CECD

CENTER FOR ENGINEERING CONCEPTS DEVELOPMENT

2021 Report



CECD 20th Anniversary Celebration

UNIVERSITY OF MARYLAND

Foreword

CECD is twenty-one years old and continues to be a platform for experimenting with new ideas in engineering research and education with special attention to the impact of engineering on society. I'm pleased to report that we continue to be supported by ARL, NSWC-IHEODTD, the State of Maryland, and the Neilom Foundation.

One hundred guests helped us celebrate our twenty years of activities highlighting innovative activities of contemporary interest that benefit the economic welfare of the State of Maryland and the Nation. This report provides a brief overview of those accomplishments as well as ongoing activities that bring great credit to our faculty and students that comprise CECD.



Davinder K. Anand
Professor and Director
CECD

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Research Projects

The True Cost of Waste: Current Issues in Electronic Waste

Dylan A. Hazelwood, Michael G. Pecht, Maria C. Sanchez, Davinder K. Anand.

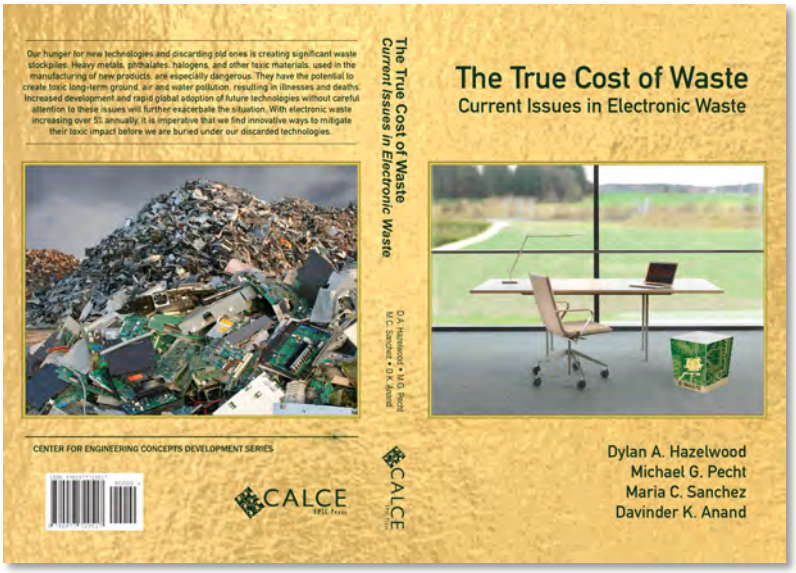
Despite the indisputable negative consequences of electronic waste, there is still a significant lack of global and representative data on the handling, recycling, and final disposal of electronics. The only consensus to be found across different sources is the fact that the amount of e-waste is growing at an alarming rate. One of the driving goals of our activity is to recommend the most inexpensive, environmentally conscious, and socially acceptable handling and disposition of the material that users have identified as e-waste.

The most important value of this effort comes from understanding the costs associated with the handling, processing, and final disposition of the material. A True Cost of Waste (TCOW) index for each material stream would provide valuable information that not only includes the physical processing costs but also the environmental impact and social responsibility components. Such an index will establish a measurement tool that values sustainable practices as part of the economic analysis of alternative disposal technologies and policies.

Worldwide data estimates show that the annual generation of e-waste grew from 33.8 to almost 50 million tons from 2010 to 2017, translating to approximately 5% annual growth.

If this e-waste were harvested efficiently, it is estimated that the value of the recovered materials would be approximately US$75 billion. E-waste is the fastest growing category of waste generated and has significant long-term health issues due to the toxicity and complex diversity of electronics components and materials.

The problems associated with e-waste are clear. We need to have a better understanding of the best method to define and handle millions of tons of e-waste before it becomes billions of tons! We must understand the true value of e-waste and the true cost of electronic products both financially and socially from cradle to cradle, and we should encourage engineers to integrate sustainability in the design of electronic packaging to support the circular economy. As we excel in the manufacturing and usage of electronics, we must find innovative ways to dispose of them and return them, as best as we can, to the original elements from which they were manufactured. In this work we address many of these issues and make recommendations on how to handle e-waste in an optimal manner.



Research Projects

The Technological Manipulation of Humanity

Dylan A. Hazelwood

Are we still in control of our choices and actions? Technologies are making choices for us every day of lives, whether overt or subtle, and our acquiescence only accelerates our loss of control.

Technology companies are rapidly creating new marketplaces without effective oversight, where children are selling themselves to the highest bidder, and where child labor laws will never reach. Who will protect our kids from those who would use technology to manipulate and harm them, all in the interests of generating corporate profits?

How and what we eat are being manipulated for profit unlike any time in our history by companies who have developed and adopted the extraordinary technological tools to do so. Our attempts at control over our own foods are failing, with record levels of obesity, diabetes, and other ailments.

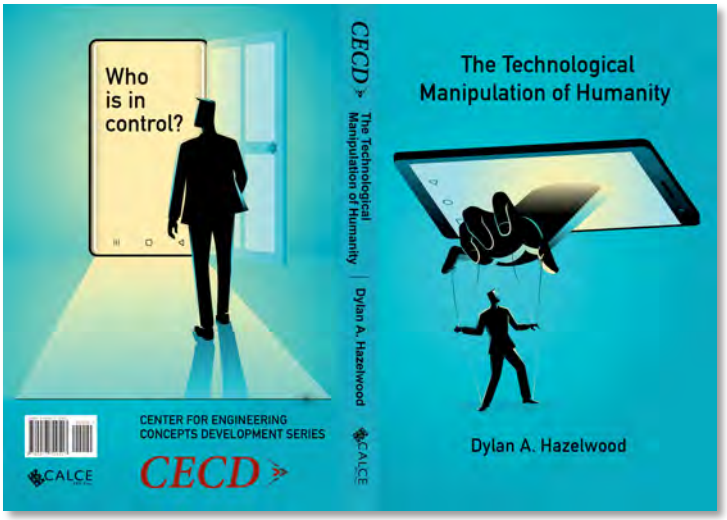
We have welcomed the adoption of artificial intelligence and big data in the practice of medicine to improve the performance of human doctors, and to give us powerful new predictive capabilities. Yet during the COVID-19 pandemic, countries were severely underprepared to provide for even basic necessities, and many were unable to control the spread of the disease. Meanwhile, technology was used effectively to increase surveillance and control of citizens.

Political forces and their affiliates successfully use a combination of psychology and extraordinary amounts of our personal data to manipulate us into voting for their political party. While technology can be an influence multiplier for individuals and their causes, ultimately, we are being tracked, targeted and individually manipulated as political pawns of those who seek power.

Will automation truly benefit us in the long term? Much has been made of jobs disappearing due to automation, but what of the impact on the human workers who remain, driven to perform beyond their capabilities by hyper-efficient robotic helpers? Technologists espouse that as greater automation in its various forms is introduced into our lives, the more efficient we will become. However, we may be inviting manipulation for the purposes of chaos and mayhem.

We need to recognize that young students want more from their educational experiences and are looking to create a positive impact on society. Can we change the mindset of those who will create future technologies to avoid negative and unwanted consequences? What should be done, and can philanthropy play a role?

Those who create and wield technologies hold tremendous power. This can be used either to build us up as a society or to cut us down. Is there any way to ensure that technological developments increase our happiness?



Research Projects

Phthalates: Hidden Danger

Dylan Hazelwood, Michael Pecht, Sami Ainane.

Phthalates, pronounced “tha·leits,” are a family of odorless and colorless low volatility chemical substances produced by the reaction of phthalic anhydride with a range of alcohols, such as methanol, ethanol, and tridecyl (C13) alcohol.

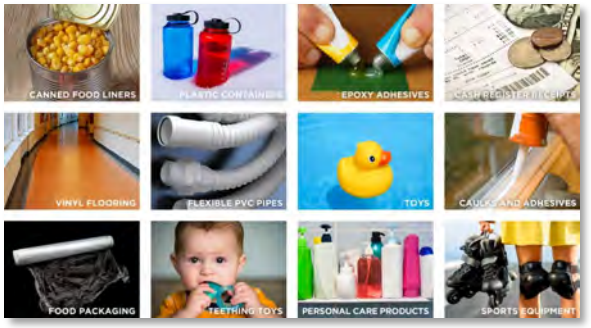
Phthalates can be found in a wide variety of products we use in our daily lives, typically seen as plasticizers, adding flexibility to plastics, or as fragrances. Electrical wiring, garden hoses, food wraps, vinyl flooring, adhesives, detergents, shampoos, and some cosmetics contain these substances. In PVC, a widely used plastic, plasticizer molecules fit between the polymer chain in the PVC, separating the polymer chains, weakening the intermolecular forces between them, and adding flexibility, transparency, durability, and longevity to the plastic. Due to their low cost and wide use, in 2017, 65% of the world's plasticizers were phthalates.

While exact figures are difficult to pin down, it is estimated that the yearly global production of phthalates exceeds 18 million pounds, of which 90% are used as plasticizers and the rest used as solvents or dissolving agents for other materials. China represents the largest market with a share of 45% of the global use, followed by the US and Europe with a combined share of 25% of use, and the remainder is spread around the world.

One estimate of the global market for plasticizers is more than $15 billion, and it is predicted that the market will grow at a rate of 6% from 2019 to 2024, due to the increasing demands in the construction, automotive, healthcare, and consumer goods industries.

However, these compounds have complicated interactions with humans. Several phthalates have been identified as potential endocrine disruptors as they have been associated with hormonal changes, decreased sperm count, decreased sperm motility, birth defects in the male reproductive system, obesity, diabetes, and thyroid abnormalities. Endocrine disruptors have been found in products made from PVC, detergents, flame retardants, food, toys, cosmetics, and pesticides, all containing phthalates.

Because of their ubiquitous usage by humans and their ability to leach into the environment, a number of phthalates have been researched for potential health and environmental effects. In the past few years, researchers have linked phthalates to asthma, attention-deficit hyperactivity disorder, breast cancer, obesity and type II diabetes, low IQ, neurodevelopmental issues, behavioral issues, autism spectrum disorders, altered reproductive development, and male fertility issues. The EPA’s chemical action plan for phthalates raises concerns about possible association between phthalates exposure and adverse effects on human health. However, phthalates represent a very large class of chemicals, of which only a few have been studied.



Phthalate product categories

As the scientific community and media outlets have begun to position phthalates as a potentially serious global health hazard, legislation has followed suit in order to regulate well-known exposure methods. Laws passed in the US, EU and China have aided in limiting phthalate introduction into children’s toys and foods, yet certain other exposure methods have yet to be addressed. Manufacturers have switched from specific regulated phthalates to similar chemical compositions that do not fall under regulatory rules, but have been found to have similar effects on humans. Significant efforts are being undertaken by the authors to identify and report on phthalate exposure issues, and to educate a mostly unaware public of the health dangers with a future book to be released by CECD.

Research Project

Tools and Techniques for Pandemics: COVID-19 Disease Dynamics

Balakumar Balachandran

COVID-19 was declared as a pandemic by the World Health Organization on March 11, 2020. As a computational tool for addressing such pandemics, data-driven dynamics has been pursued by using a generalized logistic function model and extended compartmental models with and without delays.

The pursued data-driven approach is based on infection data for local counties in the state of MD, the different states in the US, US, and different countries in the world. The generalized logistic function model has been used to pursue a statistical approach (see Fig. 1). With regard to the extended compartmental model, a new quarantine (Q) compartment is introduced in addition to the traditional susceptible (S), exposed (E), infected (I), and recovered (R) compartments. In this SEIQR model, distributed delays have been introduced to capture the variability in an individual's response (see Figures 2 and 3). The logistic function based models can be considered as special cases of the compartmental models with just the S and I compartments. A representative result obtained for the US during the multi-phase evolution of COVID-19 is shown in Fig. 4. The predictions and forecasting for the total number of infection cases as well as the daily infection case increments match up well with the data [1]. The model results are found to agree well with data for other countries and different states in the US.

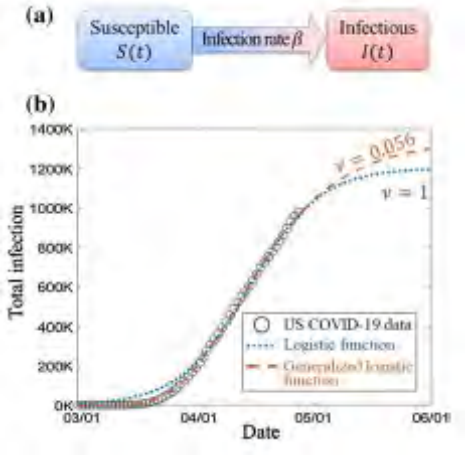


Fig. 1: *A model based on S and I compartments and statistical fits obtained with the logistic function and the generalized logistic function. COVID-19 data for the US has been used.*

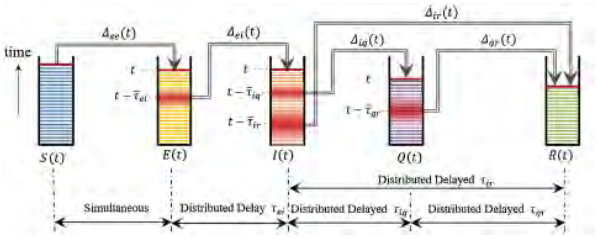


Fig. 2: *SEIQR model construction with delays between compartments.*

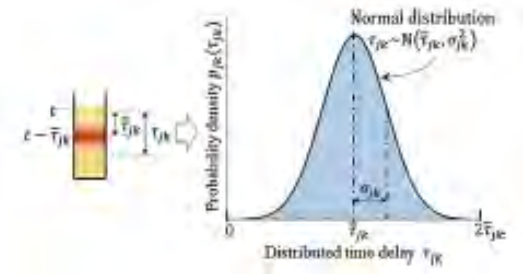


Fig. 3: *Illustration of a distributed delay between two compartments.*

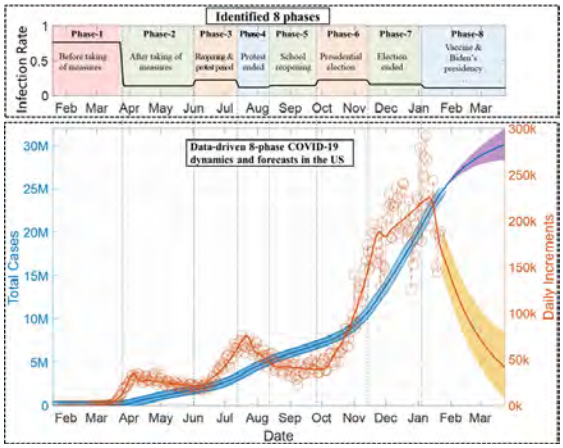


Fig. 4: *Evolution of the COVID-19 infection cases in the US from February 2020 onwards.*

Other Activities: During late spring to the summer period of 2020, the models developed in this work were used to generate forecasts for the infection dynamics, shared with the Campus Leadership and the USM Chancellor for Fall 2021 planning.

Reference: Liu, X., Zheng, X., and Balachandran, B. (2020). COVID-19: Data-Driven Dynamics, Statistical, and Distributed Delay Models, and Observations, *Nonlinear Dynamics*, //doi.org/10.1007/s11071-020-05863-5

Research Projects

Small Scale Soil Blast Behavior

William Fourney

When an explosive detonates that is buried in either soil or water, the resulting dome is not smooth. There are locations where the material is moving faster or slower than the material surrounding it. See, for example, the two high speed photographs of a dome in saturated sand shown below.

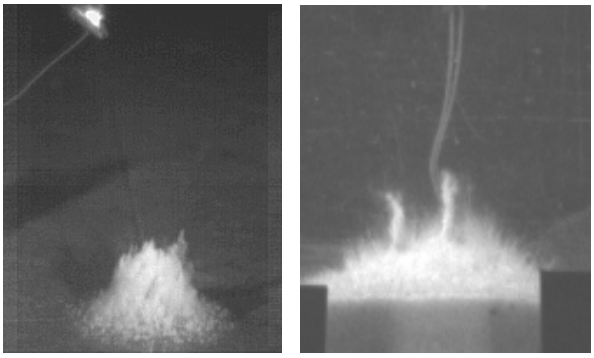


Fig. 1 *High-speed footage of buried explosion*

Notice the jets in certain areas in both images in Figure 1. When this material is brought to rest when hitting the bottom of a military vehicle the velocity in transformed into pressure. The higher the velocity is the higher the resulting pressure will be. Hence the pressure at any point on the bottom of the vehicle will not be a smooth continuous function but will vary greatly from point to point. Furthermore, if one were to conduct two identical tests these areas of higher pressure will not be located at the same point. We have found after running hundreds of tests that to get pressure distributions that correlate with computer predictions that one must conduct a number of tests and then average the resulting pressure at a given point. We have also shown that these resulting average pressure-time profiles can be integrated over time and distance to give the correct impulse delivered to the target.

We have not used commercial pressure transducers to measure our pressure time curves at any given location since they are expensive and also only survive at most a couple of tests. Instead, we have developed the use of four-foot-long Hopkinson bars to measure the pressure time curves. We use 1/8th inch diameter rods with two strain gages mounted 12 inches up from the bottom of the bar which is inserted into holes at various location on the target plate and measure the stress wave traveling up the bar. We then correct the amplitude of the signal to account for any loss in the first 12 inches of travel to predict what the pressure was at the impact point on the plate. This works very well in that an electronic pulse occurs when the explosive detonates which is picked up on the strain gages. The time delay between the detonation time and time the signal is read on the strain gage dies out before the actual signal is recorded. Two strain gages are used at the 12-inch location in order to cancel the bending effects and double the axial strain which is what we are interested in. We use Hopkinson scaling (cube root) and typically our scaling factor is 10. ARL has a lab very similar to ours but conduct their tests with larger charge sizes and therefore their scaling factors are typically smaller than ours. We typically only use 8 bar locations in our lab and they would like to use 32 bar locations to better define the resulting pressures from any one test. That is, they would like to get more data from any one test to better define the variations that occur from point to point.

The overall aim of this research program is to transport the techniques developed in our lab to their lab and to conduct tests that better define the soil conditions used in the tests conducted. In our previous work we examined the resulting pressure profiles when using dry sand, saturated sand, and water as our burial media. We also have found in an earlier joint effort with ARL that soil type does not seem to make much difference in the impulse delivered to a target but the air-filled voids in the soil is the major parameter to be concerned with. Air filled voids are a function of both the amount of moisture in the soil as well as the amount of compaction given to the soil.

Progress to Date

The Dynamic Effects Laboratory provided data, analyses and experimental methodology from gram scale plate deformation and HPBA experiments previously conducted. We also consulted on scale-up design of experiments at ARL.

We conducted small-scale blast tests using a prescribed sandy clay with varying soil water content and density, and provided results and analyses as appropriate to document results and findings. We have done a very extensive series of tests (60) with the clay soil provided by ARL, and have written a draft paper to present the results in the open literature. We tested this soil with three different water contents and a variety of compressions to arrive at a given air filled void (AFV). The air-filled voids reached ranged from 1% to 47%. Although impulse delivered to the target plate correlated well with AFV we found at a given AFV that the impulse was higher the higher the moisture content. See Figure 2.

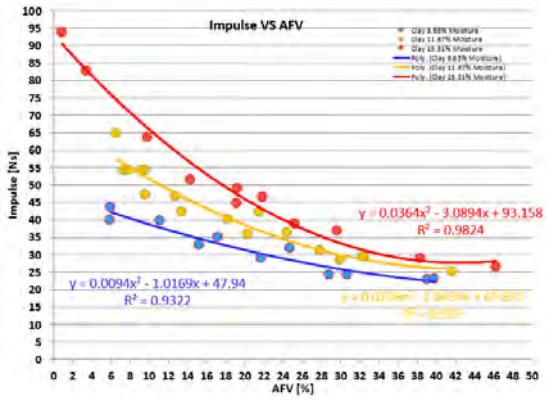


Fig 2. *Impulse versus air-filled void for clay.*

We have also conducted a series of tests which uses an "engineered soil" also provided by ARL. We found that the engineering soil behaved a very similar manner to the clay soil. See Figure 3.

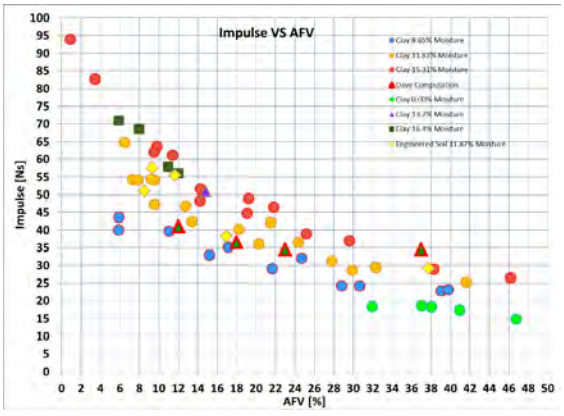


Fig 3. *Impulse versus air-filled void for the clay and engineering soils.*

We have conducted a series of tests using the engineered soil where-in we controlled the amount of air-filled voids (by controlling the amount of moisture in the soil (11.87%) and the amount of compression applied). We removed various amount of soil in the vicinity of the charge to examine the impulse in comparison to a control test where no soil was removed. See Figure 4.

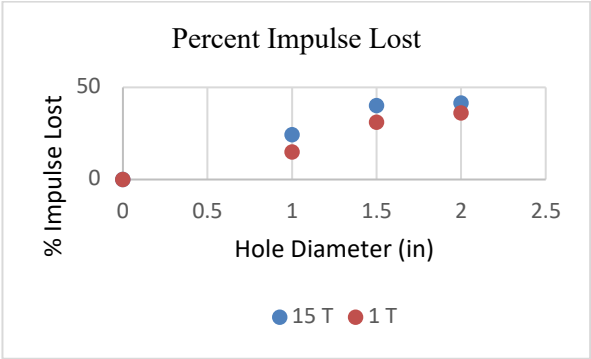


Fig 4. *Percent of impulse delivered to the target as a function of the diameter of the soil removed from above the charge.*

The charge used was 1 inch in diameter. For a hole diameter of 1 in the figure above we essentially removed all of soil above the charge and this resulted in a loss of about 20% of the impulse being delivered to the target. When soil was removed out to twice the diameter of the charge about 40% of the available impulse was lost. For more soil removed it appears that no more impulse will be removed. So about 60% of the impulse delivered to the plate comes from the soil below the top of and surrounding the charge. This does change somewhat based upon the compaction applied (i.e. air-filled void).

The current effort is concentrated on scale up efforts of the HPBA fixture at ARL. We are currently conducting tests using the engineered soil in conjunction with Hopkins Bars to measure not only the impulse delivered to the plate but also the pressure time history at various points on the target plate (as a function of air-filled voids). We are currently using 8 Hopkins Bars in the testing at University of Maryland but the desire is to move the experiments to ARL where 32 Hopkins Bars will be utilized. The results of these tests will provide data on the pressure versus time histories as well as impulse delivered to the plate as a function of air-filled voids of the soil.

Research Projects

Computational Sciences for Defense-Critical Materials

Peter W. Chung

Multi-channel Energy Transport through Energetic Materials: A long held belief is that shock energy induces initiation of an energetic material through an energy up-pumping mechanism involving phonon scattering through doorway modes. Researchers in CECD are developing a unique 3-phonon theoretical techniques based on perturbation theory for the study of energy up-pumping in RDX. The work specifically considers possible doorway pathways through which energy transfer and up-pumping may occur. The calculation accounts for individual phonon modes which are then analyzed in bands. Scattering is handled up to the third order term in the Hamiltonian based on Fermi's Golden Rule. The unprecedented degree of fidelity and the quantum mechanical foundations of the approach offer direct validation of experimental spectroscopic investigations that show that phonon-mediated initiation mechanisms can be a significant route through which energy can localize and create hot spot conditions.

For the up-pumping model for initiation to work, strong scattering must occur among a) modes at the low frequencies close to the frequencies associated with mechanical shock, b) the frequencies of the modes believed to serve as the doorway modes, and c) the modes associated with the largest distortions of the bonds, so-called vibrons, likely to possess dissociation energies which, when released, can sustain exothermic reactions.

In this work, the perturbation theory is used to calculate the 3-phonon scattering rates and the mode-to-mode scattering rate matrix for all modes in the energetic material Cyclotrimethylenetrinitramine ($C_3H_6N_6O_6$, also commonly known as RDX) under ambient conditions. The role of all phonon modes in the transfer of vibrational energy is investigated with full consideration of the statistical nature of scattering and the probabilistic mode-to-mode transfer of energy.

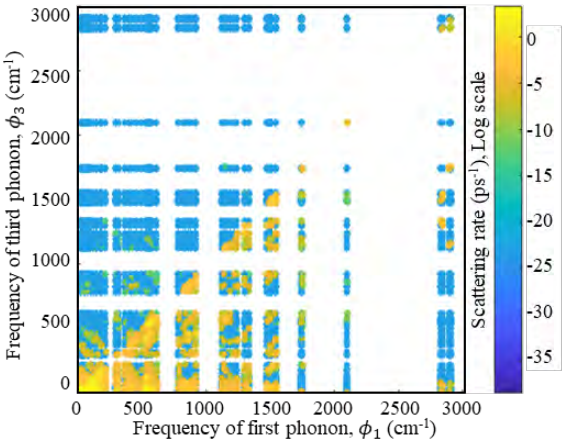


Fig. 1 *3-phonon mode-to-mode scattering rates for all modes in RDX.*

Published Papers

G. Kumar, F.G. VanGessel, L.B. Munday, P.W. Chung, "3-Phonon Scattering Pathways for Vibrational Energy Transfer in Crystalline RDX," *in review*, 2021.

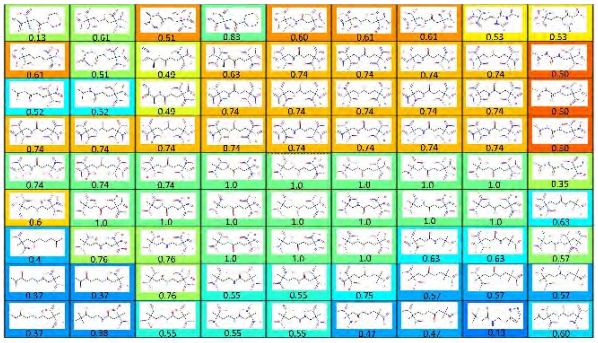
G. Kumar, F.G. VanGessel, P.W.Chung, "Bond strain and rotation behaviors of anharmonic thermal carriers in RDX," *Propellants, Explosives, Pyrotechnics*, 45 (2), 169-176, 2020.

F.G. VanGessel, G. Kumar, D.C. Elton, P.W. Chung, "A phonon Boltzmann Study of Microscale Thermal Transport in alpha-RDX Cook-Off," *arXiv*: 1811.00628, 2018.

Artificial Intelligence Approaches for Energetics

CECD has developed state of the art artificial intelligence and machine learning approaches uniquely applicable for understanding energetic mechanisms and discovery of new energetic material systems. The integration of these tools into current workflows in production environments is on-going through collaborations with other academic partners and industry. UMD and CECD have been recognized leaders on showing the value of such emergent developments in detonation sciences and modeling of energetic materials, and awareness has grown that this will result in transformative leap-ahead capabilities in defense-critical technologies. To that end, basic research in fields such as machine learning for

energetic materials aligns with the need for enhanced energetic effects, as machine learned models will aid the rapid transition of new energetic concepts. This multi-thrust initiative includes the following projects:



Deep Learning for Energetic Materials Discovery: Deep learning has shown great potential for generating molecules with desired properties. But the cost and time required to obtain relevant property data have limited study to only a few classes of materials for which extensive data have already been collected. We have developed a novel deep learning method that combines a generative model with a property prediction model to fuse small data of one class of molecules with larger data in another class. The approach takes advantage of the large data available on low-level structural and chemical information for other classes of molecules and finds a joint embedding that is expressive for designing molecules for a different class in which performance data are limited. Namely, we were able to improve the design of energetic molecules by learning from non-energetic molecules and do so in a representation space that was rendered searchable.

The approach was demonstrated using a graph-based variational autoencoder that was jointly trained using physicochemical features whose associated distribution was applied as a regularization to the loss function. Using a set of 401 nitrogen-rich molecules and a larger set of 100K low-nitrogen molecules sampled randomly from an available chemical database, a latent representation was found in which molecules with improved properties could be designed. The predicted properties were validated using an independent equilibrium thermochemistry model.

Joint embedding showed remarkable improvements in cross validation scores for the neural network property predictor used in the framework. The improvements are attributed to two reasons: 1) the organization in the latent representation induced by the joint embedding and the manual features and 2) the multi-class data augmentation from low-nitrogen molecule data.

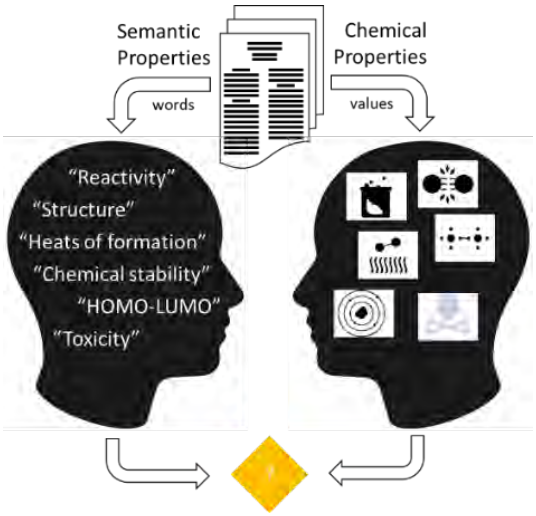
Molecules in the latent space were carefully explored. Molecules were generated over a grid of points in the latent space near molecules in the original data. The neighboring molecules showed continuous and graduated variations in their graph structures and target properties. Point-to-point traversal also revealed a rich embedding of molecules between any two arbitrary molecules in the training set. Notwithstanding the underlying non-deterministic nature of the representation, every point selected for study produced a molecule that seemed structurally similar, but not necessarily identical, to other molecules in the neighborhood of molecules in the original target data. And despite this similarity, the accompanying estimated performance property of the molecules appeared to constitute a surface that was amenable to gradient-based searches to find local extrema.

Local optimizations via gradient ascent were performed in limited neighborhoods around molecules in the training data. The vast majority of the nitrogen-rich molecules in the training set were found to be suboptimal; among the training molecules we found that over 75% were near alternative molecules with improved properties. The capability to search is potentially useful for molecule discovery or to find chemical substitutes in many food, energy, and pharmaceutical materials.

Published Papers

S. Balakrishnan, F.G. VanGessel, Z. Boukouvalas, B.C. Barnes, M.D. Fuge, P.W. Chung "Locally optimizable joint embedding framework to design nitrogen-rich molecules that are similar but improved, " *Molecular Informatics*, 40, 2100011, 2021.

D.C. Elton, Z. Boukouvalas, M.D. Fuge, P.W. Chung, "Deep learning for molecular design – a review of the state of the art," *Molecular Systems Design & Engineering,* 4(4), 828-849, 2019.



Using Language to Enrich the Scientific Process

Learning via language is highly contextual; a person reading one, and only one, research paper will likely not gain as much as one who reads the same paper but has read ten other papers before it. The context established by the other reading establishes a richer foundation whereupon new information can be placed. Representations can be described in mathematical terms using a vector space naturally equipped with norms and metrics. Distances and angles can be determined in this space. Such quantitative information can be used as cognitive tools for reasoning or analysis. With automated machine-assisted techniques, the contextual richness is no longer limited to just ten papers but, instead, can work with thousands of papers, or the entirety of all chemical literature.

CECD is developing foundational techniques to overcome the massive publication rate of scientific papers through automatable approaches that can ingest, process, and analyze large volumes of information from scientific documents specifically relevant to energetic materials. We are developing supervised and unsupervised learning methods that relate semantic concepts in technical language in energetics open literature with quantitative material properties. The methods will aid in the discovery of new materials and provide new concepts to serve as the scientists' muse that will yield integrated insights over massive numbers of technical documents.

In this work we explore how techniques from natural language processing and machine learning can be used to automatically extract chemical insights from large collections of documents. We base the work on documents from a variety of sources - journal articles, conference proceedings (including NTREM), the US Patent & Trademark Office, and the Defense Technical Information Center archive on archive.org. The documents are processed through an NLP pipeline which uses open-source NLP tools to identify the names of chemical compounds and relates them to function words ("underwater", "rocket"', "pyrotechnic") and property words ("elastomer", "non-toxic"). Relationships are obtained by doing computations with word vectors. We show that word embeddings capture latent information about energetic materials, so that related materials appear close together in the word embedding space. Such information can be used to reveal novel insights about relationships among materials or to develop approaches for discovering new materials.

Published Papers

D.C. Elton, D. Turakhia, N. Reddy, Z. Boukouvalas, M.D. Fuge, R.M. Doherty, P.W. Chung, "Using natural language processing techniques to extract information on the properties and functionalities of energetic materials from large text corpora," arXiv:1903.00415, 2019.

Research Projects

Naval Engineering Education Consortium (NEEC)

Peter W. Chung

CECD was awarded a NEEC Project to support the development of student experiences with state-of-the-art machine learning models and experimental methods for acoustic mixing of energetic formulations. The emphasis of the work is on increasing fundamental experience with skills of potential value for a future NSWC-IHD workforce. The primary technical goal of the machine learning tasks was to develop approaches for the investigation and design of HE formulations. On the experimental side, the focus is in developing a novel energetic pre-mixture additive manufacturing system by which surrogate solids as well as the liquid components (e.g., binder, plasticizer, curing agent, etc.) can all be 3D printed in a single run with high control over the pre-mix meta-structure (prior to acoustic mixing). The students focus on improving the 3D printer hardware to prevent clogging in the depositing mechanism.

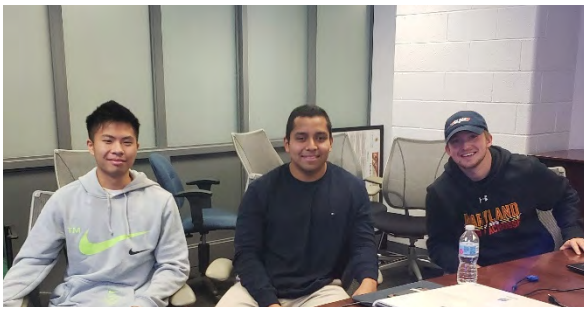


Fig. 1 *Undergraduate NEEC Project researchers.*

Additionally, powder deposition mechanisms are explored to provide a true "point-by-point, layer-by-layer" additive manufacturing process for solids as well as liquid-phase ingredients. Students also gain hands-on experience reading chemistry papers on ingredients of potential interest in the design of energetic formulations, implementing machine learning workflows, and developing analyses to apply the computer models to generative modeling of formulation ingredients.

ONR DURIP for Energetics

CECD researchers were awarded DURIP support to acquire a dedicated resonant acoustic mixing (RAM) processing and characterization facility at the University of Maryland, College Park. Key instruments of this new facility include the: (1) Resodyn LabRAM II Bench-Top Mixing System with Automatic Vacuum Package (Fig. 2), and (2) Hitachi TM4000Plus Tabletop Microscope with Tilt-Rotate Stage and AZtecOne EDS System (Fig. 3). Through additional funding support via the Naval Surface Warfare Center (NSWC) Naval Engineering Education Consortium (NEEC) program (*"Mixing and Additively Manufacturing Energetic Material Systems"; Sponsor Award Number: N001741910022*), the DURIP-supported RAM processing and characterization facility has enabled both undergraduate and graduate students to execute research activities that improve the current scientific under-standing of the process-structure-property-performance (PSP) relationships underlying RAM. In particular, students have and are continuing to apply cross-validating theory, simulation, and experimental strategies to reveal key connections between the structural arrangement of pre-mix ingredients, the energy imparted by the mixer on the mix ingredients during processing, and the properties of the final mixed material product.



Fig. 2 *Students, professors, and NSWC-IH staff member with the Resodyn LabRAM II Bench-Top Mixing System with Automatic Vacuum Package at UMD.*

These combined computational-experimental approaches for examining the connections among RAM processing, the material microstructure, and the subsequent mechanical properties and energetic performance offer a unique opportunity to train students, and in turn, cultivate a world-

class Naval Engineering workforce to meet the Navy's technology needs. Because these activities lie at the intersection of theoretical mechanics, additive manufacturing, and functional materials engineering, the RAM-based results have the potential to offer significant benefits over traditional production methods through improved reliability and repeatability of energetic performance, and ultimately, eliminating the risks associated with batch-to-batch variations. At present, however, due to the novel physical mechanisms that occur during the RAM process, many questions about material composition and overall safety remain unanswered. Thus, we envision that this new DURIP-supported RAM processing and characterization facility at the University of Maryland, College Park, will allow the PIs, undergraduate students, graduate students, and NSWC stakeholders to advance the state of the art while solving important fundamental science and technology challenges associated with using non-contact mixers to produce energetic mixtures with predicable and controllable material features. Thus, the research instrumentation provides a unique pathway toward the development of new knowledge and corresponding approaches for the manufacture and production of highly functional material systems for energetics applications.



***Fig 3**. Hitachi TM4000Plus Tabletop Microscope with Tilt-Rotate Stage and AZtecOne EDS System with PIs, students, and NSWC-IH researcher (inset).*

Research Projects

Multi-Material Polyjet Printing for Fully 3D Printed Soft Robotic Prosthetics

Ryan Sochol, Andrew Lamont (CECD Fellow)

Historically, developments in robotics have primarily relied on electronically controlled systems comprised of non-compliant materials (*e.g.*, metals and hard plastics); however, such technologies are non-ideal for emerging applications that involve human-robot interactions, such as active prosthetics. Consequently, there is growing interest in an alternative paradigm: "soft robotics". Unlike conventional robotics, soft robotic systems are comprised of compliant materials that are actuated by pneumatic and/or fluidic controls. Portable soft robotic systems, such as those designed to serve as prosthetics, require microfluidic logic to control critical actuators (*e.g.*, fingers). Unfortunately, such fluidic circuitry has necessitated highly complex and restrictive manufacturing protocols for both microfluidic circuit fabrication and subsequent integration with robotic systems. To bypass these challenges, our research efforts have focused on investigating the use of multi-material polyjet 3D printing for manufacturing soft robotic prosthetic hands with embedded microfluidic circuity.

During the course of the research period, we developed and demonstrated capabilities in two critical areas. First, we have engineered multi-material microfluidic circuit elements, including microfluidic capacitors, diodes, and transistors (Fig. 1). Experimental results from preliminary microfluidic testing revealed: (*i*) the diaphragm of the microfluidic capacitor deformed 2.63±0.42 mm at roughly 116±2.93 kPa, (*ii*) the microfluidic diode revealed full blocking of reverse flow at pressures ≥10 kPa, and (*iii*) gate pressures ≥20 kPa resulted in the complete obstruction of source-to-drain fluid flow through the microfluidic transistor.

The second component of the work has involved utilizing the polyjet 3D printing process to manufacture multi-material soft robotic hands (Fig. 2a). Preliminary results revealed that the fingers successfully bend at pressures below 50 kPa – magnitudes within the operating range of the microfluidic circuitry (Fig. 2b). We have reported these results in the form of an oral presentation and conference proceedings at the International MicroTAS Conference, and prepared an expanded journal manuscript.

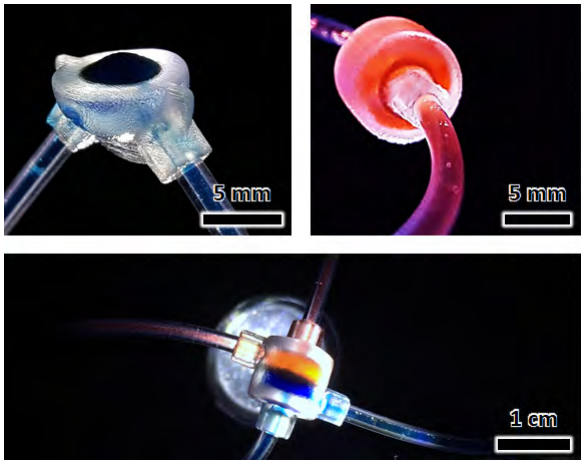


Fig. 1 *Multi-material microfluidic circuit elements manufactured via polyjet printing.*

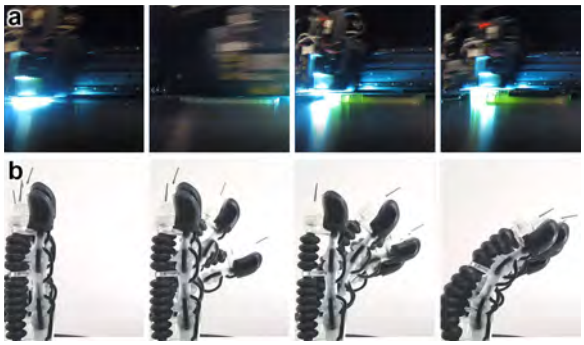


Fig. 2 (a) *Polyjet 3D printing of a prosthetic hand.* ***(b)*** *Fluidic actuation of multi-material 3D printed fingers.*

Further Development

Following the initial project work an effort was undertaken to fully integrate the microfluidic circuitry with the soft robotic hand, and 3D print the multi-material hand in a single step.

As a demonstration, the team designed an integrated fluidic circuit that allowed the hand to operate in response to the strength of a single control input. For example, applying low pressure caused only the first finger of the hand to press a button on a Nintendo game controller in the video game Super Mario Bros. to make Mario walk, while high pressure led to the character

jumping. Guided by a set program that autonomously switched between off, low, medium and high pressures, the robotic hand was able to successfully use a game controller to complete the first level of the video game in fewer than 90 seconds.

The project appeared on the cover of the July 2021 Science Advances (Fig. 1) where the paper "Fully 3D Printed Soft Robots with Integrated Fluidic Circuitry" appeared. The project garnered national media coverage, including a feature story in *Scientific American*, which noted that one-step production of this type would "make it easier for researchers to develop increasingly complex soft robots." It was also featured widely online, and covered by CBS News.

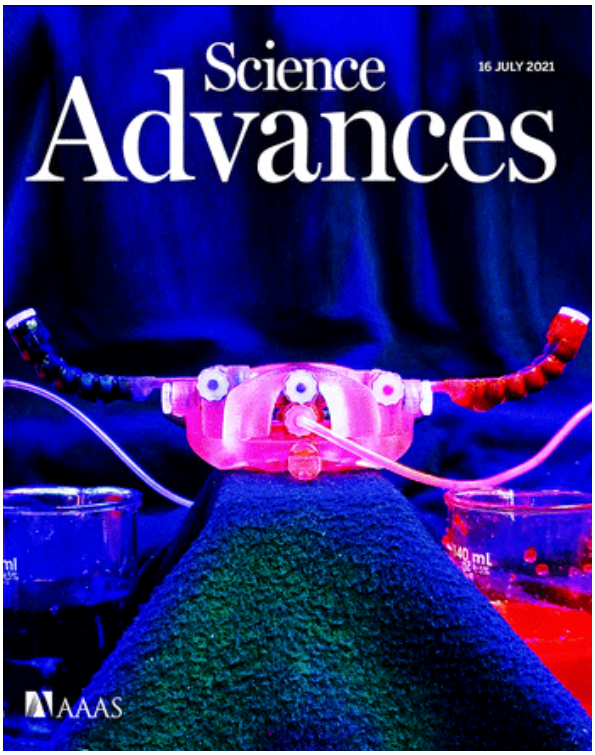


Fig. 3 *Ryan Sochol's soft robotics work featured on the cover of the July 2021 Science Advances magazine*

The research project was also made open-source. "Anyone can readily download, modify on demand and 3D-print—whether with their own printer or through a printing service like us—all of the soft robots and fluidic circuit elements from our work," noted Ryan Sochol. "It is our hope that this open-source 3D-printing strategy will broaden accessibility, dissemination, reproducibility and adoption of soft robots with integrated fluidic circuits and, in turn, accelerate advancement in the field."

The team is exploring the use of its technique for biomedical applications including rehabilitation devices, surgical tools and customizable prosthetics.

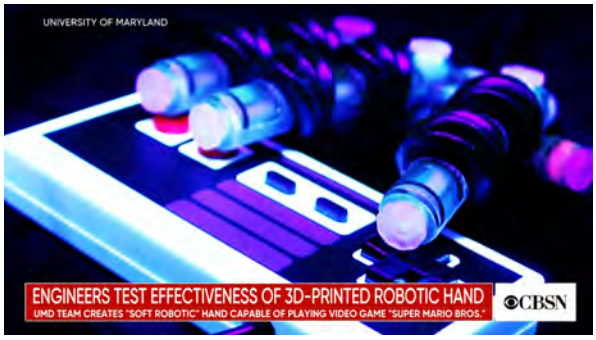


Fig 4. *CBS News features the 3D printed multi-material soft robotics project*

<u>*Published Papers*</u>

Joshua D. Hubbard, Ruben Acevedo, Kristen M. Edwards, Abdullah T. Alsharhan, Ziteng Wen, Jennifer Landry, Kejin Wang, Saul Schaffer, and Ryan D. Sochol, "Fully 3D Printed Soft Robots with Integrated Fluidic Circuitry," *Science Advances,* 2021.

Research Projects

Tools and Techniques for Pandemics: Additive Manufacturing for Developing COVID-19 PPE-Compatible Surgical Headlight Adaptors

Ryan Sochol, Students: Noemi Gonzalez, Eleanor Grosvenor, Ian Rosenthal

The novel Coronavirus disease (COVID-19) has increased the necessity of personal protective equipment (PPE) to prevent the spread of the contagious virus. To conform to safety requirements, specialists must wear powered air-purifying respirators (PAPRs) during surgery. Moreover, surgeries performed by Otolaryngologists (e.g., those within the oral cavity, nasal cavity, and pharynx) are difficult to accomplish without adequate illumination provided by surgical headlights. The use of PAPRs has eliminated the ability for these surgeons to wear headlights directly on their heads, resulting in the need for a different method for providing a light source.

To account for this new obstacle, the additive manufacturing (or "3D printing") technology, "FDM MakerBot Replicator 5th Generation Plus" holds promise for providing rapid and cost-effective products so that surgeons can wear the headlights and PAPRs simultaneously. A proposed "Scorpion" design produced by the University of Maryland Otolaryngologists via 3D printing, has been deemed unstable and difficult to manage as it is not self-adjustable and is heavy.

Three original designs were proposed, taking inspiration from applications such as camera mounts, scuba gear, mobility assistance devices, and safety harnesses. The first design, named "Giraffe" incorporated back straps for stability and a crutch-like rod for adjustability (Fig. 1a,d). The next design is the "Mini-Scorpion" which incorporates the use of a bellows mechanism for flexibility when adjusting the adaptor (Fig. 1b,e). The third and final design is the "Angler Fish" which implements a two-arm design that improves the flexibility of the self-adjustable feature (Fig. 1c). Along with the "Mini Scorpion" this design also incorporated the use of bellows. Testing will include making sure the designs fit and are dimensioned properly. Simultaneously, the stability and adjustability will also be analyzed since each design carries a specific feature that addresses these issues. Once revisions are complete, the presentation of the three designs with the University of Maryland Otolaryngologists will determine what should be included in a final design. Further evaluation such as moving through actions that are surgery-like will be completed to see how the final design performs in providing adjustability, stability, and illumination.

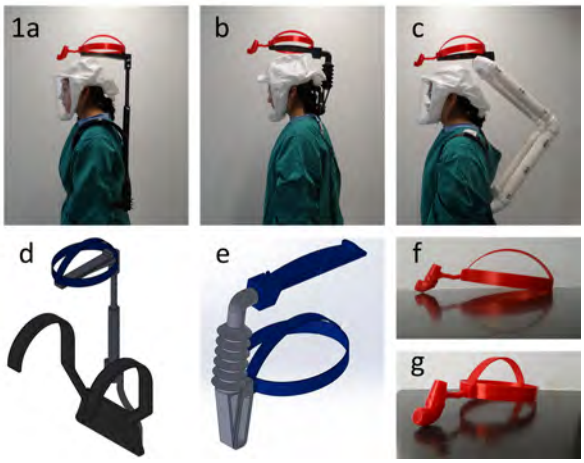


Fig. 1 *Surgical headlight adaptor product designs*

As COVID-19 continues to affect the lives of many worldwide, the use of PPE including PAPRs affects the illumination during surgeries which could result in difficulty moving forward in them. Following final printing and revisions of the presented designs, experimental testing will be conducted to further analyze the efficacy of the products. Being able to innovate a PPE-compatible headlight adaptor will further aid specialists of the broader healthcare community with surgeries In and allow us to be better prepared to handle future pandemics and outbreaks.

Research Projects

Development Engineering in Africa

Mukes Kapilashrami, United Nations

United Nations peacekeeping operations often take place in regions lacking proper governance and infrastructure, and in places with minimum commercial exploitation of the local environment and natural habitat. Under such circumstances, it becomes more challenging to manage and maintain safe operations in an active conflict zones on foreign soil.

The work of the engineering team in one of United Nations' largest peacekeeping missions – United Nations Multidimensional Integrated Stabilization Mission in the Central African Republic (MINUSCA), plays a key role in supporting peacekeeping efforts in these regions. Every peacekeeping mission has its own team of engineers and environment officers that work toward supporting its peace operations, while upholding United Nations' agenda for sustainable development and environmental sustainability.

Lack of infrastructure and proper governance in the Central African Republic (CAR), compelled MINUSCA to set up its own infrastructure supporting its field operations across the country to ensure access to most basic commodities and resources on the ground. The team in the Engineering Section at MINUSCA's Headquarters/Log Base in Bangui is responsible for planning, implementation and management of the mission's domestic infrastructure.

MINUSCA operates completely off the national energy grid, which means its energy demand is entirely met by its domestic energy grid composed of inter-connected standalone generators operating on diesel fuel. Each mission site has its own energy grid, designed to best meet the energy demand of the site, as well as projected energy demand and weather conditions.

With fifteen staff members, our Engineering Sections' Electro Mechanical team holds the sole responsibility for managing MINUSCA's energy grid, composed of over 150 generators with the collective power production capacity exceeding 4.5 MW, across the CAR.



Fig 1. *(A) Panoramic view of a typical residential peacekeeping mission camp in CAR. (B/C) engineers from Peruvian military contingent working together with local contractors in supporting MINUSCA's Engineering Section setting up a new base in the city of Bossangoa (CAR). (D/E) Where possible, MINUSCA utilizes and implement clean energy technologies in mission's field operations.*

The role of engineering has today become even more crucial as technology has made its way into development work. This has greatly enhanced the need to understand, assess, and communicate development challenges among important stakeholders, and has enabled rapid deployment of aid to afflicted communities and individuals. Social engineering characterized by (i) identifying problems and understanding the afflicted individuals and communities, (ii) determining technologies that best address the issue, and (iii) where needed re-designing technologies for use in specific cultural and environmental conditions.



Fig 2. *Engineers from the Bangladesh military contingent receiving medals from Head of Mission in South Sudan for their contribution in infrastructure support.*

Symposia

Engineering for Social Change Symposium

The University of Maryland Center for Engineering Concepts Development organized and held a Symposium on Engineering for Social Change in the Department of Mechanical Engineering at the University of Maryland in College Park.

This symposium focused on the developing field of Engineering for Social Change, how engineering education and industry could be improved by identifying unintended consequences, examining the social impact of new technologies, and integrating the areas of philanthropy and nonprofits. The event, attended by participants from the US, Canada, UAE and India, brought together professional perspectives from a range of domains – education, defense, nonprofit organizations, waste management, and social justice.

The outcomes of this symposium were a plan to revisit the topic in future to develop a conference on the subject, and the development of thought-provoking key questions in the topic area of Engineering for Social Change. These questions included:

- Would better ethics and self-awareness solve, or at least mitigate, unintended consequences?
- Where in the engineering curriculum would university faculty teach the skills needed to identify prospective consequences, then assess the magnitude of their impact and propose solutions? How has technology affected our way of learning?
- Are unintended consequences a larger problem than they used to be? If so, is this because topics of scientific interest and engineering solutions are more complex and derivative than it used to be?
- How do we practice engineering for social and environmental good? What is the best way to effect change in the developing world?
- How do we choose/identify societal problems for which the root cause or bottle neck has a strong technical component?
- Engineers should ask themselves who benefits and who pays when a product is designed? It is necessary to define an overall metric for impact.
- And ultimately, Why, How, And What is Beyond Engineering?

Attendees included David Drumheller (DoD), Bradley Gottfried (College of Southern Maryland), Sami Ainane (Khalifa University, UAE), Caroline Baillie (UCSD and Waste for Life), Mark Freedman (Covanta), P.V.M. Rao and M. Balakrishnan (IIT Delhi and Raised Lines Foundation), Yu-Ling Cheng (University of Toronto), Anne Spence (Baylor University), Robert Grimm (Do Good Institute), Michael Pecht (CALCE), Peter Sandborn (Mtech), Davinder Anand, Maria Sanchez and Dylan Hazelwood (CECD), and Jungho Kim of the University of Maryland.



Attendees of CECD's Engineering for Social Change Symposium

Engineering for Social Change Projects

ENME/ENES 467: Engineering for Social Change

Davinder K. Anand, Dylan Hazelwood, Sami Ainane, Jungho Kim, Jennifer Littlefield, Robert Grimm, and Michael Pecht.



Engineering for Social Change

Students in our unique Engineering for Social Change course have continued to examine issues at the intersection of technology, unintended consequences, nonprofits and philanthropy. Through a well-developed selection process students have selected an area of focus where technology could be used for positive social change, co-developed proposals, presented and voted as a group, and ultimately selected projects to support at local nonprofit organizations.



Students develop their grant selection process

The students have given out more than $50,000 since the program's inception as a result of our long-term partnership with the Neilom Foundation, a nonprofit organization supporting young people creating positive social impact using technology. The following is a selection of awards made by students in the course.

African Women's Cancer Awareness Association (AWCAA): Pilot Breast Cancer Screening Clinic

Students selected a project to set up a pilot breast cancer screening clinic at the AWCAA offices in Greenbelt, MD. Women in the African immigrant community were resistant to breast cancer screening, and the idea was to bring technicians and ultrasound equipment to the nonprofit's office each month to encourage screening in a comfortable space.



Students with CECD team and AWCAA

The clinic pilot was held over a one-year period with the assistance of volunteer registered nurses, nurse practitioners and pharmacists. A total of 256 women were examined, of which 48 had abnormal results. 5 were found to have stage I breast cancer, 7 had Stage II, and 4 had Stage II cancer. All sixteen were assisted in treatment.



The opening of the successful AWCAA pilot clinic

Chesapeake Bay Foundation (CBF): Solar Rotation Watering System

Students selected the Chesapeake Bay Foundation for an award to help develop a pilot solar rotation watering system to enhance soil health and improve water quality in the Chesapeake Bay region by allowing for grazing rotation of cattle.



Former Engineering for Social Change student Jenna Schueler (right), now working at CBF

CBF's innovative solar-powered livestock watering system uses the sun's energy to pump water from any nearby creek or pond to tanks that can be used to replenish watering troughs. It's an affordable, portable, off-the-grid solution for grazing cattle in fields that don't have a permanent watering system. By supporting rotational grazing and keeping livestock out of ponds and streams, local waterways stay healthy.



CBF's solar-powered watering station

Students Helping Honduras (SHH): Villa Soleada Bilingual School

Students Helping Honduras is an organization focused on alleviating violence and extreme poverty in Honduras through education and youth empowerment. Their project was to support the Villa Soleada bilingual school, currently under construction. Only 2% of the wealthiest students in Honduras get to attend a private bilingual school, and few people in the country speak English. As a result, preparing students in poorer areas with English proficiency sets them up for future success in the labor market.



Young students at the Villa Soleada Bilingual School in Honduras

ENME 482: Ideas for Social Change

A new course, under the Engineering for Social Change umbrella, *Ideas for Social Change* was piloted by Sami Ainane in Spring 2020. The course examined the application of design thinking in the context of the unintended consequences of technology, and the role of nonprofits in providing actionable and sustainable technology solutions.

Students researched social issues and responded by creating conceptual designs for affordable and sustainable solutions. They aimed to increase the general social welfare by using ideas and principles from the traditional business environment, practical skills from their previous courses, tools and techniques associated with new media and the reach of the Internet, and innovation and entrepreneurship concepts that have proven to be broadly successful.

The teams engaged in ideation processes to brainstorm, develop, and prototype solutions using technology to address their chosen issue, and created a business model for a nonprofit organization to work on the problem. An in-depth report, presentation, mission and vision statement, and business plan was developed and shared at the culmination of the semester.

Engineering for Social Change Projects

The Students' Voice: Feedback

Students of ENME/ENES 467: Engineering for Social Change:

"I believe that every mechanical engineering student should take this class to see another side of this major." – A. Ghori

"This course has inspired me to start my own non-profit." – A. Osiander

"This course also gave us the freedom we need to be creative and unique." – A. Lewwandoowa

"I have creative abilities that I had not explored before." – B. Taylor



Students discuss the course with CECD Director, Davinder K. Anand

"It is because of this course that I am actively monitoring my social media usage and constantly thinking about what I can do as an engineer to solve the problem." – B. Nasafi

"Of all the courses that I have taken throughout my college career, none has given me more information on how to make an impact on such a scale as Engineering for Social Change." – D. Principe

"Doing good is attainable for all of us, and we must uphold that as engineers to make a positive impact on our world." – G. Vinyard



Celebrating another successful year of Engineering for Social Change

"This class has helped me think so much more about what I want to do with my engineering degree." – I. Schlotterbeck

"This was the first engineering class I have taken that showed me that failure can be okay and there are multiple solutions to a problem. All of my other classes have taught me how to find the "right" answer to problems, and there was only one right answer." – J. Hogan

"Being able to have an open discussion with others simply can't be understated." – J. Johns

"The impact an individual can have on a single person, a single school, a single city is still worthwhile and still worth aspiring to. This class helped me realize that." – K. Danquah



Student teams in ESC

"I want to start my own nonprofit one day to support struggling villages in Togo … It is now clear to me that I have a responsibility as an engineer to not only consider my ethical responsibilities, but also to strive and create social change." – K. Aba

"Although this class was not what I was expecting, it ultimately became far more inspiring and educational than I originally anticipated." – L. Rosen.

"This semester has provided a lot of great insights that will surely come in handy in the future, but have already began to shape the way I see the world." – M.P. Oviedo

"With the discussion-based lectures and group projects and presentations, I have been able to think about and interact with engineering concepts in a different way. I have realized there is more to engineering than just the math and science." – M. Sampson



Students celebrate the end of the semester

"This class has given me the opportunity to see engineering from a side purely focused on helping others, and not just achieving a goal or trying to make a profit." – M. Zimmerman

"Before taking this class, I was sheltered to many important issues occurring throughout the world. This was created by many factors consisting of my "American Privilege", the mindset of if it doesn't directly affect me then why should I care, the idea that in order to help others I must first help myself creating a bubble which I lived in, as well as thinking there are a lot of people already helping so what can one extra person contribute." – P. Goldsmith

"This course helped me to open up my perspective on both life and engineering, and approach situations through all angles." – S. Johnson



A winning student team presenting their project

"I've learned how to be an engineer beyond the fundamental equations and theories we are taught in other courses." – S. Teow

"This class has encouraged me to step outside myself and truly ask where I want to focus my efforts." – W. Menjivar



Students develop an evaluation plan in the classroom

"This was the first time I had exposure to a lot of widespread issues affecting people globally that directly relate to advancements in technology and human activity." – Y. Stuherck

"This course opened my eyes not only to the possibilities of recognizing unintended consequences before they arise, but also what to do about it … I found this class as a whole to be a breath of fresh air." – Z. Hood

Engineering for Social Change Projects

Do Good Challenge 2021

Robert Grimm, Dylan Hazelwood, Davinder K. Anand.

CECD supported the Do Good Institute's 2021 Do Good Challenge, an annual competition and celebration of outstanding social change efforts by cross-disciplinary student teams across the University of Maryland campus.

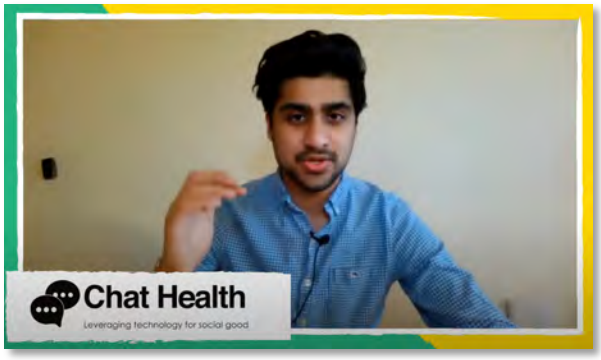
In a typical year, selected finalists deliver a pitch to a panel of expert judges on stage in front of an audience of 600 for the chance to win a share of the $20,000 in prizes. In 2021, instead of pitching in-person, students were sent personal production packages with spotlights, lapel mics, and tripods. The month-long series of virtual events culminated in the virtual Awards Premiere, which aired April 29, to celebrate the six finalist teams' impactful and innovative work and announce this year's winners. The Awards Premiere featured special messages from President Darryll Pines, Do Good Challenge alumni, family, friends, and other members of the Do Good community.



First Place Project ($5,000): ROOTS Africa is a nonprofit organization that works with agriculture students in Africa and the U.S. to increase crop yields and socioeconomic conditions for farming communities in Africa. The team raised $20,000 to support 1,000 families to stay home and safe during the pandemic, trained more than 400 farmers, and has five university chapters working in six villages and three high schools in Uganda and Liberia.



Second Place Project ($2,500): Audelia Community Response Team (ACRT) is a mutual aid group that provides food and other essential resources to those in need in Langley Park and the surrounding community, with a focus on immigrant and Latinx communities that face additional barriers to access resources. Since April 2020, ACRT has been consistently feeding 1,000+ families; raised $40,000; received donations of toys, food, household products; and helped schools with supply distribution and academic support.



First Place Venture ($5,000): *Chat Health* is a nonprofit organization that is bridging the gap between college students and medically-accurate health information through accessible SMS chatbots, which use AI to mimic human conversation. More than 4,000 students have used their chat service managed by 40 volunteers.

Second Place Venture ($2,500): *STEPS (Student Teachers Enriching Proficiency Through Service)* is a nonprofit that connects volunteers with K-12 families seeking affordable tutoring and college advising services, while donating nearly 100 percent of profits to support low-income youth. Their model has attracted 40 volunteer tutors, a growing paying client base, and has generated $15,000 in revenue to date.

Outreach

High school students join CECD in Electronic Waste Tracking Project Internship

Dylan Hazelwood, Katheryn Wang, Rushil Shah, Sandra Yen, Mya Mitchell.

Four students from high schools in the DC area undertook efforts to discover whether local electronics recyclers were recycling electronic waste on-site, or if they were shipping the waste to other countries for recycling. If the e-waste was found to be exported, the group sought to identify the locations.



Students dismantle electronic waste items to install tracking devices

If e-waste is not properly recycled, it is toxic to the environment and the workers. E-waste has many hazardous compounds, and many companies do not safely separate the compounds when recycling. The researchers chose the e-waste that would be sent out based on how likely they are to be recycled, how likely they are to be exported, and whether they can hide and protect a tracking device. They identified cathode ray tube (CRT) television and computer monitors as the least likely to be recycled, and most likely to be exported illegally. They were simple to conceal a tracker inside, but CRTs contain cadmium and lead, which makes them difficult to safely recycle and dangerous if improperly recycled.

The group considered trackers with battery lives of at least one year with daily location updates, size and weight that could be concealed easily, resistance to water and shock, and international data coverage. Fifteen tracking devices were purchased to test and deploy. The lithium batteries were replaced with alkaline batteries to avoid fires if the item was shredded in recycling facilities. During testing the trackers consistently updated their locations every 24 hours, and they were placed inside closed containers of varying materials to determine if they could penetrate the surrounding container to provide a location update.



Final presentation of the e-waste student group

The students obtained e-waste from the University of Maryland, specifically six CRTs, two printers, six computer monitors, and one laptop. The e-waste was dismantled, and the trackers were concealed and epoxied in place so that they could not be easily removed. The trackers were carefully positioned so that they would have the best view of the sky possible. The e-waste items were reassembled and sent to the recycling centers.



E-Waste Tracking devices

The students ultimately deployed trackers to four Maryland counties: Frederick, Howard, Montgomery, and Prince George's. While results were mixed, the students successfully learned about the myriad of issues surrounding electronic waste, and were able to see the results of their efforts as the trackers finally reported locations in Spain, Florida, Virginia and Georgia.

International Connections

International development of Engineering for Social Change program

Davinder K. Anand, Dylan A. Hazelwood, Michael G. Pecht.

This trip was planned to connect with international universities in the United Arab Emirates in an effort to identify and engage possible partners for CECD's Engineering for Social Change program. Further, the group visited newly constructed state-of-the-art electronic waste facilities in Dubai as a model for adoption in the United States in a pilot electronic waste recycling effort for Southern Maryland.

Enviroserve, Dubai Industrial City, UAE



Touring the Enviroserve plant in Dubai

Enviroserve's new electronics recycling plant is the largest and most modern plant in the world. The plant's use of state-of-the-art European machinery includes dust capture for both precious metals recycling and improved air quality for workers. Enviroserve CEO Stuart Fleming explained the range of coverage of electronic waste recycling for their plant, reaching throughout Africa and the Middle East. After growing up in Africa, Stuart was compelled to deal with the significant and dangerous electronic waste processing going on in the country, and thus the plant was born. While the plant had private investment from Credit Suisse, the government of Dubai decided as part of the Sheikh's 50 year plan for UAE to change waste management laws to encourage the work being undertaken at Enviroserve. The plant had the ability to process up to 3,000 tons per month at full capacity, and was planned to ramp up to full capacity in six months after our visit. They process a significant amount of R22 refrigerant recovery from equipment, clean it and resell. We shared copies of our electronic waste book, and spoke in depth about our electronic waste research and about our Engineering for Social Change program.

BITS Pilani, Dubai, UAE



Meeting on the BITS Pilani campus in UAE

The BITS Pilani Dubai campus is one of four BITS campuses – the other campuses are in India in Hyderabad, Pilani, and Goa. After an overview of the university and its programs, we discussed our successful engineering for social change program, and shared details on both this and our electronic waste efforts. We were given a tour of their campus, where 90% of the students were from India, with only 10% other nationalities. Some 50% live on the campus itself. We toured their innovation laboratory, where faculty members support students in their free time to develop projects such as the smart bin, an automated sorting solution. The smart bin had three different categories of waste, with optical and magnetic sensors sorting incoming waste and an IoT system to alert handlers to the full containers. The student projects have won 7 Dubai 2020 government innovation awards over the past two years, outsized performance given the relatively small number of overall awards each year.

United Arab Emirates University (UAEU), Al Ain, UAE



Professor Al Ahmad of UAEU with the group

Our group discussed the United Arab Emirates University (UAEU)'s various engineering and technology programs, and shared our work in Engineering for Social Change, and specifically our research in electronic waste. We presented two copies of our book to Professor Al Ahmad, and discussed future collaborative opportunities that could be explored with the University.

Khalifa University of Science and Technology – Engineering School, Abu Dhabi, UAE



Meeting with the Dean and Associate Dean of Khalifa University

In a meeting with the Dean and Associate Dean of Engineering at Khalifa University the group shared our work in Engineering for Social Change, as well as copies of our ESC book, and recently published electronic waste book. Recent changes are moving the original PI Institute and other campuses into one organization. Khalifa University has many student competitions, including engaging successful female teams in building hybrid electric vehicles, for which the University has received much public praise and significant media attention. Their student and teaching facilities were outstanding, and a model for many US universities to follow.





Touring Khalifa University's high-quality modern facilities

Celebrating 20 Years of CECD:
History of the Center for Engineering Concepts Development

The Center for Energetic Concepts Development (CECD) was established at the University of Maryland, College Park, as a cooperative research activity between the Naval Surface Warfare Center Indian Head Division (NSWC-IHD) and the University of Maryland, College Park. In response to a proposal from Professors Ronald Armstrong, Davinder K. Anand and William Fourney, an agreement was signed in 1998 which included research, graduate education, technology transfer, and exchange of technical personnel.[1]

The vision of CECD was to become the preeminent National Center concerned with the science and manufacturing of energetic materials and products for national defense and security, and further, to train the next generation of scientists and engineers working in energetics through its graduate educational and research programs. Research in Energetics comprised not only the traditional work in formulations, but manufacturing and packaging of the energetic material, as well. This included the entire gamut of engineering, design, test and evaluation, prototyping, and in some cases, manufacture of the product itself.

CECD hosted several symposia and lectures as part of our continuing activities, both here and abroad. These included topics such as Energetics, Traumatic Brain Injury, Critical Materials, Automation, Computation Enabled Materials Discovery, Data Driven Design, and Engineering for Social Change. The largest symposium we organized and supported was the International Detonation Symposium over a period of 16 years. These symposia, with an average of 350 attendees, were held in San Diego in California, Richmond in Virginia, Coeur d'Alene in Idaho and San Francisco in California.

The first CECD Research Review Day was held on May 21, 2003. It was attended by the Honorable Kumar P. Barve, the Majority Leader in the Maryland House of Delegates, Steven Mitchell, Technical Director at Naval Surface Warfare Center Indian Head (NSWC-IH) and almost fifty scientists and engineers from UMD and the Navy.



CECD's first Research Review Day was held in 2003 at the University's Inn and Conference Center.

[1] See a full history of the Center for Engineering Concepts Development (CECD) and the Mechanical Engineering Department by Davinder K. Anand and Dylan A. Hazelwood at https://doi.org/10.13016/M28C9R750

In recognition of the fact that the Southern Maryland region had a long history of contribution to the field of energetics development, CECD proposed the establishment of South Maryland Initiative for Energetics Capability Development in 2004. The base at Indian Head had been a leader in Navy ordnance development and testing for over 100 years. The need for this initiative arose from two pressing requirements, both critically linked to U.S. national security. The first was the imperative to regenerate the energetics professional workforce. The second was the essential need to develop ever more sophisticated systems in a timeframe that will ensure our national security.



MOU Signing Ceremony: US Congressman Steny Hoyer; US Senator Paul Sarbanes; Robert Kavetsky of ONR; MD Senator Thomas "Mac" Middleton; Charles County Commissioners President Wayne Cooper. Seated: Capt. Joseph Giaquinto, Commander, NSWC-IHDIV; Professor Davinder Anand, Director, CECD; Ms. Ann Smith, Dean of Career & Technical Education, College of Southern Maryland.

The Southern Maryland Initiative for Energetics Capability Development would meet emerging national needs by expanding and enhancing the mission of the Center for Energetic Concepts Development (CECD) at the University of Maryland and the establishment of the Energetics Technology Center (ETC). The initiative was funded by ONR, and ETC was founded with headquarters in La Plata, MD. ETC was developed to conduct applied research and technology development largely in Charles County Maryland facilities in partnership with the College of Southern Maryland and selected industry/technology institutions nationwide. The Center was formally established with a public ribbon cutting in La Plata, Maryland by Senator Barbara Mikulski on October 12, 2006.



Ribbon cutting ceremony for the Energetics Technology Center in La Plata, MD. Attendees included Maryland Senator Barbara Mikulski and Senator Paul Sarbanes.

On December 14, 2008, CECD celebrated its achievements in advancing the field of energetics and training the next generation of energetics experts. CECD hosted the celebration of our tenth year with University of Maryland Chancellor William Kirwan and Senator Thomas "Mac" Middleton as the keynote speakers.



CECD celebrates its 10th anniversary with guests from campus and beyond

With seventeen years of successful activities behind us, CECD entered a new era. While Dr. Anand continued as Director of CECD, Professor Peter Chung became the lead on all of our activities in energetics. Dylan Hazelwood formally became the Assistant Director and CECD now became the **Center for Engineering Concepts Development**. Rear Admiral (Ret.) Millard Firebaugh was appointed Minta Martin Professor of Practice. While we continued our work in energetics, we established a group in Engineering for Social Change (ESC). The relationship with NSWC and ARL continued, as did the support from the State of Maryland.

The Engineering for Social Change (ESC) Program and the Engineering for Social Change course was developed in conjunction with the Drs. Robert Grimm and Jennifer Littlefield of the School of Public Policy. ESC is defined as the examination and mitigation of the unintended consequences of engineering on society. As of today, over 350 students from across the Engineering college have taken the course, and $60,000 has been awarded to local non-profit organizations on behalf of the Neilom Foundation, CECD's non-profit partner in ESC. This unique course sought to inculcate in our students an appreciation of the social change engineering creates and how both for-profit and non-profit organizations can act as catalysts.



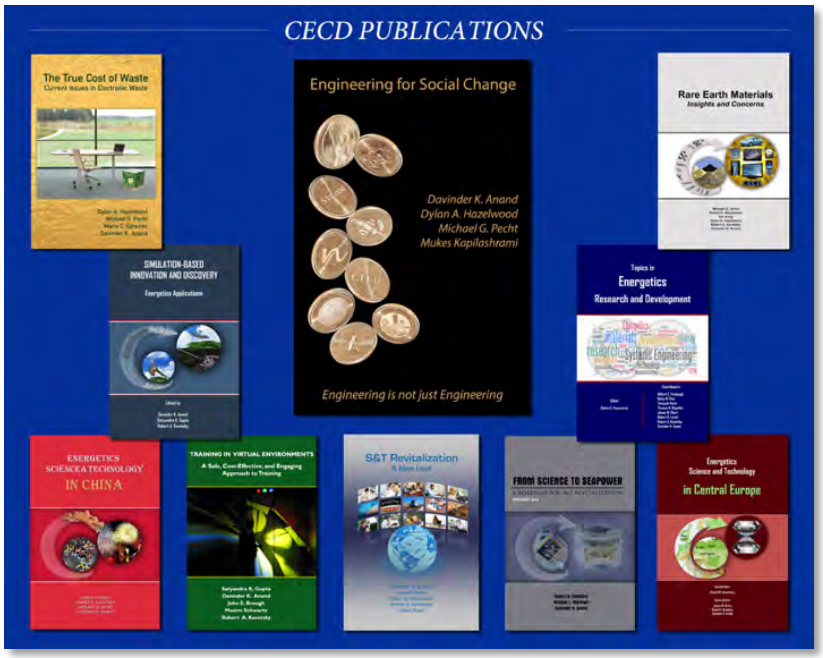
Engineering for Social Change students, Dean Pines, faculty and staff of Mechanical Engineering and the School of Public Policy celebrate the Neilom Foundation grant to V-Linc, a local nonprofit working in assistive technology.

Continuing a long-standing relationship with the College of Southern Maryland (CSM), CECD reached out in 2015 to establish an offshoot of the ESC course held at the University of Maryland. This course emphasized the mitigation of unintended consequences through social entrepreneurship. The engagement of CSM students in developing team projects with local nonprofit organizations was highly successful. After three impressive cycles, reaching dozens of local nonprofits, many CSM students and a variety of community members, the successful program then transitioned to being fully run by CSM as a permanent part of the curriculum.



CECD education outreach efforts culminate in the Entrepreneurship in Southern Maryland Challenge at the College of Southern Maryland.

A book, entitled "Engineering for Social Change: Engineering is Not Just Engineering" was authored in 2016 by members of both CECD and CALCE to encapsulate the ideas underpinning the ESC program. By 2021 almost 350 copies of this book had been provided for free to students undertaking the course, and hundreds of others circulated to the research and education community throughout the world. CECD has a long history of publishing books in niche areas of interest, having published eight previous titles.



With twenty years behind us we have an optimistic outlook for CECD, and consistent with our vision we will continue to experiment in new frontiers and niche areas of research and education.

20 Years of CECD: Supported Faculty

Department	Faculty
Mechanical Engineering	Ronald Armstrong, Shapour Azarm, Balakumar Balachandran, Amr Baz, David Bigio, Robert Bonenberger, Hugh Bruck, Steven Buckley, Jaime Cardenas-Garcia, Steven Chen, Nikhil Chopra, Peter Chung, William Cocimano, Siddhartha Das, Abhijit Dasgupta, Jaydev Desai, Donald DeVoe, Millard Firebaugh, Jerry Forbes, William Fourney, Mark Fuge, Satyandra Gupta, David Han, Henry Haslach, Jeffrey Hermann, Gregory Jackson, Mukes Kapilishrami, Robert Kavetsky, Kenneth Kiger, Thomas Klapotke, Maija Kukla, Edward Magrab, Michael Pecht, Peter Sandborn, Alba Ramaswamy, Janice Reutt-Robey, Maria Sanchez, Linda Schmidt, James Short, Elizabeth Smela, Ryan Sochol, Jelena Srebric, Miao Yu, Michael Zachariah.
Aerospace Engineering	Mark Lewis, Derek Paley, Kenneth Yu
Fire Protection Engineering	Jim Milke
School of Public Policy	Robert Grimm, Jennifer Littlefield
Chemical and Biomolecular Engineering	Bryan Eichhorn, Nam Sum Wang
Materials Engineering	Lourdes Salamanca-Riba
Electrical Engineering	Thomas Antonsen, Arthur Popper
Computer Science	Ashok Agrawala
College of Education	Matthew Miller
Department of Sociology	Jerald Hage
University of Maryland School of Medicine	Gary Fiskum and Rao Gullapalli

20 Years of CECD: The Celebration

The 20th Anniversary Celebration and Middleton Luncheon was held in the Kay Boardrooms and Rotunda, Jeong H. Kim Engineering Building, University of Maryland, College Park, MD on April 17, 2019.[2]

The celebration opened with the observation, by Director Davinder K. Anand, that "in any well-planned event there is always a last-minute surprise, and today is no different. As we were wrapping up our plans, we received notice that our very own Senator Chris Van Hollen will join us in honoring Senator Middleton. Senator Van Hollen, thank you for being here, and a very hearty welcome." He briefly reviewed the genesis of our beginning and introduced our speakers.

Speakers



The Honorable Thomas "Mac" Middleton is a longtime supporter of the Center for Engineering Concepts Development and the University of Maryland. "Mac" Middleton served in the Maryland State Senate from 1995 to 2019, representing Maryland's District 28 in Charles County. In 2018, Middleton's name was added to the U.S. Route 301 Potomac River bridge, making it officially the Governor Harry W. Nice Memorial/Senator Thomas "Mac" Middleton Bridge.



The Honorable Chris Van Hollen has served as United States Senator from the State of Maryland since November 2016. Since 2003 to 2017, he held the position of U.S. Representative for Maryland's 8th congressional district, where he served as a member of the Democratic leadership and was elected by his colleagues to be the Ranking Member of the House Budget Committee.



Dr. W. E. "Brit" Kirwan is a national leader in higher education. He led the University of Maryland, College Park campus three times, first as acting Chancellor in 1982, then again in 1988, and as the 26th President from 1989 to 1998. He then became the 12th President of The Ohio State University for a period of four years, and then returned to serve as Chancellor of the University System of Maryland from 2002 to 2015.



Dr. Balakumar Balachandran is a Minta Martin Professor and Chair of the Department of Mechanical Engineering at the University of Maryland, having served since 2010. He previously served as Director of Graduate Studies and Associate Chair from 2006 to 2010. He is a noted researcher and author of many papers and books in the area of nonlinear mechanics.

[2] See a full review of the event on the UMD DRUM system at https://doi.org/10.13016/4llk-ukei



Dr. George Dieter was an ardent supporter of CECD's Engineering for Social Change program. He was Professor Emeritus of Mechanical Engineering and Glenn L. Martin Institute Professor of Engineering, as well as Dean Emeritus of the Clark School, having served from 1977 to 1994. He was also a member of the National Academy of Engineering, and served as President of ASEE from 1993 to 1994.



Dr. Michael Pecht is the George E. Dieter Professor of Mechanical Engineering and the founder and Director of CALCE (Center for Advanced Life Cycle Engineering) at the University of Maryland. CALCE is a world leader in reliability testing, failure analysis, supply chain management, and prognostics technologies and methodologies. He was inducted into the Innovation Hall of Fame in 2011 for pioneering innovations in advanced reliability and prognostic methods for electronics.



Dr. Peter Chung is an Associate Professor in the Department of Mechanical Engineering at the University of Maryland, having joined in 2013. He serves as the Energetics Leader in the Center for Engineering Concepts Development. From 2003 to 2013, he served as Team Leader for Interdisciplinary Computational Sciences and Engineering in the Computational and Information Sciences Directorate at the Army Research Laboratory at Aberdeen Proving Ground.



Dr. Davinder K. Anand, Professor Emeritus of Mechanical Engineering Department, joined the University of Maryland faculty in 1965. His primary interest in research and teaching has been control systems. He served as the Chair of Mechanical Engineering from 1991 to 2002, and then became the Director of the Center for Engineering Concepts Development from 1999 to present. He formed the nonprofit The Neilom Foundation in 2013 to help young people at the intersection of technology and social impact.



Mr. Dylan Hazelwood serves as the Assistant Director of the Center for Engineering Concepts Development. He joined the Mechanical Engineering Department in 1998, directing information technology efforts until 2009, when he joined CECD. He is the author and co-author of several key books from CECD, and manages the Center's innovative Engineering for Social Change program.



Dr. Robert Grimm is the Levenson Family Chair in Philanthropy and Nonprofit Leadership and Director of the Do Good Institute. The Institute is housed in the School of Public Policy at the University of Maryland. It is a campus-wide hub that provides education, opportunities and resources to develop the next generation of nonprofit leaders, social innovators and civic-minded students and alumni. He has been a key partner of CECD enhancing the Engineering for Social Change program.

Pictures from the CECD 20th Anniversary Event





Senator Chris Van Hollen addresses the assembled guests



Senator Thomas "Mac" Middleton talks about his long history with CECD



Professor Davinder Anand proposes a toast to the gathered guests

At the conclusion of the Middleton Luncheon, Dr. Anand offered sincere thanks to our speakers, colleagues, friends, students, and all attendees. He observed, "you have heard where we have been, and the question is now where are we headed? No one can predict the future, but we plan to continue to experiment with new ideas in energetics that are benefitted by machine intelligence, and on the other side enlarge the scope of engineering for social change with specific emphasis on the impact and reach of engineering by all society."

In the final remarks and a toast to all the guests, he noted "this celebration is an acknowledgment of, and thanks for, the support and friendship that we have received from Senator Middleton since the inception of CECD… it is a testament to the great work my colleagues and researchers are doing, working in partnership with State and Federal Governmental Agencies and industry in various fields of interest to CECD, and so important to the vitality of a University and the welfare of our State and Nation. Thank you, and God Bless."



At the culmination of the celebration, the crowd listens carefully as Professor Anand thanks all

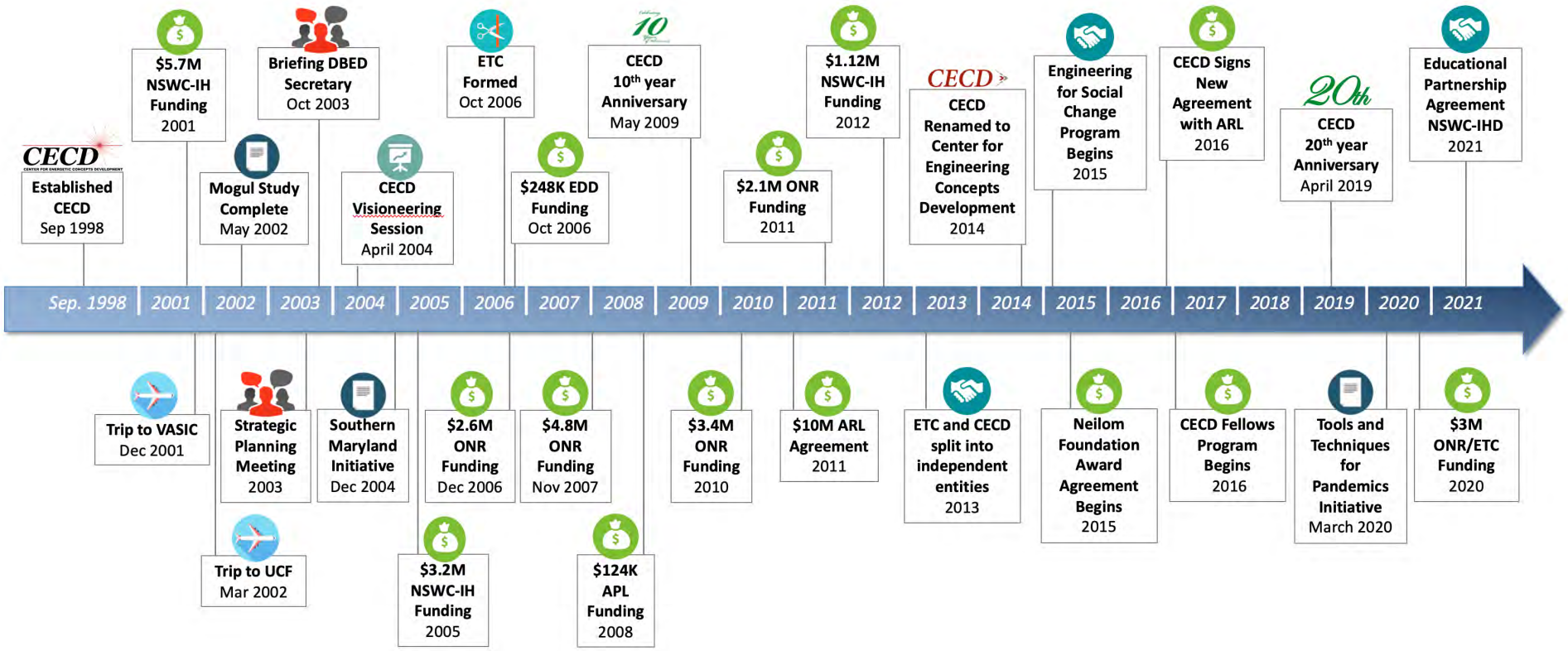


From left: Chairman Balakumar Balachandran, Dylan Hazelwood, Mike Middleton, Susan Lawrence, Professor Davinder K. Anand, Senator Thomas "Mac" Middleton, Professor Michael Pecht, Professor and Dean Emeritus George Dieter

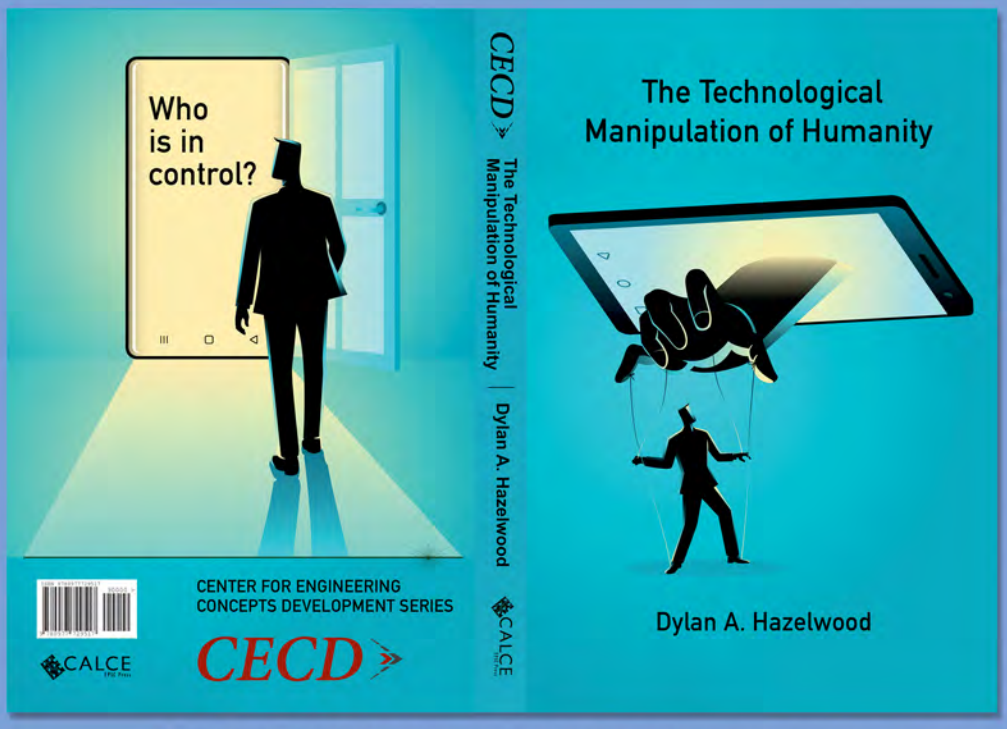


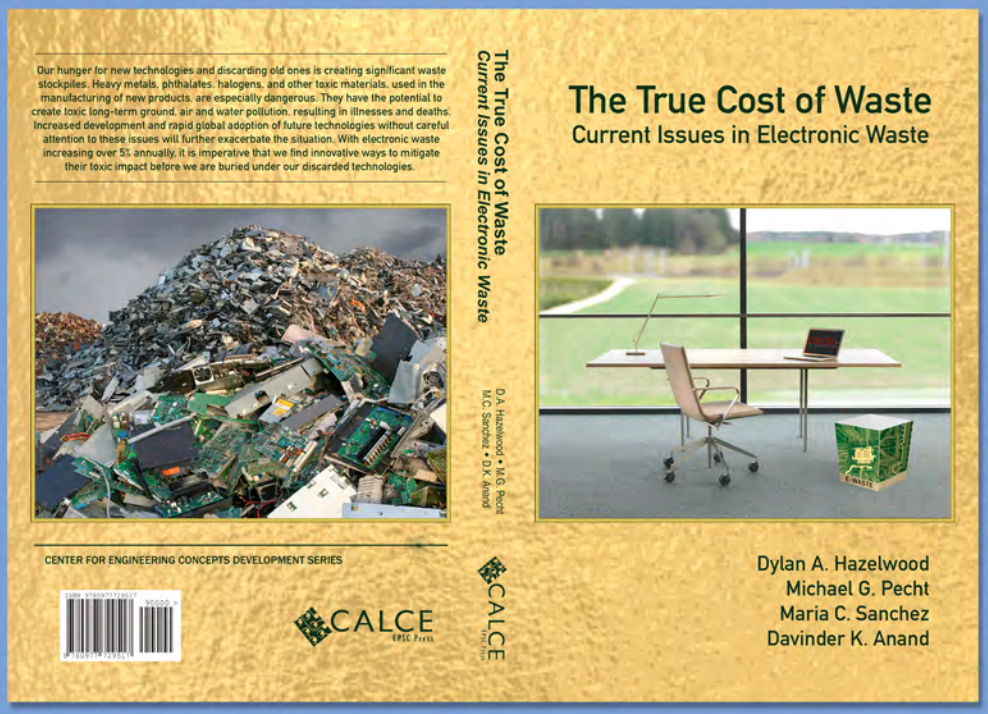
From left: Dylan Hazelwood, Davinder Anand, Senator Chris Van Hollen, Senator Thomas "Mac" Middleton

CECD Timeline



Recent CECD Publications





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