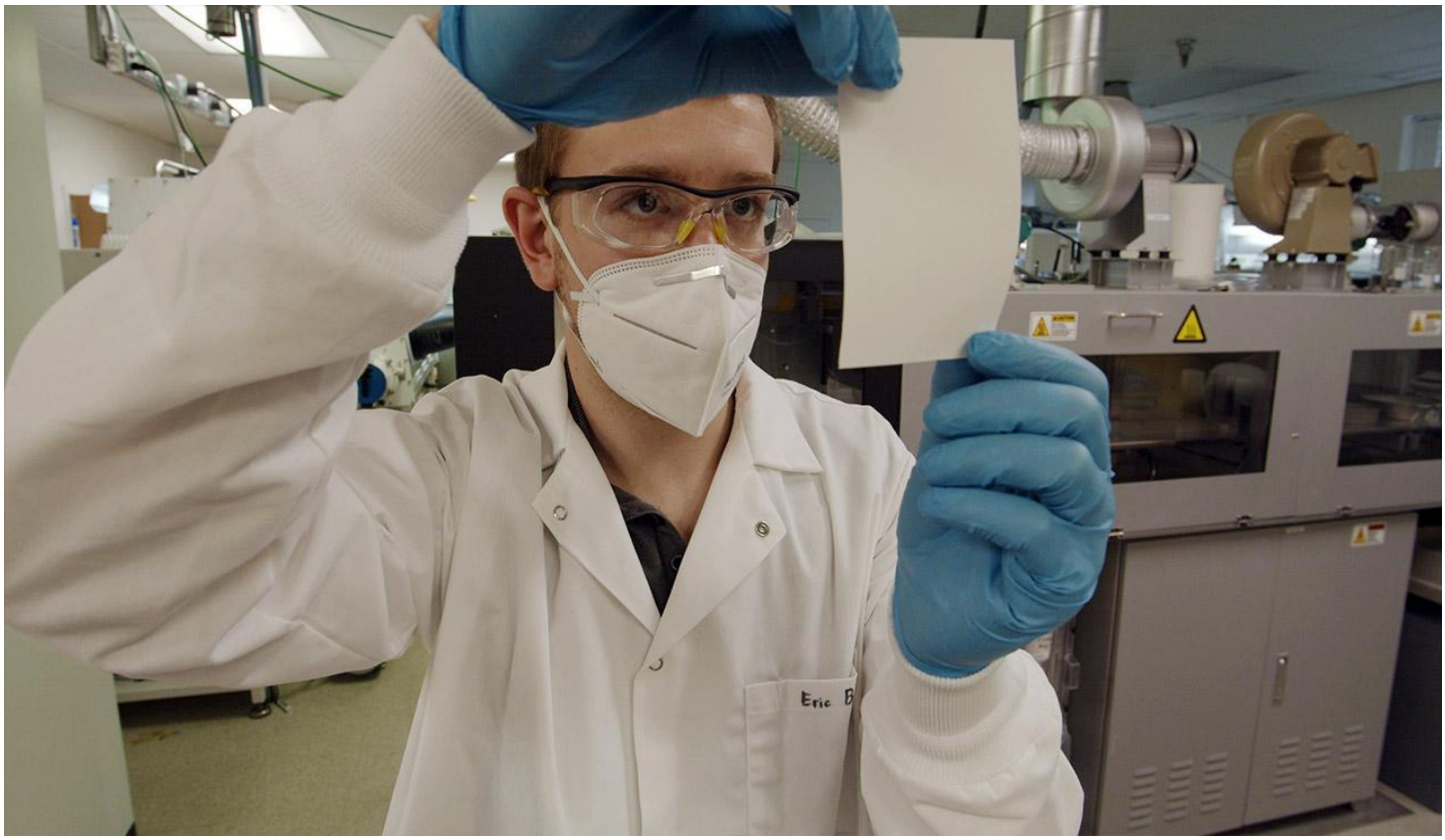
MARYLAND ENERGY INNOVATION INSTITUTE

Annual Report FY2021



UNIVERSITY OF MARYLAND, 8136 PAINT BRANCH DRIVE, COLLEGE PARK, MD 20740

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

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MARYLAND ENERGY INNOVATION INSTITUTE

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Message from the Director

Maryland as a state has been a U.S. leader in clean energy policy and on the academic side its universities have been a U.S. leader in energy research in terms of both productivity and attracting federal energy research funding. Among the many federal research awards received this is particularly exemplified by our continued leadership (among the top 3 universities in the nation) in U.S. Department of Energy ARPA-E awards having received a record 10 awards this year bringing our total to 33 awards for $74M since the agency's start in 2009.

The Maryland Energy Innovation Institute (MEI^2) was formed to translate our leadership in energy research to economic benefit consistent with our State's clean energy policy goals. Specifically, MEI^2 advances Maryland university clean energy technologies and assists in the transitioning of these technologies into marketable products and services through Maryland based entrepreneurial ventures. These energy innovations have tremendous potential to both grow the State of Maryland economy and have a positive impact on addressing global energy needs in a sustainable manner.

Since MEI^2's creation in 2017 it has helped obtain over $79M in federal energy research awards to the State of Maryland, a 33X rate of return on Maryland's SEIF investment in MEI^2 during that time-period. Moreover, it has provided 17 energy seed grants to University System of Maryland energy researchers and their spin-off companies to help them attract follow on VC investment, and in partnership with the Maryland Energy Innovation Accelerator have helped launch 15 companies in the State of Maryland, two of which were named to *Maryland's Future 20* list due to their potential to transform the Maryland economy.

Recognition of the contribution of MEI^2 and its mission to increase Maryland's energy innovation economy was clear in the overwhelming bipartisan support of SB460/ HB419 in the FY21 Legislative session. I sincerely appreciate this support and hope in FY22 we are given the mandate to continue our work for the State of Maryland.

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

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EXECUTIVE SUMMARY

MEI^2 has continued to catalyze clean energy innovation in Maryland and contribute to the State's economic growth through advancing the State's academic, national lab, and industrial energy research, and the creation of new clean energy technology companies and jobs.

On the research side federal budgets have continued to rise in the energy sector, and through MEI^2's leadership Maryland universities are among the top in federal funding for energy research. UMD received a record 10 DOE ARPA-E awards this year alone, bringing the total to 33 awards for $74M since the agency's creation in 2009. Promising new areas of funding include the recently launched Intelligence-ARPA (IARPA) energy storage program with MEI^2/UMD a key partner in two out of the eight teams selected for the program receiving $4M. In addition, MEI^2 developed several local, national, and international partnerships and contracts in support of the Institute's Energy Research and Innovation foci. This is demonstrated domestically by the UMD lead Center for Research in Extreme Batteries (CREB) with the U.S. Defense Appropriations Act allocating $10M for CREB in both FY20 and FY21. Internationally this is demonstrated by the $18M U.S. Israel Bilateral Industrial R&D (BIRD) Foundation award creating the U.S.-Israel Solid Energy Consortium (UISEC) led on the U.S. side by UMD.

Moreover, since MEI^2's creation in 2017 it has helped obtain over $79M in federal energy research awards to the State of Maryland, ***a 33X rate of return on Maryland's SEIF investment in MEI^2*** during that time-period.

As Maryland continues to benefit economically from these federal priorities in energy research, MEI^2 is also capturing innovations from this research and focusing them towards the growth of in-state clean energy development and manufacturing firms within the State of Maryland. MEI^2 and its Energy Seed Grant program have partnered with MEIA and its programs (assisting start-up creation; helping secure grants and venture funding for those companies; and providing in-kind marketing, legal, accounting services and support). ***This MEI^2/MEIA partnership has resulted in fifteen new clean energy companies being created in Maryland.*** Moreover, two of these companies (among the 17 MEI^2 Energy Seed Grants awardees) ***InventWood and Ion Storage Systems were recently named to Governor Hogan's Future 20 company list***, attracting significant follow-on investment and scaling of manufacturing in Maryland.

The contributions of MEI^2 to achieving Maryland's clean-energy and sustainability goals while advancing the Maryland innovation economy should be clear. However, ***depending on the next legislative session this will either be the last year of MEI^2 or the beginning of an even greater emphasis by Maryland on advancing a clean energy innovation economy.***

INTRODUCTION

Developing and deploying clean energy technology is crucial to producing affordable, reliable energy while reducing CO_2 emission levels, and thus critical to establishing a more sustainable world. Change in federal leadership in 2021 renewed the push for a clean energy revolution and expansion of the U.S. renewable energy sector. The clean energy sector generates hundreds of billions of dollars in economic activity and offers the U.S. a tremendous economic opportunity to invent, manufacture and export clean energy technology. The Biden Administration has set a goal to reach 100% carbon pollution-free electricity by 2035 through deploying electricity generating resources, transmission, and energy storage and leveraging the carbon pollution-free energy potential of power plants. Additional jobs will be created through supporting efficiency upgrades and electrification in buildings and investing in new technologies to reduce emissions associated with construction and transportation. Creating an electric charging infrastructure and advancing research, development and deployment efforts that drive forward renewable fuels for applications like aviation, rail and other transportation infrastructure will also boost employment and the economy all while reducing emissions.

U.S. Energy Secretary, Jennifer Granholm, and the Department of Energy (DOE) are committed to investing in innovation to improve and broaden the set of solutions to deploying affordable, reliable and resilient clean energy technologies and has focused on the manufacturing sector of the U.S., noting that "Manufacturing is at the heart of the American economy – providing good-paying jobs and creating the products that we rely on in our everyday lives." Helping reestablish U.S. manufacturing leadership while scaling up the technologies will reduce the country's collective carbon footprint and address climate change.

U.S. Secretary of State, Anthony Blinken, visited the University of Maryland (UMD), in August 2021, where he acknowledged the tremendous impact UMD innovation has played in the state and federal realm by stating, "The innovation happening here and at thousands of colleges and universities across America is a huge source of our strength – and whether America protects and invests in our strength at home is going to determine whether we remain

U.S. Secretary of State, Anthony Blinken, visits with UMD Clark School students in the Nano FabLab.

strong in the world and deliver results for the American people." He also specifically identified clean energy investment as key to the new federal infrastructure plan.

In support of these initiatives, the State of Maryland continues to demonstrate its dedication and leadership to more sustainable sources and uses of clean energy. Several bills passed in the 2020-21 legislative session demonstrate the state's commitment in shifting from fossil fuels towards clean energy and transportation. The Public Service Commission must now consider the climate effects and emissions in its regulation of gas, electric, telephone, water, and sewage disposal companies. When evaluating electricity generation, a project's impacts on greenhouse gas (GHG) emissions must be consistent with the state's reduction goals, which means cutting emissions by nearly 60% from 2006 levels by 2030, and reaching net-zero emissions by 2045, as outlined in the recently published 2030 Greenhouse Gas Reduction Act Plan.[1]

The State of Maryland is also committed to ensuring equitable access of clean power to limited income families, boosting solar production, and electrifying the state transit fleet. For those that generate their own electricity (i.e. through the use of solar panels) energy credits will not only save people money, but increase the amount of energy available on the grid. Furthermore, by 2023, all buses purchased for state transit must be zero-emission, thus providing economic, health and environmental benefits to all.

The Maryland Energy Innovation Institute (MEI^2) is actively engaged in helping the State attain these goals by investing in and coordinating interdisciplinary energy research and development (R&D) across the University System of Maryland (USM). Significant advances have been made in new solid-state and aqueous batteries for advanced energy storage, advanced wood material innovations, advanced transformers for energy routers, meta-cooled fibers for personal thermal control, novel geared infinite variable transmission for tidal power, industrial hemp biomass for biofuels, all with promising commercialization potential.

MEI^2 early stage innovation technology investments have paid off in terms of a tremendous increase in federally funded energy research. The U.S. DOE Advanced Research Projects Agency - Energy (ARPA-E) was formed in 2009 to specifically advance U.S. energy innovation. Since its inception in 2009, UMD has participated in 33 projects. In the past year alone, ten awards (for $13M) were received bringing the total to over $74M in ARPA-E funding for UMD participating teams. An additional $2.25M in funding from DOE's Basic Energy Science office was received for work on thin film platforms for advancing the science in solid state energy storage. Recently IARPA (Intelligence ARPA) started its first program on energy storage and UMD won 2 (out of 8 total) awards this year for ~$4M.

[1] https://mde.maryland.gov/programs/Air/ClimateChange/MCCC/Documents/MCCCAnnualReport2020.pdf

MEI^2 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 new U.S. - Israel Bilateral Industrial Research and Development (BIRD) Foundation Energy Storage Consortium, a $18M center with multiple academic and industry partners in Maryland and Israel. MEI^2 is also leading the Center for Research in Extreme Batteries (CREB) in partnership with the Army Research Lab in Adelphi, MD, and has been instrumental in adding industrial and academic partners as well as attracting an additional $10M to CREB in this year's U.S. Defense Appropriations Act (for a total of $20M in FY20 and FY21).

Since its creation in 2017, MEI^2 has helped obtain over $79M in federal funding for the State of Maryland economy. Thus, based on the share of the Strategic Energy Investment Fund (SEIF) that supports its activities (~$600K/yr), ***MEI^2 has demonstrated a 33X return to the State based on federal research funding alone***.

In addition, during that same time-period MEI^2 used its share of the SEIF to award $400K/year in Energy Seed Grants to USM energy spin-off companies, for a total of 17 grants to date. Moreover, through its programs and seed grants ***MEI^2 helped launch 15 companies*** in the State of Maryland which have received additional private investments and ***two of which were selected as Maryland's Future 20 by Governor Hogan and the Maryland Department of Commerce***.

MEI^2 ADVISORY BOARD

The MEI^2 Advisory Board is composed of nine members including: (1) the director of the Maryland Energy Administration (MEA) and the chair of the board of directors of the Maryland Clean Energy Center (MCEC); and (2) seven members selected based on expertise in energy technology commercialization, the clean energy industry, venture capital financing and energy research.

The MEI^2 Advisory Board convened in July 2021 for a full day of presentations articulating the resources and success of MEI^2, as well as the progress of near-term

FY2021 Advisory Board

Victor Der, Board Chair
Assistant Secretary of Fossil Energy, U.S. DOE (retired)
Ellen Williams, Vice-Chair *University of Maryland Distinguished University Professor, Former Director, ARPA-E (DOE)*
Scott Dupcak
Constellation Ventures Technology
Steven Freilich
Dupont Central Research and Development
Abigail Hopper
President & CEO, Solar Energy Industries Association
Geoff Oxnam
Chair of the board for MCEC
CEO, American Microgrid Solutions
David Rapaport
Siemens Corporate Technology
Mary Beth Tung
Director, Maryland Energy Administration

goals including final results from the third round of energy seed grant funding and introductions to the fourth round of seed grants. Outcomes and recommendations from the 2020 Advisory Board meeting were discussed as well. The Advisory Board confirmed in their letter (Appendix 2) that MEI^2 has catalyzed significant advancement in research and innovation of advanced clean energy technology toward greater economic growth in the state of Maryland. As stated in their letter the Advisory Board was impressed by MEI^2's progress in research and its excellent progress in implementing the Advisory Board's recommendations from the previous year, while identifying the ongoing effort to use relevant key performance indicators as metrics against the program goals.

The Advisory Board made the following recommendations for FY21 with the aim of MEI^2 achieving its full transformative, scholarly, and financial potential:

1. **Align MEI^2 Budget and Strategic Planning direction with MEI^2 Report recommendations:** *To the extent practicable, align MEI^2 budget and strategic planning with recommendations in the 2019 MEI^2 Report to the Governor and Legislature with the aim of building momentum around a "game plan" where MEI^2 investments in clean technology innovation are part of the State's economic strategy through innovation to provide near-term and sustainable results/benefits.*
2. **Seed grants relative emphasis on Phase-1 vs Phase-2 awards given limited funding:** *The Advisory Board recommends funding allocations to reflect an emphasis on early Phase-1 clean energy research projects while the Seed Grant fund budget remains constrained. In so doing, MEI^2 should continue the trend towards broadening the range of clean energy technology topics; maximizing diversity of universities participating; MEIA engagement is encouraged for Phase-II proposals*
3. **Alternate platform strategies for outreach events given current COVID-19 pandemic impacts:** *Virtual platforms and social media engagement should be considered; outreach should include continued efforts to inform and engage State legislators who can champion clean energy innovation for the State as well as MEI2's mission and goals.*
4. **Seek alternative funding sources that leverage industry, academia, and government partners**.

Outcomes and results from these recommendations are discussed further in this report.

CLEAN ENERGY TECHNOLOGY DEVELOPMENT AND DEPLOYMENT IN MARYLAND

Maryland has the requirements for a successful energy innovation ecosystem, but has lacked strategic focus, support, and coordination, all of which MEI^2 is working to build. Scientific and funding recommendations to create a robust clean energy ecosystem in Maryland were outlined in the MEI^2 mid-term report delivered to the Governor and State Legislature at the end of 2019. The report concludes that given the evidence regarding

support and outcomes in states similar to Maryland, the State could accomplish a ten-year goal of doubling the rate of formation of clean energy firms each year while cutting in half the rate at which firms fail. Spending for early innovation stages, rather than just deployment of commercial technologies developed/commercialized elsewhere, along with investment to provide developmental support to clean energy firms would enhance economic growth along with additional societal benefits of using clean energy technologies.

For example, ***Maryland ranks first in the U.S. in per-capita university R&D expenditures***, and second in overall per capita R&D spending; however, 85% of Maryland innovation focused spending is on health-related technologies, making it ***dead last in the U.S. in terms of diversity in innovation spending***. Moreover, while Maryland spends over $400M/yr on energy related programs, prior to MEI[2], none of the funding supports in-state development of energy innovation firms. Therefore, a ***huge opportunity exists for Maryland if it diversified its innovation spending to include an emphasis in clean energy technologies***.

Following publication of the report, informational meetings were held with State Legislators regarding potential implementation of its recommendations. From those discussions, House Bill 1426 and Senate Bill 739 were introduced by Delegates Qi, Korman, Barve, Brooks, Crosby, Fraser-Hidalgo, Lierman, Queen, Rogers, and Walker and Senator Feldman, respectively, were introduced in the 2020 Legislative session. Unfortunately, positive legislative action for HB1426 and SB729 were unable to come to a full vote due to the legislative shutdown related to COVID-19.

SENATE BILL 460

C8 lle1742
CF HB 419

By: **Senator Feldman**
Introduced and read first time: January 20, 2021
Assigned to: Finance

Committee Report: Favorable with amendments
Senate action: Adopted
Read second time: March 13, 2021

CHAPTER _____

AN ACT concerning

Economic Development – Advanced Clean Energy and Clean Energy Innovation Investments and Initiatives

FOR the purpose of altering references to the term "clean energy" to be "advanced clean energy" for purposes of certain provisions of law concerning the Maryland Clean Energy Center and the Maryland Energy Innovation Institute; altering certain findings of the General Assembly, the purposes of certain provisions of law concerning the development of clean energy industries in the State, and the purposes, powers, and duties of the Center and the Institute to include certain actions supporting clean energy innovation; designating the Center as the State green bank; altering the membership of the Board of Directors of the Center; authorizing the Center to enter into certain financing transactions with, on behalf of, or for the benefit of certain State agencies for certain purposes; requiring the Department of General Services and the Department of Budget and Management to work with the Center for certain purposes; requiring the Maryland Technology Development Corporation and the Institute to coordinate with each other in supporting certain technology companies; requiring the Institute and the Center to implement a certain accelerator program in a certain manner and to consult with certain State agencies; altering a certain reporting requirement to include certain information regarding clean energy innovation in the State; altering the purposes of the Maryland Strategic Energy Investment Fund to include providing a certain amount of funding each fiscal year to the Maryland Energy Innovation Fund; clarifying the amount of certain funding provided in a certain fiscal year; specifying the manner in which the funds may be used; providing for the elimination of the

EXPLANATION: CAPITALS INDICATE MATTER ADDED TO EXISTING LAW.
[Bracketed] indicates matter deleted from existing law.
Underlining indicates amendments to bill.
~~Strikeout~~ indicates matter stricken from the bill by amendment or deleted from the law by amendment.

In the following 2021 Legislative session, House Bill 419 and Senate Bill 460, entitled Economic Development – *Advanced Clean Energy and Clean Energy Innovation Investments and Initiatives*, were introduced by Delegate Qi and Senator Feldman, respectively. The bills identified Energy as an economic opportunity while broadening the definition of included energy technologies. It also removes the sunset date of MEI[2] funding and increases its funding to $2.1M/yr with a specific focus on innovation. The bill received favorable testimony from industry, academia and others, as well as strong bipartisan legislative support with a 97 to 40 vote in favor in the House of Delegates and a unanimous vote in favor by the Maryland Senate. Unfortunately, despite overwhelming support, Governor Hogan chose to veto the bill.

Given Maryland's energy research leadership, and the role MEI[2] provides in translating this research to energy innovation and company formation, clean energy could be a major growth area for the State of Maryland economy with appropriate innovation infrastructure. Thus, based on MEI[2]'s 33X rate of return rate on its share of the SEIF funds, the ***MEI[2] is hopeful the recent veto will be overturned; otherwise, this will be the last year of Maryland funding for MEI[2] and its work to advance the Maryland Clean Energy Innovation Economy.***

ADVANCING THE MARYLAND ENERGY INNOVATION ECOSYSTEM

MEI[2] continues to drive Maryland energy innovations in partnership with MTECH, TEDCO, UM Ventures, the Maryland Clean Energy Center (MCEC), and the Maryland Department of Commerce. MEI[2] has been extremely active advancing Maryland university energy research (sections to follow), but more than that in mentoring Maryland university energy award winners in technology commercialization from proposal stage to post award results including the launch of several Maryland energy companies.

Maryland Energy Innovation Accelerator

Launched within the MCEC portion of MEI[2] in 2019, the Maryland Energy Innovation Accelerator (MEIA) now has three levels of support for budding companies: pre-accelerator, for concepts that are still lab-based but whose inventors think may have market potential; launchpad, for researchers with published work and working prototypes or processes interested in a launching a start-up but not sure where to go next; and the full accelerator, for startups that are looking to get their first private investment for product launches. MEIA currently hosts 10 startups, including Alchemity, whose technology converts methane to fuels using a highly efficient single-step reactor, and PulseIQ!, an energy management and information service company that leverages big data and analytics to reduce costs and optimize climate control systems in older structures.

Maryland Clean Energy Company Formation

Fifteen energy innovation companies have been founded and advanced through association with MEI[2] and/or its partnership with MEIA. Among these companies two in particular are of note as ARPA-E and MEI[2] Seed Grant Awardees, and their subsequent recognition by the State of Maryland. In November 2020, Governor Hogan announced Maryland's Future 20, a list of innovative startups from various industries that have the potential to play an important role in the state's economic growth. Two of those twenty companies, InventWood and Ion Storage Systems, got their start at the MEI[2], and are recipients of the Energy Seed Grant program. More than 125 nominations were received from the business community and general public, and the final list was selected based on a variety of factors, including innovation, future growth potential, the company's Maryland story, and "wow" factor.

- **InventWood** is the result of research and technology developed by MEI^2's Dr. Liangbing Hu, Herbert Rabin Distinguished Professor at UMD under ARPA-E and other federal research awards. Their cellulose-based nanotechnologies are transforming today's most commonly-used products and creating superior, natural goods while building a more sustainable future. Currently there is approximately a $50-70M market opportunity in the wall plank industry, and commercial flooring has an even larger opportunity. InventWood makes it more efficient to process, but manufacturing scale up in a cost-effective way is key. There are ways to make the technology useable for the exterior, but the current MEI^2 Phase 1 seed grant process is more of an interior application and with additional venture capital funding underway, the company is rapidly expanding.

- **Ion Storage Systems** (ION) is the result of research and technology developed by MEI^2 director and UMD Distinguished University Professor, Dr. Eric D. Wachsman, under ARPA-E and other federal research awards. ION is commercializing solid-state battery technology that is safer, lighter, and enable form factors with tighter packing density that enhance system performance for applications ranging from defense and consumer electronics to electric vehicles and greater renewable energy deployment on the grid. A $100K MEI^2 Phase 1 seed grant to expedite the cell packaging helped take its technology to the next level and attract an $8M VC seed-round investment in 2019. ION has since received multiple federal and private contracts (including the U.S. Advanced Battery Consortium and a major European automotive company for development of automotive batteries). ION under the leadership of CEO Ricky Hanna (former Apple Executive Director of Battery Operations) is currently building and delivering commercial evaluation samples, has moved into a new, larger 20,000 ft^2 facility in Beltsville, MD and employs 22 high skilled scientists, engineers, and technicians. The company will see its first company revenue in 2023 (4 years since initial VC investment) which is an extremely short time compared to most energy start-ups.

In addition, several other companies have flourished under MEI^2 and MEIA programs:

- **AquaLith Advanced Materials** exclusively licensed a portfolio of lithium-ion battery patents from UMD. The technology utilized in these batteries allows for the storage of significantly more energy and offers lower production costs since they are formulated without transition metals. The highly concentrated aqueous electrolytes have been demonstrated to work at temperatures below -50C, which enables outdoor applications at the north and south poles. Additionally, the water-based electrolyte dramatically reduces the risk of fire in the event of a short circuit. The technology includes a new ultra-high energy cathode, a novel silicon anode and an aqueous electrolyte. AquaLith co-founders, Ted Olsen and Greg Cooper, have significant experience growing Maryland companies. AquaLith's development team is working out of space at UMD in College Park while the company builds its headquarters and factory at a site, yet to

be announced, along the I95 corridor between Riverdale and Baltimore, Maryland. AquaLith is setting out to bring the new batteries to a lithium-ion battery market that was valued around $44 billion in 2020 and is expected to more than double by 2025 as devices and other products develop.

- **NanoDirect** provides refined nanoelectronic materials intended to offer for future integrated circuit, solar conversion, energy storage, and sensor technologies. The company has developed a proprietary technique which has nanoparticle processing and purification, materials characterization and analysis and printed electronics, enabling in a new generation of flexible electronics by providing scalable manufacturing of highly refined nanoelectronic inks. Working with Susanna Thon's group at John's Hopkins, they received a Phase I energy seed grant in 2018 and a Phase II energy seed grant in 2021. To date, the company has received an additional $2M in SBIR and state funding and has launched its first Ag nanowire ink product, Direct Silver ™, and currently has samples out to 4 commercial and academic research groups for beta testing. The nanotechnology can be used as electrodes to offer either the nanoparticle inks or the thin films made from the inks as products for customers in the solar and lighting industries. The rapidly expanding Building Integrated Photovoltaic (BIPV) market and the global organic light emitting diode (OLED) materials market is growing exponentially. The market is valued at $6 billion USD and is expected to reach $25.7 billion by 2023. NanoDirect currently has exclusive licenses to 3 granted US patents assigned to Johns Hopkins University.

- **Mobile Comfort's** product the Roving Comforter (RoCo) is the world's first personal air conditioner. Mobile Comfort, a UMD spinoff and ARPA-E award winner, was established to bring the technology to market and has patents approved in the U.S. and European Union. Recipients of a Phase I energy seed grant in 2018 and a Phase II energy seed grant in 2019, they have received $1.5M in private investment to develop a residential version. Contracts are currently pending with farming and construction industries.

- **HighT-Tech** is the result of research and technology developed by MEI^2's Dr. Liangbing Hu, Herbert Rabin Distinguished Professor at UMD. HighT-Tech creates oxide powders and ceramic membranes using its proprietary high temperature shock sintering process. This process reduces sintering time, reduces materials loss, and can operate via roll-to-roll manufacturing to greatly enhance output speed. It is the recent recipient of the 2021 Nature Research Spinoff Prize ($36K) for its next-generation discovery platform to address an important technical bottleneck in industrial catalyst development. HighT-Tech is also a partner in two current DOE ARPA-E awards.

- **Cykloburn** is developing a low-emission combustion system that converts biomass into energy. The Cykloburn technology was invented by Dr. Seong Lee at Morgan State University and addresses the negative environmental effects from excess poultry litter while generating renewable energy. They have received $500K in additional funding

from TEDCO and SBIR awards in addition to MEI^2 Phase 1 energy seed grant funding in 2020.

- **BuildSci** recognizes the need for communication and collaboration in building operations to make every building smart. The services and products stand at the unique nexus of buildings, people and technology aimed at sustainable savings. The BuildSci Analyst is a platform for facility managers to "train" buildings to be better versions of themselves. This allows for strategic investment of resources, human and financial, into targeted and sustained improvements. They are the recipients of an MEI^2 Phase 1 energy seed grant in 2021, and an MII Phase 1 award. BuildSci Analyst was honored in 2019 with an Innovation Award for Higher Ed Energy Data Management.

- **Alchemity** is revolutionizing the $60 billion gas-to-liquids (GTL) processing through a novel one-step non-oxidative membrane reactor. This reactor represents a step change in process intensification over the existing technology developed 95 years ago by combining three conventional processes into a single step, thereby eliminating much of the massive capital requirements to build new GTL plants. It was the recipient of a 2018 MEI^2 Phase 1 energy seed grant and won $1000 prize for "Most Investible Start-up" from the Maryland Department of Commerce in the first round of the MEIA Accelerator pitch event.

- **Navita Tech** Hybrid Vertical Axis Wind Turbine (HVAWT) is a hybrid of two classic vertical axis wind turbine designs. The Navita Tech turbine outperforms traditional wind turbines by providing lower cut-in speed, higher power co-efficient, less noise, and longer system life due to its more rigid structural design. Distributed wind customers require turbines to be placed where the customer needs them, not where the wind resource is optimal. Thus, the best turbine is the one that performs best under the widest variety of conditions. Navita Tech, founded at UMBC, is currently with MEIA in the launchpad phase and was the recipient of a 2019 MEI^2 Phase 1 energy seed grant.

- **Manta Biofuels** is commercializing a technology and process for producing algae-based biofuels that was developed at the University of Maryland Center for Environmental Science (UMCES). These algal biofuels are produced using a low-cost high-throughput magnetic harvester with proprietary nanoparticles, as well as a low-cost hydrothermal liquefaction reactor. These innovations, along with a simplified biomass growth process, enable Manta Biofuel to produce a product that is cost effective in a competitive market. They have raised $3M in funding, including a DOE SBIR Phase II award, and are currently working on developing a 15-acre pilot scale facility.

- **ACTIVEcharge** offers an innovative approach to monitoring wind turbine blade health. This technology converts vibrational and rotational energy into electrical energy so that the sensors and data transmitters mounted hundreds of feet inside the blade do

not need batteries or any additional electrical equipment to power the sensors. The company has attracted two rounds of funding through TEDCO's Maryland Innovation Initiative and is actively developing the product while reaching out to potential partners. ACTIVEcharge has also received a $25,000 Strategic Sponsorship from Exelon.

- **PulseIQ!** is a unique and innovative energy management and information service company. It delivers significant energy efficiency and cost savings by utilizing the power of big data and analytics from their proprietary networked thermostats combined with a state-of-the-art suite of HVAC sensors, controls, automation and optimization. Since completing the MEIA program, PulseIQ! has entered into its first commercial contracts with large new clients, including a 433-unit condominium property in Washington, DC and a 249-unit condominium in Silver Spring, MD. PulseIQ! Currently has a growing and robust sales pipeline and new technical developments that will solve previously unaddressed problems for the multifamily property market.

- **CUPTech – Catalytic Upcycling of Plastics Technologies** is a startup from Johns Hopkins University whose plastic upcycling technology converts Types 3-7 plastics into BTX liquids, which are high-value hydrocarbons used to make polymers, plastics and fuels. The methodology utilizes novel catalysts and processes to convert plastics to BTX at high energy conversion and molecular transformation efficiencies. This work is currently supported by the ARPA-E REUSE project. They are currently working to bring the technology to market.

- **ATP-MD, LLC** is one of 10 startups in the nation selected for funding by the Exelon Foundation's Climate Change Investment Initiative. The Maryland-based company will commercialize its patented CRBBP Process, by which it plants and multi-tasks special bio-crops to do good things for the health and well-being of people and the planet, less expensively. Benefits will include combating Climate Change and converting the resulting plant material (biomass) into cost-advantaged bio-products. The company was also named 2020 Champion of Maryland Manufacturing.

Energy Innovation Seed Grant Program

MEI^2 is a scaffold: a fertile plot for growth. But the seeds must come from inventors, business leaders, thinkers, and network builders across the state—a diverse cohort of people and ideas to build out the vision of a cleaner, more efficient-energy future across not only Maryland, but the world. Thus, MEI^2 initiated a seed grant program to bridge the gap between academic transformative laboratory research results and the prototype demonstrations necessary to obtain investor interest. This call for seed grants is issued annually and open to all academic institutions in Maryland. Annual seed grants are awarded by MEI^2 at two levels: phase I grants up to $100,000, and phase II up to $200,000 for projects that received prior seed funding. Since its 2017 inception, 17 companies and university researchers have received funding from the seed grant program, including

partners at Morgan State and Johns Hopkins universities, the University of Maryland Baltimore County, College Park, and the Eastern Shore.

It is expected that the seed grant projects advance energy technology and economic growth in Maryland in partnership with a local university faculty or student led company. The device or process should have appropriate intellectual property protection (invention disclosure, patent application, or patent) filed with the applicant institution. At the end of the one-year project, a report that describes work done and includes a commercialization plan are required. The plan should include a clear market assessment and strategy; a viable revenue model; and a strategy for financing the plan.

The MEI[2] Investment Committee was created to independently oversee the solicitation and review of the Energy Innovation Seed Grants and other activities that support the Energy Investment Fund. Projects are reviewed for: 1) the likelihood of attracting outside funding, 2) innovative and scholarly merit, and 3) potential for commercial readiness. In addition, if approved by the MCEC Board, the Investment Committee could advise MCEC on effectively investing capital in Maryland start-up companies.

FY2021 Investment Committee

Ellen Williams, Vice-Chair *University of Maryland Distinguished University, Former Director, ARPA-E (DOE)*
Jelena Srebric
Acting Associate Dean for Research, UMD A. James Clark School of Engineering
Eric Chapman
UMD Assistant Vice-President for Research and Development
Julie Lenzer
Associate Vice President of Innovation and Economic Development and Co-Director of UM Ventures
Arti Santhanam
Executive Director, Maryland Innovation Initiative, Maryland Technology Development Corporation (TEDCO)

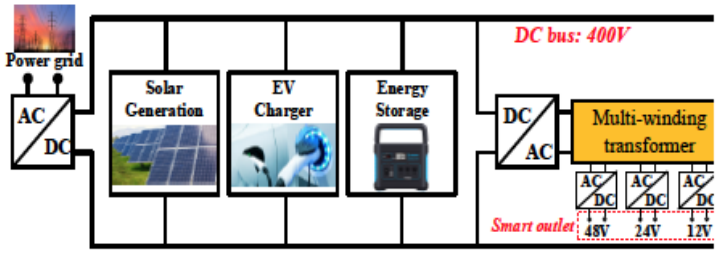
2020 Seed Grant Results and Future Development

In March 2020, the Investment Committee awarded $387K to six projects across the state system of Maryland, described below. Their mid-term reports were delivered in December 2020, with final reports and updates provided to the Advisory Board in July 2021. Due to COVID-19 research restrictions, several of the awards will continue through September 2021.

- **Multi-Winding Planar Transformer for Energy Router in Smart Homes**; Lead PI: Alireza Khaligh, Professor of Electrical and Computer Engineering, University of Maryland College Park; Partnering Company: AmpX Technologies, Inc.

  Transformers and magnetics components are ubiquitous to power electronic systems, which convert power between different voltages and frequencies used by electrical power sources and loads. This project is the first effort to design a 4-windings planar transformer, which can take an input of 400V (typical of an EV battery or solar system)

and provide three output voltages of 48V, 12V, and 5V, which are useful for residential energy router systems. This unique multi-active-bridge converter coupled through a multi-winding transformer has the advantages of high efficiency, high power density and lower cost than multiple discrete power converters. The final 1kW/100kHz converter prototype in this project was tested with the peak efficiency of 98.4% and a full-power efficiency of 97.8%, and a power density of 1.25kW/L. The initial market for the proposed planar multi-winding transformer include the energy routers for future smart homes, as well as residential and commercial buildings.



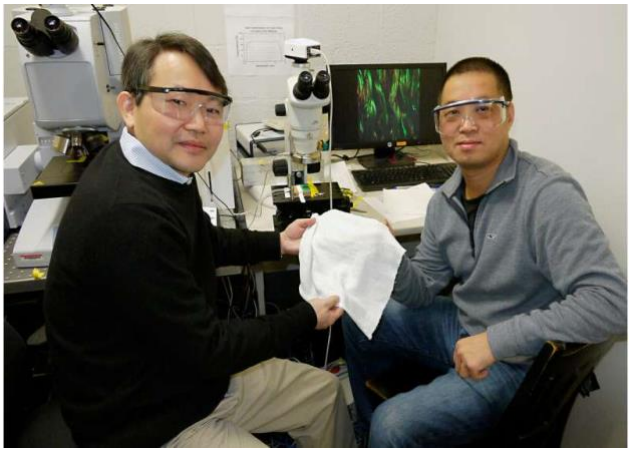
Power conversion architecture of an energy router for smart residential buildings.

- **Mind Your Feet – Knitting Meta-Cool into Socks**; Lead PI: YuHuang Wang, Professor of Chemistry and Biochemistry, University of Maryland College Park; Partnering Company: Coolwave Dynamics, LLC

  The project proposed the production of an energy-saving, thermoregulating sock prototype with a close collaboration between the university lab and Coolwave Dynamics, LLC, a spinoff from UMD that is dedicated to bring this energy-saving technology to the market. Because feet present an efficient spot for heat exchange and the cost of manufacturing will be reasonable even at this early stage of the technology, this thermoregulating sock will serve as a highly demonstrable prototype to help advance the Meta-Cool technology, which is a textile that provide thermal regulation through responsive changes in fabric infrared transmission (and hence heat exchange). The project included optimization of meta-cool fiber manufacturing, knitting and characterization of metal-cooling socks, and development of a commercialization plan. This work has led to a new manuscript and potentially new IP, and additional manufacturing trials are planned.

  On the commercialization side, Coolwave Dynamics continues to interact with potential partners, including Under Armour. Talks with multiple interested companies (mostly international) also occurred. The desire is to first bring this technology into selected markets of sports apparel and ultimately expand to other areas of applications where thermoregulation is critically needed. Over the next five years, Meta-Cool will advance to the point of being ready for large-scale manufacturing, with multiple

products developed for selected markets. Coolwave will not only bring a new level of thermal comfort to everyone, but will also save energy and help reduce greenhouse gas emissions. Cost analysis predicts that at large scale the cost of Meta-Cool production will be very competitive, even compared with commodity and less "smart" textiles. However, for early adoption, it will be necessary to target high value-added avenues to balance the initial high costs associated with smaller scales and the R&D needed for integration of our technology into specific application areas.



Professor YuHuang Wang (left) and Physics Professor Min Ouyang (right) hold a swatch of their new fabric that can

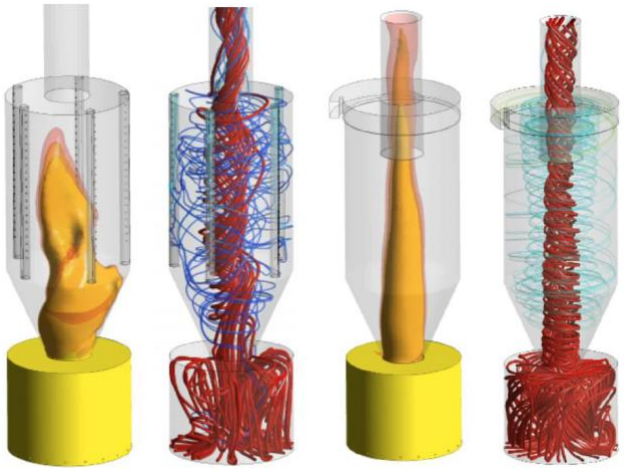
- **Utilizing Industrial Hemp Biomass for High Throughput Biofuel Production in Maryland**; Lead PIs: Jurgen Schwarz, Professor and Chair, and Sadanand Dhekney, Professor, Agriculture, Food and Resource Science, University of Maryland Eastern Shore; Partnering Company: Atlantic Biomass Company

The Atlantic Biomass fermentable sugars enzyme hydrolysis process has demonstrated that the production of commercially viable concentrations of biofuel/ bioproduct sugars can be produced from hemp biomass grown in Maryland. The enzyme portion of the process has also been used to produce commercial levels of ethanol producing sugars from Energy Beets grown at the University of Maryland Eastern Shore. The salient feature of this system is its simplicity. Pretreatment, which is seen as a necessity in many biomass conversion systems, is not used. In addition, because of high cellulose to glucose conversion rates, cellulase enzymes have been identified as being available for additional rounds of processing after enzyme hydrolysis. Because hemp bioprocessing is in the beginning stages of development, many basic and applied research milestones had to be pursued, such as determining maximum hydrolysis biomass loading and determining commercial implications of hydrolysis on difference types of hemp biomass (leaves, stems by size, and main stalks). Data from this research will be used in the remaining time of this project to design and fabricate an integrated

demonstration hardware in the 5-liter range, in which ethanol will be produced and a number of experimental parameters will be optimized.

- **Swirl Stove: Swirling combustion for efficient wood burning**; Lead PI: Taylor Myers, University of Maryland College Park; Partnering Company: MF Fire Inc**.**

  Swirling combustion is a well-established pollution mitigation technology. Little work, however, has been done to extend that technology to solid fuels in general and cord wood stoves in particular. By the end of the project period, the team will have constructed a swirling combustion wood stove prototype, tested and iterated on the design, and performed official EPA and UL testing on the final design. Through 2020, the plan accomplished three tasks: (1) design several swirling wood stoves to test different swirl strategies; (2) perform computational fluid dynamics (CFD) simulations to test the viability of swirling flows in these designs; and (3) build an initial prototype by year's end. Early results from the CFD testing found that two approaches are most effective in generating swirling flames: vertical manifolds (left) and cyclonic swirling (right). The orange colored pictures indicate approximate flame locations while the red and blue lines are streamlines that track the swirling motion of the air. Physical prototypes will be used to test these configurations.



- **Poultry Litter to Energy**; Lead PI: Seong Lee, Industrial and Systems Engineering, Morgan State University; Partnering Company: Cykloburn Technologies, LLC

  The Cykloburn system is a farm-site solution that delivers energy in the form of electricity and heat for the chicken houses. In addition to the energy savings, replacing the currently used propane heating with a lower moisture radiator heating system from Cykloburn will lead to lower ammonia concentrations, improved bird health, and improved feed conversion ratios. The goal of this project is to advance the current pilot system into an automated prototype by updating the primary air system and optimizing

the overall combustion system. By demonstrating that the system can repeatably operate on multiple farms and a range of environmental conditions, the viability can be proven. The first two project milestones have been successfully completed. After conducting extensive testing using a plexi-glass chamber, an updated primary air nozzle design has been determined. The updated design has been fabricated and installed in the pilot system located on a farm outside of Salisbury. An period of testing to model system performance across a range of conditions has begun. Completion of the third milestone requires conducting extensive testing of the pilot system on the farm located just outside Salisbury. In late March, the team from Morgan State was conducting testing of the heat exchange system develop under a MIPS award. A crack developed in the heat exchanger that necessitated its replacement. A new heat exchange system has been fabricated and was installed on June 20th. Testing to complete milestone #3 is underway, and the project finished in September, 2021.

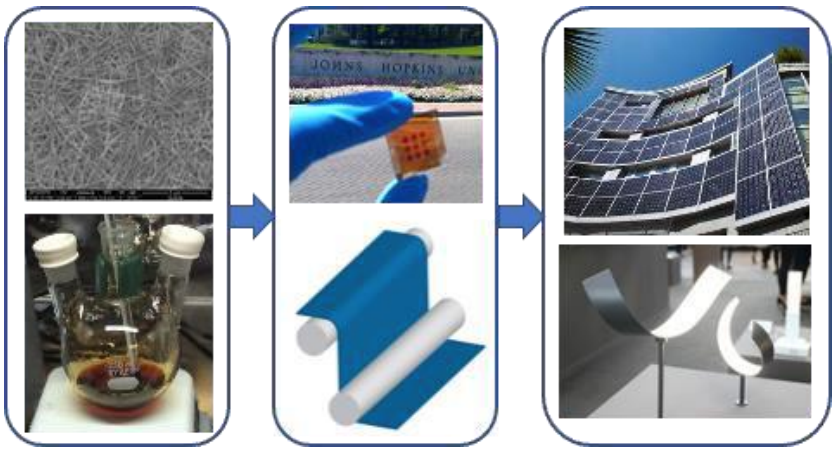
2021 Energy Innovation Seed Grants Awarded

In May 2021, four seed grant projects were awarded for a total of $400K; one of which is a Phase II project. Descriptions of each follow.

- **Scaled Electronic Inks as Transparent Conductors for the Solar Cell and Energy-Efficient Lighting Industries (PHASE II)**; Lead PI: Susanna Thon, Johns Hopkins University; Partnering Company: Nano Direct, LLC

  During the course of a Phase 1 Energy Innovation Seed Grant, electronic inks and scalable spray-cast manufacturing processes to form them into large-area films were developed and demonstrated. Here, we propose advancing this technology, performing final validation, and preparing for initial sales of our Ag nanowire product to commercial and academic research and development groups. Through market research, we have identified a specific need for both raw Ag nanowire inks and pre-manufactured transparent conductive films. By fulfilling both of these needs, we anticipate this project will enable us to penetrate deeper into the value chain. In of Q4 2020, NanoDirect has launched its first Ag nanowire ink product, Direct Silver ™, and currently has samples out to 4 commercial and academic research groups for beta testing. This initial product is part of our customer acquisition strategy for large commercial purchases of inks and to direct interest towards transparent conductive films (TCFs) using our products.

  Phase 2 funding will allow the group to demonstrate the advancement of the Ag nanowire inks product line and develop a new product line in pre-formed Ag nanowire thin films, opening up venture capital and angel network funding for follow-up investment, as well as traditional bank loans. The group has established relationships with the Chemical Angel Network, Sun Chemical, Arkema, and other potential investors. The project will support five clean-tech jobs and $900,000 in clean-tech business revenue in the state of Maryland by 2022.

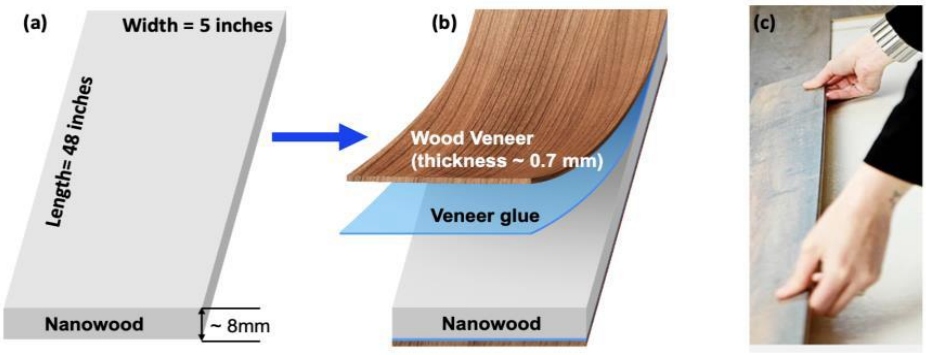


Project Concept: Solution-processed nanowire inks are formed into large-area transparent electrodes (left). This enables scalable manufacturing of flexible and color-tunable optoelectronic films (center). These films can then be used for

- **Insulating Wood Panels for Energy Efficient Wall Retrofits**; Lead PI: Amy Gong, University of Maryland College Park; Partnering Company: Invent Wood LLC

  Generally, there are two primary ways to renovate old buildings with new thermal insulation for improved energy efficiency: 1) completely remove the envelope of the building and replace it with new thermal insulation; 2) simply place thermal insulation panels on the interior or exterior of the building as an additional energy-efficient envelope. A promising alternative called Nanowood was developed by Prof. Liangbing Hu's group at UMD as part of his team's work in developing various advanced wood materials for green building applications. In this MEI^2 project, the team proposes to leverage Nanowood for a different application. Rather than focusing on an application for exterior building retrofits, they will focus on Nanowood-based 3-layer sandwich structures (Fig. 2) for interior retrofits. Commercial wood veneers will be used as the top and bottom surface protection to enhance mechanical durability.

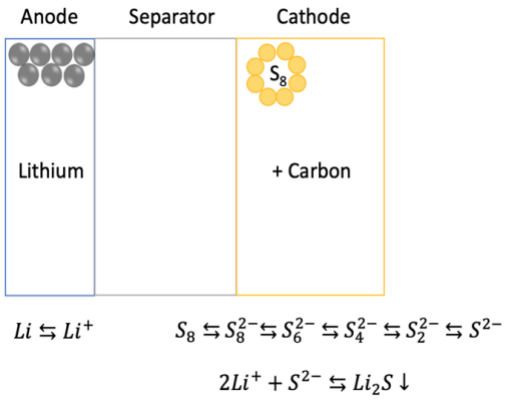
  Particularly, they will perform the following tasks for this MEI^2 project: (1) Fabricate 100 pieces of Nanowood through collaboration with Dr. Zhu at USDA Forest Product Lab using the fabrication process that is established by a SBIR project (Task 1), (2) Assemble and evaluate the performance (mechanical and thermal properties) of veneer-Nanowood-veneer sandwich structures as viable wood panel products (Task 2), and (3) Perform customer studies, market assessments and revenue/cost modeling of Nanowood insulation panels for energy efficient interior retrofit applications.



Veneer-Nanowood-veneer 3-layer insulation panels that can be used for interior retrofit wall applications with up to 10-20% energy saving.

- **A Digital Twin For Lithium-Sulfur Battery Management**; Lead PI: Hosam Fathy, University of Maryland College Park; Partnering Company: Digitalis Technologies

This project will develop a "digital twin" for lithium-sulfur (Li-S) batteries: a software tool that automates the modeling, monitoring, and control of these batteries' dynamics. The project is motivated by the ongoing rapid growth in multiple energy storage markets. Li-S batteries are well-positioned to capitalize on this growth, thanks to their potential to surpass existing lithium-ion technologies in terms of specific energy, cost effectiveness, and sustainability. Multiple companies are pursuing the commercial deployment of Li-S batteries, including startups plus one established global battery manufacturer. Incorporating a new battery chemistry into a commercial product requires a new battery management system (BMS) for monitoring and managing this chemistry. This is especially important for Li-S batteries, where aging phenomena such as polysulfide shuttle require online monitoring and control in order to maximize battery performance and longevity. The ultimate goal is to market the proposed technology through a Maryland startup company, *digitaLiS Technologies*. The target customers for this digital twin include: (1) Automakers (e.g., Ford, GM, FCA, Toyota, Tesla, etc.); (2) Manufacturers of portable consumer electronics (e.g., Apple, Samsung, etc.); and (3) Companies deploying stationary battery storage for power grid, distributed solar, and datacenter applications (e.g., Solar City, Google, Microsoft, etc.).The target customers for this digital twin include: (1)

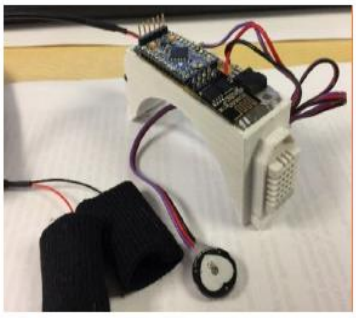


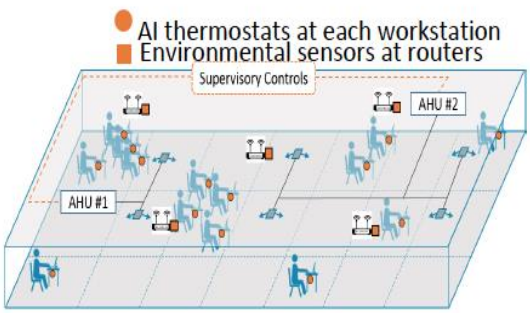
Components and reactions in an Li-S

Automakers (e.g., Ford, GM, FCA, Toyota, Tesla, etc.); (2) Manufacturers of portable consumer electronics (e.g., Apple, Samsung, etc.); and (3) Companies deploying stationary battery storage for power grid, distributed solar, and datacenter applications (e.g., Solar City, Google, Microsoft, etc.).

- **Translation of UMD Research Findings into an AI Thermostat Prototype for Thermal Comfort and Load Shedding**; Lead PI: Jelena Srebric, University of Maryland College Park; Partnering Company: Build Sci, Inc.

  The project is to create a prototype and demonstrate the effectiveness of AI thermostats in managing occupant driven electricity consumption in small to medium commercial buildings represented by UMD campus buildings. Specifically, two buildings, Tawes Hall (164,610 ft2 with 25% being office space) and Knight Hall (55,861 ft2 with 36% being office space), are to be each retrofitted with 50 to 100 AI thermostats, depending on the manufacturing costs, for a duration of three months. These two buildings were selected as they represent typical mixed-use campus buildings with offices, classrooms and a relatively small lab space. At present, work is done with the UMD Facility Management to implement class-schedule based controls for the classroom spaces in these buildings. Therefore, the proposed project will be able to test AI thermostat prototypes as an extension of the existing classroom controls retrofit.





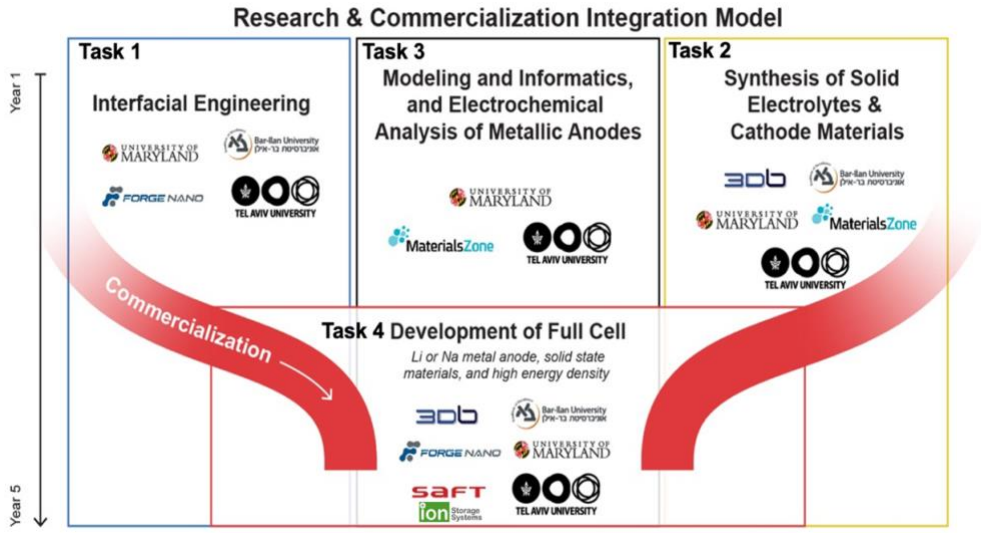
According to a recent market analysis done for BuildSci, the proposed AI thermostat has five broader market segments that include (1) Smart Thermostat Market, (2) Smart Building Market, (3) Building Management System Market (HVAC Control), (4) HVAC Market (Smart HVAC Systems), and (5) HVAC Controls Market (Dawnbreaker, 2019). Each of these market segments is a more than a billion dollars in size, and the first three segments having CAGR greater than 30%. The most immediate relevant market is the smart thermostat market estimated to be $1.285 billion in 2019 and $1.509 billion in 2020 with a CAGR of 32%. As a result of this market analysis, the team decided to focus future technology development the on smart thermostat market as an area of great opportunity for novel products that could be later expanded into service products for the smart building and the building management system markets.

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

MEI[2] leads the U.S. side of a $18.4M, five-year program, awarded by the U.S.-Israel Energy Center and managed by the Binational Industrial Research and Development (BIRD) Foundation. The BIRD Foundation manages joint research and development activities between U.S. and Israeli organizations. U.S. industrial partners on this project include Saft (located in MD), Ion Storage Systems (located in MD), and Forge Nano (located in CO). The Israeli side is led by Bar Ilan University (BIU), with additional team members including tel Aviv University, 3D Battery, and Materials Zone.



The contract began in September 2020. The project integrates knowledge-driven research with commercial-oriented translational work. The program acronym is the U.S.-Israel Solid Energy Consortium (UISEC) and web development is underway. (https://uisec.umd.edu). The technical focus is the development of Li and Na metal solid state batteries, through the development of novel solid ion conductors, coatings, and battery full cell approaches, as well as advances in the fundamental understanding of components and full cell behavior.

Center for Research in Extreme Batteries

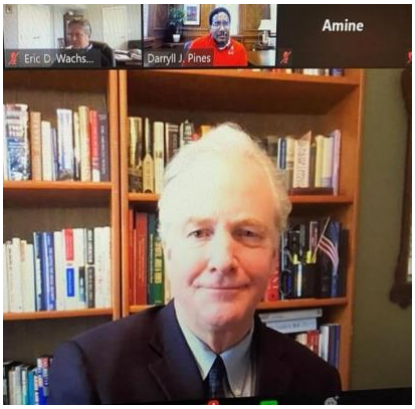
The Center for Research in Extreme Batteries (CREB) was created as a partnership between MEI[2] and the Army Research Lab (ARL) in Adelphi, MD, to develop advanced batteries for the extreme needs of defense, aerospace, and biomedical applications. It has

grown to include other Maryland partners including NIST, Saft, and Ion Storage Systems, as well as U.S. academic and national laboratory leaders in battery research including luminaries such as ***Nobel Laureate*** Stan Whittingham (for the invention of the lithium-ion battery) and U.S. ***National Medal of Technology and Innovation*** awardee Esther Takeuchi (for inventing the battery that powers all implantable cardiac defibrillators).

The FY20 U.S. Defense Appropriations Act provided $10M for CREB, with $2.8M going to ARL and $7.2M to UMD to collaborate and advance transformational Army batteries, and another $10M was appropriated in the FY21 Act. UMD leads a collaborative effort with academic, industry, and federal partners to foster and accelerate research for advanced battery materials, characterization techniques and technologies for extreme high energy & power densities, with extreme charging capabilities and extreme safety under extreme working environments to enable U.S. warfighter transformational overmatch for multi-domain operations. Dr. Eric Wachsman and Dr. Chunsheng Wang lead the effort at UMD. The focal themes including: Extreme Charging; Extreme Safety; Extreme Voltage; Extreme Evaluation; and Extreme Transformational Innovations to directly address the most challenging barriers to implementing this cutting-edge battery research to enable U.S. warfighter transformational overmatch for multi-domain operations.

CREB
CENTER FOR RESEARCH IN EXTREME BATTERIES

On January 15, 2021 over 140 people from more than 40 organizations across the U.S. virtually attended the biannual CREB meeting. U.S. Senator Chris Van Hollen, a keynote speaker at the meeting devoted to public service and clean energy, spoke to UMD's broader research efforts. He thanked the CREB family for doing this research during turbulent health and political times. "You have carried on steadily with important work to supply military with 21st century tools to push the boundaries of energy technology beyond what we thought possible," Van Hollen said. "This research will have huge benefits for defense and non-defense units alike." The senator acknowledged what has been done thus far, stating he was happy to help facilitate a way forward and the importance of political, academic and military partnerships.



RESEARCH FUNDING AWARD HIGHLIGHTS

Significant financial support of research into new energy technologies was obtained in FY21. Examples of these include CREB and BIRD above, as well as awards from DOE Basic Energy Science, two from IARPA, and ten from the DOE ARPA-E.

FY20 Major Research Funding

- **CREB ($20M)**
- **BIRD ($18M)**
- **10 DOE ARPA-E ($13M)**
- **DOE Basic Energy Science ($2M)**
- **IARPA ($4M)**

ARPA-E Awards

UMD continues to be among the top of all U.S. academic institutions in APRA-E awards. Since July 2020, ten additional ARPA-E projects received funding, bringing the total to 33 awards with over $74M in funding. These 10 projects include:

- **ULTIMATE - Ultrahigh Temperature Impervious Materials Advancing Turbine Efficiency**
  New Environmental - Thermal Barrier Coatings for Ultrahigh Temperature Alloys ($0.6M) The team will leverage a unique, ultrafast high-temperature sintering (UHS) method for gas turbine use in the aviation and power generation industries. (JC Zhao, MSE UMD)

- **REEACH - Range Extenders for Electric Aviation with Low Carbon and High Efficiency**
  Hybrid SOFC-Turbogenerator for Aircraft ($2.8M) The project will develop a hybrid gas turbine/fuel cell system that can be used to power large aircraft such as the Boeing 737 (Eric Wachsman, MSE / Chris Cadou, AE UMD)

- **ASCEND - Aviation-class Synergistically Cooled Electric-motors with integrated Drives**
  Advanced Electric Propulsion System ($1.8M) (Hugh Bruck, ME UMD)

- **HITEMMP - High Intensity Thermal Exchange through Materials, and Manufacturing Processes**
  Highly Compact Metallic Heat Exchangers for Extreme Environments ($2.2M) The project will develop a compact, extreme environment heat exchanger (EEHX) for application in supercritical carbon dioxide electric power generation cycles for hypersonic aircraft and land-based distributed power generation. (Hugh Bruck, ME UMD)

- **DIFFERENTIATE - Design Intelligence Fostering Formidable Energy Reduction and Enabling Novel Totally Impactful Advanced Technology Enhancements**
  MULTI-source Learning Accelerated Design of high-Efficiency multi-stage compRessor (MULTI-LEADER) ($0.6M) The project will work to accelerate the design of high-efficiency multi-stage compressors, via machine learning (ML), with considerations of aerodynamics, structures and additive manufacturability through their framework, MULTI-LEADER. (Mark Fuge, ME UMD)

Learning Enabled Network Synthesis (LENS) ($0.7M) The project will develop an AI-accelerated search technique, LENS, to quickly discover new design concepts for energy applications. (Mark Fuge, ME UMD)

Invertible Design Manifolds for Heat Transfer Surfaces (INVERT) The project will create inverse design tools for the development of enhanced heat transfer surfaces at reduced computational cost($1.4M) (Mark Fuge, ME UMD)

- **Special Projects**
  Advanced Catalyst Manufacturing Enabled by Direct Joule Heating ($0.5M) (HighT Tech/ Changwei Wang, MSE UMD)

  Electrothermal Conversion of Methane into Hydrogen and High-Value Carbon Fibers ($1.5M) Project will develop an energy-efficient, scalable approach to convert methane into hydrogen and valuable graphitized carbon fibers (GCFs) (JHU/Bing Hu, MSE UMD)

DOE Basic Energy Science

UMD will conduct a 3-year investigation "Thin Film Platforms to Advance Scientific Frontiers in Solid State Energy Storage," supported by $2.25M in funding from the U.S. DOE Office of Basic Energy Science through its materials chemistry program. The research is aimed at illuminating the fundamental science of electrochemistry at the nanoscale, which determines the power and energy performance of electrical energy storage devices. Gary Rubloff, a distinguished university professor in the Department of Materials Science and Engineering (MSE), is the principal investigator on the project. Paul Albertus (MEI^2 Associate Director), Sang Bok Lee (NanoCenter Director) and A. Alec Talin (MSE Adjunct Professor and distinguished member of the technical staff at Sandia National Lab) will serve as co-investigators. The research builds on unique directions of Nanostructures for Electrical Energy Storage (NEES), an Energy Frontier Research Center (EFRC) sponsored by the DOE-BES from 2009 to 2020 and funded for $27.2M. In the new DOE-BES program, researchers will exploit thin film fabrication techniques to create 3D structures capable of providing new measurements and insights currently inaccessible in conventional batteries. Some of these will address what architectural shapes and dimensions are favorable not only for power and energy, but for stability during charge/discharge cycling. Others are aimed at determining properties of important interfaces buried underneath layers of battery materials and identifying how ion behave when a battery is charging or discharging. Precision 3D battery architectures, controlled at the nanoscale, provide a unique opportunity to advance the fundamental scientific understanding of battery processes.

Intelligence ARPA (IARPA)

The Intelligence Advanced Research Projects Agency announced their first energy storage program in 2020. The program is entitled: Robust Energy Storage for Intelligence Logistics in Extreme, Novel and Challenging Environments (RESILIENCE). Planned research tracks include: (1) high power density and high energy density batteries for applications such as unmanned aerial vehicles (UAVs), and (2) batteries with long calendar life, super-

high reliability, power pulses on demand and a small size for field-based electronics. There are 3 phases of the program over the course of 4 years with very aggressive goals as part of the program. UMD is contributing to two of the eight projects funded. The first UMD project is for *high-energy and high-power batteries using multi-functional electrolytes and conversion cathodes*. The UMD budget is $3.25M over three phases including $1.23M for phase 1 which officially began on August 18, 2021. The 2nd project is based on *long calendar life for high energy, solid state batteries*. The UMD budget fort the 2nd project is $500K over the 2 phases including $300K in Phase 1 which begins August 2, 2021.The goal of each project is to develop and deliver, for independent testing, battery technology that exceeds present capabilities and enables new applications for the intelligence community and other customers.

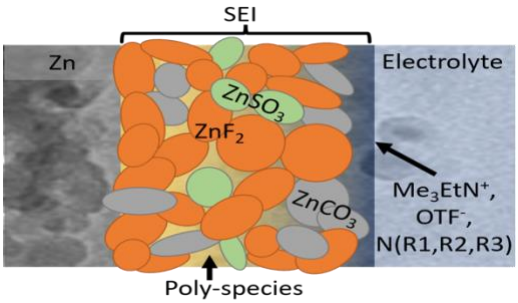
RESEARCH HIGHLIGHTS

Significant and impactful research progress was also made in FY21. Multiple papers were published in high profile journals such as *Science* and *Nature*. A few results are highlighted below.

Battery Technology

Fluorinated interphase enables reversible aqueous zinc battery chemistries, Cao, L., Li, D., Pollard, T., Deng, T., Zhang, B., Yang, C., Chen, L., Vatamanu, J., and Wang, C.; *Nature Nanotechnology*, (2021); DOI: 10.1038/s41565-021-00905-4.

Dr. Chunsheng Wang's team created a new and more stable fluorinated interphase, which enables reversible water-based zinc battery chemistries. Metallic zinc is an excellent battery material because it has a high capacity, low redox potential, high abundance and low toxicity. It can be used in cells that are very safe, but has challenges associated with poor cycling. By engineering the electrolyte – the portion of a battery that carries ionic current – the group created a zinc electrode that provides stable charge and discharge. The newly created interphase that allows such stable cycling is mainly composed of hydrophobic inorganic fluoride, which transports zinc ions but blocks water penetration. Such chemistry limits undesired reactions involving the electrolyte or the zinc itself, and enables long-term use of aqueous zinc batteries.



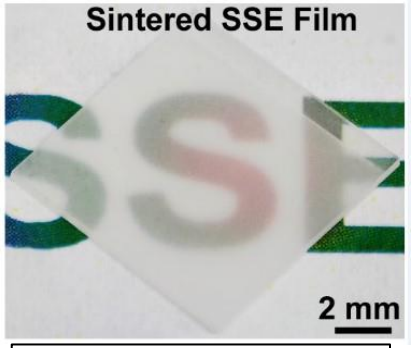
A rechargeable zinc-air battery based on zinc peroxide chemistry, Sun, W., Wang, F., Zhang, B., Zhang, M., Küpers, V., Ji, X., Theile, C., Biekerm P., Xu, K., Wang, C. and Winter, M., *Science* (2021) DOI: 10.1126/science.abb9554.

Research teams around the world are working to develop high performance, eco-friendly, safe and cost-effective batteries. The zinc-air battery (ZAB) is an attractive alternative to

the lithium-ion battery currently dominating the energy storage market; however, the conventional ZAB can be unstable due to undesired reactions that lead to battery degradation. To solve this problem, an international research team, co-led by Dr. Chunsheng Wang and collaborators, has developed a novel chemistry for the ZAB, which – based on a non-alkaline, water electrolyte – overcomes the undesired reactions. This non-alkaline electrolyte brings a previously unknown reversible zinc peroxide (ZnO_2)/O_2 chemistry to the zinc-air battery. By making the electrolyte hydrophobic, water is excluded from the near surface of the cathode, which it is participate in undesired reactions. Compared with the conventionally used strong alkaline electrolytes, this newly developed non-alkaline aqueous electrolyte enables a ZAB with a long cycle life and a high energy density.

Printable, high-performance solid-state electrolyte films, F Ping, W., Wang, C., Wang, R., Dong, Q., Lin, Z., Brozena, A.H., Dai, J., Luo, J. and Hu, L., *Science Advances*, (2020), DOI: 10.1126/sciadv.abc8641.

Ceramic solid-state electrolytes (SSE) promise to be a viable solution to address a safety issue of using high-energy lithium metal in a battery, by blocking the lithium (Li) dendrites that cause short circuit and thermal runaway. Professor Bing Hu's group has developed a new method of printing and sintering a variety of SSE thin films. The high-quality and high-performance SSE thin films can be obtained after rapid (~3 s) high-temperature (~1500°C) sintering, ensuring minimal Li loss and high crystallinity. Hu's group has called this method "printing and radiative heating" (PRH), a solution-based and printable technique for synthesizing ceramic SSE films. This approach not only leads to dense and uniform microstructures for the SSE thin films, but also ensures superior ionic conductivity. Notably, the fabrication process – from precursor to final product – only takes ~5 min, which is ~100 times faster than conventional methods. The technique is also general, with the ability to sinter a range of high-performance solid-state films.



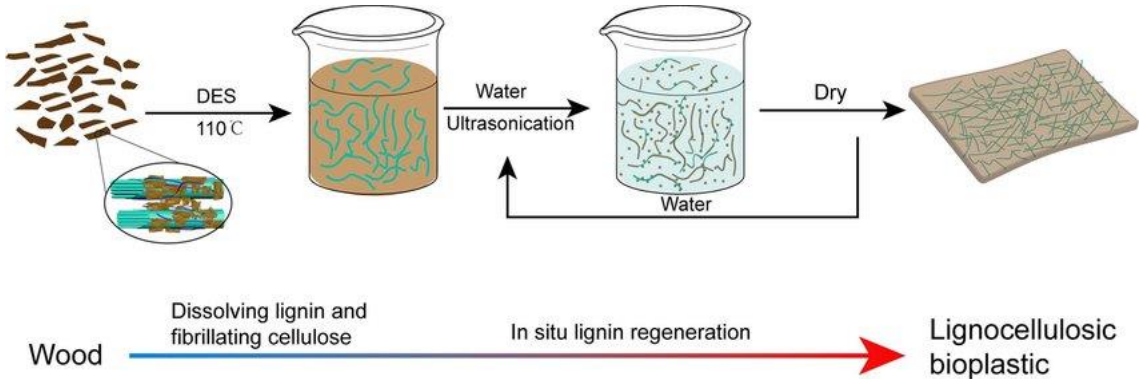
Ceramic solid-state electrolyte (SSE) thin film

Materials Innovation

A Strong, Biodegradable and Recyclable Lignocellulosic Bioplastic, Xia, Q., Chen, C., Yao, Y., Li, J., He, S., Zhou, Y., Li, T., Pan, X., Yao, Y., and Hu, L., *Nature Sustainability*, (2021), DOI:10.1038/s41893-021-00702-w.

Renewable and biodegradable materials derived from biomass are attractive candidates to replace non-biodegradable petrochemical plastics. However, the mechanical performance and stability in wet conditions of biomass is usually insufficient for practical applications. Dr. Liangbing Hu's research group recently developed a simple yet cost-effective *in-*

situ lignin regeneration approach to synthesize a strong, large-scale, water stable, biodegradable and recyclable lignocellulosic bioplastic, produced 100% from an abundant and inexpensive wood powder, which is generally discarded as waste. The porous structure of natural wood is deconstructed to form a homogeneous cellulose-lignin 'soup' that features nanoscale entanglement and hydrogen bonding between the regenerated lignin and cellulose micro/nanofibrils. Large-scale lignocellulosic bioplastic films can then be fabricated by simply casting the cellulose-lignin soup into a mold. This strong, water-stable, biodegradable and recyclable lignocellulosic bioplastic with a substantially reduced environmental waste footprint is a strong candidate for replacing widely used petrochemical plastics.

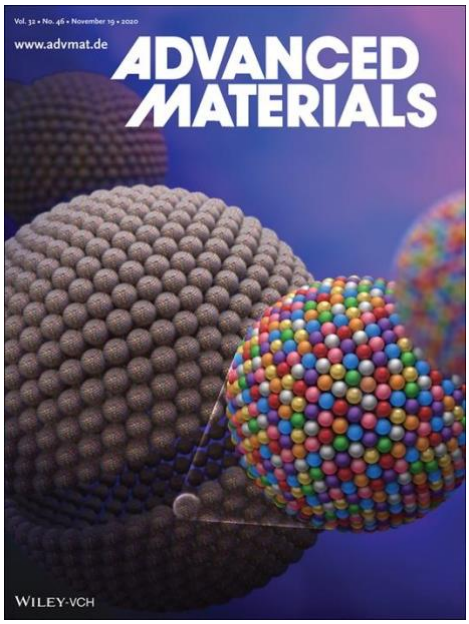


Determining the three-dimensional atomic structure of an amorphous solid, Yang, Y., Zhou, J., Zhu, F. , Hu, L., and Miao, J., *Nature* (2021), DOI: 10.1038/ s41586-021-03354-0.

A research team in the UMD Department of Materials Science and Engineering has synthesized, for the first time, a multinary metallic nanostructure dispersed on thin graphene substrates. This is achieved by using a unique far-from-equilibrium synthesis technique called 'high temperature thermal shock'. Upon rapidly heating to a high temperature, these elements are mixed uniformly; rapid quenching (on the order of 10^5 K/ s) immediately following could lead to rapid solidification, which is fast enough to avoid crystallization thus forming the unique metallic glass nanostructures. The work will pave the way for the determination of the 3D structure of a wide range of amorphous solids, which could transform our fundamental understanding of non-crystalline materials and related phenomena.

Catalytic Materials: Continuous Synthesis of Hollow High-Entropy Nanoparticles for Energy and Catalysis Applications, Wang, X., Dong, Q., Qiao, H., Huang, Z., Saray, M.T., Zhong, G., Lin, Z., Cui, M., Brozena, A., Hong, M., Xia, Q., Gao, J., Chen, G., Shahbazian-Yassar, R., Wang, D. and Hu, L., *Advanced Materials* 2020, DOI: 10.1002/adma.202070341. (Cover)

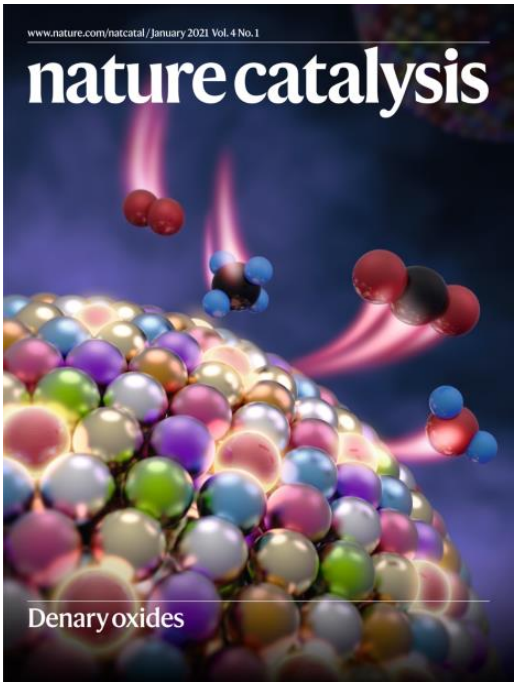
A multi-institutional research team led by Dr. Liangbing Hu at UMD has developed a continuous high temperature "droplet-to-particle" nanomanufacturing technique to produce a hollow, high-entropy alloy structure as catalysts for Li-O_2 batteries – the study was recently featured on the cover of *Advanced Materials*. Combining multiple precious- and nonprecious-metal elements in a hollow high-entropy alloy (HEA) structure as catalysts can efficiently improve the usage of active sites, enhance activity, and achieve high stability. The formation of these hollow HEA nanoparticles is enabled through the decomposition of a gas-blowing agent in which a large amount of gas is produced in situ to "puff" the droplet during heating, followed by decomposition of the metal salt precursors and nucleation and growth of multimetallic particles. The high ratio of active sites per mass of these hollow HEA nanoparticles makes them promising candidates for energy and electrocatalysis applications. As a proof-of-concept, this work demonstrated that these materials can be applied as the cathode catalyst for Li–O_2 battery operations with a record-high current density per catalyst mass loading of 2000 mA $g_{cat.}^{-1}$, as well as good stability and durable catalytic activity. This work offers a viable strategy for the continuous manufacturing of hollow HEA nanomaterials that can find broad applications in energy and catalysis.



Denary oxide nanoparticles as highly stable catalysts for methane combustion, Li, Tangyuan and Yao, Yonggang and Huang, Zhennan and Xie, Pengfei and Liu, Zhenyu and Yang, Menghao and Gao, Jinlong and Zeng, Kaizhu and Brozena, Alexandra H. and Pastel, Glenn and Jiao, Miaolun and Dong, Qi and Dai, Jiaqi and Li, Shuke and Zong, Han and Chi, Miaofang and Luo, Jian and Mo, Yifei and Wang, Guofeng and Wang, Chao and Shahbazian-Yassar, Reza and Hu, Liangbing, *Nature Catalysis* (2021), DOI: 10.1038/s41929-020-00554-1 (Cover)

Dr. Hu's research group once again graced the cover of a journal article in 2021 for their research on oxide nanoparticles. Oxide nanoparticles with diverse elemental and structural properties are widely used in catalysis, energy, environmental and biomedical applications. Recently, multi-elemental oxide (MEO) materials, composed of four or more metal cations

in a homogeneous phase, have garnered broad attention. The mixing of multiple elements brings new functionality to materials, which exhibit excellent durability in long-term operations as a result of the 'entropy stabilization effect.' The composition of existing oxide nanoparticles, however, has been constrained to a maximum of five metal cations and is limited by conventional synthesis methods. Typically, conventional approaches adopt relatively low temperature and near-equilibrium conditions for synthesis, which are incapable of efficiently mixing more elements.



The research team developed a novel strategy to design and synthesize a library of MEO nanoparticles (up to 10 cations) with tunable composition, size and structure. This strategy employs a rapid, non-equilibrium, high-temperature Joule heating method that can greatly expand the compositional space of oxide nanoparticles. The UMD team, together with their collaborators, synthesized a type of denary oxide nanoparticles as the catalyst for methane combustion reactions. Compared to current state-of-the-art catalysts, higher catalytic activity and superior stability were achieved. The study opens a vast compositional space for future development of oxide nanoparticles, and enables high-throughput material synthesis and discovery for many potential applications.

OUTREACH AND EDUCATION

MEI^2 is actively engaged across campus, the state and nation in educational and outreach efforts. MEI^2 also issues a quarterly newsletter to over 600 faculty, as well as government and industry leaders/researchers. Independently, MEI^2 Director Dr. Eric Wachsman continues to be consulted and interviewed frequently regarding his battery technology and grid energy storage. In the past year, ABC 7 in D.C. reached out to him regarding Chevrolet Bolt fires, while ABC and Fox affiliates in D.C. both interviewed Dr. Wachsman about potential power grid failures in Maryland similar to those experienced in Texas due to crippling extreme weather systems this past year. Based on the Advisory Board's recommendation to pursue alternative outreach platform strategies, the following activities were conducted.

Carbon Dioxide Removal: A Call to Action

MEI^2 held a virtual event in collaboration with MEIA on Earth Day focusing on carbon dioxide removal (CDR). The goal is to help move university CDR technologies to market via federal funding opportunities and the new $100M CDR XPRIZE funded by Elon Musk.

The Earth Day event included speakers from XPRIZE and DOE as well as faculty and students working on CDR technologies. All presentations including those by Lynn Brickett, DOE Senior Program Manager for Carbon Capture, and Michael Leitch, Technical Director for CDR XPRIZE can be viewed at: https://energy.umd.edu/carbon

Engineering Market Momentum

MEI[2] created a promotional video focusing on solutions for energy power and efficiency and the products that are being transferred out of the lab and into the market. Products include MEI[2] innovations: stronger-than-steel wood that replaces metal in cars and planes and slashes steel production emissions; Lightweight, long-lasting, and backpack-sized non-flammable battery packs that soldiers and rescue workers carry with them wherever they go; and a compact, cordless air-conditioning robot that follows you on a muggy summer day, keeping you comfortable while drastically reducing the cost and environmental impact of cooling huge office or warehouse spaces. For more information and to view the video: https://eng.umd.edu/energy

The Maryland Energy Innovation Institute: Engineering Market Momentum

Clean Energy Business Network proposal

MEI[2] partnered with the Clean Energy Business Network on a DOE eXCHANGE proposal focusing on a Mid-Atlantic Clean Energy Innovation Cluster. The Mid-Atlantic Energy Innovation Cluster proposed to leverage partnerships across the energy innovation ecosystem to help startups commercialize innovative energy hardware technologies. The cluster would provide online tools to Energy Program for Innovation Clusters (EPIC) startups and partners nationwide, bolstering the nationwide impacts of the EPIC program.

Student Competitions

MEI[2] is partnering with AES Clean Energy, a Fortune 500 company specializing in clean power generation and distribution worldwide, to co-host a student competition for Fall 2021. Pre-contest planning occurred in the spring of 2021. Teams of students will work together to develop an innovative solution to a proposed problem centered around challenges or new technology currently facing the clean energy space. The competition will have the following focus areas: Interdisciplinary students; Opportunity for innovation related to the AES business; Real-world renewable energy experience and exposure; and AES brand awareness among students and college campuses. The program would begin with a graduate student pilot and head towards a full-scale competition in the spring of 2022. Additional partners include Howard University, Johns Hopkins University, and George Washington University.

MEI[2] held a student video contest in honor of Earth Day 2021. Undergraduate and graduate students were encouraged to consider potential solutions utilizing clean energy technology, energy efficiency, energy storage, emission reduction, job production and other multi-disciplinary innovative approaches towards long-term sustainability in their video submissions. Eligibility was open to individual and teams of current students. Each video had to address the following questions:

- Target: What energy innovation can/might solve societal issues?
- Method: Is there a specific issue to society? Describe the technology/method that you would use to approach long-term sustainability.
- Local Impact: Based on your best estimates, what would be the cost of implementing your solution and the value of improving the resiliency and sustainability in your neighborhood or on campus?
- Broader Impact: What is the lasting impact not only for the university campus, but also for our nation and the world?

First place was awarded to Elyas Masrour, a freshman Computer Engineering student, at the UMD for his video on emerging battery technology. His video noted that an Electric Power Reserve Station on or near campus would truly be an investment in the future. Building one in the DMV area could give local energy providers the confidence to begin constructing new renewable energy sources and allow them to decommission old, unsustainable ones. Currently, UMD is working hard towards achieving net-zero carbon

emissions by 2025. Including a station such as this in those plans could begin to spread that commitment to sustainability into the communities around campus. Second place went to Vincent Lan, sophomore in Materials Science and Engineering, and his partner Adrian

Seemangal, a sophomore in Geographic Information Science for their video on cool roofs. And finally, third place was awarded to Terry Goolsby, Materials Science and Engineering, and her partner Andrew Hicho, a freshman in the school of Public Policy. They chose to focus on geothermal energy because of the immense energy benefits, 24/7 system run time, zero fossil fuels needed, and the longevity of the system. They are also interested in the geothermal business model and the vast, largely untapped market potential. The top three videos from the contest can be found on the newly created MEI^2 YouTube channel: https://www.youtube.com/channel/UCLcR1ZpPhgC-3CsYJzU9Pxw.

Wells and Hulka Graduate Energy Fellowships

MEI^2 awarded two Harry K. Wells graduate fellowships and one Barbara Hulka graduate energy fellowship in March 2021. The fellowship comes 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 Wells recipients are Gaurav Iyer (CHBE) and Bryson Clifford (MSE). Iyer proposes to develop carbon molecular sieve (CMS) hollow fiber membranes from novel polyamide precursors for sustainable H_2 purification. The work will pave the way towards a new class of CMS membranes attractive for small molecules separations. Clifford aims to address the safety issue of Li-metal batteries while achieving high performance. The motivation is to address the core underlying limitations (i.e., safety & performance) of current energy transport/storage technologies and gain detailed understanding of interfacial phenomena, which is critical to improvements in performance, increase the reliability, and reduce the cost of state-of-the art Li-metal batteries.

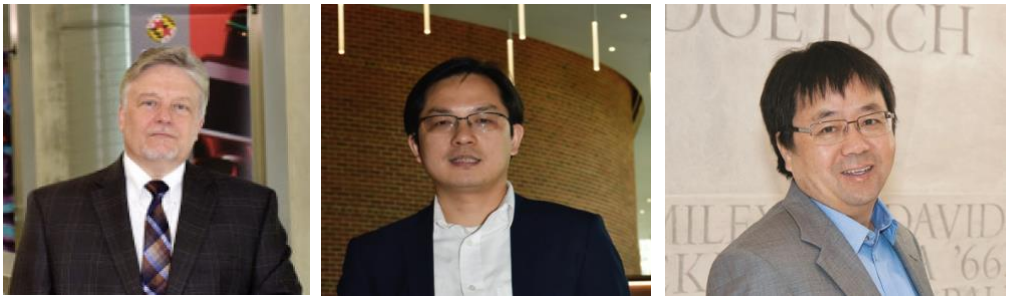
Since 2007, Mrs. Barbara Hulka has donated $20K annually to award a faculty-sponsored graduate student pursing research in sustainable energy with specific emphasis in the areas of alternative energy research, solar energy conversion, biofuels, wind energy, wave energy, and ocean thermal or geothermal energy. The Hulka Fellowship recipient is Amy Chen (MSE). Chen aims to address the formation mechanisms and catalytic stability of multimetallic nanoparticles by applying liquid phase transmission electron microscopy (LP-TEM) in addition to conventional electrochemical testing methods. The proposed experiments will provide fundamental insights that will inform rational nanoparticle catalyst design to improve both their activity/selectivity and resistance to degradation.

Faculty Research Honors

Several MEI^2 faculty were acknowledge this past year for their outstanding contributions to the energy research field. Director Eric Wachsman was awarded the university's highest honor bestowed to a tenured faculty member, the title of Distinguished University Professor, for his "research accomplishments in fundamental ionic transport, electrocatalysis, advanced electrochemical energy conversion and batteries, and service and technological leadership to the state of Maryland and UMD". In addition, ***Dr. Wachsman was elected President of The Electrochemical Society***, the most prestigious international scientific society focused on critical energy technologies such as energy storage and conversion, with members ranging from Thomas Edison to the recent Nobel Award recipients for the invention of the Lithium-ion battery.

Both Dr. Wachsman and Dr. Chunsheng Wang were nominated for the 2021 UMD Invention of the Year award for their technologies, "Membrane Reactor for Natural Gas Conversion to High-Quality Fuels" and "Reversible Chemistry in Graphite Cathode for Safe, High-Energy Batteries", respectively. Dr. Wang's invention was awarded Invention of the Year for its safe and sustainable reversible battery chemistry using water and salt electrolytes and graphite cathode. The result of this pioneering chemistry is an aqueous high-energy lithium-ion battery that is safe, sustainable, and less expensive than batteries currently on the market. Once scaled, this battery could be used in applications such as smartphones, wearable devices, electric vehicles, airplanes and large-scale energy storage.

In addition, Dr. Wachsman and Dr. Liangbing Hu were ranked in the top 2% of world scientists in a recent Stanford report based on citations from 1996 through 2019. Dr. Hu was also named a 2021 Fellow of the Material Research Society and 2021 Distinguished Scholar-Teacher. Both Dr. Hu and Dr. Wang were named to Clarivate's 2020 list of most highly cited researchers. Clarivate researchers have demonstrated significant and broad influence in their chosen field(s) through the publication of multiple papers frequently cited by their peers over the last decade. Their names are drawn from the publications that rank in the top 1% for field and publication year in the Web of Science citation index.



From left to right: Dr. Eric Wachsman, Dr. Liangbing Hu, Dr. Chunsheng Wang

APPENDIX 1. MEI^2 FY21 Budget

	Budget	Actual	Difference
Salaries	$190,000	$196,990	-$6,990
Seed Grants	$400,000	$400,000	$0
Events/Outreach	$12,665	$5,326.80	$7,338.2*
Communications/ Reporting	$3,500	$1,321	$2,179
Equipment/Supplies	$9,212	$6,827.62	$2,284.38
Travel	$8,048.00	$250	$7,798*
Totals	$623,425	$597,615.42	$12,609.58

* Due to impacts of COVID-19 a number of activities/expenses were curtailed relative to budget, especially Events/Outreach and Travel.

APPENDIX 2. Letter from MEI^2 Advisory Board

UNIVERSITY OF MARYLAND

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

July 27, 2021

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

Dear Dr. Wachsman,

Following the July 9, 2021, meeting of the Maryland Energy Innovation Institute (MEI^2) Advisory Board, this letter was prepared reflecting inputs from the MEI^2's Advisory Board members. The letter contains observations and recommendations for the sustained successful growth of MEI^2. After detailed deliberations, discussions and presentations on the progress in transformative clean energy research at MEI^2, the Advisory Board reaffirms its confidence in the leadership and management of MEI^2.

With respect to clean energy innovation, the Advisory Board continues to be impressed with the cutting-edge research affiliated with MEI^2 and the University. The presentations to the Advisory Board highlighted significant clean energy research including advances in new solid-state batteries for advanced energy storage, advanced wood materials innovation, extreme batteries, advanced transformers for energy routers, meta-cooled fibers for socks, novel geared infinite variable transmission for tidal power, industrial hemp biomass for biofuels, all with promising commercialization potential.

The Advisory Board commends MEI^2 for its continuing success in establishing University of Maryland as a leader among universities. The Advisory Board notes that MEI^2 and the University have secured significant funding and won multiple awards in clean energy research. Its success on both the domestic and international fronts is reflected in its Center for Research in Extreme Batteries (CREB) as well as an effective partnership in the U.S. Israel Bilateral Industrial R&D (BIRD) Foundation. The ratio of other funding secured to dollars invested by MEI^2 and the University continues to impress. MEI^2 and the University continue to be among the very top US academic institutions in DOE's ARPA-E awards. Ten awards (for $13M) were received in the past

year, bringing the total awards to 33 for over $74M since the agency's inception in 2009. An additional $2.25M in funding from DOE's Basic Energy Science office was received for work on thin film platforms for advancing the science in solid state energy storage.

Promising new areas of funding include the recently launched IARPA (Intelligence ARPA) first energy storage program and MEI^2/UMD is part of two out of the eight teams selected for negotiations.

The Advisory Board notes that the Seed Grants program has to date awarded a total of 17 grants with annual grant funding of $400,000 over a four-year period averaging slightly over 4 grants per year. More significantly, the Advisory Board commends MEI^2 for its remarkable 23-fold leveraged return to the State of Maryland on the Strategic Energy Investment Fund (SEIF) which supports MEI^2 activities including the Seed Grants Program.

As in the past, the Advisory Board is encouraged that MEI^2 continues to work in close coordination with MCEC and Maryland Energy Innovation Accelerator (MEIA) to realize maximum potential for overall benefits to each program. The Advisory Board applauds the successful achievements of MCEC over the past 12 years, in which it has leveraged $119M in private investment to deploy clean energy solutions from $9.4M in federal, state and local funding. It is noted that MEIA is in its second year of assisting in start-up creation; helping secure grants and venture funding for those companies; and providing in-kind marketing, legal, accounting services and support. MEIA recently recast their offerings into three programs based on the different types of support needed as concepts mature:

- Pre-accelerator: Concept/idea stage, initial development
- Launchpad (new): Formation stage and technology validation in a lab environment
- Accelerator: Demonstration stage, customer and partner identification and in-field prototypes

The Advisory Board agrees with the revised MEIA approach to support a broader "pipeline" of companies at earlier technical readiness levels (TRLs) aimed at providing guidance and assessing the prospects of successfully transforming ideas and concepts into demonstrations and prototypes.

The Advisory Board's recommendations from the July 13, 2020, meeting briefings andthe reported status of MEI^2's actions in response are as follows:

- **Align MEI^2 Budget and Strategic Planning direction with MEI^2 Report recommendations**: Status: The budget and strategic planning is aligned withthe MEI^2 Report recommendations as reflected in both Senate and House Bills identifying Energy as an economic opportunity eventually making it into the bills of 2021 Legislative Session. The MEI^2 2022 planning budget assumes flat

funding as a baseline unless and until increases and removal of sunset provisions included in these bills are enacted into law. All testimony for these bills during the Legislative Session was favorable and included the following facts: University of Maryland is one of the top 3 academic institutions in the US for ARPA-E awards; since its creation in 2017, MEI^2 has helped obtain over $55M in federal funding for the State of Maryland economy; MEI^2 has provided a 23X rate of return on Maryland's investment based on its share of the Strategic Energy Investment Fund ($2.4M to date –note rate of return is actually higher now since testimony).

- **Seed grants relative emphasis on Phase-1 vs Phase-2 awards given limited funding.** Status: Ongoing- The MEI^2 program is now in its 4th year. The seed grants bridge the gap between transformative academic research and the prototype/process demonstrations needed to elicit investor interest through technology development and the creation or advancement of university start-up companies within the state of Maryland. Grants for larger, latter phased (Phase 3) projects are a challenge as these require higher levels of total funding. Consideration of funding Phase-3 projects would be subject to available grant funds as well as on their ability to secure substantial cost-sharing from other entities.
- **Alternate platform strategies for outreach events given current COVID-19 pandemic impacts**. Status*:* MEI^2 engaged in the following outreach events using alternative platforms:
  - MEI^2 partnered with the Clean Energy Business Center on a DOE eXCHANGE Proposal for a Mid-Atlantic Energy Innovation Cluster
  - Conducted Earth Day events: Student video contest in clean energy solutions towards long-term sustainability; Carbon Dioxide Removal: ACall to Action; MEI^2 and MEIA workshop on XPRIZE event aimed at enabling University of Maryland teams to compete.
  - Created an MEI^2 You Tube Channel
  - MEI^2 Created a Market Momentum video with assistance from the Clark School of Engineering
  - MEI^2 working with AES to develop a Clean Energy Competition to be launched as a pilot program in Fall 2021.

- **Seek alternative funding sources that leverage industry, academia, and government partners**. Status: Awards and agreements with the Army Research Lab (ARL) the Bird Foundation and IARPA are several of note:
  - $10M in FY20 Defense Appropriations Act and $10M in FY21 Defense Appropriations Act were received by the Center for Research in Extreme Batteries (CREB) within UMD/MEI^2 .
  - The BIRD Foundation partnership represents an increased emphasis in engagement with industry and universities. MEI^2's project is focused on energy storage, entitled the US – Israel Solid Energy Center (USISEC),

emphasizing safe and energy dense solid-state batteries. Of this $18.4M project, the Maryland team lead by UMD is receiving $4.4M.

- IARPA recently launched a RESILENCE program reflecting its newinterest in clean energy aiming to increase energy density by 2x and calendar life by 10x. The University is part of two of the eight teamsselected.

Having deliberated on the information and discussions from this meeting, the Advisory Board recommends the following:

- Briefing Updates to State Decisionmakers: Continue to work with the University on briefing updates to State decisionmakers: Calling out the enormous **tangible** benefits and returns to the State from investments in MEI^2's successfully and transparently conducted clean energy program; commending the State for its insight in making clean energy part of the State's economic development portfolio; and encouraging the State to continue its funding support for MEI^2 that has a proven record of securing highly leveraged funding through partnerships that have created new, high-value jobs and launched numerous clean energy businesses in the state. In addition, the briefing should note the potential of MEI^2's role in positioning the state to receive increased RGGI funding as a result of successful commercialization of in-state clean energy technologies in the future.

- Improving Seed Grants Program guidance and participation: Continue to engagewith MEIA to focus on enhancing the quality and number of proposals. Also, recommend that the Investment Committee review the final deliverable grant reports to ascertain relevant lessons learned and quantify successful outcomes (e.g., any follow up funding received, the TRL level achieved, etc.) to help improve the grant solicitation process cycle. This effort should include feedbackto non-selected proposers encouraging their participation in future solicitations. Active outreach to grant proposers should identify MEIA as a resource and suchlanguage should be included in the solicitation guidance. In addition, follow up with more personal attention to recipients is encouraged.

- Early Engagement with new Dean of Engineering: MEI^2 as part of its early engagement with the new Dean of Engineering should indicate the Advisory Board would like to have a meeting with him to discuss the need for continued support for MEI^2 and its strategic value to the University and to the State in growing a clean energy development portfolio. Furthermore, an important Advisory Board position to convey is that MEI^2 continues to be a catalyzing force in the State's clean energy development and will be a key driver in supporting President Pines sustainability grand challenge.

- Filling Advisory Board and Committee Vacancies: Identify qualified candidates to fill one (potentially two) vacancy on the Advisory Board and one (preferably from the private sector) for the Investment Committee.

The Advisory Board commends MEI^2 for its continued transparency in its administrative processes, decision-making, program implementation activities, and resultant tangible benefit, most notably a return of value (23X) of Regional Greenhouse Gas Initiative (RGGI) funds to the state, in-state high value jobs creation and assistance to clean energy startup companies arising from MEI^2's programs. The Advisory Board notes that as current federal budgets are rising in the energy sector, the state could benefit from an economic strategy that increases investments in clean energy to leverage funding aligned with federal priorities in energy.

Finally, the Advisory Board congratulates the following MEI^2 researchers with faculty appointments who have been deservedly recognized with numerous awards this year for their distinguished achievements:

- Dr. Eric Wachsman was named a Distinguished University Professor and elected President of the Electrochemical Society (ECS).
- Dr. Liangbing Hu was named 2021 Distinguished Scholar Teacher and a 2021Fellow of the Materials Research Society.
- Dr. Chunsheng Wang was the recipient of the 2021 ECS Battery Division Research Award and the 2021 Winner of the UMD Invention of the Year Award.
- Both Dr. Wachsman and Dr. Hu were ranked in the top 2% of World Scientists(by Stanford analytics).

As always, the Advisory Board pledges its full commitment in its role to advise MEI^2 on the strategic development and alignment of its priorities with the UMD College Park, the University System of Maryland, and the State of Maryland. The Advisory Board thanks all the meeting participants in the discussion and presentations on the impressive progress in clean energy innovation.

Sincerely,

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

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

Scott Dupcak
Managing Director, Constellation Technology Ventures

Steven Freilich
Director of Materials Science, Dupont Central Research and Development (retired)

Abigail Hopper *
CEO, Solar Energy Industry Association

Geoff Oxnam
Founder & CEO, American Microgrid Solutions, LLCChair of the Board, Maryland Clean Energy Center

David Rapaport
Head, Research Collaboration Management, Siemens Technology

Mary Beth Tung *
Director, Maryland Energy Administration

(* Absent from July 9 Meeting)