for medical devices. Batteries for active implants must have maximum reliability and predictability over a lifetime than could be 15 years or longer. Over the last 50 years, the industry has seen incredible advances in technology which have led to smaller devices that last longer and support improved device functionality such as sensing and communication. That evolution is expected to continue with further reduction of battery size resulting in even smaller devices, less invasive implant procedures and proliferation of active implants in the digital health ecosystem and as treatments for additional disease states.

Hydrogen Hub

Following on a strategic research initiative visit with Washing Gas Light Company in the fall of 2022, hydrogen research emerged as a potential collaboration. Hydrogen energy has the power to slash emissions from multiple carbon-intensive sectors and open up economic opportunities to clean energy businesses and workers across the country. Getting hydrogen right would mean unlocking a new source of clean, dispatchable power, and a new method of energy storage. It is also another pathway for decarbonizing heavy industry and transportation. At UMD, research on hydrogen safety and hydrogen fuel cell development are already underway. Washington Gas has shown significant interest in partnering with UMD in both of these areas.

Energy Innovation Hub: Research to Enable Next-Generation Batteries and Energy Storage

UMD/MEI^2 partnered with University of Texas at Austin (UTA), lead organization for the center proposal, on a *Center for Earth-abundant Energy Storage (CErES)* innovation hub proposal. Additional partners included Brown University (Providence, RI), and Oak Ridge National Laboratory (Oak Ridge, TN). The mission of CErES is to design energy storage systems based on earth-abundant materials that are more sustainable and enable long duration storage, by drawing inspiration from designs and phenomena present in nature. CErES will focus on understanding how energy storage materials, architectures, and interfaces can be modified to enable battery chemistries that benefit from the greater earth-abundant elements, like Na, K, Mg, and Zn, thus also minimizing ethical and political sourcing issues. This pursuit would identify strategies for accommodating changes in elements/materials, while also enhancing energy storage performance. CErES will establish foundational knowledge associated with atomic/molecular phenomena in the bulk and at interfaces to accelerate the adoption of future energy storage systems based on earth-abundant materials. Further, CErES will seek creative approaches gleaned from biological phenomena relevant to electrochemistry and energy storage. For example, living systems take a bottom-up growth process, all components are compatible with each other, ion transport – an essential process in a functioning battery – is efficient, directional, and selective, and damage can be self-healed. Nature has optimized these characteristics by evolutionary processes over millennia involving dynamical phenomena that have thus far not been translated to man-made devices. By learning from nature, CErES will design materials, architectures, and dynamical processes that enable higher performance, more stable, and more scalable earth-abundant chemistries than Li-based systems.

NSF Clean Energy Technology Conference Proposal

In June, 2023, MEI^2 submitted a conference proposal for: Offshore wind and bioenergy clean technology development and deployment in Maryland. The proposed conference was to assist the state of Maryland in developing a clean energy innovation ecosystem that will enhance the State's educational, economic, and social commitments to energy efficiency, clean technology and the environment. The conference will focus on two specific areas of significant interest to Maryland: (1) offshore wind/wave technology and (2) net-zero fuels/bioenergy.

OUTREACH AND EDUCATION

MEI^2 is actively engaged across campus, the state and nation in educational and outreach efforts. A quarterly newsletter is issued to over 700 faculty, government and industry leaders and international researchers. Independently, MEI^2 Director Dr. Eric Wachsman continues to be consulted and interviewed frequently regarding his battery technology and energy storage for the grid.

Engineering Sustainability Day

On April 28, 2023 MEI^2 hosted the 11th Engineering Sustainability Day with a focus on "Powering a Greener Future". Industry leaders Washington Gas and Constellation sponsored the event in addition to hosting a luncheon for all presenters and attendees. UMD entrepreneurs as well as current and previous MEI^2 Energy Seed Grant recipients demonstrated their innovative technologies to faculty, students and industry leaders attending the event. Students from across campus (including AGNR, CMNS, ENG, and the Business school) attended, and were able to get a better understanding of how to maximize technology's positive impact on the long-term availability of natural resources while minimizing its negative impact.

On display were a broad range of technologies and start-ups including:

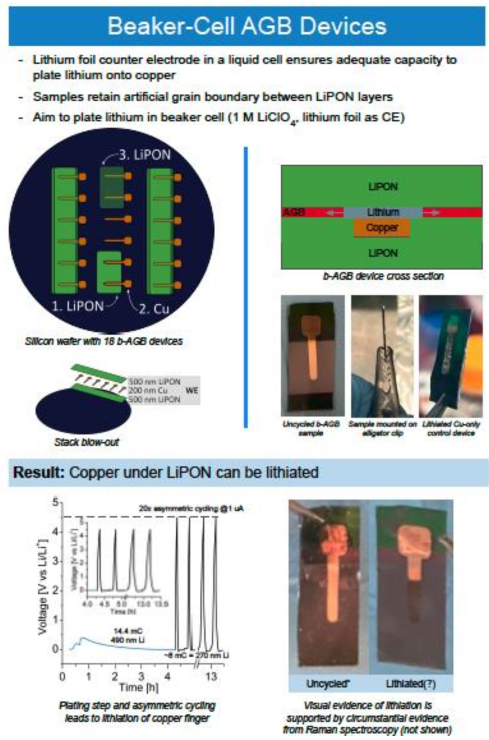
- AGNR student, Emily McCoy who discussed "Biological Conversion of Food Waste to Bioenergy and Bioplastics", her work with AGNR Professor Stephanie Lansing. She is focused on understanding the waste sources that exist, particularly the quantities of food waste, and determining what opportunities exist to create renewable resources and energy from that waste.
- Alchemity, a UMD based start-up, that will convert stranded natural gas that might otherwise be flared or vented, a major contributor to greenhouse gas (GHG) emissions, to value-added chemical products. By turning a waste gas source into a liquid commodity chemical, this technology can bring a valuable contribution to reducing the emissions of industrial operations.
- NextGlass, UMD start-up based on Vacuum Insulated Glass technology created by Professor Jungho Kim and Assistant Research Professor Ratnesh Tiwari. Their novel metal edge seal geometry using a low-temperature sealant results in low-cost VIGs, no stresses and thus high

reliability, and much lower edge conduction. The design reduces overall VIG fabrication time by about 80% and requires minimal capital equipment cost due to low temperature processing.

- WH-Power, another UMD start-up that is developing a new type of rechargeable battery made from crab shell derived material (chitosan) and zinc metal recently patented by the research groups of Professor Liangbing Hu and Professor Robert M. Briber at the UMD.
- Maryland start-up HaloCyTech and Morgan State University Professor Viji Sitther, who are utilizing cyanobacterial biomass in naturally available brackish waters for production of biofuels and other natural bio-products, providing a cost-effective alternative to fossil fuel.

Research Experience for Undergraduates

This past year, MEI[2] partnered with the UMD Department of Materials Science and received a three-year NSF Research Experience for Undergraduates and Teachers (REU/RET) grant. The program is entitled "Summer Research Experiences in **Re**newable and **S**ustainable **E**nergy **T**echnology (ReSET)". Undergraduate students and secondary STEM educators were encouraged to apply to this summer REU/RET program. The projects covered a broad range of energy related materials and materials-limited issues and proposed solutions using ceramic, metal, organic materials and more. Topics included low temperature, low energy consumption ways to fix nitrogen in fertilizer or fuels, rapid nanomanufacturing of materials for energy applications, the fabrication and testing of solid-state batteries, and low environmental impact approaches to make transparent electrodes for devices. Participants acquired experience in state-of-the-art, hands-on scientific methods, data analysis, modeling and simulation, and best practices in laboratory safety protocols.



Over the course of 10 weeks (June – August 2023), eight undergraduate students and 2 high-school STEM teachers worked with UMD professors on a specific research project. The high-school teachers were required to introduce new energy related curriculum into their upcoming fall classes. High school students gained knowledge and hands on research experience in renewable energy in a real-world context. Students and teachers also visited local UMD start-up companies, the UMD nuclear reactor and the UMD nano-fabrication lab and also attended career development seminars on ethics, career pathways, and entrepreneurship.

Upon completion of the program, two of the undergraduates will be continuing their research remotely at their home institutions. Lukas Karapin-Springorum will continue his research with the Rubloff group in developing tunable artificial grain boundaries in thin film electrolytes to study the development of Li dendrites. Likewise, Nina Borodin will continue her work with Dr. Yifei Mo using computationally efficient Machine Learned Potentials (MLPs) to reproduce diffusional properties for materials like lithium garnet $Li_7La_3Zr_2O_{12}$ (LLZO).

Graduate Energy Fellowships

MEI^2 awarded one Harry K. Wells graduate energy fellowship and one Barbara Hulka graduate energy fellowship in March 2022. Both fellowships come with a 20K stipend for research and a 4K award for conference travel and materials. Mr. Harry K. Wells (B.S. ’43, mechanical engineering) established an endowment to support engineering graduate student research in the field of sustainable energy generation and/or storage. The 2023-24 Wells recipient is Bhuvsmita Bhargava, Chemical Engineering student. She will be assessing the thermal safety of solid-state battery material sets by quantifying Differential Scanning Calorimetry (DSC) heat flow and using material characterization techniques. She will use material characterization techniques like XRD and TGA-GCMS, along with additional baseline identification tools such as cooling scans and modulated DSC with different pan types to accurately quantify DSC heat flow and identify key exothermic reactions that cause self-heating pertaining to a specific cell chemistry.

Since 2007, Mrs. Barbara Hulka has donated $20K annually to award a faculty-sponsored graduate student pursing research in sustainable energy with specific emphasis in the areas of alternative energy research, solar energy conversion, biofuels, wind energy, wave energy, and ocean thermal or geothermal energy. The Hulka Fellowship 2023-24 recipient is Apurva Anand, Aerospace Engineering student. He is working on meta-machine learning for efficient design of wind energy applications. The primary outcome of the proposed work is the development and application of a physics informed machine learning module that can be used as both aerodynamic design tool, and database for wind turbine airfoils, with significantly lower computational costs and higher accuracy. Major milestones include: implementing field-inversion machine learning in 2D; developing T-NNs module with support for the Data Puncturing strategy; and generating databases for wind turbine airfoils.

APPENDIX 1. MEI² FY23 Budget

FY23 Budget Expenditures and FY24 Approved Budget

For the past six years UMD has provided additional resources beyond the reported expenditures for MEI² including basic business and management personnel as well as the operation of a lab facility that has been available for university and start-up company use. The added funding in 2023 was received too late to be used for some of the budgeted expenses; however, a majority of it was encumbered for the Energy Seed Grant program as per budget due to the large number of qualified proposals received.

	FY23 Budget	Actual	Difference	FY24 Budget
Energy Seed Grants	$650,000	$650,000	$0	$650,000
Salaries/Fringe	$270,691	$228,622	-$42,069	$242,127
Events/Outreach	$5,000	$4,457	-$543	$13,000
Communications Printing	$2,500	$2,889	+$389	$2,500
Equipment-Office Supplies	$8,000	$9,186	+$1,186	$20,000
Travel	$5,000	$13,123	+$8,123	$10,000
Subtotal	$941,191	$908,277	-$32,914	$937,627
SubAward (MCEC)	$1.2M	$1.2M	$0	$1.2M
Totals	**$2,141,191**	**$2,108,227**	**-$32,914**	**$2,137,627**

APPENDIX 2. Letter from MEI^2 Advisory Board

UNIVERSITY OF MARYLAND

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

Maryland Energy Innovation Institute

May 31, 2023

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 April 28, 2023 meeting.

The Advisory Board welcomes its newest member, Paul Pinsky, Director of the Maryland Energy Administration and former Maryland State Senator.

OBSERVATIONS

First and foremost, as the MEI^2 is well into its sixth year of operations, the Advisory Board congratulates MEI^2 for having successfully completed its first five years as a clean energy research entity that has brought forth many impressive advances. It is also noted that much more could be accomplished if funding resources were significantly increased as MEI^2 has demonstrated its ability to leverage private sector funding and investments. It accomplishes this in a collaborative and coordinated effort with the Maryland Clean Energy Center (MCEC) and the Maryland Energy Innovation Accelerator (MEIA), and of course through the support of key state legislators and officials. It is without question that MEI^2's potential is not constrained by the lack of innovative concepts, but rather by limited funding whose increase could spur more successful launches of clean energy entities for the state.

MEI^2, MCEC and MEIA continue to coordinate well to develop ideas, help launch startups and support their early operations, which are essential to establishing a basis from which to compete for investments and contracts to sustain viability and growth. If a Founders Fund for clean energy which has been proposed in legislation were established, it would help in-state startup companies gain access to resources essential to successful transition to sustainable enterprises.

The Advisory Board commends the premiere faculty associated with MEI^2 who continue to received recognition and distinguished awards from various widely respected organizations. In addition, the Advisory Board recognizes the University's prominence in patents awarded (20th

world-wide rank and 10^{th} among public institutions) primarily at the College Park campus, and notes that over one third of these are related to energy innovations. The significant share of patents in energy innovation attests to the impact and efficient use of research funding in this area. This is particularly striking considering that fewer than 25% of the patents were related to health/biotechnology innovation, a sector that has received and continues to receive significantly more funding support than clean energy innovation from the State.

Seed Grants Program: The R&D supported by MEI^2's Seed Grant program funding continues to be game changing. Since its inception, the seed grant program has made 27 awards to 26 companies that have created 117 jobs; spawned 51 patents; attracted $63.5 million in private investments and $4.2 million in revenue generation. The Advisory Board also notes that seed grant awards have resulted in several game-changing companies that have become success stories. As a prime example, Ion Storage, a Seed Grant recipient from 2019, is unequivocally the Seed Grant program's greatest success story thus far. Ion Storage accounts for a significant portion of the Seed Grant's key accomplishments including over $25 million in sponsored research, the creation of 55 jobs and $40 million in venture capital funding, and is now housed in a 20,000 ft^2 manufacturing facility. Other examples of successes from seed grant recipients include game changing companies such as InventWood, Nano Direct/Materic LLC, Mobile Comfort, and Alchemity. Much of the success is also due to the coordinated efforts and support from MCEC and MEIA.

In addition to the Seed Grant program, specific areas of collaboration in clean energy research continue to impress, notably the BIRD Foundation Israel Solid Energy Consortium in which the U.S. side is ahead of schedule on its milestones. Also, the Center for Research in Extreme Batteries continues to attract attention from applications in defense, space and biomedical areas.

As mentioned in our previous letter to MEI^2, the University has extensive research and technology facilities, programs and expert capabilities, including those at MEI^2. However, the importance and impact of the Seed Grant program cannot be over emphasized. Moreover, it is noted that there are currently no energy-focused incubation facilities in the state of Maryland which are sorely needed to support Seed Grant recipient companies.

The Advisory Board recognizes the importance of MEI^2's continuing coordinated outreach effort with MEIA to provide updated fact-based information on progress and achievements to state legislators, and to seek out champions and advocates to support a sustainable innovation ecosystem in clean energy for the state.

Both MCEC and MEIA continue to make significant progress toward program strategic goals and metrics against Key Performance Indicators (KPIs) including successful leveraging of private capital, job hours, private sector partnerships and greenhouse gas emissions reductions. It is noted that a more robust level of state investment in clean energy is needed to build upon these successes. In support of climate technology commercialization, MCEC facilitates access to capital and operates financing programs using leveraged or direct investment. It provides specialized procurement and technical support to facilitate project implementation. MEIA's focus is on three programs: 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.

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. Specifically, important funding is needed for a Founders Fund (previously introduced in legislation but yet to be enacted) to help grow startups and attract private investment. In addition, an increase is needed to the statewide Green Bank at MCEC which is currently much smaller than those of other states. An approach to assessing the state's total landscape in clean energy technology innovation could be the convening of a "blue ribbon" panel similar to that done in the bio-tech area. The aim of the panel would be to assess the state's competitiveness relative to that of other states in clean energy technology.

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 July 27, 2022 are as follows:

Seed Grant Program**:**

- Formalize the relationship with MEIA to enhance the Seed Grant proposal process to strengthen the business case in proposal submissions.
- Open eligibility criteria of Seed Grant proposers to all full-time faculty beyond tenured or tenure tracked faculty.
- Update the strategy and priorities regarding phase 1 and phase 2 awards within available Seed Grant funds.

Status: Successfully implemented these recommendations which are now ongoing.

University's Grand Challenges Climate Change Priority: Proceed with matching fund proposal that includes participation from other university program offices and colleges as an integrated climate change initiative.

Status: Although the submitted proposal was not selected, the proposed concept of an integrated climate change initiative as a Grant Challenge remains an important approach to addressing the University's climate change priority and warrants further consideration in future calls for proposals. It is noteworthy, however, that a climate-adaptation focused institute lead by Distinguished University Professor Ellen Williams was selected. Furthermore, both Distinguished University Professors Wachsman and Williams are on the University Climate Working Group, a committee established by the President and Provost to consider how to advance the University's Strategic Goal for addressing climate change in the context of the State's Climate Solutions Now Act and emissions reductions goals.

Outreach: Expand tailored outreach material for targeted audiences to optimize impact, visibility and support for MEI^2's role in reducing greenhouse gas emissions through advances in clean energy.

Status: MEI^2 experienced an inordinate delay in receiving funding for this outreach activity. As such, it was only able to focus on core outreach activities as were conducted in prior years, and will endeavor to plan coordinated outreach with MEIA (see Recommendations section below). **.** *Nonetheless, specific progress in outreach included: Constellation and Washington Gas sponsored Engineering Sustainability Day; 2nd year National Science Foundation (NSF) funded Research Experience for Undergraduates (REU) (summer 2023) -*

tripled the number of students that applied; Met with new Maryland Governor Wes Moore to discuss energy innovation as an economic driver.

Early Engagement with new Dean of Engineering:

Status: Completed. As a carryover from prior recommendation the Advisory Board met with Dean Samuel Graham on September 23, 2022. Dean Samuels expressed his support for MEI^2 and the Seed Grant program.

ADVISORY BOARD RECOMMENDATIONS TO MEI^2

After discussions, inputs and deliberations, the Advisory Board makes the following actionable recommendations to MEI^2:

Develop a five-year MEI^2 strategic plan with vision, goals, priorities and targeted metrics consistent with and supportive of the greenhouse gas emissions- reduction goals of Climate Solutions Now Act.

As a matter of context, the above referenced legislation calls for a 60% reduction in greenhouse gas emissions by 2031 and net zero by 2045. This will necessitate an increase in clean, renewable energy to replace those energy sources which produce a large portion of greenhouse gas emissions. While not yet the force of law, Maryland Governor Moore's additional call for 100% clean power by 2035 dovetails with the mandated goal of the Climate Solutions Now (CSN) Act.

Maryland's Department of the Environment (MDE) is required to finalize and submit a final plan to achieve the Climate Solutions Now reductions (an implementation plan, if you will) by December of this year with an interim plan distributed in June to spur feedback and debate towards the final plan. The CSN calls for: the state to lead by example and shift the state's auto fleet to EV's or hybrids; a 20% reduction in greenhouse gases from all large (35,000 sq. foot or larger) buildings and net zero for state operations by 2040; and states that ("…the General Assembly supports moving towards broader electrification of both existing buildings and new construction as a component of decarbonization;"), among other initiatives in the legislation.

The Advisory Board suggests convening around the time of MCEC's Clean Energy Summit on Decarbonization on October 17, 2023, in College Park to conduct a facilitated discussion on a vision driven strategic plan for next 5 years aimed at achieving growth and positive outcomes for MEI^2, the university and the State. A draft outline for such a plan should be sketched out by MEI^2 in advance of the meeting. The discussion could be structured to:

- Construct a vision and mission statement for MEI^2 in the context of clean energy and climate change mitigation via net reduction of greenhouse gas emissions.
- Conduct a self-assessment of MEI^2's strengths, weaknesses, opportunities and threats (SWOT analysis)
- Engage industry board members (Washington Gas, Exelon, Constellation Energy) for feedback on their priorities.
- Invite other major industries in Maryland as well as government agencies on priority areas as part of discussions.
- Map out potential markets and time frames.

- Project how many new clean energy start-ups could be accelerated to becoming viable companies if funding is increased by 2X to 5X.
- Recommend avenues be pursued to broaden State's climate and clean energy tech to be comparable to State's emphasis on bio tech, in support of sustaining the net zero emissions target by 2045.

Explore Private Sector Membership to enhance value and broaden funding support to MEI^2: Examine other models of private sector donor membership like those at MIT and University of Michigan and avenues that create value to members (e.g., devise a value proposition model that plays to the strengths of MEI^2 and considers priorities/motivations of potential donor members)

Fill vacant Advisory Board seat due to departure of Dr. Theresa Christian from Exelon.

Outreach: Continue to coordinate outreach materials development between MEI^2 and MEIA with new products by the next annual Advisory Board meeting. For consideration are faculty supervised internships (beyond the NSF Summer REU program) that could be sponsored by Washington Gas, Constellation, Exelon and others. The program could be developed with the University's Engineering Foundation or College Park Foundation. It could be fashioned as a matching fund program.

Consistent with the strategic plan recommendation above, there is a need for a long-term outreach growth/vision and should be included as part of the discussion meeting with the Advisory Board around the time of MCEC's Energy Summit.

As always, the Advisory Board is fully committed to advising MEI^2 on the strategic development 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 participation in the discussions on the progress and direction in MEI^2 in clean energy innovation.

Sincerely,

Victor Der
Chair, Advisory Board, Maryland Energy Innovation Institute Assistant Secretary of Fossil Energy, US DOE (Retired)

Ellen Williams
Vice-Chair, Advisory Board, Maryland Energy Innovation Institute Director, UMD Earth System Science Interdisciplinary Center Distinguished University Professor UMD
Former Director, Advanced Research Projects Agency-Energy (ARPA-E)

Mallik Angalakudati,
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Thomas Greszler
SAFT research development, R&D Manager North America
Geoff Oxnam

Founder & CEO, American Microgrid Solutions Chair of the Board, Maryland Clean Energy Center

Paul Pinsky
Director, Maryland Energy Administration

David Rapaport**
Head, Research Collaboration Management, Siemens Technology
(*Unable to attend April 28 Meeting; ** remote attendance)