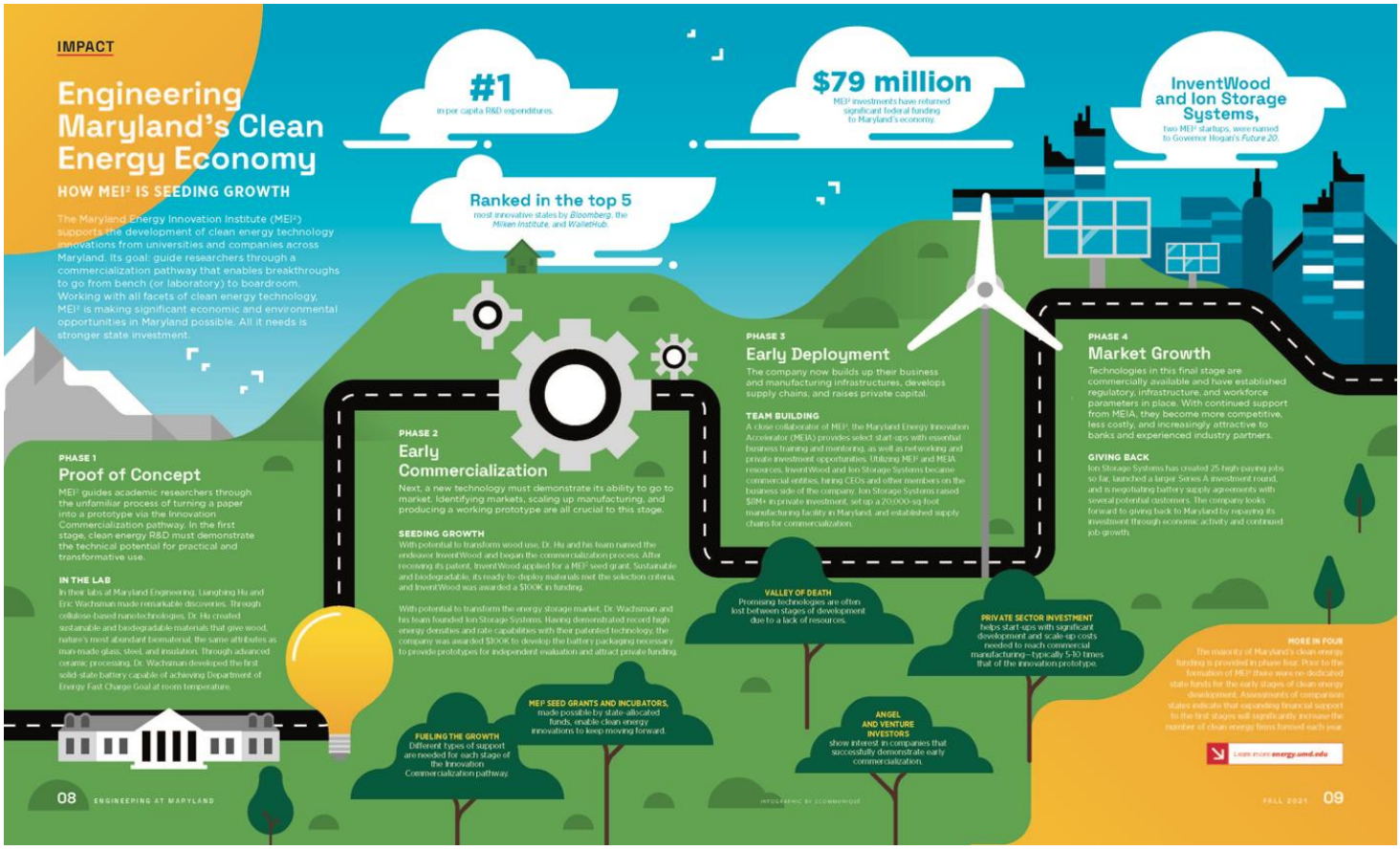
MARYLAND ENERGY INNOVATION INSTITUTE

Annual Report FY2022



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

MESSAGE FROM THE DIRECTOR

First off, I want to thank the State of Maryland Legislature for their support of the Maryland Energy Innovation Institute (MEI^2) and its mission to simultaneously address the global grand challenge of climate change while growing Maryland's economy, by advancing the clean energy innovation coming out of its world class universities. In particular Senator Feldman and Delegate Qi for their leadership in sponsoring SB460 and HB419, respectively, in the recent legislative special session, as well as their sponsorship and that of their co-sponsors of SB739 and HB1426 in the previous session and all of the legislators who voted in favor of these bills in these sessions. Without them the funding of MEI^2 would have sunsetted with FY2022 and I would be writing this as the final MEI^2 annual report.

FY2022 was an excellent year for energy innovation in the state of Maryland based on the continued and growing success of MEI^2 since its inception in 2017. Through coordination of the MEI^2 Seed Grant program and the Maryland Clean Energy Center's (MCEC's) Maryland Energy Innovation Accelerator (MEIA) program 20 new energy innovation companies have been formed in Maryland, two of which were selected by the Department of Commerce as "*Maryland Future 20*" companies. From a survey of these Maryland innovation companies there were 17 responses stating they had created 81 F/T and 8 P/T jobs, filed 51 patents, obtained $46M in private investment and $38M in grant funding, and produced $3.7M in revenue.

This is in addition to the growing university R&D base that feeds this energy innovation ecosystem. For example, the University of Maryland, College Park (UMD), continues its dominance in the U.S. Department of Energy (DOE), Advanced Project Agency-Energy (ARPA-E) awards with 36 awards for a total of $80M in funding since ARPA-E's inception in 2009. UMD's federal energy research awards alone since the 2017 inception of MEI^2 are $96M which is a 30X return on investment based on its share of the Strategic Energy Investment Fund (SEIF) that supports the MEI^2 programs. Moreover, this research productivity resulted in 22 energy-related US patents in 2021 that helped the University System of Maryland (USM) be recognized as being in the top 10 of US public institutions and top 20 in the world for issued patents in 2021, with a majority of those going to UMD and a majority of those (34%) related to energy innovation. Based on this world leading energy patent productivity Maryland's has tremendous potential for economic development from home grown, innovative clean energy technologies, and should consider this when setting its R&D investment priorities.

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

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EXECUTIVE SUMMARY

Through strong legislative action in the last session Maryland has confirmed its support of the Maryland Energy Innovation Institute (MEI^2) and its mission to advance Maryland-based technology companies engaged in clean energy innovation. The passage of SB460/HB419 ensured the continuation of MEI^2 to both grow the Maryland economy and addresses the grand challenge of climate change.

MEI^2 is actively engaged in helping the State attain these goals by investing in and coordinating interdisciplinary energy research and innovation across all academic institutions within the State. These MEI^2 early-stage innovation investments have paid off in terms of a tremendous increase in federally funded energy research. To date, UMD has participated in 36 U.S. Department of Energy (DOE) Advanced Research Projects Agency – Energy (ARPA-E) for over $80M. 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 cooperative funding in addition to the $20M in the U.S. Defense Appropriations Act (FY20 and FY21). MEI^2 also secured an additional $1.8M from the National Science Foundation (NSF) for advanced energy materials and $0.4M for a renewable and sustainable energy research program for undergraduate students. Since its creation in 2017, MEI^2 has helped obtain over $96M 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 (~$3.3M over the past 5 years), MEI^2 has demonstrated a **30X return to the State based on federal research funding alone**.

MEI^2 also continues to develop international and domestic research partnerships to pursue advances in scientific understanding and technical innovation that will lead to commercialization for a wide range of societally relevant applications including renewable energy generation and storage and the effective use of energy. MEI^2 is leading the U.S. - Israel Bilateral Industrial Research and Development (BIRD) Foundation Energy Storage Consortium, an $18M center with multiple academic and industry partners in Maryland and Israel. The MEI^2 director is also Thrust Lead in a major U.S. - German collaboration on energy storage which includes multiple U.S. and German national laboratories and universities.

Furthermore, MEI^2 is actively engaged across campus, the state, and the nation in educational and outreach efforts. MEI^2 hosted an NSF Research Experience for Undergraduates in the summer 2022, participated in the AES Energy Innovation Challenge and provided students with recruitment opportunities from government and private industry.

Moreover, since 2017 MEI^2 has used its share of the SEIF to award $400K/year in Energy Seed Grants to academic institutions and their associated energy spin-off companies throughout the State. As a result of this MEI^2 Seed Grant Program, in partnership with the Maryland Clean Energy Center's (MCEC's) Maryland Energy Innovation Accelerator (MEIA) program, 20 new energy innovation companies have been formed in Maryland creating over 81 F/T and 8 P/T jobs, 51 patents filed, $46M in private investment and $38M in grant funding awarded, and producing $3.7M in revenue. One such seed grant recipient and Maryland start-up company, Ion Storage Systems, has alone garnered $40M in private investment funding, $25M in R&D, and has hired over 45 employees, all benefitting the Maryland economy. This one $100K MEI^2 Seed Grant award has assisted in providing a **650X return to the State in private and federal funding**.

INTRODUCTION

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

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

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

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

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

MEI^2 drives energy technology innovations across the state academic institutions in conjunction with Mtech and the Maryland Department of Commerce. In contrast, MCEC as a green bank investment vehicle, facilitates capital to support technology commercialization and project development, as well as provide a needed link to energy sector stakeholders and industry partners. Recently as part of this partnership and its innovation advancement focus, MCEC stood up the Maryland Energy Innovation Accelerator (MEIA) that focuses on the business side of innovation, providing business, legal, and entrepreneurial training programs that directly complement the technology innovation focus of MEI^2 to create an integrated energy innovation ecosystem.

MEI^2 Advisory Board

As per the enabling legislation there is an MEI^2 Advisory Board to provide advice to the Director on the management of the Institute. The MEI^2 Advisory Board consists of the following: 1) the chair of the board of directors of the Maryland Clean Energy Center; 2) the director of the Maryland Energy Administration; and 3) seven members selected by the Director based on

expertise in energy technology commercialization, the clean energy industry, venture capital financing, and energy research. Three new Advisory Board members were introduced during the July 2022 meeting. These new members replace previous members Abigail Hopper, SEIA and Scott Dupcak, Constellation Ventures.

- **Mallikarjun Angalakudati, CFA,** Senior Vice-President of Strategy and Innovation Utilities at Washington Gas. He has a broad and deep experience in gas and electric utility business, with executive level experience in both industry and consulting roles. He is proficient in corporate and operational strategy development and execution. He also has a successful history of developing and leveraging analytical and quantitative insights in driving business results; as well as a demonstrated ability to drive revenue, profitably manage engagement margin, and coach direct reports and staff to success.
- **Dr. Theresa Christian,** Director of Technology and Innovation at Exelon. She works to deepen Exelon's understanding of emerging technology opportunities across the electricity value chain and to build constructive partnerships with the research and technology development communities. Prior to joining Exelon, she conducted research at the National Renewable Energy Lab on novel semiconductor materials for opto-electronic applications, including multi-junction solar cells. She also assumes a position on the MEI^2 Investment Committee.
- **Thomas Greszler,** Cell Development Manager at Saft America. He is skilled in business plan analysis; financial and technical due diligence. He has a strong intuition on the function, value and application of new technologies and products and is accomplished at using data analytics to find solutions to complex technical and business problems. He is strategically and big-picture focused and an expert in electrochemical systems, including Li-ion batteries, fuel cells, and ultracapacitors.

FY2022 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)*
Mallikarjun Angalakudati
Sr. Vice-President Strategy & Innovation Utilities, Washington Gas
Theresa Christian
Director of Technology & Innovation, Exelon
Steven Freilich
Dupont Central Research and Development
Thomas Greszler
Cell Development Manager, Saft America
Geoff Oxnam
Chair of the board for MCEC
CEO, American Microgrid Solutions
David Rapaport
Siemens Corporate Technology
Mary Beth Tung
Director, Maryland Energy Administration

The MEI^2 Advisory Board meets annually to provide advice, review progress on previous goals, and provide follow-on recommendations. The Advisory Board confirmed in their letter (Appendix 2) that MEI^2 has been achieving its goals catalyzing significant advancement in research and innovation of advanced clean energy technology toward greater economic growth in the state of Maryland.

IMPORTANT FY2022 LEGISLATION

The clean energy industry generates hundreds of billions of dollars in economic activity and offers the U.S. and Maryland a tremendous economic opportunity to invent, manufacture and export clean energy technology. The State of Maryland is committed to addressing carbon emission

reduction, energy efficiency, and the electrification of transportation as demonstrated by several legislative actions that took place in FY2022.

The *Economic Development – Maryland Energy Innovation Institute* legislation that created MEI^2 officially took effect on July 1, 2017 with an initial sunset date of June 2022 that would have thus ended MEI^2 at the end of FY2022. However, as part of that Act a report was mandated to provide scientific and funding recommendations for the creation of a robust clean energy ecosystem in Maryland and be delivered to the Governor and State Legislature at the end of 2019. The report concluded 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 or commercialized elsewhere, along with investment to provide developmental support to clean energy firms would enhance economic growth along with additional societal benefits of deploying clean energy technologies.

Following publication of the report, informational meetings were held with State Legislators regarding potential implementation of its recommendations. From those discussions, HB1426 and SB739 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. In the following 2021 Legislative session, HB419 and SB460, entitled *Economic Development – Advanced Clean Energy and Clean Energy Innovation Investments and Initiatives*, were introduced by Delegate Qi and Senator Feldman, respectively. Although the bill was initially subjected to a gubernatorial veto in May 2021, strong bipartisan support from the General Assembly overturned the veto during a legislative special session in December 2021. Led by State Senator Brian Feldman and State Delegate Lily Qi, 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/year with a specific focus on innovation.

> **"*MEI^2 has proven to be a sound investment for Maryland and I look forward to continuing our partnership in advancing our clean energy economy*." State Delegate Lily Qi**

In addition, the *Climate Solutions Now Act of 2022* (SB528) increases the statewide Greenhouse Gas Emissions reduction requirement to 60% from 2006 levels by 2031, with a target of net-zero emissions by 2045, providing requirements and restrictions to meet the goals. The bill addresses methane emissions from landfills, establishes new and alters existing requirements for buildings, increases and extends energy efficiency and conservation programs, addresses environmental justice with labor and employment initiatives, provides programs and requirements for the purchase of zero-emission vehicles, and creates new entities with special funding to support activities. As part of the Maryland General Assembly's 2022 Climate Solutions Now Act, a $15M Climate Catalytic Capital Fund was established. The purpose of the fund is to leverage increased private capital investment in technology development and deployment including projects planning to: (1) reduce greenhouse gas emissions and combat climate change impacts; (2) facilitate the electrification of the transportation sector; (3) enable improvement in energy management and efficiency in the building sector; (4) expand the deployment of clean energy generation and storage capacity; (5) target implementation of said energy measures for low-to moderate income

households; (6) allow for the deployment of advanced clean energy technology; and (7) provide for the creation of a Maryland Green Bond Program. MCEC is charged with overseeing the $5M annual fund (in FY24, FY25, FY26) in and establishing a committee appointed by the MCEC Advisory Board to manage the fund. At least 40% of the funds are intended to focus on investments in projects to address underserved communities and facilitate environmental justice. As such it should be noted from the underlined section above that "the purpose of the fund is to leverage increased private capital investment in technology development" which is directly in line with the purpose and focus of the MEI^2.

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

- The *Inflation Reduction Act* is helping build a robust clean energy economy by powering homes, business and communities with clean energy by 2030 through solar panels, wind turbines, grid-scale battery plants; advancing cost-saving clean energy projects at rural electric cooperatives; strengthening climate resilience and protecting 2 million acres of national forests; and creating millions of clean energy jobs in America. The Inflation Reduction Act also aims bring down the sticker price of electric vehicles, providing Americans tax credits to purchase new and used electric vehicles, as well as making an additional $3 billion accessible to help support access to EV charging for economically disadvantaged communities through the Neighborhood Access and Equity Grant Program
- The *CHIPS and Science Act*, which will bolster U.S. leadership in semiconductors and science and technology research includes $67.9 billion for the DOE, a $30.5 billion increase over baseline funding for this agency.
- The $2.5 billion *Discretionary Grant Program for Charging and Fueling Infrastructure*, which will ensure charger deployment meets the Biden-Harris Administration priorities, including equity commitments for increasing EV charging access in rural, underserved and overburdened communities.

ADVANCING THE MARYLAND ENERGY INNOVATION ECOSYSTEM

MEI^2 continues to drive Maryland energy innovation in partnership with MCEC, Mtech, TEDCO, UM Ventures, and the Maryland Department of Commerce. Since its inception it has focused on advancing Maryland university energy research activity and translating the results of that energy research through a Seed Grant Program to prototype/process demonstrations of sufficient technology readiness level (TRL) to attract private, VC type, investment. Over the past five years, MEI^2 has used its share of the SEIF to award ~$400K/year in Energy Innovation Seed Grants to academic institutions and their associated energy spin-off companies throughout the State.

The Maryland Energy Innovation Accelerator (MEIA), launched in 2019 within the MCEC portion of MEI^2, takes a whole ecosystem-based approach to supporting future companies through a venture development program that complements the MEI^2 Seed Grant Program. MEI^2 inventors and scientists are matched with the business executives (Energy Executives in Residence) to support and mentor those teams in the accelerator while matching them with support from professional services sponsors, such as lawyers, accounts and marketing and branding firms. As

such the MEI^2/MEIA collaboration provides traditional academic research a pathway into commercialization through a more comprehensive energy innovation ecosystem. MEIA currently has 13 companies in the program, including Alchemity (in the launchpad stage) and HighT-Tech (in the accelerator stage), both of which will be discussed in further detail.

An economic development survey done in conjunction with MEIA has solidified the importance in continuing support for MEI^2. MEIA alumni have created 15 full-time jobs and 5 part-time jobs. Additional grant funding received amounts to $6.8M and private investments totaled $5M. The total revenue generated from these participants is $3.4M and 45 patents were filed.

Economic Development By the Numbers

20 Companies Formed

81 F/T Jobs Created

51 Patents Filed

$45.8M Private Investments

$38.4M Grants Awarded

$3.8M Revenue Generated

MEI^2 has awarded 22 Energy Innovation Seed Grants over the past five years. Two of these seed grants received Phase I and Phase II funding, and four of these seed grants began initially in April 2022. Therefore, results from the MEI^2 economic survey done are from the 16 unique seed grants issued. These companies have garnered $34.5M in federal funding; $41.6M in private investments; and generated $0.4M in revenue. In addition, 68 full-time jobs and 3 part-time jobs were created and 6 patents filed. Other success metrics include standing up a 20,000 ft^2 manufacturing facility in Maryland; a $20M Letter of Intent; and supplying materials to advanced manufacturers such as Under Armor, Apple, and EWI.

The combined numbers from MEI^2 and MEIA shown in the table above take into account that InventWood and Alchemity have benefitted from both MEIA and MEI^2 programs. Based on the results received, investment in clean energy technology has paid off greatly for the State of Maryland, and should continue to be a priority.

FY2022 Investment Committee

Ellen Williams, Vice-Chair *University of Maryland Distinguished University, Former Director, ARPA-E (DOE)*
Robert Briber
Associate Dean for Research, UMD A. James Clark School of Engineering
Claire Broido Johnson
Managing Director, Maryland Momentum Fund
Eric Chapman
UMD Assistant Vice-President for Research and Development
Ken Porter
Director of UM Ventures
Arti Santhanam
Executive Director, Maryland Innovation Initiative, Maryland Technology Development Corporation (TEDCO)

MEI^2 Energy Innovation Seed Grant Program

Since its inception MEI^2 has focused on advancing Maryland's energy research and translating this research to economic growth, as such MEI^2 initiated a seed grant program to bridge the gap between academic transformative laboratory research results and the prototype demonstrations necessary to obtain investor interest. An MEI^2 call for seed grant proposals is issued annually and open to all academic institutions in Maryland. Annual seed grants are awarded at two levels: phase I grants up to $100K, and phase II up to $200K for projects that received prior seed funding. The project should advance energy technology and economic growth in Maryland. The device or process should have appropriate intellectual property protection (invention disclosure, patent application, or patent) filed with the applicant institution. Applicants are expected to address the following in their proposals: 1) innovation and

technical merit, 2) the likelihood of attracting follow-on funding, and 3) the potential for commercialization. The MEI^2 Investment Committee was created to independently oversee the solicitation and review of the Energy Innovation Seed Grants and other activities that support the Energy Investment Fund. Since its 2017 inception, 21 companies and university researchers have received funding from the MEI^2 Seed Grant program including the University of Maryland Baltimore County, College P ark, and Eastern Shore, and Morgan State and Johns Hopkins universities.

MEI^2 Seed Grant awardees presented during the 2022 MEI^2 Advisory Board Meeting and the following Energy Seed Grant reception with Maryland State delegates Lily Qi and Marc Korman in attendance. During the presentations, Atlantic Biomass/UMES (a 2020 seed grant recipient) signed a $20M Letter of Intent with Bionoid, Inc., signaling their joint commitment to producing commercial quantities of Sustainable Aviation Fuels (SAF) from residual hemp biomass. At the conclusion, State Delegate Marc Korman remarked, "*Outside this room, the future of energy and the environment can look pretty bleak given the daily news. But inside, there is so much cause for optimism with the technological breakthroughs being studied*."

State Delegate Marc Korman and MEI^2 Director Eric Wachsman at Enegy Seed Grant reception – July 2022

Quantifying the Success of MEI^2 Energy Innovation

MEI^2 has been extremely active advancing Maryland university energy research, 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. MEIA and MEI^2 both conducted an economic development survey of their accelerator and seed grant programs. To date, 81 full-time and 8 part-time jobs have been created in Maryland from these new companies. Notable success stories include Ion Storage Systems (ION), HighT-Tech, and Manta Biofuels.

Ion Storage Systems

Ion Storage Systems (ION), selected as a “Maryland Future 20” company in December 2020, is one such success story. Founded in 2015 and spun out of the Maryland Energy Innovation Institute, ION has developed a groundbreaking 3D ceramic electrolyte architecture that addresses the key issues hindering the commercialization of solid-state batteries. ION’s nonflammable technology offers safe operation, greater abuse tolerance, and both volume and weight reduction.

In a June 2022 press release by Toyota Ventures, following their investment in a successful $30M Series A funding round, Lisa Coca, Climate Fund partner for Toyota Ventures remarked, "ION's bi-layer cell design is a breakthrough for the industry. The architecture addresses the technological barriers that have historically plagued solid state batteries, and it enables critical next-generation performance metrics for widespread adoption – including high-energy density, strong cycling performance, wide temperature range, and fast charging. We believe this is a game changing technology and are proud to support ION's expert team as they work to unlock the potential and power of solid-state batteries."

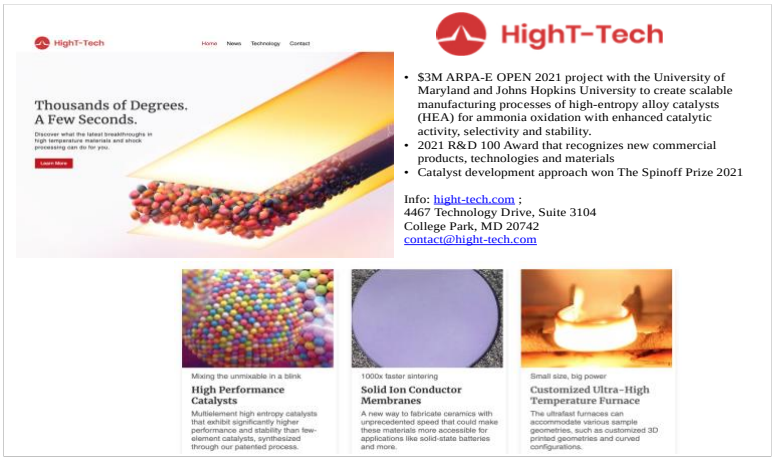
"ION's bilayer cell design is a breakthrough for the industry" Lisa Coca, Climate Fund partner for Toyota Ventures

By focusing on the design of the anode/electrolyte structure, ION has been able to meet next-generation performance metrics, including high-energy density, strong cycling performance, wide temperature range, and fast charging. The manufacturability of ION's technology also sets the company apart as it largely borrows from existing lithium-ion manufacturing processes or already-scaled ceramic processing. ION's first commercial application is wearable batteries, with plans for the company's second target market to focus on consumer electronics. With those two beachhead markets underway, ION will be well-positioned for deployments in the battery market for EVs. To date, ION has secured over $40M in private investment, more than $25M in sponsored R&D, have hired over 40 employees and operates a 20,000ft^2 Maryland manufacturing facility.

HighT-Tech

HighT-Tech, a recent graduate from the MEIA accelerator program has shown tremendous growth as well. The company is the recent recipient of an ARPA-E award for $3M. With cooperation from UMD and Johns Hopkins University, the team will create scalable manufacturing processes of high-entropy alloy catalysts for ammonia oxidation with enhanced catalytic activity, selectivity, and stability. The catalysts can potentially reduce the use of precious metals, enhance energy efficiency, and improve the economic and environmental impact of chemical industries.

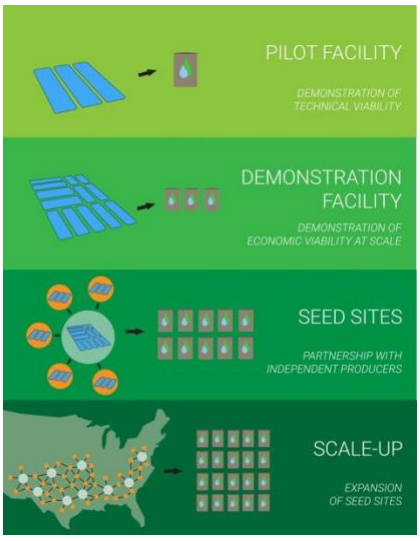
HighT-Tech is also the recipient of the 2021 Spinoff Prize, a Nature Research Award (a €30,000 cash prize). The company's approach and business plan to make catalysts from combinations of cheaper metals, which would still perform the same as conventional ones, won over the 2021 judges. Their technique to use alloys addresses the technical and expensive bottleneck the sector currently faces, significantly reducing the risk of technological or commercial failure. The wide scope use of catalysts for a broad range of applications, means that in the long term, HighT-Tech's technology could be applied to make materials for catalytic converters in cars, emission systems in power plants and a variety of chemical reactions that rely on expensive noble-metal catalysts, such as refining petroleum, therefore having a long-term sustainable impact on an important sector.



"HighT-Tech perfectly demonstrate what The Spinoff Prize sets out to recognize – excellence in science and innovation, as well as smart entrepreneurship." Richard Hughes, VP Publishing, Nature Research Award

Manta Biofuels

Manta Biofuels entered the MEIA cohort in Fall 2020. The company is using algae to make a cost-competitive, renewable replacement for crude oil. Since the company was founded, they have raised $3M in funding, including a DOE SBIR Phase II award. The funds were used to validate each step of the process in the field, and the company is currently working on developing a 15 acre pilot scale facility.



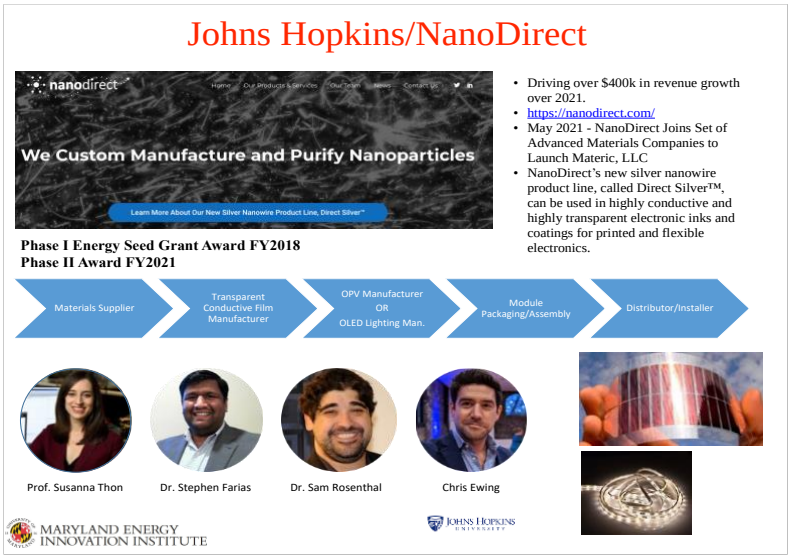
Manta Biofuels uses a simple, agricultural method for growing algae in shallow, open ponds, similar to how rice is grown in paddies. They then collect algae from the ponds using their patented magnetic harvesting technology. This process allows them to concentrate algae in preparation for conversion of the biomass to renewable oil. To convert the concentrated algae to crude oil, the algae is exposed to high temperature and pressure in a process known as hydrothermal liquefaction. The oil can be used in the existing liquid fuels infrastructure, with one key difference: the fuels produced from their product are renewable and carbon neutral.

FY2021 Energy Innovation Seed Grants

After one year, MEI^2 Seed Grant projects are expected to: 1) Provide a summary of expenses and a scientific progress report describing the work done and include a commercialization plan as a final deliverable for the project including clear market assessment and strategy, a viable revenue

model, and a strategy for financing the plan; and 2) Submit a proposal to at least one external funding agency within 18 months of receiving the seed funding, and provide information on the outcomes of the seed funding (e.g., grant funds, publications, conferences) annually. In May 2021, four seed grant projects were awarded for a total of $400K; one of which was a Phase II project. Follow on efforts and successes from the 2021 seed grants are discussed below.

- *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



A major factor affecting the next-generation photovoltaics and energy-efficient lighting sectors, as well as other optoelectronic technologies, is the lack of large-area, flexible, high-performing transparent conductors. NanoDirect LLC has partnered with Professor Susanna Thon's Group at Johns Hopkins University to solve this problem by developing high-purity silver nanowire inks that can be formed into flexible, large-area transparent conductors. During the course of a Phase 1 Energy Innovation Seed Grant, we demonstrated these inks and developed scalable spray-cast manufacturing processes to form them into large-area films. During the course of this Phase 2 Energy Innovation Seed Grant, the group has advanced this technology, performed final validation, and are preparing for initial sales of their Ag nanowire product to commercial and academic research and development groups. Through market research, they have identified a specific need for both raw Ag nanowire inks and pre-manufactured transparent conductive films. By fulfilling both of these needs, this project will enable them to penetrate deeper into the value chain. As of Q4 2021, 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.

Phase 2 funding is supporting the advancement of our Ag nanowire inks product line and development of 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. We have established relationships with the Chemical Angel Network, Sun Chemical, Arkema, and other potential investors. The goal for this project is to support five clean-tech jobs and $900,000 in clean-tech business revenue in the state of Maryland by the end of 2022.

The team has made significant business progress during the current project. Prior to the proposal, an equity partnership was formed with DiPole Materials, LLC., SciGenesis, LLC., and Abri Sciences, LLC., three other materials manufacturing companies based in Baltimore, MD. This partnership was launched under a new brand Materic Group. Materic Group expanded from 6 technical employees to 12 technical employees in 2021. We have also added 3 full time sales and marketing staff and 1 media/content generation staff in 2021. The group has also expanded out lab

footprint and production facility to 6,000 square feet and added a series of chemical processing facilities, 3D printers, and characterization equipment.

NanoDirect also completed a regional I-Corps program with Prof. Thon in May 2021 to help inform product development. During I-Corps the group interviewed 16 different target customers and identified a matrix of over 250 potential customers to use for our future launch and reach out plans. These interviews included materials suppliers/TCF manufacturers, researchers, OPV and lighting manufacturers, display manufacturers, and automotive manufacturers. Our research seems to strongly point against OLED lighting as a potential market for the product but did identify BIPV applications and new opportunities for automotive transparent conductors.

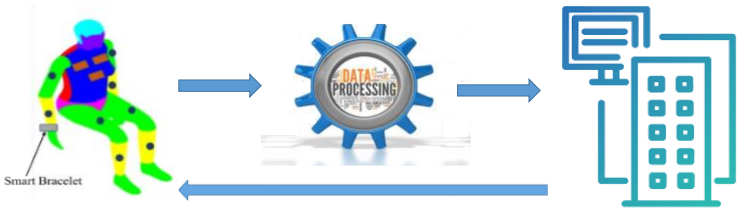
- *Insulating Wood Panels for Energy Efficient Wall Retrofits*; Lead PI: Amy Gong, University of Maryland College Park; Partnering Company: Inventwood, LLC

InventWood is committed to transforming the world by developing cellulose-based materials that are high-quality, cost-effective, and environmentally-sustainable. Insulation materials are integral to the energy efficiency of any building or home by lowering the thermal conductivity of the building and creating an envelope to prevent energy loss. InventWood augments the performance of regular wood to create innovative products. This project examined a new insulative material, nanowood, and a wall covering/wall plank solution with nanowood as a core to improve the overall thermal envelope of a home or structure. The goals of the energy seed grant included: (1) Fabricating up to 30 pieces of Nanowood through collaboration with the USDA Forest Product Lab using the fabrication process that was established by a previous SBIR project; (2) Assemble and evaluate the performance (mechanical and thermal properties) of veneer-Nanowood-veneer sandwich structures as viable wood panel products); (3) Perform customer studies, market assessments and revenue/cost modeling of Nanowood insulation panels for energy efficient interior retrofit applications.

The priority for commercialization will initially be in the U.S., but there are additional opportunities particularly in Northern Europe and Japan, where there is a cultural affinity for wood wall décor. InventWood assumes that this will be accomplished via a licensing model whereby InventWood provides the technology, know-how, and IP protection in exchange for royalty payments. Insulating wall planks offer an exciting market opportunity. Nevertheless, significant additional resources will be needed to bring the products to market. The InventWood team is exploring ways to trademark the name ‘nanowood’ (which has been used as a generic term in many contexts including throughout this document).

To commercialize this technology and other wood innovations, InventWood was founded as a spinoff company by Dr. Hu and Dr. Amy Gong, and Nanowood development has been funded by the DOE Building Technology Office (BTO) (both Phase I and Phase II, totaling $1.15M), with a project focus on process optimizations, scale up manufacturing, and integrations into window frames and building exterior retrofits for energy savings. Since its inception, InventWood has hired 6 full-time employees and raised over $2M in funding. The research has also graced the cover of *Nature* and *Science* magazine on numerous occasions, most recently October 2021.

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



Since the inception of the project, the digitaLiS team has continued to work on four main research fronts related to this project, resulting in four potential publications (one submitted, three in preparation). The main research thrusts include: (1) optimizing the laboratory cycling trajectory of an Li-S battery for identifiability. Theoretical foundations for solving this problem were developed with MEI[2] and NSF funding and experimental validation is ongoing; (2) exploitation of the dependence of Li-S battery impedance on state of charge (SOC) to improve SOC estimation accuracy. A novel algorithm was developed for the accurate detection of the "dip point" in Li-S battery cells during discharge, potentially enabling more accurate SOC estimation and Li-S pack balancing; (3) invention of a novel technology for the creation of virtual third reference electrodes in more traditional lithium ion batteries, leading to potential improvements in battery prognostics and diagnostics.

The goal is to launch a startup company, digitaLiS, that will commercialize a digital twin for lithium-sulfur battery systems, as well as a battery management system based on this digital twin. The team has worked with the MEIA technology accelerator initiative to pursue an iCorps-like customer discovery effort. To date, more than 25 customer discovery interviews were conducted. Discussion with experts from different industries, including battery and BMS development companies, electric vehicle, eVTOL, energy storage, electronic devices companies and national labs are continuing.

Preliminary results from this customer discovery effort indicate significant interest in Li-S battery technologies from the aerospace industry, a potential beachhead market where the need for more energy dense batteries is quite acute. The ability of a battery management system to estimate and manage Li-S battery performance, longevity, health, and safety is mission-critical from the perspectives of aircraft/spacecraft/drone performance, endurance, safety, and ultimately insurability. However, the current players in the Li-S technology market are focusing the majority of their efforts on electrochemistry innovation as opposed to BMS development. As a result, there is an unmet market need for a company that can serve as a BMS technology provider in this emerging market. This need exists both during the product development phase, where such an advanced BMS can assist in advanced cell characterization, as well as during the product deployment phase, where an advanced BMS can help maximize cell performance, safety, and longevity.

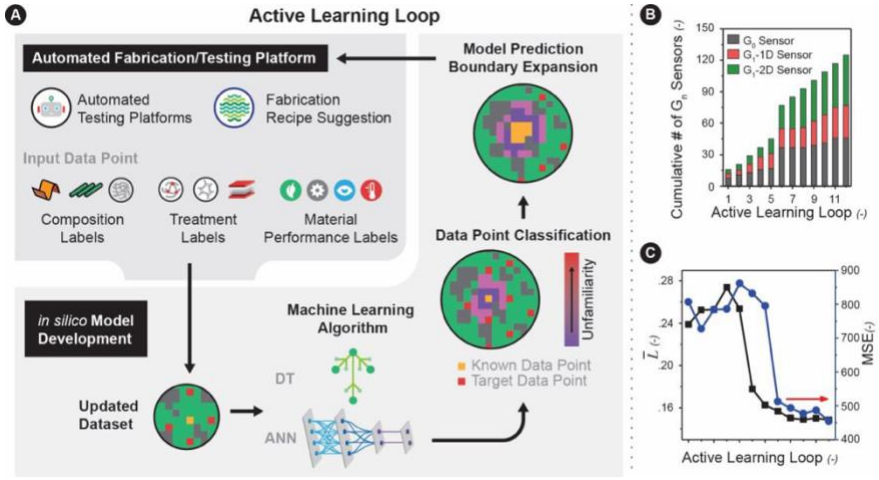
- *Translation of UMD Research Findings into an AI Thermostat Prototype for Thermal Comfort and Load Shedding*; Lead PI: Jelena Srebric, University of Maryland College Park; Partnering Company: Build Sci, Inc.

Building cooling is the fastest-growing end use in buildings, having tripled over the past three decades. In addition, human thermal comfort is an essential factor to optimize occupants' working environments. To fix the issue of the energy consumption and occupant dissatisfaction, one of the ways is to control the building system according to the real-time feedback from occupants. One of the important parts of this control system is the data collection platform. This seed grant proposed an optimization of the data collection platform, named the AI thermostat. The AI thermostat was designed based on a mouse, which is necessary for daily office work. For the hardware development, a heart-pulse sensor, a temperature sensor and an accelerometer were assembled with a mouse. For the software development, algorithm of the sensor was designed. The program of data collection and logging was implemented. A probabilistic model was developed for data prediction if the data collection was interrupted. The system identification method was tested to fit the dynamic model of human thermal comfort in real time. In the future, the AI thermostat will be implemented in the environmental chamber of City@UMD research center for the HVAC system control experiment.

FY2022 Energy Innovation Seed Grants

In April 2022, four Energy Seed Grants were awarded to the following academic institutions/companies. Their six month progress reports are forthcoming. A short synopsis of each is given below.

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



Development of a ML prediction model *via* active learning and automated platforms.

New approaches to high-performance building thermal insulation will be developed in this project. Through APD processes, the group will aim to screen, optimize, and scale up the base formulation of non-flammable clay-cellulose-silica aerogels to achieve competitive *R*-values and structural stability. Dr. Chen's lab will focus on developing the fast-screening methodologies of sol-gel formulation accelerated by high-throughput optical microscopies and emerging machine learning (ML) frameworks. Liatris' technical team will enhance the formulation scalability of clay-cellulose-silica aerogels by using scale pilot processes.

The acceleration of machine learning (ML) cycles *via* the proposed approach will create a significant advantage and impact relative to current industry state-of-the-art. Conventional aerogel product design for thermal insulation is based on a case-by-case basis and requires many trial-and-

error experiments, which are time consuming and cost ineffective. Conventional design of experiment methods is not targeted enough to rapidly optimize the sol-gel transition and APD processes to manufacture silica aerogels. The collaboration between Liatris and Dr. Chen's enable a unique approach to developing fast screening methods of silica aerogel formulation.

Commercial manufacturing partnerships are envisioned, where the technology is licensed to a third party who manufactures the product. The proposed work is a major accelerator and risk mitigator for enabling these economic benefits at large scale. The targeted product composition can be achieved with any type of aerogel processing; however, the cost/performance ratio critical for buildings requires rapid progress toward a repeatable ambient processing scheme.

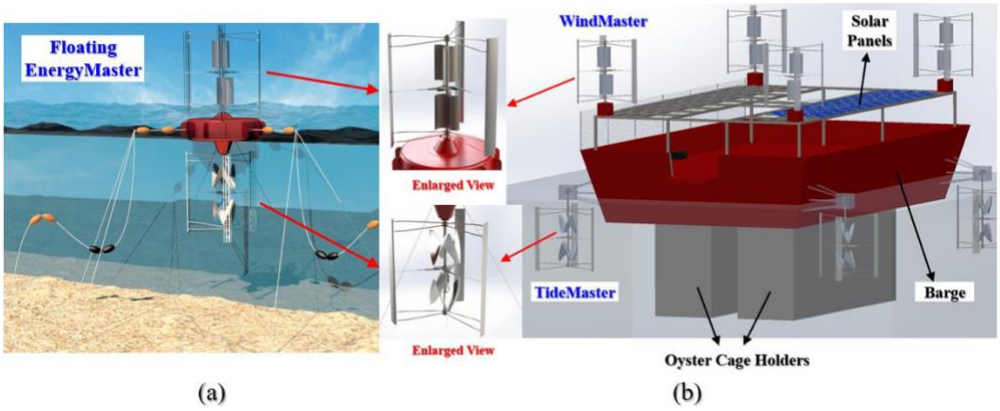
- *Large-Scale Biofuel Production Using a Novel Cyanobaterium*; Lead PI: Viji Sitther, Morgan State University; Partnering Company: HaloCyTech LLC

The project will focus on scaled-up cyanobacterial biomass research with the aim of achieving large-scale biofuel production. Biofuels offer a sustainable, efficient, and environmentally conscious energy source. The research is being conducted at Morgan's Patuxent Environmental and Aquatic Research Laboratory (PEARL), located in Saint Leonard, Maryland (Calvert County), and situated in close proximity of the Chesapeake Bay watershed on the Patuxent River. The location and infrastructure of PEARL will enable access to saline water from a tidal tributary of the Chesapeake Bay and will facilitate the cost-effective production of renewable energy. The goal of this project is to advance to a pilot system to obtain reliable and repeatable batches of biomass, produce bio-crude, and test fuel properties. By using brackish, water which contains a uniform salt composition of essential elements to support growth, high yield will be achieved while minimizing input costs. Based on discussions with agencies and companies, this technology will be key to secure further investment to develop and commercialize the product. The approach to generating biomass entails an efficient cultivation system with an enhanced yield in biomass, which will result in increased gross profit due to reductions in artificial lighting, CO_2 input, and freshwater supply needs, in addition to shorter cultivation time (e.g. more harvest cycles in less time). Reduced cost on the "front-end" will also lead to a more affordable end product for the consumer, which would be a key differentiator from the current market for algal/cyanobacteria-derived natural products. Key customers will include the U.S Navy/military, commercial transportation, general consumers, HVAC/heating companies, and electric utility companies. The relationships with these customers will be built with sales, marketing, and public relations, and with large networks by selling directly to retailers and third-party firms.

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

The University of Maryland, Baltimore County (UMBC) proposes to translate innovative renewable energy harvesting research into the "EnergyMaster" technology, including the "WindMaster" technology for distributed offshore wind energy harvesting and the "TideMaster" technology for low-speed tidal/wave energy harvesting. In this project, the "EnergyMaster" will be integrated into a solar-powered oyster farming barge developed by Solar Oysters LLC to improve the barge's energy production capability and resiliency. Note that the "EnergyMaster" can be integrated into any existing deep-sea floating platform to provide portable, efficient, and sustainable aero-hydro energy harvesting strategies for various applications, such as aquaculture and ocean cleanup. Preliminary research findings indicate that the energy harvesting efficiency of

the “EnergyMaster” at realistic wind speeds, such as 5~10 m/s, can achieve at peak about 80% of the Betz limit, the maximum efficiency that can be achieved by any turbine in an open fluid flow; and the efficiency at realistic tidal current speeds (i.e., 1~3 m/s), can achieve at peak about 87% of the Betz limit. To enable private investment, field tests of the “WindMaster” will be carried out on a pier owned by MAPC at Baltimore to validate this technology.



Both wind energy and tidal energy have large potential markets in aquaculture. U.S. aquacultural exports are estimated to increase by 33% by 2025 and the global fish consumption is expected to reach 178 million tons in 2025, increasing the demand for power for operations. Additionally, the declining water quality in locations such as the Chesapeake Bay can be alleviated by restoring the oyster population and density, which can filter hundreds of gallons per day to remove excess sediment and nitrogen. Expanding applications to ocean cleanup will further enlarge the market size, as there are 0.8 million to 2.7 million metric tons of riverine plastic flowing into the oceans every year. Excess energies produced by the “EnergyMaster” may be routed to the grid or other farms using Ørsted’s power transmission lines. In addition, considering that Maryland’s renewable portfolio standard has required that 25% of all electricity sold in Maryland should be generated from renewable energy resources by 2025, design, development, and dissemination of appropriate renewable energy technologies, such as the proposed “EnergyMaster” technology, are important to meet the ever-growing energy requirement for Maryland’s economic growth.

- *Low-cost Vacuum Insulated Glass*; Lead PI: Junho Kim, University of Maryland College Park

This project's goal is to validate a new low-cost edge sealing method for Vacuum Insulated Glazing (VIG) windows that are as insulating as the surrounding walls. VIG technology has the potential to disrupt the estimated $25 billion per year window market, but the industry has yet to adopt it due to higher costs. Although the team has demonstrated that the technology works in proof of concept and preliminary reliability testing, extensive durability research is required to guarantee such windows a 50-year life. The proposed technology validation aims to perform industry-acceptable reliability testing and improve manufacturing methods as needed to de-risk the technology. A thorough reliability/durability testing will boost confidence and reduce risk, making additional private funding for the development of a pilot manufacturing line very appealing. A reliable, lower-cost VIG will disrupt the market by replacing double-pane windows. This is especially significant given the push for Net Zero Energy buildings and Net Zero Green House Gas Emissions by 20502. Over the years, the DOE has made significant investments in the development of highly insulating windows, particularly VIGs. As energy efficiency standards become more stringent, double-pane windows will need to be replaced with either triple-pane glazing or VIGs. VIGs are a preferred choice because they are much thinner and lighter. The goal

of the MEI^2 project is to improve the seal with a secondary seal, test the sealing for reliability, and investigate a gettering method that can significantly reduce the time required to reach an acceptable vacuum level.

ENERGY PATENTS

In a report released recently by the National Academy of Inventors (NAI) and the Intellectual Property Owners Association, according to the U.S. Patent and Trademark Office (USPTO) the University System of Maryland (USM) ranks 20th in the world and 10th among U.S. public institutions for patents awarded in 2021. A total of 98 patents to five USM institutions were awarded, the highest ranking USM has earned since this annual report was first issued in 2013. (for more info: *https://today.umd.edu/usm-ranks-in-top-20-of-patent-earning-institutions-worldwide*)

Analysis of these issued patents shows the majority (65) were awarded to UMD, and of these the majority 22 (34%) of them are related to energy innovation, while only 15 (23%) are related to health/biotechnology innovation and 9 (14%) are related to quantum innovation.

However, as demonstrated in an MEI^2 2019 report (mentioned earlier in this report) to the State of Maryland on the *Present Status and Future Potential of Maryland's Clean Energy Innovation System*, within Maryland over 85% of its R&D spending supports health related R&D, while only 1% of state R&D funds support the energy sector.

Based on its world leading energy patent productivity Maryland has tremendous potential for economic development from home grown, innovative, clean energy technologies. As such, Maryland should consider this when setting its R&D investment priorities.

RESEARCH HIGHLIGHTS

Significant financial support of research into new energy technologies was obtained in FY22. Examples of these include CREB and BIRD awards mentioned above, as well as three from the DOE ARPA-E, DOE Basic Energy Science, and two from IARPA.

FY22 Major Research Funding
- **CREB ($9M)**
- **3 DOE ARPA-E ($6.35M)**
- **NSF Materials Genome Initiative ($1.8M)**

ARPA-E

In the last fiscal year, UMD has added three more ARPA-E awards bringing the total to 36 awards for over $80M since 2009. UMD continues to be one of the top three academic institutions in number of awards received. Under the category of Special Projects, Dr. Liangbing Hu, UT Austin, and USDA received $750K for their project *Nanotechnology-Enabled Transformer Life Extension*. The group will develop a power transformer that can operate for 80 years to increase grid reliability by making use of cellulosic material and nano-additives.

Under the Open 2021 category, UMD received two awards. The first was awarded to Liangbing Hu and HighT-Tech for $3M. The *Scalable Manufacturing of High-Entropy Alloy Catalysts for Ammonia Oxidation* project will focus both on high-entropy alloy development and scale-up for use in an ammonia oxidation to nitric acid process, saving operating and capital costs.

The second award is to Paul Albertus and Liangbing Hu for their *Fast-Charging, Solid-State, Roll-to-Roll Processed Li Metal Batteries Enabled by Intercalated Ions in Cellulose Molecular Channels*. The $2.6M project will build on a recent *Nature* paper from Hu's group on an ion-

conductive cellulosic material, to develop a high-energy, fast-charging, solid-state battery with processing advantages association with roll-to-roll manufacturing.

National Science Foundation

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

Publications

Significant and impactful research progress was also made in FY22. Multiple papers were published in high profile journals such as *Nature* (ranked first in impact internationally) and *Science* (ranked 3rd in impact internationally). Not only have many papers appeared in these journals this last fiscal year, but they have actually graced the cover of these journals several times, twice in October 2021 (Chunsheng Wang, battery cover; Liangbing Hu, Moldable Wood cover). Several notable FY22 research publications are discussed below.

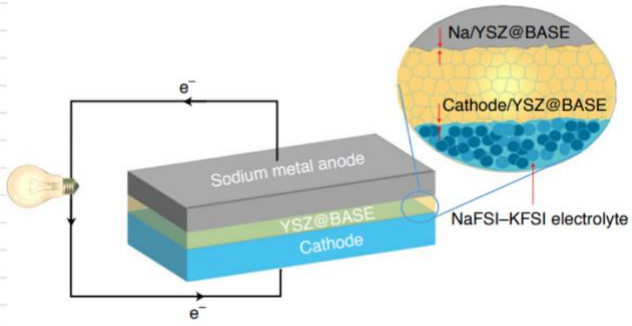
Battery Technology

- *Solvation sheath reorganization enables divalent metal batteries with fast interfacial charge transfer kinetics*, Hou, Singyuk and Ji, Xiao and Gaskell, Karen and Wang, Peng-fei and Wang, Luning and Xu, Jijian and Sun, Ruimin and Borodin, Oleg and Wang, Chunsheng, *Science* (cover shown below), **374**, 6564, (2021).

Divalent rechargeable metal batteries such as those based on magnesium and calcium are of interest because of the abundance of these elements and their lower tendency to form dendrites, but practical demonstrations are lacking. Hou et al. used methoxyethyl amine chelants in which the ligands attach to the metal atom in more than one place, modulating the solvation structure of the metal ions to enable a facile charge-transfer reaction. In full battery cells, these components lead to high efficiency and energy density. Theoretical calculations were used to understand the solvation structures.

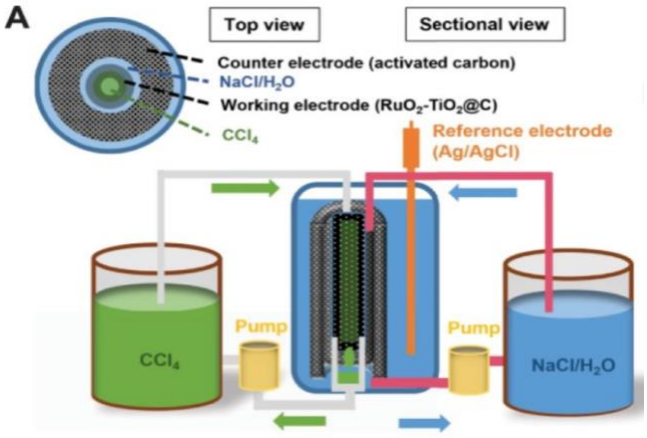
- *High energy and low-cost membrane-free chlorine flow battery*, Singyuk Hou, Long Chen, Xiulin Fan, Xiaotong Fan, Xiao Ji, Boyu Want, Chunyu Cui, Ji Chen, Chongyin Yang, Wei Want, Chunzhong Li, and Chunsheng Wang, *Nature Communications*, **13**, 1281 (2022).

The research group in the UMD Department of Chemical and Biomolecular Engineering (ChBE) led by Chunsheng Wang created a reversible chlorine redox flow (Cl_2/Cl-) battery conceptualized by the chlorine production in chloro-alkali industry. In particular, the chlorine is produced by oxidizing the chloride ions in the aqueous sodium chloride solution and stored in the water-immiscible organic flow. This design enables highly reversible energy storage and the removal of the costly ion-permeable membrane used in most redox flow batteries. This chlorine flow battery, which is highly scalable, provides a safe, reliable energy storage alternative at an affordable cost. Moreover, the membrane-free design enables both anionic and cationic charge carriers, thus expanding the chemical space for redox-active materials to be explored for RFBs in the future.



- *Interfacial-engineering-enabled practical low-temperature sodium metal battery*, Tao Deng, Xiao Ji, Lianfeng Zou, Obinna Chiekezi, Longsheng Cao, Xiulin Fan, Toyosi Adebisi, Hee-Jung Chang, Hui Wang, Bin Li, Xiaolin Li, Chongmin Wang, David Reed, Ji-Guang Zhang, Vincent Sprenkly, Chunsheng Wang and Xiaochuan Lu, *Nature Nanotechnology*, **17**, 269-277 (2022).

Sodium (Na), a naturally occurring and abundant material, has been studied widely as a practical choice in next-gen energy storage. Na-batteries, having similar qualities of lithium-ion batteries, provide a safe, attractive alternative to Li-ion batteries, although Na-batteries are not without challenges. Dendrite formation, in particular, remains a hazard as does high interfacial resistance between solid electrolytes and electrodes. To circumvent this problem, a collaborative research team at the University of Maryland (UMD) and North Carolina A&T State University, has developed an yttria-stabilized zirconia (YSZ)-enhanced beta-alumina solid electrolyte (YSZ@BASE) for low-temperature Na-batteries, which exhibit an extremely low interface impedance ($3.6\,\Omega\,cm^2$) with the Na metal anode, while achieving an extremely high density (~$7.0\,mA\,cm^{-2}$). This battery chemistry suppresses the Na dendrite formation, while maintaining robust interfacial contacts, lower electronic conduction, and preventing the continual reduction of BASE via oxygen-ion compensation during more than 500 hours of cycling. This work represents a new class of sodium batteries with a significantly lower

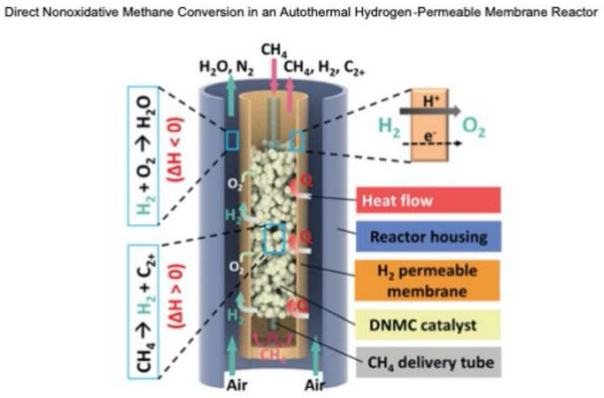


operating temperature, which translates into a safer solid-state battery than others in the same class currently on the market.

Advanced Catalytic Processes to Reduce Greenhouse Gasses

- *Direct Nonoxidative Methane Conversion in an Autothermal Hydrogen-Permeable Membrane Reactor*, Mann Sakbodin, Emily Schulman, Sichao Cheng, Yi-Lin Huang, Ying Pan, Paul Albertus, Eric Wachsman, and Dongxia Liu, *Advanced Energy Materials***, 11,** 46, (2021).

For the first time ever, scientists at UMD have converted methane (CH_4) into value added commodity chemicals such as ethylene and benzene with no greenhouse gas (GHG) production, a tremendous opportunity for both the chemical and natural gas industries. Dr. Dongxia Liu and Dr. Eric Wachsman have developed a direct nonoxidative methane conversion (DNMC) membrane reactor which transforms CH_4 to higher value hydrocarbons and hydrogen (H_2) in a single step. By coupling a DNMC-catalyst with an H_2-permeable membrane, the team demonstrated an integrated membrane reactor that circumvents thermodynamic limitations leading to high CH_4 conversion to value added chemicals in a single step without requiring conventional high cost and complicated separation schemes. Moreover, by using a simple air sweep on the other side of the membrane the team demonstrated that by oxidizing the permeated H2 to water all of the heat required for autothermal operation is achieved. This one-step membrane reactor is highly scalable, not only up for large scale chemical production but is a game changer as a small-scale modular gas-to-liquid reactor for stranded natural gas. Moreover, it provides a potential step change reduction in capital cost due to integration of catalysis and separation in a single unit while also dramatically increasing energy efficiency and eliminating GHG emissions.



- *Programmable Heating and Quenching for Efficient Thermochemical Synthesis*, Qi Dong, Yonggang Yao, Sichao Cheng, Konstantinos Alexopoulos, Jinlong Gao, Sanjana Srinivas, Yifan Wang, Yong Pei, Chaolun Zheng, Alexandra Brozena, Hao Zhao, Xizheng Wang, Hilal Ezgi Toraman, Bao Yang, Ioannis Kevrekidis, Yiguang Ju, Dionisios Vlachos, Dongxia Li and Liangbing Hu, *Nature*, **605**, 470 (2022).

A multi-institutional research team led by Liangbing Hu has developed a rapid Joule heating technique to conduct thermochemical reactions, which can be used to produce green and value-added feedstock chemicals from methane conversion and ammonia synthesis. Using this green electricity, the method provides a unique opportunity to reduce carbon dioxide emissions compared to conventional heating methods. The rapid Joule heating can not only electrify a process, thus, setting the foundation for sustainable manufacturing, but it also enhances reaction performance above conventional systems. This technique can toggle product selectivity in methane pyrolysis toward value-added C_2 products, and improve nanocatalyst stability in ambient pressure ammonia synthesis to enable high yield, which are difficult to attain by conventional chemical reactors.

- *Multi-principal elemental intermetallic nanoparticles synthesized via a disorder-to-order transition*, Mingjin Cui, Chunpeng Yang, Sooyeon Hwang, Menghao Yang, Sean Overa, Qi Dong, Yonggang Yao, Alexandra Brozena, David Cullen, and Liangbing Hu, *Science Advances*, **8**, 4 (2022).

The group has for the first time demonstrated the single-phase nanoscale multi-principal element intermetallics (MPEIs) with up to 8 different metals – completely devoid of particle growth, or phase separation - via a novel multi-element disorder-to-order strategy. This approach demonstrates a general strategy for synthesizing MPEI nanoparticles, not only providing a step toward octonary intermetallics, but also enabling the synthesis of MPEIs at the nanoscale. To achieve this, the group rapidly heated metal-salt precursors on a carbon substrate at 1100 K. Once cooled, they reheated the nanoparticles for five minutes, again at 1100 K, to encourage atomic rearrangement (thus ensuring the elements would fall in proper order), which gave way to a more stable MPEI arrangement. Then, the elements were rapidly cooled. The result was MPEI nanoparticles boasting an intermetallic structure with multiple elements. What makes this work special is the nano-MPEIs in this case demonstrate high activity and stability in catalysis. Nano-MPEIs have not been achieved previously by traditional wet chemistry or long-time sintering processes.

Elsevier Study on Battery Research

Finally, a citation analysis in the fall of 2021 from Elsevier, a leading scientific publishing company, showed that among solid-state battery publications those based on garnet-electrolytes are the fastest growing topic and moreover revealed UMD is the top ranked U.S. university in terms of number of publications in this topic and globally in terms of citations of those papers. Results are from the Elsevier product SciVal, a data analysis and visualization tool based on the Scopus database, which indexes the abstracts and references of approximately 25,000 academic journals from 7,000 publishers.

Topics showing high momentum over the past 10 years were further analyzed. Research analysis identified solid-state batteries as a major topic of rapid growth between 2011 and 2020. In 2011, there were 66 publications on solid-state battery technology, but by 2020, 722 papers were published on the topic. In a study conducted for the period 2015-2019, UMD ranked #4 globally and top in the U.S. in terms of solid-state battery Scholarly Output (number of publications), while also having the highest citation impact globally of those publications, the field-weighted citation impact (FWCI). The number one global ranking in citation impact speaks to the quality of UMD's solid-state battery research as indicated by scientific peer review. In terms of impact is how this research translates into commercial products by university start-up companies, as shown above in this report.

PARTNERSHIPS AND COLLABORATIONS

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

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

The U.S.-Israel Solid-State Energy Consortium (UISEC) is developing lithium and sodium metal solid-state batteries for advanced energy storage applications. In addition to three "All Hands" meetings, each of which had several presentations, there were numerous additional discussions and visits among consortium members (CMs). In October 2021, Dr. Eitan Yudilevich, Executive

Director of the Bird Foundation, visited the University of Maryland. Dr. Yudilevich had the opportunity to touch base with representatives from the UMD, Ion Storage Systems and Saft on their achievements in developing market-ready solid-state battery components and cells, and to meet with UMD - A. James Clark School of Engineering leadership to discuss the unique US-Israel Energy Center model and potential future areas of cooperation.

In June 2022, UISEC met in person for the first time at UMD. Joined by industrial partners, ION, Saft, Materials Zone, and Forge Nano, new collaborations and projects were scoped for future milestones towards the goal of improving solid-state battery technology.

Current achievements include:

- Advances in the development of coatings at several CMs, including UMD (e.g., the development of a Na+-conducting NaPON layer), TAU (e.g., with electrophoretic deposition of lithium aluminate films, BIU (e.g., of LiPON on cathode powders), and Forge Nano (e.g., with the transfer of LiPON recipes from UMD and translation to powder coating).
- Development of solid electrolyte powders (e.g., Li+-conducting argyrodites at BIU, Na+-conducting NaSICON at UMD) and cathode materials (e.g., Co-free Li insertion materials at BIU).
- Two joint research papers were published (Peled and Albertus groups) and several additional joint publications are underway.

Future collaborations discussed at the in-person meeting in June 2022 include:

- providing sulfide and NaSICON pellets for testing in pressure cell setup, with a reference electrode.
- ALD on Li metal for test in 3DB cells
- Spray approaches for Masked Systems and NaSICON porous cathode
- Continued advances in the development of full battery cells at 3DB (e.g., >100 cycles at 1C charge/discharge and commercial loading), BIU (e.g., half and full cell studies including with polymer electrolytes), and ISS (e.g., prototype lithium metal cells).

Members of the UISEC at UMD in June 2022.

A new consortium website is now located at: https://us-isr-energycenter.org/energy_storage/.

Center for Research in Extreme Batteries

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

The CREB Bi-annual meeting in December 2021 focused on batteries in extremely low temperature environments. Over 130 government, industry and academic leaders participated in the hybrid meeting. Naval and Army research laboratory personnel discussed Department of Defense needs for these batteries, including warfighter support as well portable and reliable wearable devices in cold regions. Scientists from NASA's jet propulsion laboratory also discussed the need for better battery power on their Mars surface missions.

Industry and academic leaders introduced new approaches to improving the capacity and high-power performance at ultra-low temperatures, such as delivering high power capability down to -40 °C with improved high (>55°C) temperature stability through electrolyte modification. Another approach includes a novel Liquefied Gas Electrolytes which allow for operation from -60 to +60 C while maintaining excellent cycle life and improving safety. These novel chemistries have the potential to replace conventional carbonate-based electrolytes in several Li-ion applications, particularly where low temperature performance or safety is mission critical.

In June 2022, the CREB bi-annual meeting focused on Science & Technology Enablers of a Domestic Extreme Battery Supply Chain. The U.S. currently depends on unreliable foreign sources for lithium, nickel, cobalt, graphite and manganese. Development of a domestic extreme battery supply chain is a national security enabler. Discovery of alternative materials can be another national security enabler. An overview of the supply chain was first discussed including defense and federal initiatives to secure the battery supply chain. Later discussions focused on educational resources to meet the needs of the battery industry as well as the challenges in supporting lithium batteries with domestic suppliers. New battery chemistries for relieving the supply chain issues were discussed. Finally, start-up perspectives on reducing the reliance on Chinese manufacturing were brought forth. Ultimately, the U.S. needs to: (1) Make retaining IP through U.S. based manufacturing a priority; (2) Build highly skilled teams from varied U.S. industries; (3) Attract and foster domestic & world class talent; (4) Design products that remove foreign materials reliance; and (5) Promote partnerships between U.S. companies and universities.

OUTREACH AND EDUCATION

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

the past year, *The Wall Street Journal*, *The Washington Post*, FOX DC news affiliate, and Maryland Public Television (MPT) have interviewed Dr. Wachsman for news segments regarding faster charging batteries and the future of electric vehicles. MPT's State Circle program highlighted the emerging energy technologies at UMD and the need to get away from fossil fuels and focus on renewable energy sources.

Student Recruitment

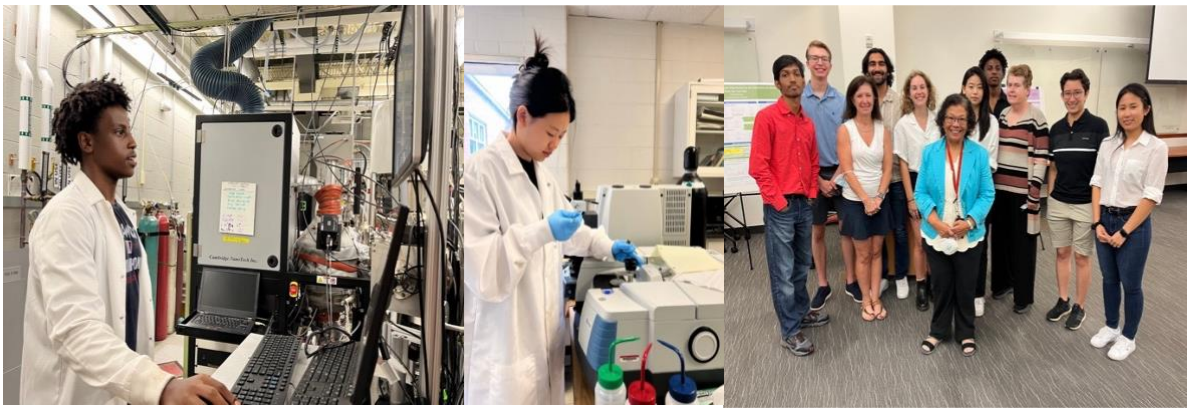
Based on the Advisory Board's recommendation to pursue alternative outreach platform strategies (especially in regards to students), MEI^2 initiated the following activities. Two student recruiting events were held – one with federal research defense labs and one with a private fuel cell company. In September 2021, All UMD STEM (*graduate and undergraduate*) students and faculty were invited to join in a discussion with DoD representatives on potential DoD fellowships and internships available. An overview of why the Army and Navy demands for advanced batteries are growing and why driven, sharp, and talented students are needed to join the workforce was presented. A brief introduction to the Science, Mathematics and Research for Transformation (SMART) Scholarship Program, the Navy Undersea Research Program (NURP), and the Naval Research Enterprise Internship Program (NREIP) were also provided. Over 45 students and faculty were in attendance.

The following March 2022, Watt Fuel Cell Corporation hosted an online recruiting event for graduating students interested in joining the team as a Fuel Cell Development Engineer, Mechanical/Thermal Engineer or Formulation Chemist. UMD STEM (*graduate and undergraduate*) students were invited. Watt is a developer and manufacturer of Solid Oxide Fuel Cell ("SOFC") stacks and systems that operate on common, readily available hydrocarbon fuels such as propane, natural gas, JP-8, and diesel. Their mission is to provide portable, quiet, light, efficient, affordable, and environmentally responsible energy solutions to a range of power markets with its superior hybrid power products and advanced manufacturing capabilities.

Research Experience for Undergraduates

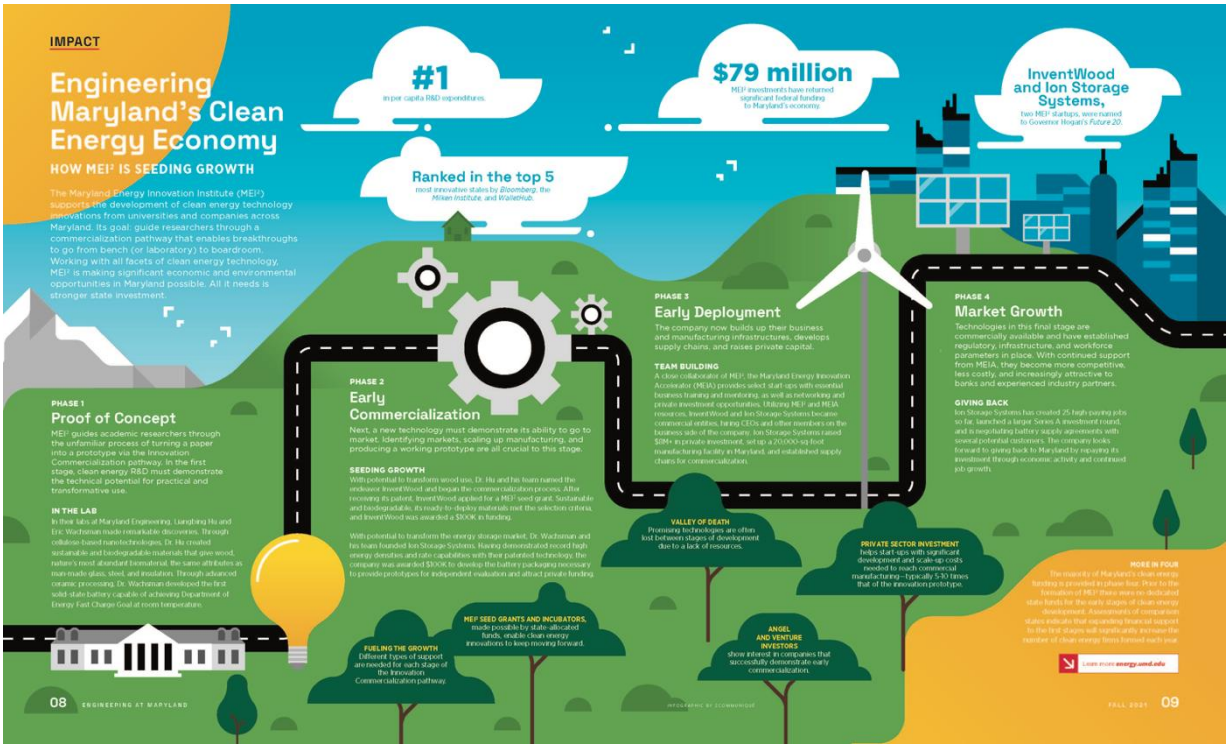
This past year, MEI^2 partnered with the UMD Department of Materials Science and received a three-year NSF Research Experience for Undergraduates and Teachers (REU/RET) grant. The program is entitled "Summer Research Experiences in **Re**newable and **S**ustainable **E**nergy **T**echnology (ReSET)".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

Over the course of 10 weeks (June – August 2022), eight undergraduate students and 2 high-school STEM teachers worked with UMD professors on a specific research project. The high-school teachers were required to introduce new energy related curriculum into their upcoming fall classes. High school students gained knowledge and hands on research experience in renewable energy in a real-world context. Students and teachers also visited local UMD start-up companies, the UMD nuclear reactor and the UMD nano-fabrication lab and also attended career development seminars on ethics, career pathways, and entrepreneurship.



Informatics

The MEI^2 Infographic (shown below) was created to help Legislators, private industry and others better understand the Institute's role and highlight successes in transitioning energy research into marketable products and services.



Graduate Energy Fellowships

MEI^2 awarded one Harry K. Wells graduate energy fellowship and one Barbara Hulka graduate energy fellowship in March 2021. Both fellowships come with a 20K stipend for research and a 4K award for conference travel and materials. Mr. Harry K. Wells (B.S. '43, mechanical engineering) established an endowment to support engineering graduate student research in the field of sustainable energy generation and/or storage. The 2022-23 Wells recipient is Alex Hall (MSE). Alex proposes to use computational methods to investigate superionic conductivity in mixed-anion solid electrolytes. This investigation has the potential to yield new design principles and materials for applications in solid electrolyte and Li-ion battery design. This work is greatly needed as the world continues its shift toward electric vehicles and the production of consumer electronics soars requiring safe and improved batteries. Understanding the effects of mixed anion compositions in SICs can enable ASSBs with performance rivaling current organic liquid electrolytes. Adoption of theses ASSBs can increase the efficiency of electric vehicles, grid storage, and consumer electronics while improving their safety and reducing their environmental impacts. Outside of batteries, lithium superionic conductors are being used in ionic transistors, solid-state sensors, and fuel cells. Insights from the proposed work will be applicable across these fields to improve lithionic devices.

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 2022-23 recipient is Funke Okunrinboye (ChBE). Funke's research aims to fundamentally understand carbon and reductant flow mechanisms in two electroactive microbes (EAMs; *Shewanella oneidensis* and *Clostridium ljungdahlii*). These microbes are capable of assimilating externally supplied electrons into their metabolism as energy and reductant sources. This ability enables these microbes to reduce CO_2 to fuels and facilitates carbon-efficient biofuel synthesis. This research will seek to identify rate-limiting steps in these organisms that can be altered for improved synthesis of biofuels by the organisms. She will also study metabolic symbiosis between the two EAMs *S. oneidensis* and *C. ljungdahlii,* and test for microbial consortium effects when these two organisms are cultured together. The study will provide insight into carbon and reductant flow partitioning in the synthesis in these organisms, as well as identification of genetic engineering targets for optimized metabolite synthesis.

APPENDIX 1. MEI^2 FY22 Budget

FY22 Budget Expenditures and FY23 Approved Budget

FY22 is the fifth year of the original FY18 legislation that established MEI^2, and thus the budget at the beginning of the fiscal year remained $1.5M consistent with the original legislation. However, with the General Assembly's overturning of the SB460 governor veto an additional $600K (split equally between MEI^2 and MCEC) was provided in May 2022 with the caveat that the additional funds (in FY22 only) must be encumbered by the end of FY22 (June 30, 22). As one month was not sufficient to solicit and review new seed grant opportunities, additional funds were spent on salaries and user facility equipment and supplies as shown in table below.

For the past five years UMD has provided additional resources beyond the reported expenditures for MEI^2 including basic business and management personnel as well as the operation of a lab facility that has been available for university and start-up company use. Therefore, part of the additional funding in FY22 was used to offset these unrecovered costs.

Going forward, the FY23 budget was approved by the Advisory Board. The majority of additional funding ($250K out of $300K) will increase the Energy Seed Grant program. However, salary numbers have increased to help cover part of the previously unrecovered UMD finances expended to manage the Seed Grant program and user facility, as well as to reflect the State Legislature granted raises to state employees in FY22.

	Budget	Actual	Diff	FY23 Budget
Seed Grants	$400,000	$400,000	$0	$650,000
Salaries	$200,000	$370,809	$150,809	$270,691
Events/Outreach	$10,000	$5372	$2,628	$5,000
Communications/ Reporting	$3,000	$1500	$1500	$2,500
Equipment/ Supplies	$10,000	$62,756	$50,756	$8,000
Travel	$8,000	$7116	$2884	$5,000
SubTotal	$631,000	$847,553	$55,447	$941,191
SubAward (MCEC)	$900,000	$1,188,446	$11,554	$1.2M
Totals	**$1,531,000**	**$2,035,999**	**$67,001**	**$2,141,191**

APPENDIX 2. Letter from MEI^2 Advisory Board

UNIVERSITY OF MARYLAND

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

Maryland Energy Innovation Institute
August 16, 2022

Dear Dr. Wachsman,

The Maryland Energy Innovation Institute (MEI^2) Advisory Board has prepared this letter reflecting its members' inputs from the July 27, 2022, meeting. This letter is intended to provide the Advisory Board's perspectives and recommendations with the aim of sustaining the success and growth of MEI^2.

First and foremost, the Advisory Board appreciates and thanks Maryland State Senator Feldman and Delegate Qi for their legislative leadership in championing MEI^2's sustained existence beyond its sunset date and its increased funding in the 2021 and 2020 legislative sessions, as well as Delegates Korman, Barve, Brooks, Crosby, Fraser- Hidalgo, Lierman, Queen, Rogers, and Walker who cosponsored the House Bill in the 2020 session. The Advisory Board further appreciates Delegates Qi's and Korman's demonstrated interest and active participation in this year's meeting and SEED grant poster session event.

The Advisory Board welcomes its newest members and thanks the past members for their time and support in advising MEI^2. With the addition of the new board members, a full quorum now exists that continues a balanced representation from industry, research and academia along the value chain from research and technology development to market entry and commercialization.

With respect to clean energy research and innovation, the Advisory Board continues to be impressed with the cutting-edge progress affiliated with MEI^2 and the University. The Advisory Board notes the continued significant advances and collaborations in clean energy research programs have yielded tangible outcomes and benefits to its partners and to the State. This is evident in the over 16 Energy Innovation companies that have been founded and advanced through their association with the MEI^2 Energy Seed grants and/or in partnership with the Maryland Energy Innovation Accelerator (MEIA).

The Advisory Board notes the continuing growth of the return on investments MEI^2 has made which has leveraged a return of over 33 times its Strategic Energy Investment Fund (SEIF) which includes the SEED Grants, in addition to the creation of new jobs in Maryland. As impressive as these returns are, the Advisory Board envisions even greater potential for enhanced in-state economic benefits and jobs creation by increasing investments in clean energy and climate solutions as part of the State's economic portfolio. A significant start is the Climate Solutions Now Act of 2022. This legislation is aimed at pushing the frontiers of clean energy and addressing

climate change as a major State of Maryland priority with its $15M Climate Catalytic Capital Fund to be administered by the Maryland Clean Energy Center (MCEC).

The University's extensive research and technology incubation facilities, programs and expert capabilities, including those of MEI^2, can collectively act as a "magnet" to attract and retain out-of-state companies and encourage startups within the state. This de-facto "one-stop shopping" offers the advantages of incubating new ideas, creative solutions and problem solving for companies that choose to establish their manufacturing in close proximity.

The Advisory Board again commends MEI^2 for its contributions to the continued recognition of the University as a leader among universities, with special congratulations for being named #1 in the world rankings on Solid-State batteries by Elsevier, a scientific publishing company. Not only is the University first in scholarly output and citations, but also scientific impact.

The Advisory Board notes that administering the Seed Grants program was conducted in face of some uncertainty prior to MEI^2 gaining its status as a sustained entity. As such, with limited known funding at the time, the SEED Grant program was constrained in making the number of awards for this fiscal year. Nonetheless, there were 7 Phase-1 projects awarded in comparison to 4 from the prior fiscal year. The Advisory Board also notes that increasing the number of proposal submissions both for Phase-1 and Phase-2 could yield a broader range of promising concepts from which to select.

The Advisory Board acknowledges the continued coordination between MEI^2 and MCEC and MEIA. A formal mechanism to enhance closer coordination could enhance the potential for successful projects leading to overall benefits to each program. The Advisory Board notes that MCEC and MEIA continue to make great strides toward their program strategic goals and has in place a clear set of metrics to track progress through their Key Performance Indicators (KPIs).

The reported status of MEI^2's actions in response to the Advisory Board's recommendations arising from the July 9, 2021, meeting are as follows:

- **Briefing Updates to State Decisionmakers**: Status: MEI^2 met with numerous legislators and provided testimony. It successfully obtained strong bipartisan support to make MEI^2 "permanent" entity with increased funding ($2.1 million/year).
- **Improving Seed Grants Program guidance and participation**: Status: MEI^2 is continuing to engage with MEIA in its effort to enhance the quality and quantity of proposals as part of its grant solicitation cycle. This remains an ongoing continuous improvement effort drawn upon cumulative data from proposal submissions and awards.
- **Early Engagement with new Dean of Engineering**: Status: A meeting with the new Dean still needs to be scheduled as there are competing priorities for his time. However, the importance of such a meeting is clearly recognized and MEI^2 will target for a meeting sometime during the Fall of 2022.
- **Filling Advisory Board and Committee Vacancies**: Status: This recommended action has been completed with the addition of new Advisory Board and Committee members.

After discussions, inputs and deliberations, the Advisory Board recommends the following actions by MEI^2:

- **SEED Grant Program**:

    - Formalize the relationship with MEIA to enhance the SEED grant proposal process which requires proposers to seek out MEIA support resources with the aim of strengthening the business case in proposal submissions.
    - Open eligibility criteria of SEED grant proposers to all full-time faculty beyond tenured or tenure tracked faculty to encourage broader participation in the program.
    - Update the strategy and priorities regarding phase 1 and phase 2 awards within available SEED grant funds.

- **University's Grand Challenges Climate Change Priority**: Proceed with matching fund proposal which includes participation from other university program offices and colleges as an integrated climate change initiative. The aim is to yield sustainable benefits and outcomes for the University and the State which could be an exemplar for emulation
- **Outreach:** Expand tailored outreach material for targeted audiences to optimize impact, visibility and support for MEI^2.
- **Key Performance Indicators (KPIs)**: Update and improve clarity of performance metrics and tracking progress against those metrics as part of an updated MEI^2 strategic plan. To the extent possible, also include jobs creation as a metric to track.

As always, the Advisory Board is fully committed to advising MEI^2 on the strategic development and alignment of its priorities with the University and the State of Maryland. The Advisory Board thanks all the meeting participants for their time and contributions to the discussions on the progress and direction in MEI^2 in clean energy innovation.

Sincerely,

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

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

Mallik Angalakudati,
Senior Vice President, Strategy & Innovation, Washington

Theresa Christian, PhD

Director, Technology & Innovation, Exelon
Steven Freilich***
Director of Materials Science, Dupont Central Research and Development (retired)

Thomas Greszler**
SAFT research development, R&D Manager North America

Geoff Oxnam
Founder & CEO, American Microgrid Solutions, LLC Chair 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 27 Meeting; **In-person representation by Xilin Chen; ***Afternoon remote attendance)