Maryland Energy Innovation Institute
Annual Report
FY 2018

MARYLAND ENERGY INNOVATION INSTITUTE

University of Maryland 8136 Paint Branch Drive, College Park, MD 20740

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

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MARYLAND ENERGY INNOVATION INSTITUTE

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Message from the Director

The Maryland Energy Innovation Institute (MEI^2) is committed to catalyzing and developing clean energy technologies and assisting in the transitioning of these technologies into marketable products and services through Maryland based entrepreneurial ventures. These energy innovations have tremendous potential to both grow the State of Maryland economy and have a positive impact on addressing global energy needs in a sustainable manner.

Examples of a few of the University of Maryland based energy innovations being developed in partnership with local spinoff companies include game changing solid state batteries that are intrinsically safe and high performing as well as aqueous lithium ion batteries with increased efficiency and longevity. Both battery technologies would be beneficial to the defense and aerospace industry, consumer electronics, commercial grid storage and the biomedical industry. Energy saving technologies for building heating/cooling systems and personal heating/cooling devices for consumer use, as well as advanced photovoltaics and the conversion of agricultural waste and natural gas to value added chemicals are also under development.

MEI^2 continues to increase the visibility of Maryland's energy and environmental research while providing a centralized Institute for the needs of the State Government with respect to energy expertise.

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

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 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 are in the State.

The University of Maryland (UMD) has similarly made major investments setting up the UMD Energy Research Center (UMERC) to coordinate and grow interdisciplinary (from science and technology to policy) energy R&D across the campus, as well as other investments in environmental and climate change research such as the Global Sustainability Initiative (GSI), and others. These investments have paid off in terms of a tremendous increase in federally sponsored energy research. For example, UMD is currently number one in the U.S. in terms of number of Department of Energy (DOE) Advanced Research Projects Agency - Energy (ARPA-E) awards, participating in over $50M so far, and leads a major ($31M) multi-institutional DOE Energy Frontier Research Center "Nanostructures for Electrical Energy Storage" (NEES). In addition, it has paid off in terms of prestige on the environmental side by for example being asked by the Secretary General of the United Nations to host the 2016 Climate Action Summit.

UMD has also made major investments in entrepreneurship, with numerous faculty developing commercially viable energy technologies and spin-offs (such as Redox Power Systems, Ion Storage Systems, Versa Volt, Invent Wood, etc.). Commercial success of these university energy spin-off companies will transition UMD to the highest echelon of academic energy entrepreneurship (e.g., the Stanford Precourt Institute for Energy and the MIT Energy Initiative) and in partnership with the other Maryland higher education institutions provide the opportunity for even greater research funding and prestige for academic institutions across the State. Furthermore, this will then be the energy innovation catalyst to create the *technology push* needed for Maryland to generate the jobs created in the state by its *market pull* policies.

Finally, an energy business ecosystem and creative financing approaches are necessary to achieve the greatest impact for the adoption of advanced energy technologies. The Maryland Clean Energy Center (MCEC), created by the General Assembly in 2008, was set up to advance the development and adoption of clean energy products, services and technologies as part of an overall economic development agenda to help the State attain energy generation, demand reduction and greenhouse gas emission reduction goals. The alignment of MCEC energy financing and deployment activities with Maryland academic institution energy research and innovation activities provides the opportunity to transition Maryland into not only an academic leader in energy research, but a U.S. leading state in energy innovation and economic impact. This then is the goal and incentive for creating the Maryland Energy Innovation Institute (MEI^2).

THE MARYLAND ENERGY INNOVATION INSTITUTE

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 Senate-Bill-313/House-Bill-410 to create MEI^2, and in so doing linking by statute the academic energy innovation across the State through MEI^2, with the financing, business development, and energy deployment of MCEC in order to attract and develop private clean energy innovation in Maryland, and further authorizing $7.5 million in RGGI funding over 5 years for these two entities. The Act officially took effect on July 1, 2017. Summarized here are the actions taken in the subsequent year by MEI^2.

MEI^2 Objectives

MEI^2 will provide 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 Institute will develop solutions to global and local energy problems (*i.e.* cleaner and renewable energy solutions; more efficient use and storage of energy) and assist the transfer of knowledge and resources to the public while providing additional employment opportunities through locally based entrepreneurial ventures. Moreover, as specified in the legislation the purpose of MEI^2 is 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.

MEI^2 Director

Per legislation, the Director of the University of Maryland Energy Research Center (UMERC), a University of Maryland faculty member, shall be the Director of the Institute. As such Dr. Eric Wachsman, Director of UMERC and the William L. Crentz Centennial Chair in Energy Research with appointments in both the Department of Materials Science and Engineering, and the Department of Chemical Engineering at the University of Maryland, is the inaugural Director of MEI^2. Dr. Wachsman is a Fellow of both The Electrochemical Society (ECS) and the American Ceramic Society (ACerS), a member of the World Academy of Ceramics and Vice President of ECS. His research is focused on solid ion-conducting materials and electrocatalysts, and includes the development of solid oxide fuel cells, solid-state batteries, ion-transport membrane reactors, and solid-state gas sensors using advanced ion conducting materials. He has more than 250 publications and 20 patents on these energy technologies, and to date 3 companies have been formed based on these inventions.

MEI^2 Advisory Board

The MEI^2 Advisory Board advises the Director and UMD on the management of the Institute. Per legislation the Institute Board consists of the following nine members: 1) the chair of the board of directors of MCEC; 2) the director of the Maryland Energy Administration; and 3) seven members selected by UMD based on expertise in energy technology commercialization, the clean energy industry, venture capital financing, and energy research. From the members, the Institute Board selects a chair and vice-chair. The Advisory Board was created and currently consists of the following members:

- **Victor Der, MEI^2 Board Chair**
  Assistant Secretary of Fossil Energy, U.S. DOE (retired)
  Adjunct Professor, Columbia University
  During his DOE career, Dr. Der played a vital role in developing, implementing, and leading several key programs within the Office of Fossil Energy. Prior to becoming the Assistant Secretary of Fossil Energy, he was Deputy Assistant Secretary for Clean Coal, where he was responsible for directing clean coal R&D. Included in these responsibilities were implementation of energy policy initiatives and priorities relating to clean coal utilization and its role in climate change mitigation, including carbon capture and storage. He also is a principal co-founder of Vicaris Energy and Technology, LLC, a venture capital entity focusing on new technology start-ups, and advising domestic and international clients in strategic low-carbon energy technology, projects and policy.

- **Ellen Williams, MEI^2 Board Vice-Chair**
  University of Maryland Distinguished University Professor
  Former Director, ARPA-E (DOE)
  Dr. Williams earned her B.S. in 1976 from Michigan State University and her Ph.D. in 1981 from the California Institute of Technology. Her research interests are in surface chemistry and nanotechnology. She founded the University of Maryland Materials Research Science and Engineering Center and served as its Director from 1996 through 2009. She served as Chief Scientist at BP from 2010-14, and as Director of the U.S. Department of Energy's Advanced Research Projects Agency-Energy (ARPA-E) from 2014 until early 2017.

- **Joseph Dominquez**
  Senior Vice-President, Exelon Corporation
  Dominguez joined Exelon in 2002 as Associate General Counsel, responsible for all litigation matters in the Mid-Atlantic region. In 2012, Dominguez became Senior Vice President, Governmental and Regulatory Affairs and Public Policy for Exelon Corporation. He has experience in broad-based litigation practice counseling large and small corporations, institutions and government entities.

- **Abigail Hopper**
  President & CEO, Solar Energy Industries Association
  Abigail Ross Hopper is the President and CEO of the Solar Energy Industries Association, the national trade organization for America's solar energy industries. She oversees all of SEIA's activities, including government affairs, research, communications, and industry leadership. She served formerly as the Director of the

Maryland Energy Administration (MEA) and has broad experience in the energy sector, including working with a wide variety of stakeholders as well as legal expertise. Abby led the MEA from 2012, first as Acting Director and then as Director in June 2013. She also served concurrently as Energy Advisor to Maryland Gov. Martin O'Malley since 2010. As MEA Director, Abby was pivotal in ensuring the passage of the Maryland Offshore Wind Energy Act of 2013.

- **Geoff Oxnam, chair of the board for MCEC**
  CEO, American Microgrid Solutions
  Geoff Oxnam is a veteran utility executive and microgrid project manager with more than a decade in public power utility management. Geoff has managed strategic planning, operations, and marketing and communications efforts for utility, telecommunications and environmental organizations. Prior to launching American Microgrid Solutions, Geoff served as Vice President of Operations for Easton, Utilities (Easton, Md.), a public power utility that provides electricity, natural gas, water, wastewater, cable television, broadband Internet, Digital voice calling and IT professional services.

- **Philip Perconti**
  Director, U.S. Army Research Laboratory
  Philip Perconti is credited with leading recent efforts that have expanded ARL's business model for Open Campus - another signature ARL vehicle to facilitate tech transfer - to not only bring collaborators into ARL, but also bring its research staff into partner facilities. Under his leadership, ARL now extends across the country at ARL West (University of Southern California), ARL South (University of Texas at Austin), ARL Central (University of Chicago), and the under development ARL Northeast, to be located in the greater Boston, MA area. ARL has also established CRADAs with regional universities/partners around each hub to shape the ARL extended hub and spoke model. In addition Perconti has assisted in the establishment of small businesses through lab collaboration and technology transfer. Recent examples include Per Vivo Labs and Gox Studio who recently licensed ARL intellectual property.

- **Jigar Shah**
  Founder, Generate Capital Inc.
  Jigar Shah is the President and Co-Founder of Generate Capital. Jigar was the founder and CEO of SunEdison (NASDAQ: SUNE), where he pioneered "no money down solar" and unlocked a multi-billion-dollar solar market, creating the largest solar services company worldwide. After SunEdison, Shah served as the founding CEO of the Carbon War Room, a global non-profit founded by Sir Richard Branson and Virgin Unite to help entrepreneurs address climate change.

- **Mary Beth Tung**
  Director, Maryland Energy Administration
  As Director of the MEA, Dr. Tung works to ensure that Maryland's energy portfolio benefits Maryland residents, businesses and local government organizations by improving the effective use of all of energy resources available in the state. Dr. Tung oversees nearly 40 energy related programs including grants that benefit low-to-

moderate income families, commercial and industrial entities, and residential. As deputy secretary of the Maryland Department of the Environment, Dr. Tung helped develop innovative solutions for the department to work more efficiently while providing guidance and support to its science-based efforts. Previously, Dr. Tung had worked extensively in the legal and scientific communities. As an attorney, she specialized in business law, intellectual property, and biotechnology patent law.

Inaugural MEI^2 Advisory Board Meeting

On August 14, 2017, MEI^2 convened the first Advisory Board meeting at UMD with seven Board members in attendance (with Scott Dupcak, Managing Director – Constellation Technology Ventures, Exelon Corporation, serving as proxy for Joseph Dominguez). Victor Der was elected as Chair of the Board and Ellen Williams was elected Vice-Chair. After a full day of presentations articulating the success and resources of the UMD Energy Centers, Innovation Programs and University Start-Ups, as well as an overview of the new Institute, the Advisory Board recommended three main thrusts for the Institute: 1) Research, 2) Innovation, and 3) Finance. The Advisory Board agreed that the ultimate metric for success of MEI^2 is the development of programs that create sustainable clean energy related jobs and economic growth in Maryland thereby showing a return on the state's investment.

MEI^2 was encouraged by the Advisory Board in FY18 to expand its reach by developing partnerships and collaborations, engaging in outreach and education activities, and initiate the following *Innovation Programs* as a first step in achieving the Institute objectives.

- **MEI^2 Energy Innovation Seed Grants**
  Initiate an open annual funding solicitation across all Maryland academic institutions and affiliated energy spin-off companies to overcome the "Valley of Death" between previously obtained academic transformative laboratory research results and prototype demonstrations of sufficient scale to obtain investor interest.

- **MEI^2 Industry Research Program**
  Develop an industry research consortia program focused on pre-competitive energy technologies of interest to those companies. As research is pre-competitive, IP will remain with the Maryland academic institutions. MEI^2 will thus provide matching funds as a multiplier incentive for industry sponsorship of this research on an open solicitation basis to Maryland academic institutions.

- **MEI^2 Matching Fund Program**
  To expand Maryland energy research and increase academic faculty participation, MEI^2 will look to provide State-matching funds for MEI^2 affiliated faculty pursuing federal energy research grants as opportunities arise. These are typically in the ~10-20% of federal funds received level. In particular, the Institute will look to attract major MEI^2 aligned federally funded centers such as the DOE Advanced Manufacturing Office (AMO) or NIST Manufacturing Hubs.

In examining the Institute as a whole, the Advisory Board encouraged looking at potential funding and investment opportunities through MCEC capabilities. As MCEC has bonding authority and can make investments to advance clean energy solutions, the Advisory Board suggested MEI^2 explore opportunities to go beyond financing the deployment of energy efficiency and generation projects. Possible suggestions included leveraging revenue in the Incubator, interest bearing loans for patent costs of companies in the Incubator and convertible note investment prior to Series A. The Advisory Board believes MCEC should ensure close coordination between the MEI^2 Investment Committee (described below) and the MCEC Financing Advisory Committee to advise them on such investments and due diligence matters. A summary of their advice and recommendations is provided in their letter to the MEI^2 Director attached in appendix.

Following the inaugural Advisory Board meeting, state and university leaders gathered at UMD to officially launch MEI^2. In attendance for the launch, U.S. Senator Chris Van Hollen and Maryland State Senator Richard Madaleno both spoke about the importance of the next generation of energy and the need for a clean energy revolution. UMD President, Wallace Loh, welcomed everyone to the Institute launch, Darryll Pines, Dean of UMD's A. James Clark School of Engineering and Nariman Farvardin Professor, noted that clean energy is one of the leading engineering challenges of the 21st century and that both the university and the state are committed to this issue. Mary Beth Tung, director of the Maryland Energy Administration and Joshua Greene, chairman of the MCEC board and vice president of A.O. Smith, echoed the Governor's and MCEC's commitment to clean energy technology and to the growth and investment of jobs in this area. Also present were Maryland State Delegate Tawanna Gaines, other government officials, and corporate partners, as well as UMD researchers affiliated with the Institute who showcased examples of the kind of battery, fuel cell, solar, and energy efficiency technologies that MEI^2 will work to move into commercial use.

UMD President Wallace Loh, U.S. Senator Chris van Hollen, State Delegate Tawanna Gaines, State Senator Richard Madaleno, Dean Darryll Pines, MEI2 Director Eric Wachsman, MEA Director Mary Beth Tung.

INNOVATION PROGRAMS

Consistent with the enabling legislation mandate and Advisory Board recommendations MEI^2 initiated innovation programs starting with the Energy Innovation Seed Grants and the mechanism to solicit and evaluate these grants.

Institute Investment Committee

The Advisory Board agreed to establish an MEI^2 Investment Committee to oversee the solicitation and review of the Energy Innovation Seed Grants and other activities that support the Energy Investment Fund. Ellen Williams was elected as Chair of this committee. The Board agreed that committee members should come from local

investment companies, Commerce, other universities, and UMD research administration. Members of the committee include:

- **Ellen Williams, Chair**
  University of Maryland Distinguished University
  Former Director, ARPA-E (DOE)
  Dr. Williams earned her B.S. in 1976 from Michigan State University and her Ph.D. in 1981 from the California Institute of Technology. Her research interests are in surface chemistry and nanotechnology. She founded the University of Maryland Materials Research Science and Engineering Center and served as its Director from 1996 through 2009. She served as Chief Scientist at BP from 2010-14, and as Director of the U.S. Department of Energy's Advanced Research Projects Agency-Energy (ARPA-E) from 2014 until early 2017.

- **Robert Briber**
  Associate Dean for Research, UMD A. James Clark School of Engineering
  Dr. Briber's research interests include X-ray and neutron scattering, thermodynamics, and the structure of polymers. He is also a principal investigator for the Functional Macromolecular Laboratory which focuses on the synthesis, characterization and processing of novel polymer-based nanostructured systems used in a variety of technological fields, ranging from medicine and pharmaceuticals to energy storage and microelectronics.

- **Eric Chapman**
  UMD Assistant Vice-President for Research Development
  Chapman is responsible for building strong ties to federal funding agencies, federal Labs, industry, medical centers, foundations and other universities to facilitate the development of large, multi-disciplinary proposals and initiatives. He works closely with the Vice President for Research and the Director of National Research Initiatives to bring together and support teams of faculty from various disciplines and Colleges to pursue funding opportunities and to build cross campus, innovative research programs and initiatives.

- **Julie Lenzer**
  Associate Vice President of Innovation and Economic Development and Co-Director of UM Ventures
  As Associate Vice President of Innovation and Economic Development and Co-Director of UM Ventures, Lenzer is charged with fostering and supporting the development that is currently underway in the UMD Research Park and Greater College Park. She will also promote and facilitate productive, university-wide collaboration to launch startup ventures based upon University intellectual property, as well as maximize synergies between UMD and the University of Maryland, Baltimore (UMB) to leverage strengths of each and encourage technology commercialization.

- **Jigar Shah**
  Founder, Generate Capital Inc.
  Shah is the President and Co-Founder of Generate Capital. Jigar was the founder and CEO of SunEdison (NASDAQ: SUNE), where he pioneered "no money down solar" and unlocked a multi-billion-dollar solar market, creating the largest solar services company worldwide. After SunEdison, Shah served as the founding CEO of the Carbon War Room, a global non-profit founded by Sir Richard Branson and Virgin Unite to help entrepreneurs address climate change.

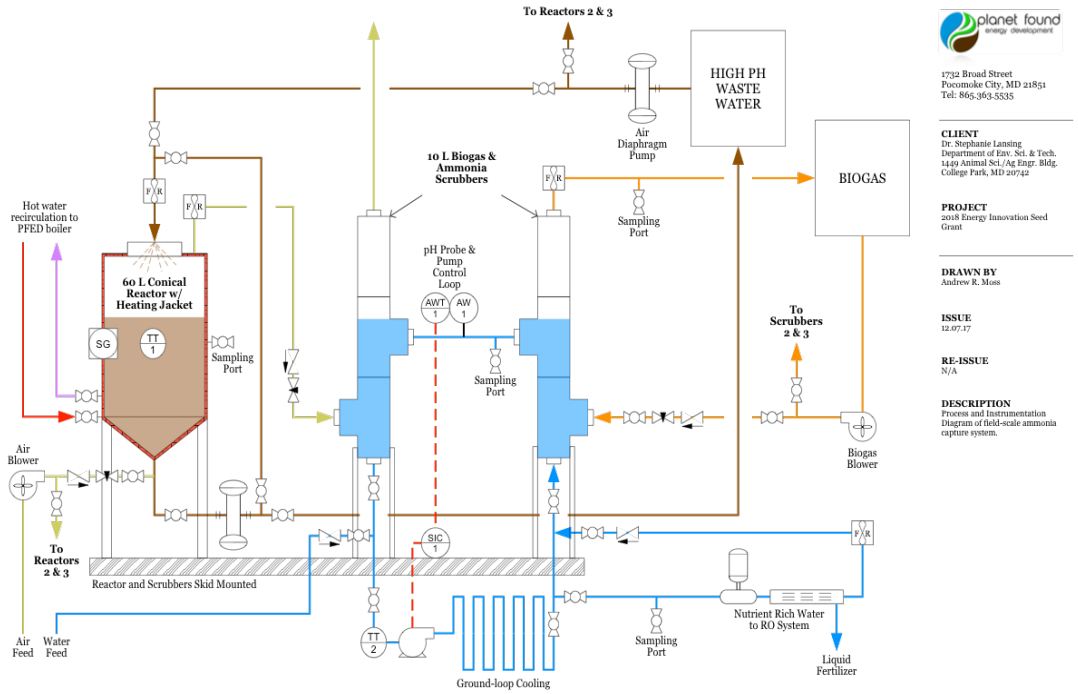
- **Parag Sheth**
  Director, CMO, TEDCO
  For the past 20 years, Sheth has successfully led sales and marketing efforts for several venture-backed startups and multi-nationals. He has time and again built multi-million dollar businesses starting from scratch as well as rapidly grown existing businesses across the globe. His expertise scales across verticals, company size and geography.

Energy Innovation Seed Grants

MEI^2 is focused on translating university energy research into new clean energy companies in the State of Maryland and thus simultaneously benefiting our environment and creating high paying jobs to help our State economy. As a near-term priority, MEI^2 initiated a seed grant program to bridge the gap between academic transformative laboratory research results and prototype demonstrations to obtain investor interest. It is expected that the projects selected will advance energy technology and economic growth in Maryland in partnership with a local university faculty or student led company. The device or process should have appropriate intellectual property protection (invention disclosure, patent application, or patent) filed with the applicant institution. At the end of one year, a report that describes the work done and includes a commercialization plan will be the final deliverable for the project. The plan should include a clear market assessment and strategy; a viable revenue model; and a strategy for financing. All full-time tenured or tenure track faculty members at any Maryland state academic institution or Maryland companies affiliated with and commercializing inventions created by those faculty are eligible to apply. In 2018 the call was for multiple seed grant awards with a maximum award ceiling of $100,000. The total amount of funding available for the 2018 Seed Grant Program was $400,000.

The MEI^2 Investment Committee reviewed proposals from academic institutions across the State. Projects were reviewed for: 1) the likelihood of attracting outside funding, 2) innovative and scholarly merit, and 3) potential for commercial readiness. In the first round, 10 proposals were submitted from three different academic institutions in Maryland. Based on the MEI^2 Investment Committee selection, in January 2018, MEI^2 awarded four - $100K Seed Grants for Energy Innovation:

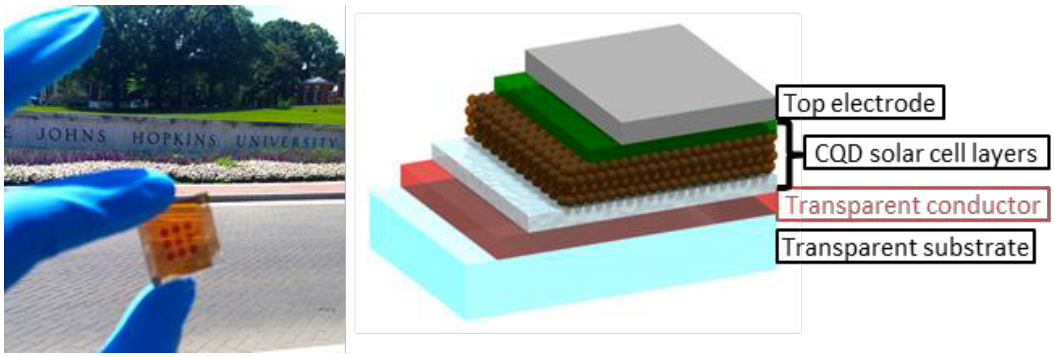
- **Biogas Enhancement and Ammonia Extraction for Increased Revenue in Waste-to-Energy Systems**;
Lead PI: Stephanie Lansing, Associate Professor, Department of Environmental Science & Technology, University of Maryland College Park, Partnering Company: Planet Found Energy Systems, LLC
The project goal is to scale an effective design for a combined biogas scrubbing and nutrient capture system (NCS) that enhances biogas quality while producing stable, revenue-generating N-fertilizer from the effluent of an anaerobic digester (AD). The overall objective is to evaluate the AD-NCS design at the prototype-scale using the optimized design from lab-scale studies, with material characterization, dynamic modeling of a full-scale reactor, and a financial analysis of the pilot-scale system. The results will be incorporated into a life cycle assessment (LCA) to determine the sustainability of the system compared to the status quo and assist with marketing of the process to waste water treatment plants (WWTPs), farmers and regulators. The



Design drawing pilot-scale reactor of the ammonia scrubber using biogas.

testing is conducted at the PFED digester site in Pocomoke City, MD, with on-site metering of the system and verified laboratory testing at UMD. The results can not only be used on manure-based digesters but also suitable for any wastewater digester, including large-scale (DC WATER) and small-scale (developing countries), resulting in large reductions in nitrogen pollution and the creation of the fertilizer production that is easily transported and biogas with enhanced CH_4 content and less impurities within a small treatment footprint. Seed grant funding will allow the research to go from lab scale to field scale in an applied system.

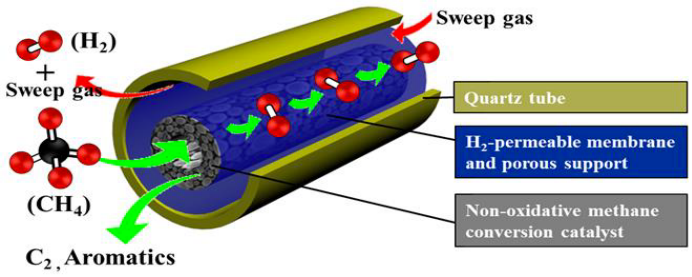
- **Large Area Quantum Dot Solar Cells for Building Integrated Photovoltaics**;
  Lead PI: Susanna Thon, Department of Electrical and Computer Engineering, Johns Hopkins University; Partnering Company: NanoDirect LLC
  The project goal is to improve on the technology and enter the building photovoltaic market. Novel systems including organic and quantum dot based PV allow for light weight films that can be applied to windows and facades similar to a window tint. These PV systems allow for capture over substantial areas compared to roof-top solar, however they are currently limited in efficiency at commercial scales. NanoDirect in conjunction with Johns Hopkins University is developing novel transparent conductors that will solve this scaling problem. By producing high-purity silver nanowire transparent conductors, the group will enable maintenance of lab-scale efficiencies of quantum dot solar cells at commercially viable large-scale areas. NanoDirect will develop transparent conductive films using silver nanowires and furnish them to Professor Thon's laboratory for solar cell manufacturing. The final product of the proposed work is a working prototype module of a commercial system Seed grant funding is providing the opportunity to scale up to marketability.



Left: Photograph of a partially-transparent colloidal quantum dot solar cell substrate fabricated in the Thon lab, containing nine small-area red-tinted solar cells. Middle: Layer structure of a colloidal quantum dot solar cell (illuminated through the bottom plane); the critical transparent conducting electrode is highlighted in red.

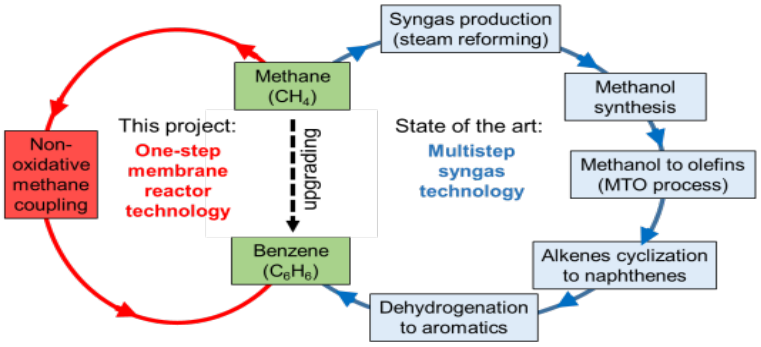
- **Prototype Study of One-Step Membrane Reactor for Stranded Natural Gas to Liquids**;
  Lead PI: Dongxia Liu, Assistant Professor, Department of Chemical & Biomolecular Engineering, University of Maryland College Park; Partnering Company: Protonic Membranes
  Flaring and venting of stranded natural gas is a major waste of energy and contributor to greenhouse gas emissions. Therefore, distributed modular gas-to-liquid (GTL) conversion is a necessity as liquids are easier and less costly to transport than gas. The novel direct one-step GTL proposed is significantly simpler than the syngas process, which means lower investment costs and the utilization of stranded gas. Seed grant funding is allowing the development of a prototype reactor using this one-step process. The prototype reactor will be demonstrated to major chemical (Shell) and

industrial gas (Praxair) companies who have already indicated interest as well as providing performance data for robust techno-economic models. The highly flexible and scalable nature of the reactor system offers the companies the ability to scale to



Membrane reactor composed of dense hydrogen permeable membrane and NMC catalyst for one-step natural gas upgrading.

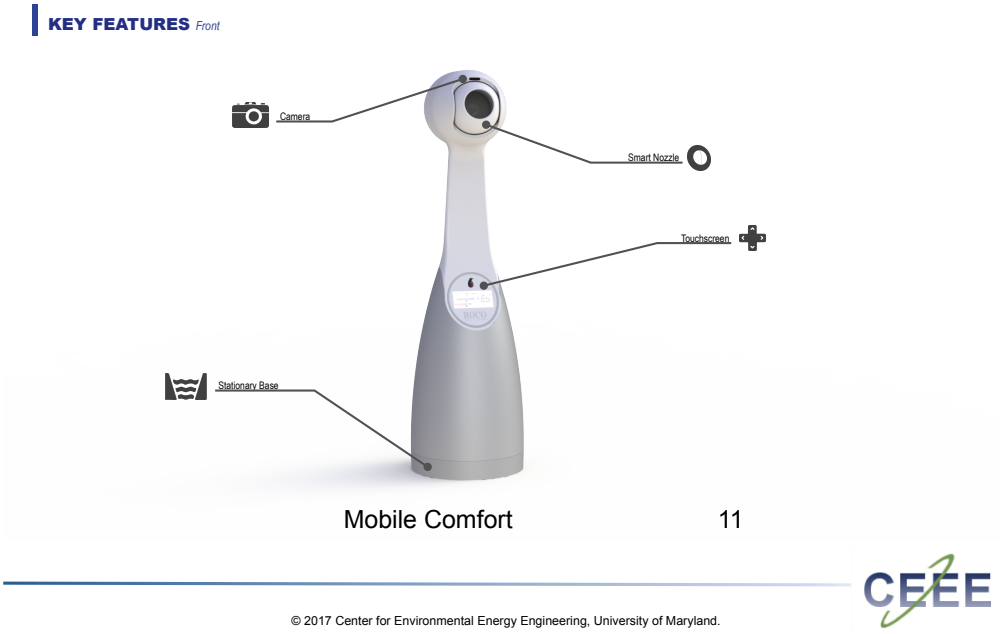
match the size of the targeted resources and easily integrate with existing facilities. It is expected that the prototype demonstration of the one-step GTL membrane reactor technology through this project will attract vast investments from the chemical and gas industry.



GTL processes for methane upgrading via NMC in one-step membrane reactor technology versus syngas approach in multi-step

- **RoCo (the Roving Comforter)**;
  Lead PI: Reinhard Radermacher, Professor and Director Center for Environmental Energy Engineering, University of Maryland College Park; Partnering Companies: Mobile Comfort, Daikin and Alliance Material Handling
  The main objective of this project is to foster the commercialization of a first-of-its-kind personal mobile air-conditioning device called "RoCo". RoCo delivers cooling directly to an individual person. It consists of a mobile platform and a battery-operated vapor compression air-conditioner, which provides cooling to a single person as needed. Waste heat is stored in a phase change material (PCM) to avoid rejecting heat into the indoor environment in which RoCo is being used. The seed grant is allowing for the development of prototypes, the scaling up of production, and field testing/evaluation in several markets. For increased commercial viability, improvements will be made to the thermal conductivity of the PCM and implementation of the smart nozzle. Preliminary conversations with Daikin and Alliance Material are helping move the technology to a point where the product can be produced in volume. Discussion are ongoing with Daikin to

manufacture and/or distribute the product on a consumer level and Alliance Materials to adapt the technology to high value commercial applications.



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.

Breakthrough Energy Ventures

Breakthrough Energy Ventures (BEV), a $1B 20-year fund with investors such as Bill Gates, Jack Ma, Richard Branson, Jeff Bezos and others, reached out to Dr. Wachsman and MEI^2 about creating a network of researchers and entrepreneurs within UMD and establishing collaborative research. BEV is interested in investing in new energy technologies and companies that can have a significant impact on mitigating climate change. Twelve research faculty members met with BEV on January 23, 2018 to discuss potential collaboration. Follow up occurred one week later with the membrane reactor technology team.

Korean Electronics Technology Institute (KETI) MOU

MEI^2 and the Korea Electronics Technology Institute (KETI) located in Seongnam, Republic of Korea, announced a five-year partnership to accelerate research and innovation of energy technologies. On April 21, representatives from UMD, MEI^2, KETI, and the Korean Ministry of Trade, Industry, and Energy (MOTIE) gathered in Potomac, Maryland, to sign a memorandum of understanding to officially launch the partnership. The Institutes will cooperate and develop joint projects in fields of common interest. These fields include electrochemical energy storage and conversion, innovative power plant cooling technologies, energy efficiency and building heating/cooling, advanced energy materials, and intelligent transportation systems. This collaboration with KETI will provide additional resources to translate university research into companies and jobs within Maryland, and ultimately toward commercialization of the jointly developed technologies. MEI^2 is currently submitting a $3M collaborative proposal with KETI, additional Korean universities, and industry to MOTIE.

KETI President Chungwon Park, MOTIE Minister Ungyu Paik, MEI^2 Director Eric Wachsman, UMD Provost Mary Ann Rankin, UMD President Wallace Loh

U.S. – Germany Battery Workshop

MEI^2 is participating in the coordination of next generation battery research between U.S. and German government agencies. Dr. Wachsman has been asked to be the U.S. technical lead on solid-state battery cathode interfaces in partnership with multiple U.S. and German universities and national laboratories.

Center for Research in Extreme Batteries

The Center for Research in Extreme Batteries (CREB) aims to foster and accelerate collaborative research in advanced battery materials and technologies and characterization techniques. CREB's focus is on batteries for extreme performance, environments and applications (for example: defense, space, biomedical applications). Participation in CREB is open to national and defense labs, universities, and industry. CREB is a cooperative research and development agreement between UMD and the Army Research Laboratory. The spring biennial meeting highlighted changes being made in the Army through the Army's new Modernization Command and the effect it will have on energy storage through their top priorities in Soldier Lethality, Next Generation Combat Vehicle (NGCV) and Future Vertical Lift.

General Technical Services, LLC

MEI^2 partnered with General Technical Services (GTS) on a proposal for the U.S. Army's Soldier Tactical/Expeditionary Power and Energy Generation Services which was successfully awarded to GTS. The contract is for advanced research for power generation, energy storage, management, and distribution. Several power electronics enabling technologies will be developed including: energy storage extreme lightweight

materials and components with advanced electrochemical technologies that can enable safe operation for longer than three days; state-of-the-art fuel cells; and energy harvesting wearable and portable technologies for on-the-move and stationary power generation from alternative or renewable energy sources for longer than three days.

ManTech
Homeland Defense Information Analysis Center contract (HDIAC) proposal support - MEI^2 partnered with ManTech on a DoD proposal to support alternative energy, which consists of novel, non-traditional and emerging sources and technologies for harvesting, generating, storing, transmitting/transporting and reusing energy. An award was made to ManTech and the scope of this contract is focused on the research and analysis of subject matter in the areas including but not limited to renewable energy including solar, hydro and wind power; geothermal; fossil fuels; hydrogen energy; bio-energy; biofuels; advanced energy storage, distribution and generation; portable, efficient and compact power technologies; energy recovery and conversion including resource reuse and transformation; micro-scale power sources; novel electrical and magnetic materials; biomimetic; and nuclear batteries.

Exelon
Exelon Corporate Strategy contacted MEI^2 to become one of their academic research partners. Exelon is currently evaluating UMD's Master Research Agreement.

Regional Manufacturing Institute of Maryland
MEI^2 is collaborating with the Regional Manufacturing Institute of Maryland to develop joint innovation programs including introductions between researchers and Maryland manufacturing companies to develop local supply chain opportunities.

RESEARCH HIGHLIGHTS
Significant progress was made in multiple energy research areas by UMD faculty in FY18 as indicated by numerous papers published in high profile journals such as *Science, Nature* and *Proceedings of the National Academy*. A few of them are highlighted below.

High-rate lithium cycling in a scalable trilayer Li-garnet-electrolyte architecture
Gregory T. Hitz, Dennis W. McOwen, Lei Zhang, Zhaohui Ma, Zhezhen Fu, Yang Wen, Yunhui Gong, Jiaqi Dai, Tanner R. Hamann, Liangbing Hu, Eric D. Wachsman; Materials Today (https://doi.org/10.1016/j.mattod.2018.04.004).
Solid-state lithium batteries promise to exceed the capabilities of traditional Li-ion batteries in safety and performance. A new approach to reduce electrolyte thickness, while increasing both the strength and the electrode contact area, is to use a trilayer porous-dense-porous solid electrolyte architecture shown below. The trilayer design surmounts the obstacles described above and is fabricated with the low cost and easily scalable tapecasting process, drawing on well-developed design and manufacturing concepts from solid oxide fuel cells. At the center of the trilayer design is the exceptionally thin, dense middle layer strengthened by the mechanical support of the outer porous layers, making the "electrode-supported cell" strong enough to handle with ease. This dense layer is much thinner than typical solid electrolytes, providing short lithium ion conduction pathways to correspondingly decrease cell resistance. On opposite sides of the dense layer are two highly porous layers, each of which forms a 3D network

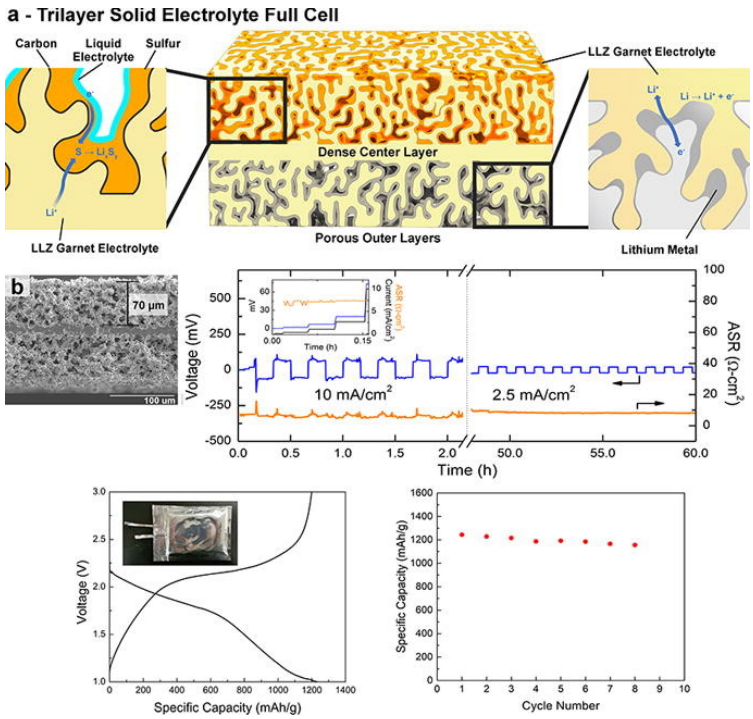


Diagram of a trilayer lithium garnet cell with high interfacial surface area, short lithium ion conduction pathways, and minimized use of electrolyte material.

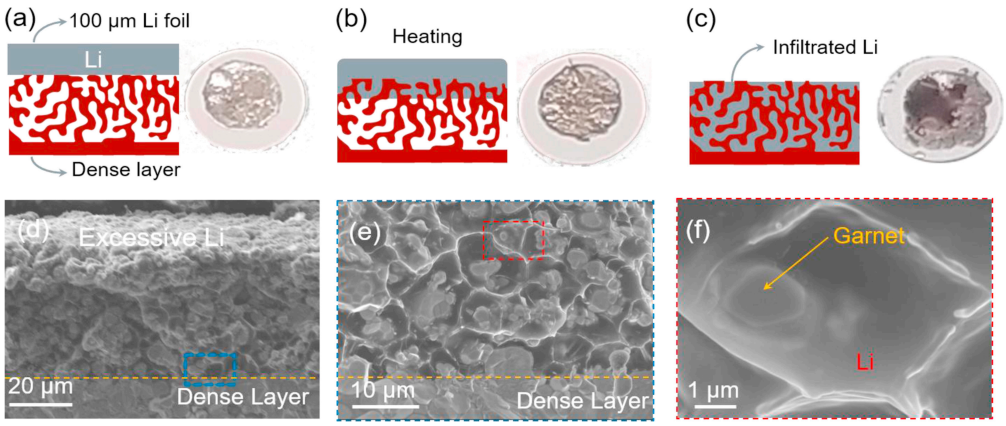
of ionically conductive electrolyte that provides the opportunity for high loading of accessible active material creating an anode structure that is 2–3 the full anode-mass specific capacity of a conventional graphite anode. The trilayer solid electrolyte reduces cell resistance in multiple ways to enable high rate cycling, while also reducing the proportion of solid electrolyte (thus, increasing proportion of active material), and could help bring high-rate, high energy density solid-state batteries closer to market viability. This is currently the only solid-state battery technology to achieve the DOE Vehicle Technology Office (VTO) fast charge goals for current density.

All-in-one Lithium-Sulfur Battery Enabled by a Porous-Dense-Porous Garnet Architecture

Shaomao Xu, Dennis W. McOwen, Lei Zhang, Greg T. Hitz, Chengwei Wang, Zhaohui Ma, Chaoji Chen, Wei Luo, Jiaqi Dai, Yudi Kuang, Emily M. Hitz, KunFu, Yunhui Gong, Eric D. Wachsman, Liangbing Hu, Energy Storage Materials, https://doi.org/10.1016/j.ensm.2018.08.009

A high energy density solid-state all-in-one lithium metal battery has been achieved for the first time using a trilayer garnet based solid-state electrolyte. Both the cathode and the anode are infiltrated into the porous layer and are separated by a dense layer of ceramic electrolyte. The all-in-one cell design ensures continuous pathways for $Li^+$and electrons that lead to a lower resistance, all solid-state lithium metal anode with low interfacial impedance, and low local current density at a given projection current density. As a proof-of-concept, we demonstrated an all-in-one lithium sulfur battery with high energy density. The all-in-one structure eliminates lithium polysulfide shuttling and lithium dendrite growth, making it a solid-state Li-S battery with high coulombic efficiency. With high mass loading of lithium (4.3 mg/cm^2) and sulfur (5.4 mg/cm^2) in the trilayer structure, stable battery operation with high energy density of 272 Wh/kg_{cell} has been achieved for over 50 cycles. Other than Li-S battery, the all-in-one battery design can enable a variety of cathode chemistries and shows a new direction of architecture for

solid-state lithium metal batteries. This unique architecture allowed for continued safe operation of the battery even after the packaging was cut open and exposed to air.

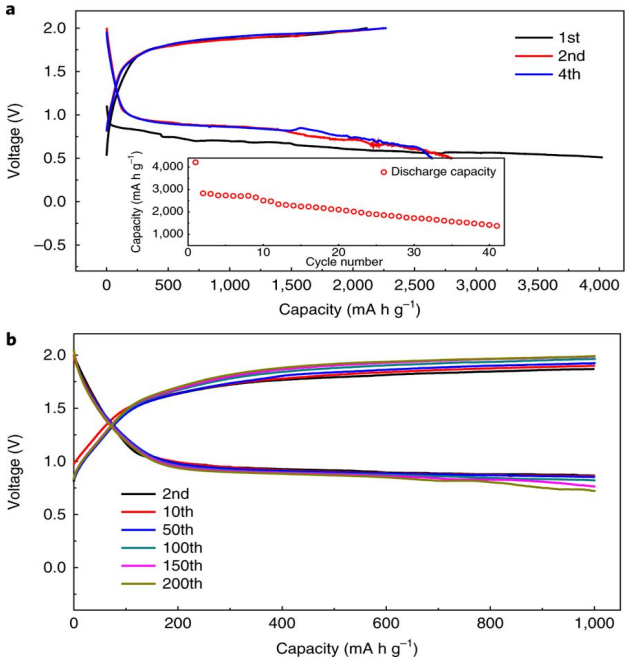


Formation of 3D lithium metal anode.

Highly reversible zinc metal anode for aqueous batteries

Fei Wang, Oleg Borodin, Tao Gao, Xiulin Fan, Wei Sun, Fudong Han, Antonio Faraone, Joseph A Dura, Kang Xu & Chunsheng Wang, Nature Materials, volume 17, pages 543–549 (2018)

Together with colleagues at the U.S. Army Research Laboratory (ARL) and National Institute of Standards and Technology (NIST), the UMD engineers combined old battery technology (metallic zinc) with new (water-in-salt electrolytes). Building on prior UMD advances to create safer batteries using a novel aqueous electrolyte instead of the flammable organic electrolyte used in conventional lithium-ion batteries, the researchers cranked up the energy of the aqueous battery by adding metallic zinc – used as the anode of the very first battery – and its salt to the electrolyte as well. This highly concentrated aqueous zinc battery also overcomes other disadvantages of conventional zinc batteries, such as the capacity to endure only limited recharging cycles, dendrite (tree-like structures of crystals) growth during usage and recharging, and sustained water consumption, resulting in the need to regularly replenishing the batteries' electrolyte with water. Because most water molecules in the new electrolyte are strongly bonded by the highly



Electrochemical performance of the Zn/0_2 full cell.

concentrated salt, the water in the aqueous zinc battery's electrolyte will not evaporate in an open cell. This advance revolutionizes zinc–air batteries, which are powered by oxidizing zinc with oxygen from the air, such as those used in energy grid storage. Zinc batteries would provide a powerful and inexpensive means of energy storage if they could be rechargeable. This research uncovered ways to control which molecules in the electrolyte surround the ions that move back and forth in a battery when storing and releasing energy.

Carbothermal shock synthesis of high-entropy-alloy nanoparticles

Yonggang Yao, Zhennan Huang, Pengfei Xie3, Steven D. Lacey1, Rohit Jiji Jacob, Hua Xi, Fengjuan Chen, Anmin Nie, Tiancheng Pu, Miles Rehwoldt, Daiwei Yu, Michael R. Zachariah, Chao Wang, Reza Shahbazian-Yassar, Ju Li, Liangbing Hu, Cover of Science; 30 Mar 2018: Vol. 359, Issue 6383, pp. 1489-1494.

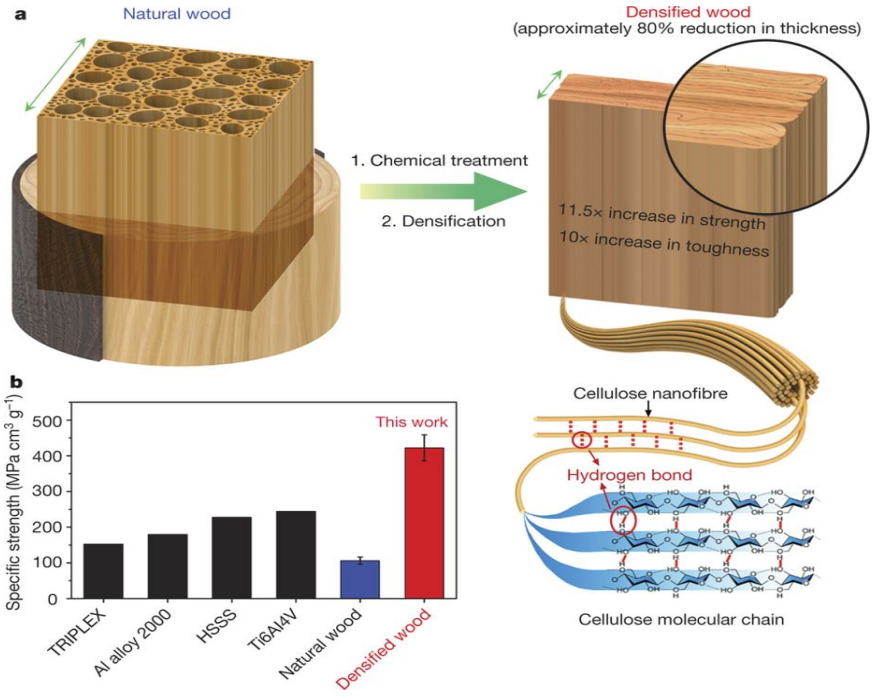
The research is the first to create nanoscale particles composed of up to eight distinct elements generally known to be immiscible, or incapable of being mixed or blended together. The blending of multiple, unmixable elements into a unified, homogenous nanostructure, called a high entropy alloy nanoparticle, greatly expands the landscape of nanomaterials. To create the high entropy alloy nanoparticles, the researchers employed a two-step method of flash heating followed by flash cooling. Metallic elements such as platinum, nickel, iron, cobalt, gold, copper, and others were exposed to a rapid thermal shock of approximately 3,000 degrees Fahrenheit, or about half the temperature of the sun, for 0.055 seconds. The extremely high temperature resulted in uniform mixtures of the multiple elements. The subsequent rapid cooling (more than 100,000 degrees Fahrenheit per second) stabilized the newly mixed elements into the uniform nanomaterial. This advance in nanoscience opens vast opportunities for a wide range of applications that includes catalysis (the acceleration of a chemical reaction by a catalyst), energy storage (batteries or supercapacitors), and bio/plasmonic imaging, among others.

Processing bulk natural wood into a high-performance structural material

Jianwei Song, Chaoji Chen, Shuze Zhu, Mingwei Zhu, Jiaqi Dai, Upamanyu Ray, Yiju Li, Yudi Kuang, Yongfeng Li, Nelson Quispe, Yonggang Yao, Amy Gong, Ulrich H. Leiste, Hugh A. Bruck, J. Y. Zhu, Azhar Vellore, Heng Li, Marilyn L. Minus, Zheng Jia, Ashlie Martini, Teng Li & Liangbing Hu, Nature, volume 554, pages224–228 (08 February 2018)

Researchers have found a way to make wood more than ten times stronger and tougher than before, creating a natural substance that is stronger than titanium alloy. Over 40 news outlets have reported on the findings. This research explores the capacities of wood's natural nanotechnology. This new way to treat wood makes it twelve times stronger than natural wood and ten times tougher and could be a competitor to steel or even titanium alloys. Strong and durable, it is also comparable to carbon fiber, but much less expensive. The process begins by removing the wood's lignin, the part of the wood that makes it both rigid and brown in color. Then it is compressed under mild heat, at

about 150 F. This causes the cellulose fibers to become very tightly packed. Any defects like holes or knots are crushed together. The treatment process was extended a little further with a coat of paint. These wood-based emerging technologies are currently being commercialized through a UMD spinoff company, Inventwood LLC.



Processing approach and mechanical performance of densified wood.

OUTREACH AND EDUCATION

MEI[2] is actively engaged across campus, the state and nation in educational and outreach efforts. MEI[2] also issues a quarterly newsletter to over 600 faculty, as well as government and industry leaders/researchers.

ARPA-E 2018

MEI[2] has been extremely active in mentoring UMD ARPA-E award winners in technology commercialization from proposal stage to post award results, using Redox Power Systems and Ion Storage Systems as examples. At the 2018 ARPA-E Summit, two UMD awards were highlighted on the technology showcase stage including Dr. Lei Zhang, Herbert Rabin Distinguished Professor of Civil Engineering and Director of the Maryland Transportation Institute at the University of Maryland, who demonstrated how personalized and real-time incentives is precisely delivered to individual travelers for significant energy savings. Professor Hugh

Professor Lei Zhang discussing IncenTrip at ARPA-E.

A. Bruck and David Hymas, PhD student, demonstrated a novel Polymer Composite Heat Exchanger enabled by a Novel Additive Manufacturing technique to yield superior thermal performance at reduced pressure drops and with substantial weight reduction when compared to state of the art corresponding heat exchangers. Dr. Wachsman participated in the Summit Pitch and Networking Event sponsored by the American Energy Innovation Council (AEIC) and was an ARPA-E panelist for the *A Solid Advance in Next Generation Lithium-Based Batteries* session. Dr. Chunsheng Wang was also awarded UMD's 17th ARPA-E grant in May 2018, more than any other university in the country.

David Hymas demonstrating novel UMD heat exchanger at ARPA-E.

Solar Decathlon

MEI^2 faculty and students participated again in the 2017 DOE sponsored Solar Decathlon, the preeminent international competition for energy efficiency technology with its entry entitled, reACT (Resilient Adaptive Climate Technology). The house demonstrated that homes help people live in harmony with nature while at the same time harnessing her gifts of solar energy, water, and food. The UMD team won first place in the U.S. and 2nd place overall in the world. Each time UMD has entered the Solar Decathlon, the team has placed first in the U.S. and either first or second overall (2007, 2011, 2017).

Engineering Sustainability Day 2018

The 8th annual Engineering Sustainability Day, April 23, 2018 focused on "Innovation" and the transfer of research technology to commercialized products and services. Nissan Leaf and the Department of Energy's Hydrogen Fuel Cell car team were on hand to demonstrate such technologies that are now commercially available. Other industry leaders, including Lynn Abramson, President of the Clean Energy Business Network, provided a keynote address on growing the clean energy economy through small businesses. Over 130 faculty, students, and industry leaders attended the event held in the new Clark Hall.

Maryland Day 2018

Each year the University of Maryland (UMD) welcomes thousands of visitors for one day to celebrate learning and discovery. The 20th anniversary of this event, on April 28, showcased scientific demonstrations, exhibitions and performances. In addition to the many engineering exhibitions on display, MEI^2 and the Department of Energy's (DOE) Fuel Cell Technologies office jointly showcased two of the world's first commercial hydrogen fuel cell cars on loan to DOE, and the innovative technology needed to power them. Early-stage research and

development efforts supported by DOE have helped cut the cost of fuel cells by 60% and quadrupled their durability in the past decade.

Vanessa Trejos, DOE Engineer, was on hand with MEI^2 staff to discuss hydrogen as a clean, sustainable, versatile and energy efficient carrier. Hydrogen can be produced from a variety of domestic sources and could have a huge impact on other economic applications including energy storage, electronics and even food processing. The cars get over 360 miles per tank of hydrogen, a fuel economy of up to 66 miles per gallon of gasoline equivalent, can refuel in minutes, and emit no pollution. UMD Ph.D. students in Material Sciences and Engineering were on hand to provide younger attendees with a simpler demonstration of electrolysis and show how hydrogen can be used as a clean energy source.

Accelerating Climate-Mitigating Technology Development and Deployment

A high-level, invitation only workshop was organized by Dr. Ellen Williams and held at UMD with Venture Capitalists, academia and government leaders in attendance. The goal is to develop approaches for mitigating climate change through energy innovation. Additional workshops and ongoing communication among the group will continue.

Clean Energy and Sustainability Extravaganza

MEI^2 partnered with Leaders in Energy to sponsor the 4th Annual Clean Energy and Sustainability Extravaganza in February 2018 at UMD. This year the focus was on clean tech innovation and entrepreneurship. Guest speakers included representatives from the Association of Energy Engineers (AEE) and the AEE-Baltimore Council on Women in Energy and Environmental Leadership (CWEEL). Additional exhibitors included Advanced Biofuels Association, Clean Energy Business Network, InScope, Lockheed Martin, Mosaic Power, Nissan, Recurrent, Shannon Enterprises, Standard Solar, Water Management Inc., and the UMD School of Public Policy. The forum was a unique opportunity for faculty and students to connect with professionals in the clean energy and sustainability community.

SUMMARY

The Institute was officially enacted in July 2017. An Advisory Board and an Investment Committee were established with members from academia, industry and government. The Investment Committee solicited for the Energy Innovation Seed Grants, which are open to all academic institutions in the state of Maryland. The Advisory Board was pleased with the selection and progress of the four energy seed grants that were awarded in January 2018. A major focus of these seed grants is the transfer of research to marketable technologies, and the Advisory Board can see that the grants have been used to expand research from lab scale to field scale in an applied system and scale up prototype development for market testing of other technologies. MEI^2 also continues its progress in research through a number of awards funded by the Department of Energy's Energy Efficiency & Renewable Energy (EERE) and Advanced Research Projects Agency - Energy (ARPA-E) programs, the later continuing to be more than any other university in the U.S.

MOUs and partnerships were created to establish future research collaborations and attract investments. MEI^2 continues to reach out across the state to leverage resources and funding, and will participate with the Maryland Clean Energy Center in their Energy Summit in October 2018. The Advisory Board was pleased by MEI^2's outreach and engagement and the number of energy partnerships established or under development, ranging from industry, such as discussions initiated by Exelon for UMD to be one of its University Partners, to international, such as the MOU with the Korean Electronics Technology Institute (KETI) and subsequent joint proposal to the Korean Ministry of Trade, and Industry, and Energy (MOTIE).

Based on these activities MEI^2 is catalyzing the transformation of academic energy research across the University System of Maryland to the formation of energy companies and high technology jobs for the State of Maryland.

APPENDIX. LETTER FROM MEI^2 ADVISORY BOARD

MARYLAND ENERGY INNOVATION INSTITUTE

MEI2 Advisory Board
Engineering Lab Building
College Park, MD 20742
Tel: 301-405-9378; Fax: 301-405-8514
www.energy.umd.edu

October 30, 2017

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

Dear Dr. Wachsman,

Following the August 14, 2017 inaugural meeting of the Maryland Energy Innovation Institute (MEI^2) Advisory Board, this letter was drafted on behalf of MEI^2's Advisory Board members, and contains recommendations for the success and growth of MEI^2. After a full day of presentations articulating the success and resources of the University of Maryland's Energy Centers, Innovation Programs and University Start Ups, as well as an overview of the new Institute, the Advisory Board is pleased with the merger of the University of Maryland's Energy Research Center (UMERC) and the Maryland Clean Energy Center (MCEC) to create MEI^2, and sees many opportunities for research, innovation, and financing to advance clean energy technology and economic growth in the state of Maryland.

The Advisory Board was impressed by UMERC's progress in research as well as the number of awards funded by the Department of Energy's Energy Efficiency & Renewable Energy (EERE) program and the ARPA-E program, more than any other university in the U.S. The Board was also pleased with the broad expertise and engagement across the entire UMD campus with respect to energy research and innovation. The new Tech Ventures building will also encourage the creation of start up companies within the state of Maryland.

The Advisory Board reviewed the mandate and potential powers of the Institute and agreed that the three main foci of the Institute should be: 1) Research 2) Innovation and 3) Finance. The Board agreed that a key metric to the success of MEI^2 is developing programs to help create jobs and economic growth in Maryland thereby showing a return on the state's investment. MEI^2 should also strive to become self-sustaining over the next five years.

The Board also reviewed the proposed budget plan for the coming fiscal year and agreed with the level of funding to initiate Energy Seed Grants. The initial sum of the seed grant funding will be between $350-400K in the first year. The seed grant program should bridge the gap between academic transformative laboratory research results and prototype demonstrations to obtain investor interest. This call should support multiple seed grant awards with a maximum award ceiling of $100,000 USD and be available to all faculty members at any Maryland state academic institution. The Advisory Board agreed to stand up an Investment Committee, chaired by Dr. Ellen Williams, to review the seed grant proposals. Additional members of the investment committee should come from UMD research administration and local investment companies. The Committee may be called on in the future to make innovation investment assessments for MCEC.

The Board also agreed with MEI^2 developing a state-matching fund for faculty members pursuing federal energy grants. MEI^2 was encouraged in this endeavor to reach out to federally funded centers such as the DOE Advanced Manufacturing Office and NIST Manufacturing Hubs.

In examining the Institute as a whole, the board encouraged looking at potential funding and investment opportunities through MCEC capabilities. As MCEC has bonding authority and can make advancements to advance clean energy solutions, the Board suggested MEI^2 explore opportunities to go beyond the deployment of finances. Possible suggestions included lease revenue in the Incubator, interest-bearing loans for patent costs, and convertible note investment prior to Series A. The Advisory Board supports MCEC standing up a Financing Advisory Committee to advise them on such investments.

The Advisory Board therefore, makes the following recommendations so that MEI^2 can achieve its full transformative, scholarly, and financial potential:

- Establish an Investment Committee with Dr. Ellen Williams as chair
- Solicit an open state-wide call for Transformative Energy Innovation Seed Grants
- Pursue federal collaboration with the Army Research Laboratory (ARL), NASA Goddard Space Flight Center (GSFC) and others.
- Establish a Financing Advisory Committee to develop a financing innovation capability to support program building.

The Advisory Board remains fully committed to participating in the development and alignment of MEI2 priorities with the UMD College Park, the University System of Maryland, and the State of Maryland.

Sincerely,

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

Ellen Williams
Vice-Chair, Maryland Energy Innovation Institute

Distinguished University Professor UMD
Director, Advanced Research Projects Agency-Energy (ARPA-E)

Joseph Dominguez
Sr. Vice-President, Exelon Corporation

Joshua Greene
VP Government & Industry Affairs, A.O. Smith
Chair of the Board, Maryland Clean Energy Center

Abigail Hopper
CEO, Solar Energy Industry Association
Director, US Bureau of Ocean Energy Management
Director, Maryland Energy Administration

Philip Perconti
Director, Army Research Laboratory

Jigar Shah
CEO, Generate Capital

Mary Beth Tung
Director, Maryland Energy Administration

FY18 BUDGET

Maryland Energy & Innovation Institute (MEI2)
KFS: 1-123120

Category		Operating Budget	Encumbrances	FY18 Expenditures	Variance Budget
Salaries & Wages					
(Director, Assoc Director, Program Coord.)		$192,980.00		$85,268.21	$107,711.79
Seed Grant & Entrepreneuship(s)		$375,240.00			
Dr. Lansing/ Agr., ENST			$100,000.00		
Dr. Radermacher/ ECE-UMD			$100,000.00		
Dr. Dongxia Liu - ChBE			$100,000.00		
Dr. Thon/ John Hopkins Univ			$100,000.00		
Outreach / Events		$38,000.00		$19,445.54	$18,554.46
Total(s) - UMD		**$606,220.00**	**$400,000.00**	**$104,713.75**	**$101,506.25**
MCEC		$893,780.00			
Invoice #1 (processed 9/14/17)				$223,445.00	
Invoice #2 (processed 9/15/17)				$223,445.00	
Invoice #3 (processed 12/7/17)				$223,445.00	
Invoice #4 (processed 03/01/18)				$223,445.00	
		$1,500,000.00	$400,000.00	$998,493.75	$101,506.25